SESAR 2020

PNOWWA Solutions Workshop Presentations

D7.1 – SESAR 2020 Industrial Research Solution workshop presentations

PNOWWA

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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

This document gathers together PNOWWA Stakeholders Workshop 2018, PNOWWA Webinar 2017, SESAR Innovation Days, SESAR 2020 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.

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Abbreviations

ANSP	Air Navigation Safety Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
AUA	Austrian Airlines
CET	Central European Time
CSI	Critical Success Index
DIW	De-icing Weather index
DLR	German Aerospace Center
EFHK	Helsinki airport
ENS	Ensemble
FMI	Finnish Meteorological Institute
HR	Hit Rate
IER	Information Exchange Requirement
LFV	Swedish ANSP
LOWI	Innsbruck Airport
LOWW	Wien Schwechat Airport
NWP	Numerical Weather Prediction
ROC	Receiver Operating Characteristic
SID	SESAR Innovation Days
TAF	Terminal Aerodrome Forecast
TAM	Total Airport Management
TRL	Technological Readiness Level
WP	Work Package

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None

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None

Executive Summary

PNOWWA – Probabilistic Nowcasting of Winter Weather for Airports – is an Exploratory Research project developing methods to support the Air Traffic Management (ATM) challenged by winter weather. PNOWWA will demonstrate very short-term (0-3h nowcast) probabilistic winter weather forecasts in 15min time resolution based on extrapolation of the movement of weather radar echoes.

This document describes presentations of PNOWWA solutions given at various workshops, conferences, SESAR Innovation Days, and SESAR Industrial Research Project Solution meetings, either organised by the PNOWWA project or with participation of the PNOWWA team.

The **PNOWWA stakeholder workshop** was held in Vienna from 27th to 28th 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 **SESAR 2020 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** organised by three other SJU-funded projects.

Finally, the PNOWWA work has also been presented at four international **conferences.**

In conclusion, 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.

1 Introduction

PNOWWA – Probabilistic Nowcasting of Winter Weather for Airports – is an Exploratory Research project developing methods to support the Air Traffic Management (ATM) challenged by winter weather. PNOWWA will demonstrate very short-term (0-3h nowcast) probabilistic winter weather forecasts in 15min time resolution based on extrapolation of the movement of weather radar echoes.

The results of PNOWWA's research aim to be applied to all precipitation dependent solutions at a local (airport) scale when Mission Trajectories will be defined for flights. In the Proposal it was assumed that many of SESAR 2020 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 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". None of these (or even others) has organized suitable workshops. Therefore, the PNOWWA consortium was unable to produce and deliver the planned deliverable ***D7.1 "SESAR 2020 Industrial Research Solution workshop presentations"*** after 12 months.

Instead, contacts to these IR-Projects were established via Solution PJ.18-04b by investigations and inquiries on a bilateral level in the second year of PNOWWA. During the Intermediate Review Meeting, held in Brussels, the consortium in cooperation with the SJU officers, decided to supersede the content of that deliverable with a collection of the various presentations of PNOWWA given during the course of the project.

This document, hence, describes presentations of PNOWWA solutions given at various workshops, conferences, SESAR Innovation Days, and SESAR Project Solution meetings, either organised by the PNOWWA project or with participation of the PNOWWA team.

The **PNOWWA stakeholder workshop** was held in Vienna from 27th to 28th of February 2018 where in total 14 presentations highlighted the requirements and means to mitigate the impact of winter weather from users' perspectives and R&D attempts. The presentations were lively discussed among the 17 participants from aviation industry and R&D communities. Emphasis was laid on how to use probabilistic weather forecast in the aviation business in a pragmatic, yet beneficial way.

The **PNOWWA stakeholder webinar** was held on 04.10.2017 by Webex. A total of 21 participants representing aviation stakeholders and research entities were following three presentations on

“Synthesis of user needs for Probabilistc Nowcasting of Snow at the Airports”, “Approaches of probability forecasting” and “Snow nowcasts with extrapolative methods. Case studies and lessons learned”. The format of a (concise) webinar has proven to be an effective mean to disseminate and discuss research results among spatially distributed, yet interested parties in the topic of weather impact on aviation. The interest in the PNOWWA webinar was unexpectedly large.

PNOWWA topics have also been presented at two **SESAR Innovation Days** (SID 2016, 2017). Posters and short presentations have successfully been used to attract visitors of the SIDs.

Interactions with two **SESAR 2020 Industrial Research Project Solutions** have been used to elaborate on the need and requirements for probabilistic winter weather information: Solution PJ.04-02 “Total Airport Management” where processes are defined to assess winter weather impact, among others, and Solution PJ.18-04 “ATM improvement by enhanced AIM and MET” (MET) where the Content Integration and Common Component 3.1 “Airport MET Information and Alert Generation Enhancement” was identified as a link to PNOWWA activities.

PNOWWA attended (will attend) four **stakeholder workshops** organised by three other SJU-funded projects, the TBO-MET workshop 03/04.05.2018 in Salzburg, the ATM4E workshop in Berlin and a workshop organised by ACI Europe and SJU at Malta airport on 12.04.2018 in Malta.

Finally, the PNOWWA work has also been presented at four international conferences: the EGU 2016 and 2018 in Vienna, Austria, the 2nd European Nowcasting Conference 03-05.05.2017 organised by the German Meteorological Service DWD in Offenbach, Germany, and the WMO Aeronautical Meteorology Scientific Conference 2017 at MeteoFrance in Toulouse, France.

The slides of most presentations of all workshops, conferences and meetings are included in the Appendices or links are provided to respective internet pages.

2 PNOWWA Stakeholder Workshop

The PNOWWA workshop was held in Vienna, Austria, from 27th to 28th of February 2018. It brought together aviation stakeholders and scientists of other SESAR and weather/ATM related projects to discuss the use of probability measures in nowcasting of winter weather for airports.

The main objectives of the workshop were

a) to present and discuss PNOWWA concept, methods, feedback and results of the demonstration phases and survey,

b) to promote probabilistic weather information within aviation community,

c) to collect further feedback for a roadmap towards a future application of PNOWWA research results for stakeholders,

d) to strengthen the cooperation and exchange ideas on requirements and specifications, and

e) to plan possible follow-up projects.

The 17 participants came from ANSPs (Austro Control 3, Croatia Control 3, DFS 1, LFV 1), airport authorities (2), airline (1), pilots' association (1), weather service (1), and academia (4).

14 presentations were given covering improved winter weather nowcasting (7), weather impact on de-icing (1), pilot's view on winter operations (1), weather impact analyses and assessments using air traffic simulations, on staff planning and of aircraft trajectories on the environment (3), nowcast and forecast of thunderstorms (1), and meteorological uncertainty management for TBO (1).

The potential of probability nowcasts of adverse winter weather is seen for pre-emptive actions on runway maintenance and new / adequate procedures of de-icing. The impact of improved winter weather nowcasting on ATM procedures has to be further investigated by fast-time simulations and eventually real-time tests. Higher potential for new application of probability forecasts was seen for tactical planning of airport operation and especially for flight planning.

Agenda and presentations from the PNOWWA team are available in Appendix 1.

3 PNOWWA Stakeholder Webinar

The PNOWWA Stakeholder webinar was held 04.10.2017 11:00 – 11:45 (CET) by Webex. The invitations for the stakeholders were sent by email.

Reasoning for the webinar was that with help of the first online demo and contact with stakeholders before and after that we have a vision about what we can share with a larger audience within the SESAR community. Ideas and main points for the webinar were:

- Introduction of some cases. What happened, what did the system forecast, and why.
- Exceedance probabilities vs. class probabilities. Probability forecasts are not difficult to understand, but sometimes your intuition can go wrong. Short reminder about what we mean when we say "probability for 1-5 mm snow is 30%"
- World beyond PNOWWA. The user survey revealed some needs which cannot be covered with weather-radar extrapolation based nowcasts. So we should have a short summary of other information sources.

The agenda for the webinar read:

11:00 Synthesis of user needs for Probabilistc Nowcasting of Snow at the Airports.
H. Juntti, R. Kaltenböck. WP4 and WP5
11:15 Approaches of probability forecasting.
Prof. M. Laine, guest speaker
11:30 Snow nowcasts with extrapolative methods. Case studies and lessons learned.
E. Saltikoff , S. Pulkkinen and M.Hagen. WP2 and WP3
11:45 Discussion

The 21 participants came from ANSPs (Austria 2, Croatia 2, Denmark 1, Germany 2, Poland 1), industry (1), weather services (Finland 5, Germany 1, Poland 1), academia (4), and SJU (1).

The webinar had the following advertisement that was distributed to the project stakeholders and other interest groups.

This webinar, lasting less than an hour and focusing on probabilistic nowcasting of winter weather events at airports attracted many participants. It turned out as a very valuable means of communication with and dissemination towards spatially distributed parties on the user's side with very limited time.

All presentations are available for all participants in the PNOWWA website and are also attached here in Appendix 2.

4 SESAR Innovation Days

SID 2016 in Delft: A poster was presented and new contacts were made.

SID 2017 in Beograd: PNOWWA was represented with a two talks and one poster.

https://www.sesarju.eu/sites/default/files/documents/sid/2017/SIDs_2017_paper_36.pdf

https://www.sesarju.eu/sites/default/files/documents/sid/2017/SIDs_2017_paper_43.pdf

https://www.sesarju.eu/sesarinnovationdays

5 SESAR 2020 Industrial Research Project Solution Meetings

SESAR 2020 IR-Project Solution PJ.04-02 "Total Airport Management"

The SPR-INTEROP/OSED FOR V1 of PJ.04-02 "TAM" document (issued 22.08.2017) was used to understand the processes to assess MET impact for Airport Operation Center (APOC) and how PNOWWA activities and procedures could help to mitigate winter weather events.

The SPR-INTEROP/OSED FOR V1 of PJ.04-02 "TAM" (issued 22.08.2017) 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.

SESAR 2020 IR-Project Solution PJ.18-04 "MET"

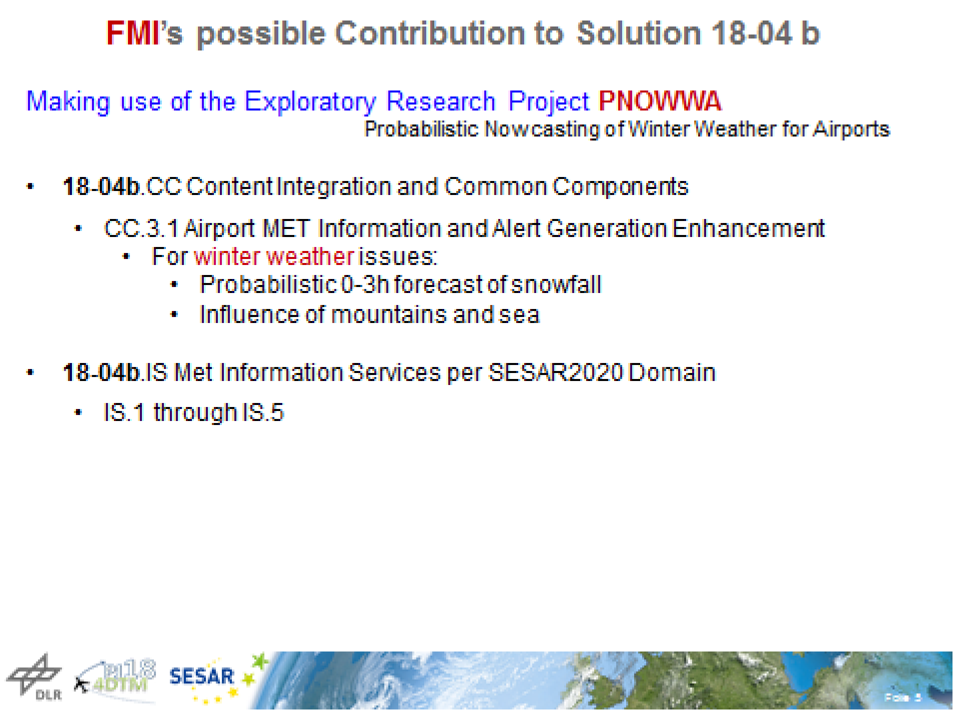
Solution PJ.18-04 "ATM improvement by enhanced AIM and MET" (MET) is an enabler solution to improve the European ATM System based on the provision of new or enhanced AIM or MET information within Project PJ.18 "4d Trajectory Management" (4DTM).

A face-to-face meeting of Solution 18-04 was held at Eurocontrol premises in Brussels on 20 April 2017 where the partners attempted to clarify their contributions and ways of working. Eurocontrol had an unsuccessful tender for meteorological support in 18-04b. At the meeting, therefore, it had to be figured out which meteorological expertise is available and who can do what with regard to meteorological services among the PJ18-04 partners.

DLR is partner in 18-04b as well as in PNOWWA and presented the PNOWWA work at this meeting, see Figure below, demonstrating the potential of PNOWWA to deliver winter weather nowcast information for the Content Integration and Common Component 3.1 “Airport MET Information and Alert Generation Enhancement” as well as for the Integration Services 1 through 5 in SESAR 2020 domains.

The PNOWWA team FMI, ACG and DLR further demonstrated 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.

It was further recommended that PNOWWA partners use their contacts from SESAR1 and other partners in SESAR2020 as COOPANS (CCL) to get into explicit contact with the PJs PJ.02, PJ.04, and PJ.07.



6 Other Conferences

PNOWWA attended the TBO-MET **stakeholder workshop** at 24/25.05.2017 in Seville, Spain, and will attend three further workshops organised by the SJU-funded projects TBO-MET at 03/04.05.2018 in Salzburg, Austria, and ATM4E in Berlin, Germany, and a further workshop organised by ACI Europe and SJU at Malta airport on 12.04.2018 in Malta.

TBO-MET Stakeholder Workshop on Meteorology and ATM, 24/25.05.2017 Seville, Spain

PNOWWA team was invited to give a talk "Provision of probabilistic nowcasts (PNOWWA project)" in that Workshop in the session "Management of Meteorological Uncertainty". Abstract of the PNOWWA presentation is in Appendix 3.

TBO-MET Stakeholder Workshop on Meteorology and ATM, 03/04.05.2018 Salzburg, Austria

PNOWWA team has been invited to give a talk on the project results and user's feedback.

ATM4E Stakeholder Workshop in Berlin, Germany

PNOWWA team has been invited to give a talk on the project results and user's feedback.

ACI/SJU Workshop at Malta Airport on 12.04.2018 in Malta

PNOWWA team has been invited to give a talk on the project results and user's feedback.

The work of the PNOWWA Exploratory Research project has also been presented at four international **conferences:** the EGU 2016 and 2018 in Vienna, Austria, the 2nd European Nowcasting Conference 03-05.05.2017 organised by the German Meteorological Service DWD in Offenbach, Germany, and the WMO Aeronautical Meteorology Scientific Conference 2017 at Meteo France in Toulouse, France.

7 Conclusions

In conclusion, 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 SESAR 2020 Project Solution meetings are also a concise mean to interact with parties who work on similar weather-dependent improvements in an aviation sector.

References

1. PNOWWA Project Management Plan
2. Probabilistic Nowcasting of Winter Weather for Airports (PNOWWA): Part A and Part B (699221)
3. Consortium Agreement For the Horizon 2020 project PNOWWA (699221)
4. PNOWWA Web Site at http://fmispace.fmi.fi/index.php?id=pnowwa

Appendix 1 Agenda and Presentations at the Workshop

<u>PNOWWA Workshop Vienna 27-28th Feb. 2018</u>

Austro Control, Wagramer Str.19, 1220 Vienna, room 16.05

AGENDA

Tuesday 27 Feb; 13-17h

Introduction

13:00-13:15 *Rudolf Kaltenböck, Austro Control*

Session 1: Introduction of PNOWWA

13:15-14:15

1a) PNOWWA Overview*. Rudolf Kaltenböck, Austro Control*

1b) PNOWWA results of the demonstration and verification. *Heikki Juntti, FMI*

Session 2: Stakeholder presentations and feedback during PNOWWA

14:15-14:30

2a) Weather Impacts on Deicing at Vienna Airport. *Wolfgang Hasil, Vienna Airport*

Coffee break

14:30-15:00

Session 2: Stakeholder presentations and feedback during PNOWWA

15:00-17:00

2b) Needs and expectations of winter weather forecasts at Munich airport. *Thomas Gerz, DLR*

2c) Winteroperation – pilots view. *Klaus Sievers, VC*

2d) PNOWWA: Surveys and interviews. *Rudolf Kaltenböck, Austro Control*

2e) Weather impact analysis based on elaborate air traffic simulations. *Martin Steinheimer, Austro Control*

2f) PNOWWA: Summary of what we learned from stakeholders in Finland. *Heikki Juntti, FMI*

Icebreaker:

17-19h

Wednesday 28. Feb; 9-15:30h:

Session 3: Science

09:00-10:30

3a) PNOWWA scientific talk. Used methods and analyses. *Martin Hagen, DLR*

3b) Potential for follow-up projects. *Heikki Juntti, FMI*

3c) Cb-LIKE - Cumulonimbus Likelihood: Thunderstorm forecasting with fuzzy logic. *Thomas Gerz, DLR*

Coffee break

10:30-11:00

Session 4: Presentation from other weather related SESAR projects and future plans

11:00-12:30

4a) Meteorological Uncertainty Management for Trajectory Based Operations (TBO-Met). *Damian Rivas, University of Seville*

4b) Multi-criteria environmental impact assessment and optimization of aircraft trajectories (ATM4E). *Sigrun Matthes, DLR*

4c) Impact assessment of weather on staff planning at RTC (Remote Tower Centre). *Igor Kos/Croatia Control and Tatiana Polishchuk LIU/LFV*

12:30-13:30

Summary and Discussion

PNOWWA
Probabilistic Nowcasting of Winter Weather for Airports

Project - Overview

Rudolf Kaltenboeck *(Austro Control)*
H. Juntti, E. Saltikoff, A.M.Harri, H.Haukka, J. Hirvonen, H. Hohti, S.Pulkkinen, A. von Lerber *(FMI)*
M.Hagen (DLR)

PNOWWA Workshop Vienna
27-28 Feb 2018

Founding Members

Content

Winter weather - aviation

- Snow
- Sleet (Snow and Rain mixed)
- Freezing Rain / Drizzle
- Frost
- (Icing)
- (LVP)

Winter weather influences at airports

- **Runway maintenance** (runway closed, contamination)
- **De-icing**
  - need, timing
  - choose of anti-icing fluid and duration of actions
- **ATM** - Approach/Tower (capacity of airport and LVP)
- **Airliner**
- Luggage handling, fuelling, parking, passenger ground transform etc.

Effects of adverse winter weather to airports can be mitigated to maintaining safe, punctual, efficient and environmentally friendly air traffic

What´s PNOWWA?

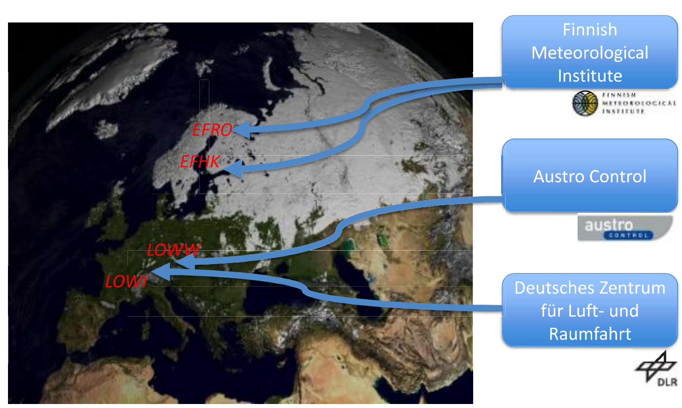
„Probabilistic Nowcasting of Winter Weather for Airports"

Single European Sky ATM Research Programme (**SESAR**)
(EU+Eurocontrol)
SESAR H2020 Exploratory Research

Project-duration: 4/2016-4/2018

Probabilistic 0-100%
"Nowcasting" ...... short range forecast 0-3 hours

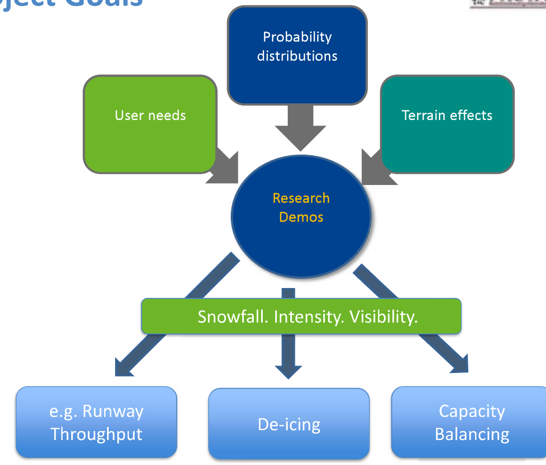
PNOWWA participants



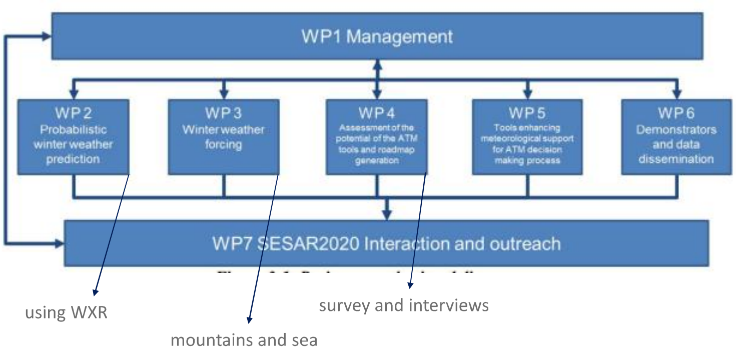
PNOWWA Objectives

1. To develop methods for **probabilistic 0-3h snow forecasts**
2. To understand impact of **mountains and sea** to snowfall
3. To identify and promote use of **probability forecasts** in variety of airport activities

Project Goals



PNOWWA organizational diagram



Weather radar based nowcast methodes

Nowcasting
- from minutes to hours
- why do we use weather radar for nowcasting

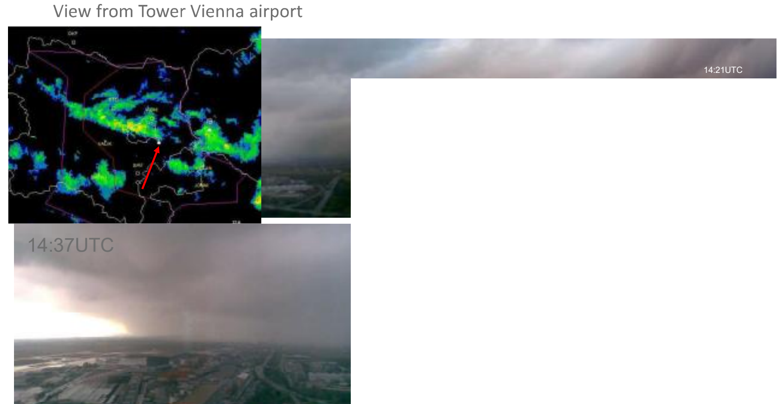
-

In short range forecasting (0-3h), 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.

- detection of existing **precipitation**
- weather radar has high temporal and spatial **resolution** over far ranges
- **movement** and **development**
- Nowcasting with extrapolation of radar images in PNOWWA
  - Time= distance/speed

Nowcasting using weather radar winter squall line

View from Tower Vienna airport

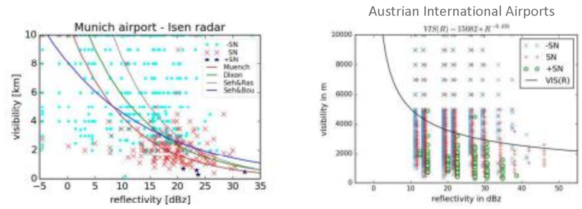


Nowcasting using weather radar winter squall line

View from Tower Vienna airport

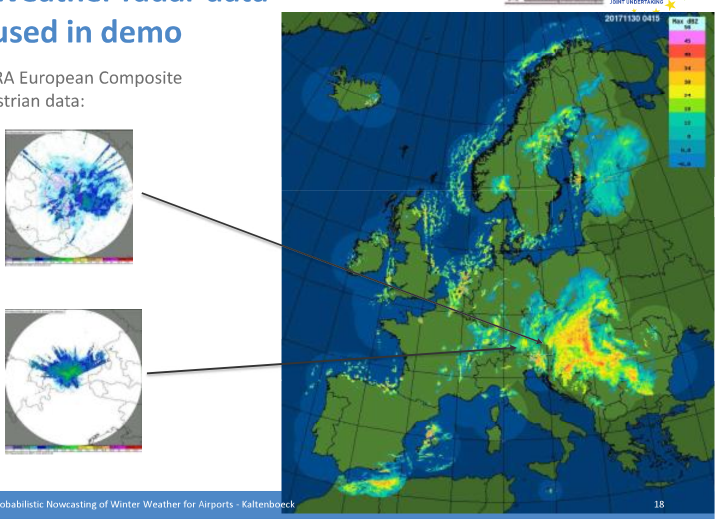
from WXR to user thresholds e.g. visibility

-



Weather radar data used in demo

OPERA European Composite
+ Austrian data:



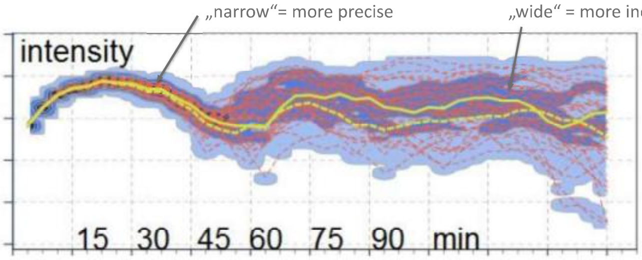
Use of probabilistic forecast

- natural intrinsic **variability of weather**
- user must choose proper **probability thresholds,** which gives them the correct balance of alert and false alarms for specific applications.

- ensembles….an objective **quantity of uncertainty** results, which means increasing risk of wrong decision with lower likelihood.
- **objective** support for user specific **decision**-making processes.

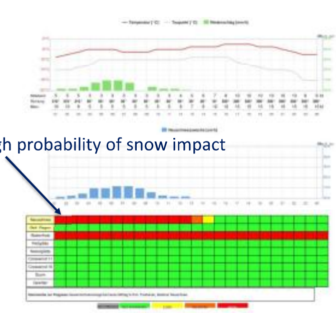
Probability Forecast e.g. ensemble

„narrow"= more precise
„wide" = more inexact

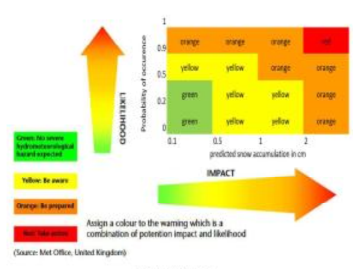


Probabilistic Forecast e.g. LOWW – medium range /days

Ensambles of numerical weather prediction model

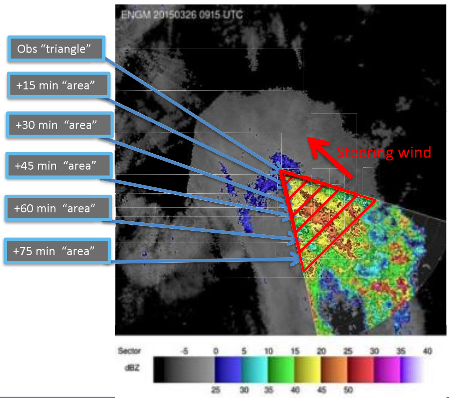


Impact based matrix



Nowcasting using weather radar
Extrapolation + Ensemble Generator
1) Andersson

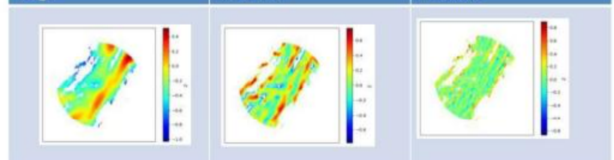
- determine motion vector
- generate ensemble
  - from upflow sector texture
- probability
  - deliver objective measure of uncertainty
  - growing with time, related to precip field texture



Nowcasting using weather radar
2) STEPS short term ensemble prediction system

Ensemble Generator:

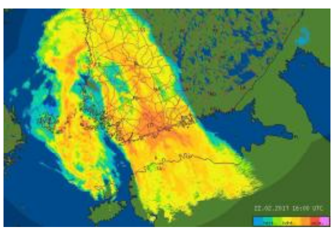
- radar images decomposed to different scales …. Spectral decompo
- uncertainty due to growth and decay modeled by a stochastic random field
- 51 ensembles

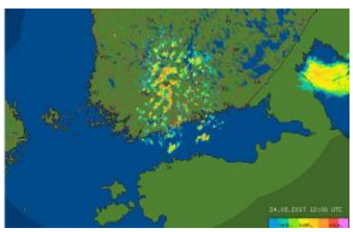


Large	Medium	Smallest
Long-living features which move as they are	Inbetween	To be quickly replaced with random noise , smoothed out in output

Use of probabilistic forecast limitations

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





Frontal system …… hours-days   Showers ……. minutes-1 hour

Terrain effects

Mountains:

- Flow classification of 14 cold front passages in southern Germany.

(60 % show frontal delay / upslope enhancement)

Sea:

- Forecast quality is lower for precipitation systems arriving from sea.

PNOWWA Scientific demo

- online service with automatic update (15min)
- Tailored products to:
  - Runway maintenance
  - De-icing agents
  - Tower
  - (Airliner)
- Probabilities of the weather categories defined with users
- Forecasted parameters:
  - Accumulation of DRY snow
  - Accumulation of WET snow
  - Probability of freezing rain
  - Probability of freezing of wet runways
  - De-icing weather type (categories dependent on the time of individual plane de-icing duration
  - Decrease of visibility CAUSED BY SNOW (fog or mist is not considered)

Demo conversion tables from radar reflectivity to forecast paramters

	dry snow	wet snow
Temperature in °C	≤ -0	-0 °C ≤ and ≤ +3 °C
Dewpoint in °C	≤ -1	≤ 0

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

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

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

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

Effect on aircraft	DIW=3, severe	DIW=2, medium	DIW=1, light	DIW=0, no need for de-icing
Ice on plane	Freezing rain/drizzle			
Snow on plane	Heavy snow or sleet, visibility casued from precipitation below 2 km, deduced from weather radar information	Light/moderate snow or sleet, visibility cased from precipitation above 2 km, deduced from weather radar information		
Frost on plane			Risk for frost formation on the plane surface. Temperature between -3 … +1 and humidity over 75%	
No remarkable contamination on plane				All other cases

Conclusions

- successful installation of demonstrators
- collected user feedback
- rising awareness about probabilistic forecast

PNOWWA … Probabilistic Nowcasting of Winter Weather for Airports

http://pnowwa.fmi.fi

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

Founding Members

Results of the demonstration and verification

Heikki Juntti,
Elena Saltikoff, Finnish Meteorological Institute (FMI)
Rudolf Kaltenbock, Austrocontrol

PNOWWA (Probabilistic Nowcasting
of Winter Weather for Airports)

SESAR JOINT UNDERTAKING

Founding Members

Airports and dates of verification

PNOWWA SESAR JOINT UNDERTAKING

In Finland Rovaniemi (EFRO) and Helsinki (EFHK) airports

In Austria Wien (LOWW) and Innsbruck (LOWI) airports

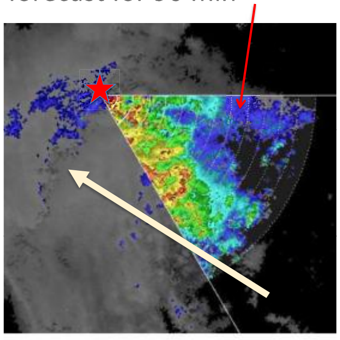
A few days were selected, when it has been snowing on each airport to investigate how well PNOWWA prototype forecasted the timing, type and intensity of precipitation.

Principle of demostratation Andersson & Ivarsson 1991

PNOWWA SESAR JOINT UNDERTAKING

- Motion assumed to be same as 850 hPa wind from numerical weather prediction model
- Uncertainty growing with time, related to precip field texture

Pixels in 6th sector = forecast for 90 min



Runway maintenance demo

PNOWWA SESAR JOINT UNDERTAKING

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0
1-5 mm	40	90	100	70	30	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
less than 1 mm	0	0	0	40	70	60	60	[illegible]	60	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]n
over 5 mm	0	0	0	0	0	0	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]
3-5 mm	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]
1-2 mm	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	0	0	0	0
less than 1 mm	100	100	100	100	100	100	100	[illegible]	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	[illegible]	[illegible]	[illegible]	135-150 min	150-165 min	165-180 min	180-195 min
prob	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	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	[illegible]	120-135 min	135-150 [illegible]	[illegible]	[illegible]	[illegible] min
prob	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]

DRY SNOW

PROBABILITIES OF CLASSES (2017)EXCEEDANCE PROBABILITIES (2018)

Wet SNOW

FREEZING RAIN

FREEZING OF WET RUNWAYS

De-icing demo

PNOWWA SESAR JOINT UNDERTAKING

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	40	40	40	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	40	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

De-icing time of individual airplane is directly dependent on the weather during stay of it on ground.

During weather conditions of high DIW de-icing time of aircraft is long.

DIW=3 -> ice or a lot of snow on the aircraft

DIW=2 -> some amount of snow on the aircraft

DIW=1 -> only frost on the aircraft

DIW=0 -> no de-icing need

Tower demo

PNOWWA SESAR JOINT UNDERTAKING

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	40	40	40	30
VIS over 3000 m	0	0	0	40	70	60	60	50	60	70	70	70	70

Only influence of snow precipitation is taken into account!
No fog, mist or drifting/blowing snow

Different approaches to probabilities

	45 min	60 min	75 min	90 min
> 10 mm	0	0	0	0
5-10 mm	30	60	50	30
1-5 mm	40	0	0	0
< 1 mm	30	40	50	70

Most probable class (used 2017)

	45 min	60 min	75 min	90 min
> 10 mm	0	0	10	0
> 5mm	30	20	40	20
> 1mm	70	60	50	30
< 1 mm	30	40	50	70

Exceedance (used 2018)

EFRO 7-13.12.2017

- During that **week** it snowed every day.
- 7 days is enough long period to make some conclusions about the level of quality of PNOWWA nowcasting demonstration product.
- To investigate how well PNOWWA estimates the timing and intensity of snow probabilistic forecasts were categorized. Then it was estimated that **the most probable value get from PNOWWA was the deterministic forecast**. After that it was possible to form contingency tables.

Date (06 UTC-> next day 06 UTC)	Precipitation (mm)	Increase of snow depth (cm)
7.12.	2,1	3
8.12.	8	4
9.12.	4,6	4
10.12.	2,8	2
12.12.	0,4	-2
12.12.	15,6	13
12.12.	0,3	-1
13.12.	2,2	-1

EFRO 7-13.12.2017 De-Icing

Over forecasted DIW class

FORECAST->	DIW0	DIW1	DIW2	DIW3	DIW4	sum. Obs
DIW0	307	8	2	0	0	317
DIW1	49	167	2	0	0	218
DIW2	19	5	1	0	0	25
DIW3	0	1	0	0	0	1
DIW4	0	0	0	0	0	0
sum Forec.	375	181	5	0	0	561

Under forecasted DIW class

60 min forecasting time

FORECAST->	DIW0	DIW1	DIW2	DIW3	DIW4	sum. Obs
DIW0	308	13	0	0	0	321
DIW1	47	173	1	0	0	221
DIW2	20	6	0	0	0	26
DIW3	0	1	0	0	0	1
DIW4	0	0	0	0	0	0
sum Forec.	375	193	1	0	0	569

180 min forcasting time

- Forecasts fits very well to observations
- Some amount of under forecasting is recognized

Forecast hit to same Class than observation

- Similar "balance" than 60 min forcasts
- Quality of 180 min forecast as good as 60 min

EFRO 7-13.12.2017 dry snow

Over forecaste DIW class

FORECAST->	PDSN_0	PDSN_1	PDSN_2	PDSN_3	sum. Obs
PDSN_0	532	4	0	0	536
PDSN_1	24	1	0	0	25
PDSN_2	0	0	0	0	0
PDSN_3	0	0	0	0	0
sum Forec.	556	5	0	0	561

Under forecasts DIW class

60 min forcasting time

FORECAST->	PDSN_0	PDSN_1	PDSN_2	PDSN_3	sum. Obs
PDSN_0	542	1	0	0	543
PDSN_1	26	0	0	0	26
PDSN_2	0	0	0	0	0
PDSN_3	0	0	0	0	0
sum Forec.	568	1	0	0	569

180 min forcasting time

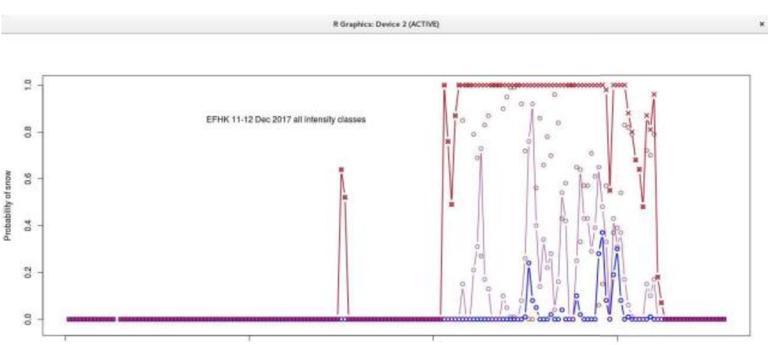
- Similar type of results than in DIW
- More clear under forecasting
- Only light snow cases

Forecast hit to same Class than observation

- Quality of 180 min forecast as good as 60 min

Conclusion:
Hits well, some amount of underforecast tendency

EFHK 11-12.12.2017



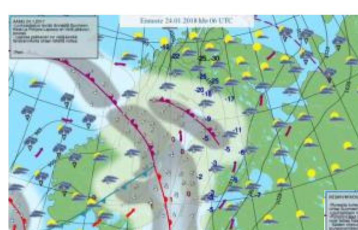
30 min forecast

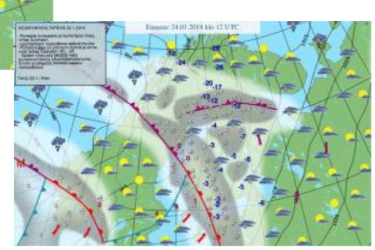
Valid time

Time series of different intensities. x=15 min o=**30 min forecast**.
Probability of over 10 mm/15 min was always smaller than 40%.
Probability of at least 1 mm/15 min was even 100%.
Probability of at least 5 mm/15 min was something in between.

Conclusion: Logical

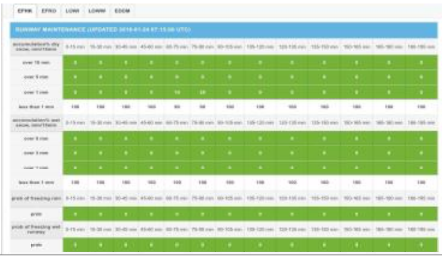
EFHK 24.1.2018

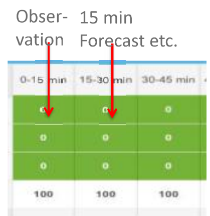




Warm and cold fronts went over Helsinki.
During previous day it was forecasted heavy snow disturbing air traffic remarkably.

EFHK 24.1.2018 At 7:15 UTC





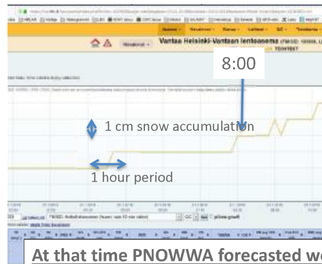
METAR 2018-01-24 06:50:00;EFHK 240650Z 16018G30KT **2000 -SN DRSN** OVC007 M04/M05 Q1009 BECMG 3000 -SN

- PNOWWA showed only slight indication of snow starting from 8:15 (10-20% prob).
- Yet it was snowing moderately + drifting snow, visibility about 2 km in METARs even at 6:50. At 8:20 METAR visibility was 1300 m
- Accumulation of snow was 1 cm/h = 2-3 mm/15 minutes

-> So in this case PNOWWA-observation and forecasts clearly underestimated the intensity of snow and didn't recognize the beginning of it. Drifting isn't taken into account in PNOWWA

EFHK 24.1.2018 8:00 UTC

- high probabilities for over 1 mm/15 min but bellow 5 mm snow accumulation (0,4-1,2 cm/h class).
- snow rate has increased and will stay moderate at least next 1-2 hours ahead. That fits well the



__At that time PNOWWA forecasted well the amount and timing of snow yet the probabilities decreased to the end of period__. The heavy snow continued to the end of forecasting period yet the probabilities decreases clearly.

EFHK 24.1.2018 9:15 UTC

Metar time	METAR visibility	8:45 PNOWWA	9:15 PNOWWA
8:50	0700	1500-3000	-
9:20	0700	1500-3000	1500-3000
9:50	1200	Over 3000	Over 3000
10:20	0700	Over 3000	Over 3000
10:50	1100	Over 3000	Over 3000
11:20	1000	1500-3000	1500-3000
11:50	1900	Over 3000	Over 3000
12:20	1500	Over 3000	Over 3000
12:50	1800	Over 3000	Over 3000
13:20	2500	Over 3000	Over 3000

In the table above it is presented visibility in METAR and most probably visibilities forecasted by PNOWWA.
In that case __Tower product under estimated visibility one METAR class__. __The timing of changes in visibility seems to be logical with PNOWWA. Remark that part f visibility decrease is caused by drifting snow.__

EFHK 24.1.2018 10:45 UTC

- PNOWWA forecasted the end of more than 1 mm/15 min snow about 11:15 as it happened also in METARs.
- Clear indications of coming freezing period after 2 hours starting at 12:30 UTC.
- METARs shows __that freezing drizzle started one hour later than forecasted__

EFHK 24.1.2018 13:30 UTC

13:30 UTC PNOWWA products estimates freezing period to be 2 hours from 14 to 16 UTC. In METARs it was observed between 13:50-15:20, so the __timing of frezing in PNOWWA was very good. Probability__ of freezing rain was estimated with 40% which is __nearly equal to__ 30% forecasted in __TAF__.

EFHK 24.1.2018

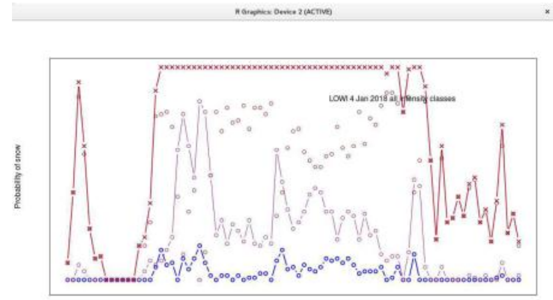
Conclusions of that day PNOWWA demonstration product quality :

- __So PNOWWA-observation and forecasts clearly underestimated the strength of snow in early morning, but later the strength corresponded well with the measured accumulation of snow__
- __PNOWWA forecasted well the timing of changes of the intensity in snow rate, but it didn't recognize properly the start of snow.__
- __PNOWWA had tendency to forecast lower probabilities in the end of forecasting time than in nearest minutes.__
- __Tower product under estimated visibility__
- __Timing and rate of probability of freezing phenomena was forecasted well__

Temperature and intensity

Rudolf Kaltenbock continues….

LOWI 04.1.2018



X-axis: Start-End 00-24
Y-axis: 0-100% (95% as you state: end never 100% for 1mm/15min)

Time series of different intensities. x=15 min o=30 min forecast.
Probability of over 10 mm/15 min was always smaller than 20%.
Probability of at least 1 mm/15 min matches shows clearly start and end but never 100%
Probability of at least 5 mm/15 min was something in between.

LOWI 04.Jan 2018
wrong SN predicted - RASN only (no RWY contamination)

12:50

13:20

15:40

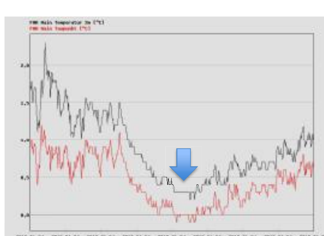
ICAO has defined the types of snow as follows
- Dry snow – can be blown if loose or compacted by hand, will fall apart again upon release.
- Wet snow – can be compacted by hand and will stick together and tend to form a snowball.
- Compacted snow – can be compressed into a solid mass that resists further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

Method used in PNOWWA as defining the wetness of snow. No sleet in algorithm used. Also more sophisticated methods exists, but no used.

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

LOWI 04.Jan 2018
RASN

SAOS54 LOWI 041320 METAR LOWI 041320Z 28008KT 4000 RASN FEW002 SCT010 BKN022 00/00 Q1005 R08/29//95 TEMPO 6000 RASN=



here too low vis predicted
opposite than usal in case of SN

LOWI 4.Jan 2018

Conclusions: proper temperature information needed

APOC react even without snow

LOWW 13-14.Jan 2018
wet instead of dry snow

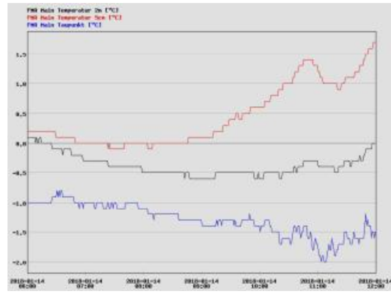
RUNWAY MAINTENANCE (UPDATED 2018-01-14 08:30:00 UTC)

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	0	30	60	60	60	70	70	70	60	30	20	10	0
less than 1 mm	100	70	40	50	40	30	30	30	40	70	80	90	100
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

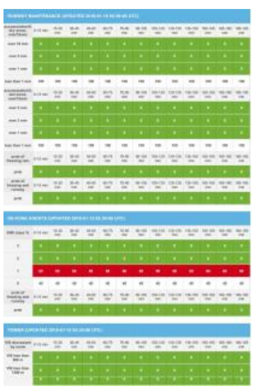
SAOS51 LOWW 130850 METAR LOWW 130850Z 33008KT 2100 -DZ BR SCT003 BKN004 00/00 Q1027 R88/29//95 TEMPO 3000 BKN005=

VIE surface temperature 1-2 °C; air temp. >0°C

LOWW 13-14.Jan 2018
wet instead of dry snow



LOWW 14-15.Jan 2018
freezing wet runway missed



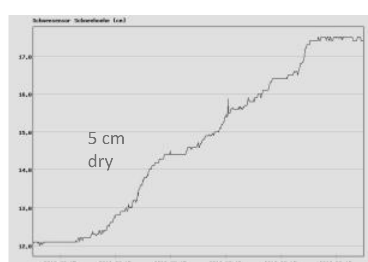
LOWW 14-15.Jan 2018
freezing wet runway

Standort	Datum	Zeit	Boden	B.t Trend	Status	Zustand	Luft	L.t Trend	Tau-punkt	Tief 5	Tief 15	Tief 35	Nieder-schlag	Ausfall
A9	15.01.2018	05:39	-3,3	⬇	Standby	Chemisch	-2,5	⬇	-2,5					

surface temperature needed (cloud cover)

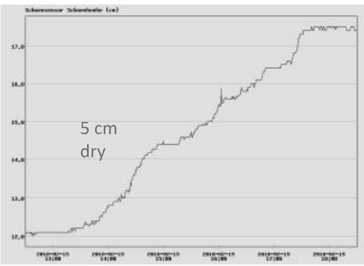
timing

LOWI 15.Feb 2018
start of SN missed



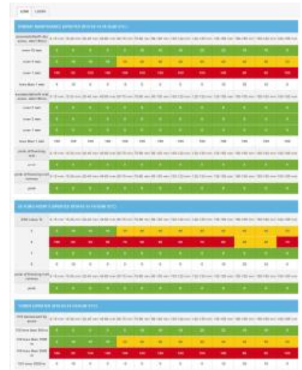
LOWI 15.Feb 2018
13:45 UTC: start of SN missed

WXR signal available



LOWI 15.Feb 2018

14:15 UTC SN included



15:15UTC end of snowfall

LOWI 15.Feb 2018

13:20 UTC

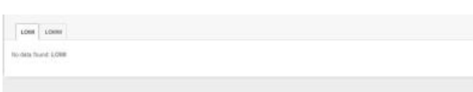
14:00UTC

14:20 UTC

LOWI 15.Feb 2018

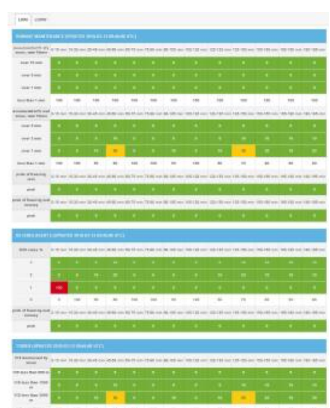
16:00 UTC

LOWI 15.Feb 2018
16:16UTC
technical



Compare to missing browser update (old Java)

Singular jumps
e.g LOWW DIW



more happen in mountainous areas

Conclusions of PNOWWA case studies/verification

- Even the Andersson method forecasts pretty well the timing of precipitation. Yet there is also cases when it misses the beginning of precipitation and sometimes shows too early end of precipitation.
- Some amount of under forecasting is recognized in the strength of snow
- The level of probability of the snow seems to be in right scale and results are logical when compared to the observations. PNOWWA demo product seems to decreases the probability of snow to the end of forecasting period.
- Tower product under estimated visibility one METAR class
- The form of snow (wet/dry) algorithm needs improvements. Also more accurate observations than METARs are needed. Surface temperature and runway condition model would be useful tool for improve maintenance product.
- Verification of other methods on duty.

-> PNOWWA PRODUCT GIVE VALUE FOR AIRPORT OPERATIONS, BUT THERE IS STILL ROOM FOR DEVELOPMENT

PNOWWA Probabilistic Nowcasting of Winter Weather for Airports

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

AIRCRAFT DEICING/ANTI-ICING

Presentation
PNOWWA Project &
Stakeholder Workshop

General

Aircraft operators have to adhere to the

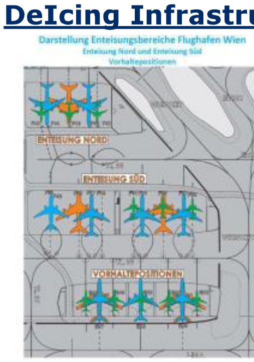
Clean Aircraft Concept

Aircraft has to be free of frozen contaminants during take off

Deicing:	Removal of frozen contaminants from aircraft surfaces
Anti-Icing	Protection against the formation of frost, snow and ice on treated aircraft surfaces for a certain period

General

DeIcing Infrastructure



Dedicated deicing area:
Deicing North
- 3 Aircraft Stands (ICAO Cat. C)

Deicing South
- 5 Aircraft Stand (ICAO Cat. C)

Coordination:
Taxiing from parking position to deicing area is coordinated by ATC

Deicing Capacity

Capacity parameter
- weather condition
- condition of aircraft on deicing pad
- deicing procedure

Capacity during weather condition

- Frost	more than 50 aircraft per hour
- Freezing Precipitation	
Light	42 aircraft per hour
Moderate	30-35 aircraft per hour
Heavy	20- 30 aircraft per hour

Deicing fluids

Type 1 de-icing fluid
- Clariant Safewing MP I 1938 ECO (80)
- Non thickened fluid with 80% glycol and 20% water
- Removal of frozen contaminants from aircraft
- mixed with water;
- fluid mixtures 4%/96% to 69%/31% (v%/v%)

Type 4 de-icing fluid
- Clariant Safewing MP IV Launch
- Thickened fluid with 50% glycol; 49% water 1% thickener
- Protection against refreezing of aircraft surfaces for a certain period
- mixed with water
- fluid mixtures 50%/50%, 75%/25% and 100%/0% (v%/v%)

Deicing storage capacity

Fluid Storage capacity

- type 1 150.000 l
- type 4 140.000 l

Additional fluid stock

- from December to the mid of march
- 100.000 l of each fluid type

Day fluid stock will last in severe weather conditions

- type 1 3 to 4 days
- type 4 3 to 4 days

Deicing vehicles

Safeaero 220	
Number:	10
Nozzle height:	0,5-20m
Tankcapacity :	7200
T1	2100L
T4	1200L
H2O	3600L
T1 Fluid Mix:	4%-69%
T4 Fluid Mix:	50% 75% 100%
Throw range:	8m

Safeaero 223XXL	
number:	1
Nozzle height:	0,5- 23m
Tankcapacity:	13000L
T1	4000L
T4	2000L
H20	7000L
T1 Fluid Mix:	4%-69%
T4 Fluid Mix:	50% 75% 100%
Throw range:	8m

Vestergaard Elephant BETA	
number:	4
Nozzle height:	1,5- 19m
Tankcapacity:	8000
T1	2500L
T4	2000L
H20	3600L
T1 Fluid Mix:	15%-69%
T4 Fluid Mix:	100%
Throw range:	8m

Enteisungsfahrzeuge 2017/2018

Safeaero 220

Safeaero 223XXL

Vestergaard Elephant BETA

Weather impact /General

In regard to aircraft deicing the weather has an influence on 3 aspects

Handling: Short time staff planing

Airport: Collaborative Decision Making (CDM)

Airlines: Holdovertimes

Weather impact /short time staff planing

Deicing staff:

- 40 vehicle operators & 24 Icemen
- active frost: up to 10 operators and 6 Icemen per shift
- precipitation: up to 14 operators and 8 Icemen per shift

Short time planning horizon:

- daily check of weather situation for next day

Weather Criterias:

- OAT, humidity, precipitation

Goal:

- reliable weather forecast for an efficient short time deicing staff planning

Weather impact /CDM

Goal:

To optimize the utilisation of deicing area

To avoid long taxi times with running engines

Process (Winter ops)

ATC has to be informed about:

- number of permanent available deicing vehicles on deicing area
- number of available deicing positions
- weather factor

Considering this figures ATC is calculating CDM Times (e.g. TSAT)

Constant figures

- deicing vehicles/area

variable figure

- weather factor

Weather impact /CDM

Weather factors

variable part: deicing times

constant part: phase before/after deicing (communication,…)

Weather/Aircraft condition	Weather factor (deicing time ICAO class C)	
- Frost (little contaminants)	1	(6 min)
- Freezing mist/fog (little contaminants)	1,5	(7,5 min)
- Freezing fog/drizzle (little contaminants)	1,75	(8,4 min)
- Very light snowfall (little contaminants)	2	(9 min)
- Light snowfall (little/moderate contaminants)	2,5	(10,5 min)
- Moderate snowfall (moderate contaminants)	2,75	(11,3 min)
- Moderate snowfall (Turnaround)	3	(12 min)
- Moderate to heavy snowfall/Ice rain (Night Stop)	4/5	(15/18 min)

Weather impact /CDM

Determination of weather factor

- is determined visually by the deicing supervisor on the ramp for a certain period (e.g. departure peak)

Outcome/Experience after one month

- weather factor is subject to change within a short period
- impact on airport capacity and increase on taxi times

Weather impact /HOT

Holdovertime:

- Estimated time for which an anti-icing fluid will prevent the formation of frost, snow or ice on treated aircraft surfaces

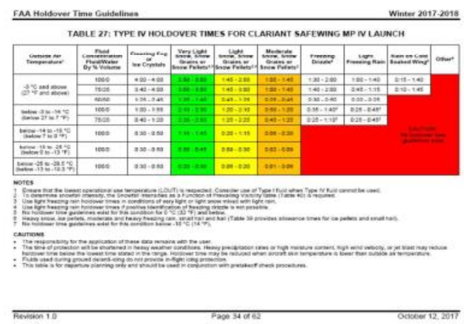
Present System

- Precipation rate for calculating HOT is based on visibility and weather situation and personal evaluation of involved parties.
- Last decision for Holdovertime is always up to the PIC

New advanced system (Austrian)

- precipitation rate is measured in real time referring to a liquid water equivalent system
- Precise Holdovertime is issued to PIC

Weather impact /HOT



FAA Holdover Time Guidelines — Winter 2017-2018

TABLE 27: TYPE IV HOLDOVER TIMES FOR CLARIANT SAFEWING MP IV LAUNCH

Outside Air Temperature[1]	Fluid Concentration Fluid/Water By % Volume	Freezing Fog or Ice Crystals	Very Light Snow, Snow Grains or Snow Pellets	Light Snow, Snow Grains or Snow Pellets	Moderate Snow, Snow Grains or Snow Pellets	Freezing Drizzle	Light Freezing Rain	Rain on Cold Soaked Wing	Other
-3 °C and above (27 °F and above)	100/0	[illegible]	[illegible]	[illegible]	[illegible]	1:30 - 2:00	1:00 - 1:40	0:15 - 1:40	[illegible]
	75/25	3:40 - 4:00	[illegible]	[illegible]	[illegible]	1:40 - 2:00	0:45 - 1:15	0:10 - 1:45	
	50/50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
below -3 to -14 °C (below 27 to 7 °F)	100/0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	75/25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
below -14 to -18 °C (below 7 to 0 °F)	100/0	0:30 - 0:50	[illegible]	[illegible]	[illegible]				
below -18 to -25 °C (below 0 to -13 °F)	100/0	0:30 - 0:50	[illegible]	[illegible]	[illegible]				
below -25 to -29.5 °C (below -13 to -13.3 °F)	100/0	0:30 - 0:50	[illegible]	[illegible]	[illegible]				

NOTES

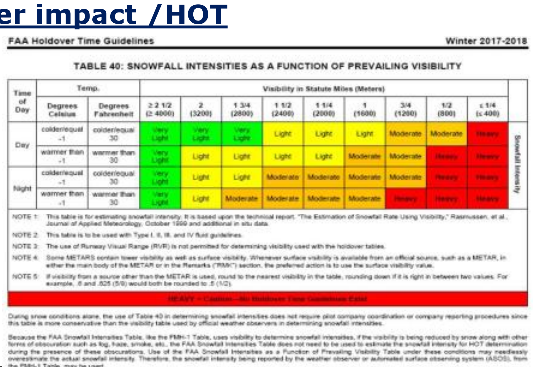
[illegible]

CAUTIONS

[illegible]

Revision 1.0 — Page 34 of 62 — October 12, 2017

Weather impact /HOT



FAA Holdover Time Guidelines — Winter 2017-2018

TABLE 40: SNOWFALL INTENSITIES AS A FUNCTION OF PREVAILING VISIBILITY

Time of Day	Temp. Degrees Celsius	Temp. Degrees Fahrenheit	≥ 2 1/2 (≥ 4000)	2 (3200)	1 3/4 (2800)	1 1/2 (2400)	1 1/4 (2000)	1 (1600)	3/4 (1200)	1/2 (800)	≤ 1/4 (≤ 400)
Day	colder/equal -1	colder/equal 30	Very Light	Very Light	Very Light	Light	Light	Light	Moderate	Moderate	Heavy
Day	warmer than -1	warmer than 30	Very Light	Light	Light	Light	Light	Moderate	Moderate	Heavy	Heavy
Night	colder/equal -1	colder/equal 30	Very Light	Light	Light	Moderate	Moderate	Moderate	Moderate	Heavy	Heavy
Night	warmer than -1	warmer than 30	Very Light	Light	Moderate	Moderate	Moderate	Moderate	Heavy	Heavy	Heavy

Visibility in Statute Miles (Meters) — Snowfall Intensity

NOTE 1: This table is for estimating snowfall intensity. It is based upon the technical report, "The Estimation of Snowfall Rate Using Visibility," Rasmussen, et al., Journal of Applied Meteorology, October 1999 and additional in situ data.

NOTE 2: This table is to be used with Type I, II, III, and IV fluid guidelines.

NOTE 3: The use of Runway Visual Range (RVR) is not permitted for determining visibility used with the holdover tables.

NOTE 4: Some METARS contain tower visibility as well as surface visibility. Whenever surface visibility is available from an official source, such as a METAR, in either the main body of the METAR or in the Remarks ("RMK") section, the preferred action is to use the surface visibility value.

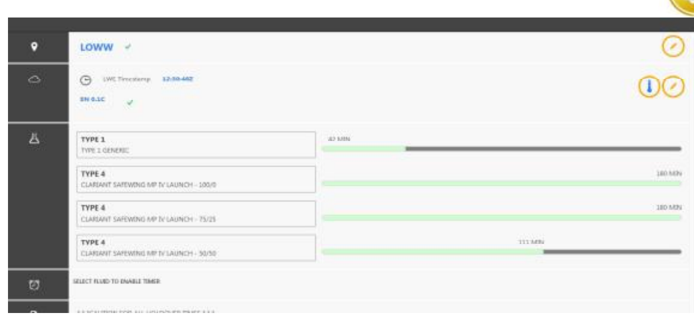
NOTE 5: If visibility from a source other than the METAR is used, round to the nearest visibility in the table, rounding down if it is right in between two values. For example, .6 and .625 (5/8) would both be rounded to .5 (1/2).

HEAVY = Caution—No Holdover Time Guidelines Exist

During snow conditions alone, the use of Table 40 in determining snowfall intensities does not require pilot company coordination or company reporting procedures since [illegible]

[illegible]

Weather impact /HOT



Weather impact /HOT

Advantage of liquid water equivalent systems

All involved party in deicing process will have the same information about the weather leading to a reduction in communication before deicing

Benefits : increase of airport capacity
reduction of operational costs for airlines
reduction of CO_2 fingerprint

Vision of liquid water equivalent systems

Not to talk about the weather situation but talking about required Holdovertimes which is based on a holdovertime determination system

PNOWWA Workshop, 27-28 February 2018 in Vienna, Austria

Needs and expectations of winter weather forecasts at Munich airport

(sbp by Munich Airport)

Thomas Gerz
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt
DLR Oberpfaffenhofen

Wissen für Morgen

DLR

WHITE winter hazards in terminal environment

The Meteorological Nowcast System WHITE for Munich Airport

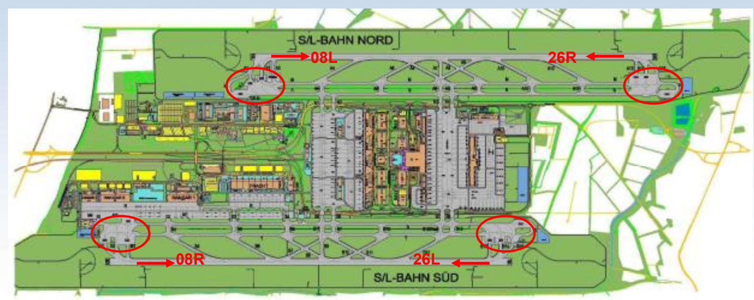
F. Keis 2015: WHITE – Winter hazards in terminal environment: An automated nowcasting system for Munich Airport. Meteorol Z. **24**, No.1, 61-82, doi:10.1127/metz/2014/0651

- ✓ Combination of various data sources
- ✓ Consideration of most hazardous winter weather scenarios
- ✓ Algorithms based on Fuzzy Logic
- ✓ Computation of winter weather objects (WWO)
- ✓ Direct contact to users/customers
- ✓ Visualisation of Nowcast results
- ✓ Additional data for scenario correction and validation

DLR LMU

EFM

De-icing areas at Munich Airport



WHITE winter hazards in terminal environment

The Meteorological Nowcast System WHITE for the terminal area of Munich airport

Nowcast for up to 2hrs:
- Snow
- Mixed Precipitation
- Freezing Precipition
- Ice Pellets
- Icing
- Surface Conditions

horizontal res. 2.8 km

temporal res. 15min

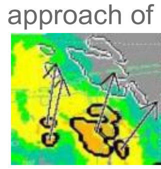
Nowcasting:
+15min
+30min
+60min
+120min

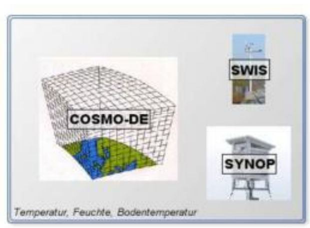
DLR

WHITE winter hazards in terminal environment

The Nowcast approach of WHITE

➢ Determination of displacement vectors from radar data





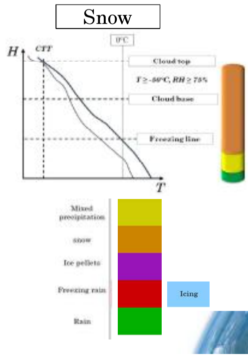
➢ Correction of First-Guess NWP forecasts by assimilation of observation data
➢ Determination and consideration of temperature and humidity trends at observation sites
➢ Adapted Blending of Trend and NWP forecasts

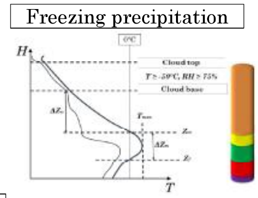
Corrected analysis fields plus derived nowcast fields (temperature, humidity, surface temperature, reflectivity)

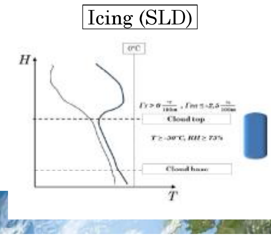
DLR

Definition of vertical winter weather objects

- *precipitation/icing analysis in each layer and*
- *analysis of surface condition result in*
- ➢ *vertically resolved winter weather objects*
- ➢ *for a given location and given instants of time*

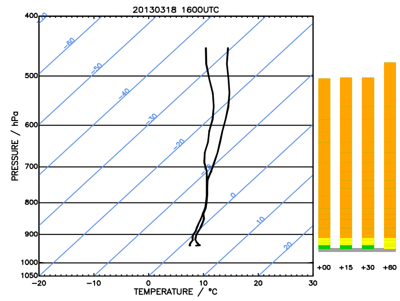




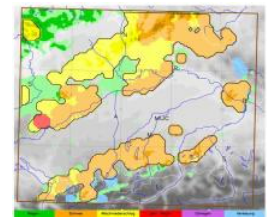


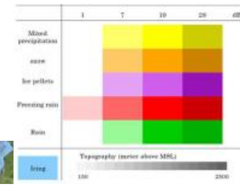
Classification and horizontal weather objects

Classification of winter weather at each grid point and for each nowcast field on the basis of the fuzzy-indicators



Aggregation of identically classified pixel in same height layer to horizontal winter weather objects

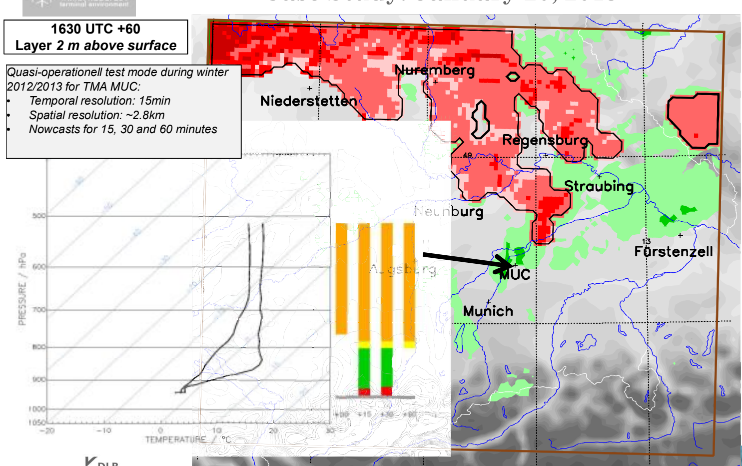




Case Study: January 20, 2013

1630 UTC +60
Layer 2 m above surface

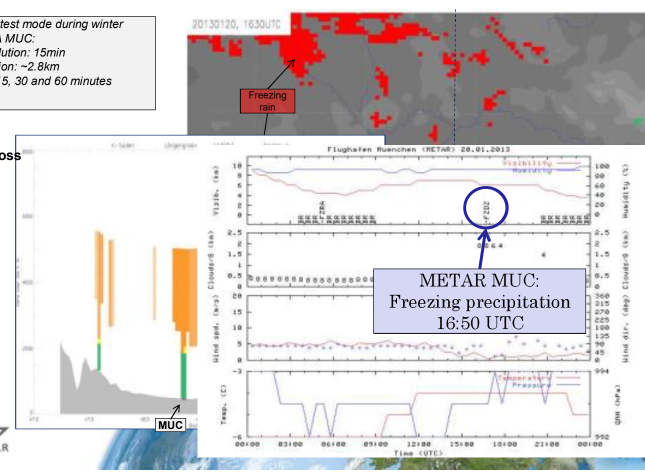
Quasi-operationell test mode during winter 2012/2013 for TMA MUC:
- *Temporal resolution: 15min*
- *Spatial resolution: ~2.8km*
- *Nowcasts for 15, 30 and 60 minutes*



Case Study: January 20, 2013

Quasi-operationell test mode during winter 2012/2013 for TMA MUC:
- *Temporal resolution: 15min*
- *Spatial resolution: ~2.8km*
- *Nowcasts for 15, 30 and 60 minutes*

Analysis:
North-South cross section



The participatory sensing concept: DLR campaigns in winter 2012/2013 and 2013/2014

Basics of the campaign:
- Quasi-operational test of WHITE
- During the winter months (December – March)
- Selected group of participants
- Output of the Nowcast system on WHITE-Webpage

Source: DFS

Source: DFS

Participants of the campaign:

DFS Deutsche Flugsicherung

The WHITE questionnaire for the DLR campaigns in winters 2012/2013 and 2013/2014

Dr. Arnold Tafferner, Tel.: 08153 281216
Institut für Physik der Atmosphäre
Oberpfaffenhofen

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Fragebogen zum DLR Winterwetternowcasting 2015/2016
Bitte ausfüllen (ganz oder teilweise) und senden an arnold.tafferner@dlr.de

Datum: ☐ Uhrzeit (UTC): ☐

Testanwender: ☐ FMG ☐ DFS/Center ☐ DFS/Tower ☐ LH HOC ☐ DWD ☐ Sonst

1. Sind die WHITE Analysen und das Nowcasting zutreffend (z.B. Schnee, Gefrierender Regen)?

☐ ja ☐ nein (bitte ankreuzen)

Kommentar? (wenn möglich mit genauer Angabe von Datum und Zeit)

2. Ist die Art der Darstellung gut? (z.B. übersichtlich, lesbar, interpretationsfrei)

☐ ja ☐ nein (bitte ankreuzen)

Verbesserungsvorschläge?

3. Ist das WHITE Produkt hilfreich? (z.B. zur Planung und Abwicklung der Betriebsabläufe)

☐ ja ☐ nein (bitte ankreuzen)

Warum?

Conclusion

- More winter campaigns are pre-requisite before a sound assessment of WHITE
- For nowcast a “seamless” observation and prediction of (3d) weather (objects) are required …

- **Observation**	**recent past, now, and upstream**
- **Nowcast**	**minutes, up to 1 or 2 hours**
- **Deterministic forecast**	**24 hours, several days**
- **Probabilistic forecast**	

… not only for winter weather but also for

- thunderstorms
- in-flight icing
- turbulence (CAT)
- aircraft wake vortex
- volcanic ash cloud
- … and climate-sensitive regions

⇒ 5D MET Advisory @ DLR

Klaus Sievers, Arbeitsgruppe Air Traffic Services, 2/2018

Winter flight operations- pilots´ view

Basics

Mother

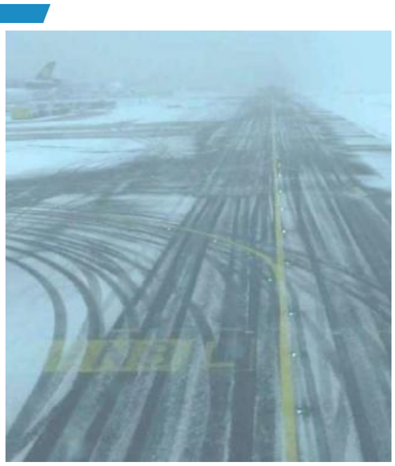
Nature

is

stronger.

ACCEPT IT –
and ANTICIPATE

The Risks: a selection



> **low braking performance during takeoff / landing**

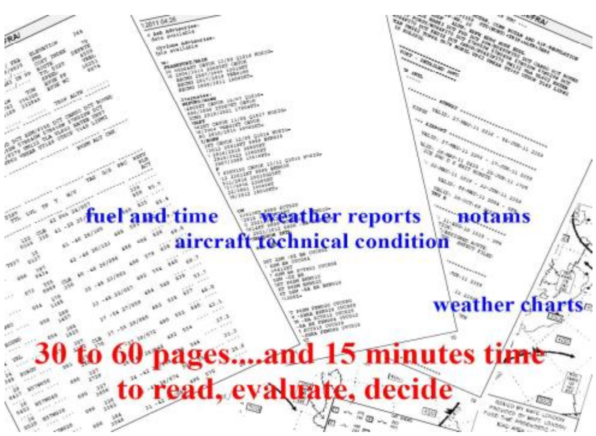
- **steering capability**
- **reduced**

The Risks: a selection

- Longer takeoff roll to liftoff
- Failure to liftoff
- Lift-off, but no climb capability
- Climb, but then roll or pitch uncontrollably
- Engine power loss or failure

https://aircrafticing.grc.nasa.gov/

Flightplanning today:



Using an eFB ? Information amount/content is unchanged.

Flightplanning today: Takeoff-/ Landing Performance Calculation

```
ATIS EDDF R SPECI 210927 SR: 0625 SS:
1654 CTR: IMC
EXPECT ILS APCH RWY 25R OR 25L
RWY: 25R 25L 18
RCR FROM 0 8 5 0 : RWY 25R TDZ WET , BA
6 1 , MID BA 5 3 , 3 0 PERCENT 5 MM WET
SN , STOPEND BA 4 5 , 8 0 PERCENT 5 MM
WET SN , RWY 25L , TDZ WET , BA 6 4 ,
MID BA 5 8 , 3 0 PERCENT SLUSH , STOPEND
BA 5 6 , 8 0 PERCENT 5 MM WET S N , RWY
1 8 WET , BA GOOD , TWY AND APRON PARTLY
SLIPPERY , , DEPARTING ACFT VIA SID
BIBOS HAVE TO EXPECT RWY 18 FO R TKOF ,
.
TRL:70
, SNOW WARNING UNTIL 0 9 0 0 , SNOW ,
ACCUMULATION 1 TO 2 C M , FREQ FOR
DEPARTING ACFT VIA SID SOBRA IS 120.150
.
20007KT WIND 18: 19005G08KT/170V230 5000
BR FEW003 BKN004  01 /01
1002
BECMG BKN006
R18/////95
```

Considerations (example):

Maximum Crosswind Component	T/O	Landing
# Non Contaminated Runway	30 knots*	30 knots
Contaminated Runway		
# Standing Water / Slush / Loose Snow	15 knots	10 knots
# Ice / Compacted Snow	10 knots	10 knots

estimate rwy state for T/O & Landing !

check technical condition, e.g. reversers

State of the Art, 2018

TAF ENGM 0818/0918 VRB05KT 6000 -SN BKN012
TEMPO 0818/0906 2000 -SN BR OVC005
BECMG 0820/0822 18010KT
BECMG 0906/0908 BKN020=

TAF ENGM 0818/0918 VRB05KT 6000 -SN BKN012
TEMPO 0818/0906 2000 -SN BR OVC005

METAR ENGM 081650Z VRB01KT 4900 -SN BKN007 M07/M08 Q1010
TEMPO 2000 -SN BKN010=

METAR ENGM 081720Z 05003KT 350V100 5000 -SN BKN006 M06/M08
Q1010 TEMPO 2000 -SN=

METAR ENGM 081750Z VRB01KT 4300 -SN FEW004 BKN006 M06/M07
Q1010 TEMPO 2000 -SN=

ATIS: recording

State of the Art, 2018

SNOWTAM

```
• FROM: 08 FEB 2018 17:41
  A) ENGM
  B) 02081741 C) 01R
  F) 4/4/6 G) 8/8/3 H) 3/3/4
  B) 02081725 C) 01L
  F) 47/4/4 G) 8/XX/XX H) 3/4/4
  N) B8/7  B9/6  ALL REMAINING TWYS/47
  R) APRON NORWEGIAN/CLSD  ALL REMAINING APRONS/47
  T) RWY 01R
  CONTAMINATION/100/100/100/PERCENT.
  SAND APPLIED SECN A/B.
  FRICTION 4 ON TAXIWAYS.
  RWY 01L
  OBSERVATION TIME RWY 01L 201802081725
  CONTAMINATION/100/100/100/PERCENT.
  SLIPPERY PORTIONS ON CENTRAL APRON. SL
  PORTIONS ON GA APRONS. FRICTION 4 ON T
  AREA IS SANDED. ICY SPOTS ON TWY AND S
  APRON.
```

No Official Info

AERODROME	A
DATE/TIME OF OBSERVATION Time of completion of measurement in GMT	B
RUNWAY DESIGNATORS	C
CLEARED RUNWAY LENGTH (meters) if less than published length	D
CLEARED RUNWAY WIDTH (meters) if less than published length; If offset to the Left or Right of RWY center line add "L" or "R"	E
DEPOSITS OVER TOTAL RUNWAY LENGTH Observed on each third of the runway, starting from threshold having the lower RWY designation number NIL - CLEAR AND DRY 1 - DAMP 2 - WET or water patches 3 - RIME OR FROST COVERED (depth less than 1 mm) 4 - DRY SNOW 5 - WET SNOW 6 - SLUSH 7 - ICE 8 - COMPACTED OR ROLLED SNOW 9 - FROZEN RUTS OR RIDGES	F
MEAN DEPTH (mm) for each third of total RWY length	G
BRAKING ACTION on each third of RWY **MEASURING EQUIPMENT**	H

MEASURED OR CALCULATED COEFFICIENT or ESTIMATED BRAKING ACTION 0.40 and above — GOOD - 5 0.39 to 0.36 — MEDIUM/GOOD - 4 0.35 to 0.30 — MEDIUM - 3 0.29 to 0.26 — MEDIUM/POOR - 2 0.25 and below — POOR - 1 9 – unreliable — UNRELIABLE - 9 - When quoting a measured coefficient use the observed two figures, followed by the abbreviation of the measuring equipment used. - When quoting an estimate use single digits)	
CRITICAL SNOWBANKS If present, insert height (cm) / distance from the edge of runway (m) followed by "L", "R" or "LR" if applicable	J
RUNWAY LIGHTS If obscured, insert "YES" followed by "L", "R" or both "LR" if applicable	K
FURTHER CLEARANCE If planned insert length (m) / width (m) to be cleared or if to full dimensions, insert "TOTAL"	L
FURTHER CLEARANCE EXPECTED TO BE COMPLETED BY ... (GMT)	M
TAXIWAY If no appropriate taxiway is available, insert "NO"	N
TAXIWAY SNOWBANKS If more than 60 cm, insert "YES" followed by distance apart	P
APRON If unusable insert "NO"	R
NEXT PLANNED OBSERVATION/MEASUREMENT IS FOR ... day / month / hour in GMT	S
PLAIN LANGUAGE REMARKS including contaminant coverage and other operationally significant information, e.g. sanding, deicing	T

Encoding ?

https://tinyurl.com/yd7bypuw

State of the Art, 2018

6 mm ?

13 mm ?

!

Sample Ops Manual Slush/Standing Water Page

All Engine Data - 737-500 / 20K Rating

Weight Reductions – 1,000 Kg

Dry field /obstacle limit weight 1,000 kg	0.25 in (6 mm) slush/standing water depth			0.50 in (13 mm) slush/standing water depth		
	Airport pressure altitude			Airport pressure altitude		
	S. L.	4000 ft	8000 ft	S. L.	4000 ft	8000 ft
35	0.0	0.0	0.0	0.3	0.5	1.0
40	0.0	0.0	0.1	0.8	1.2	2.1
45	0.1	0.2	0.6	1.4	1.9	3.1
50	0.3	0.5	1.1	2.0	2.7	4.2
55	0.5	0.8	1.7	2.5	3.4	5.1
60	0.6	1.1	2.1	3.2	4.3	6.2

Boeing Info.. https://de.scribd.com/doc/36139142/Takeoff-Landing-on-Wet-Contaminated-and-Slippery-Runways

The future

Takeoff And Landing Performance Assessment (TALPA) 101

Federal Aviation Administration

Presented to: ACI-NA
By: Michael J. O'Donnell, A.A.E. Director, Airport Safety & Standards
Date: April, 2014

TALPA History

- **Excursion at Midway Dec 2005**
- **What is TALPA**
  - Landing distance assessment at time of arrival
  - Accounting for contaminated runways at the tir
  - Requirement needed to support those goals
- **FAA formed Aviation Rulemaking C**
  - Airplane Manufacturers
  - Regulatory Authorities
  - Other Organizations
  - Airplane Operat
  - Airport Operator
- **Recommendations provided to FAA in 2009**

TALPA Concept is to Standardize

- Methods for assessing runway conditions
- Reporting of braking action by pilots
- Reporting of runway conditions through airport operators, the NOTAM system, and ATC agencies
- Airplane performance data
- Before landing performance assessments
- Terms used in runway condition reports and performance data

Federal Aviation Administration 2

http://www.aci-na.org/sites/default/files/odonnell_1.pdf

The future

FAA Advisory Circular

91-79 A

TABLE 1-1. OPERATIONAL RUNWAY CONDITION ASSESSMENT MATRIX (RCAM) BRAKING ACTION CODES AND DEFINITIONS

Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	**RwyCC**	**Deceleration or Directional Control Observation**	**Pilot Reported Braking Action**
• Dry	6	---	---
• Frost • Wet (Includes damp and 1/8 inch depth or less of water) *1/8 inch (3mm) depth or less of:* • Slush • Dry Snow • Wet Snow	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
-15 °C and Colder outside air temperature: • Compacted Snow	4	Braking deceleration OR directional control is between Good and Medium.	Good to Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (any depth) over Compacted Snow *Greater than 1/8 inch (3 mm) depth of:* • Dry Snow • Wet Snow *Warmer than -15 °C outside air temperature:* • Compacted Snow	3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium
Greater than 1/8 inch (3 mm) depth of: • Water • Slush	2	Braking deceleration OR directional control is between Medium and Poor.	Medium to Poor
• Ice	1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
• Wet Ice • Slush over Ice • Water over Compacted Snow • Dry Snow or Wet Snow over Ice	0	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil

https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-79A_CHG_1.pdf

The future

European Aviation Safety Agency

Terms of Reference

for rulemaking task RMT.0704

Runway Surface Condition Assessment and Reporting

ISSUE 1

Issue/rationale

The International Civil Aviation Organization (ICAO), through State Letters AN 4/1.2.26-16/19 of 5 April 2016 and AN/27-16/28 of 5 May 2016, adopted Amendment 13 to ICAO Annex 14 and Amendment 1 to the Procedures for Air Navigation Services (PANS)-Aerodromes respectively. These amendments introduce provisions regarding the use of a global reporting format for assessing and reporting runway surface conditions, that will be applicable by November 2020. The amendments are expected to increase safety of operations on contaminated runways; therefore, the European Agency for Safety Aviation (EASA) is going to introduce them by amending Regulation (EU) No 139/2014 and the related acceptable means of compliance (AMC) and guidance material (GM).

FAA:
Introduced
For 2016/17
Winter.

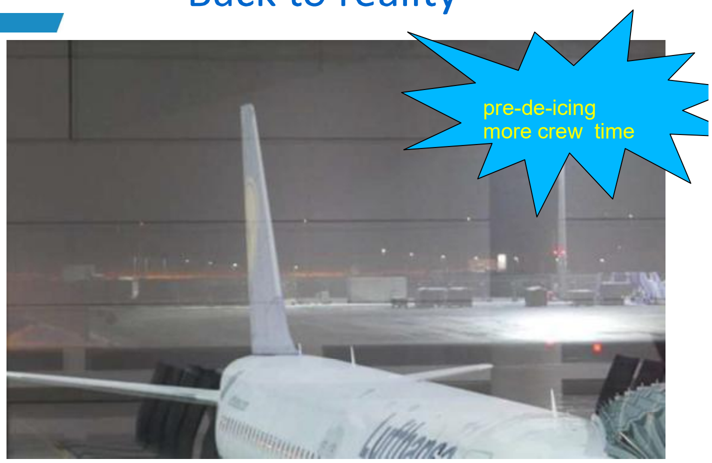
ICAO:
Introduced 2015/16,

APPLICABLE
11 / 2020

EASA plan:

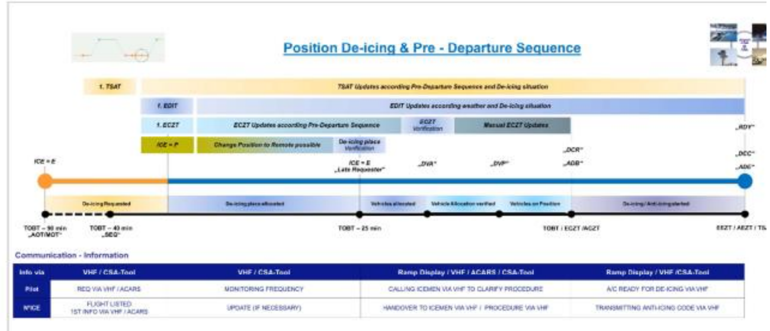
https://www.easa.europa.eu/sites/default/files/dfu/ToR%20RMT.0704%20Issue%201.pdf

Back to reality



Aircraf treatment: The Procedure

14. Anhang B - A-CDM Verfahrensposter



Pilot request: 40 – 90 min. **before de-icing !**

THE Big Guess: When are the aircraft **doors closed ?**

Frankfurt de-icing plan 2017/18 https://tinyurl.com/ybfwnlls

De-icing times: Benchmarks

15. Appendix C – Operational Benchmarks

A/C Category	1 Step: Fluid amount used in liters – Anti-icing	1 Step: Ø Duration in minutes (EDIT) – Remote	1 Step: Ø Duration in minutes (EDIT) – Position	2 Step: Fluid amount used in liters – Anti-icing	2 Step: Ø Duration in minutes (EDIT) – Remote	2 Step: Ø Duration in minutes (EDIT) – Position
A all types < 5,7 MTOW	250	10	11	200	13	14
B AT42/72, B461/2/3, CRJ1 - CRJ9, DH8A/B/C/D, E135 to E195, F50, RJ1H, RJ70, RJ85 and similar size	310	10	11	220	22	24
C A318 to A321, B727, B737, DC9, F70, F100, MD80, MD90, YK42 and similar size	370	11	13	280	23	25
D A310, B757, DC8, T154 and similar size	530	13	14	420	24	26
E A300, B767, IL76, IL86 and similar size	730	13	14	530	28	31
F A330, A342/3, B772, DC10, IL96, MD11 and similar size	840	14	15	660	22	24
G A346, B747, B773 and similar size	1010	16	18	770	30	32
H A380 and similar size	2300	18	19	1300	43	47

Please be advised that no responsibility is taken for the accuracy of the information provided above. The de/anti-icing duration times and fluid amounts used merely reflect empirical averages of the last years and do not take into consideration varying weather, contamination, precipitation and temperature conditions. For operational processes it is necessary to use the specific duration of deicing/anti-icing time (EDIT). The data used has been provided by N*ICE and based on statistical averages for past years of operation. The duration of deicing/anti-icing is based on the used procedure, preparation time, deicing/anti-icing area and the weather situation.

Notice: deicing process: Preparation time (position = 20 min. remote deicing = 10 min.) + duration (EDIT)

Duration
for holdover
calculations:

1 Step work: 17 min

Frankfurt de-icing plan 2017/18 https://tinyurl.com/ybfwnlls

The fluids, basics

FLUID (ALL SAE)	FLUID COLOR	SAMPLE HOT FOR SNOW (HR:MIN)	MINIMUM ROTATION SPEED
TYPE I	RED-ORANGE	0:06 - 0:11	NO MINIMUM
TYPE II	CLEAR OR STRAW	0:20 - 0:45	100 KNOTS
TYPE III	YELLOW-GREEN	0:10 - 0:20	60 KNOTS
TYPE IV	EMERALD GREEN	0:35 - 1:15	100 KNOTS

SAMPLE

Note:
some airports / fluid brands have higher performance

THIN, low temperature ok

Thickened,
a little precipitation ok

rare, almost not used

higher viscosity than type 2,
can take more precipitation

graphic : https://aircrafticing.grc.nasa.gov/2_3_3_1.html

The fluids, practical science

Transport Canada Holdover Time Guidelines **Winter 2017-2018**

TABLE 2: HOLDOVER TIMES FOR SAE TYPE I FLUID ON CRITICAL AIRCRAFT SURFACES COMPOSED PREDOMINANTLY OF ALUMINUM

Outside Air Temperature[1,2]	Freezing Fog or Ice Crystals	Very Light Snow, Snow Grains or Snow Pellets[3,4]	Light Snow, Snow Grains or Snow Pellets[3,4]	Moderate Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[5]	Light Freezing Rain	Rain on Cold Soaked Wing[6]	Other[7]
-3°C and above (27°F and above)	0:11 - 0:17	0:18	0:11 - 0:18	0:06 - 0:11	0:09 - 0:13	0:04 - 0:06	0:02 - 0:05	CAUTION: No holdover time guidelines exist
below -3 to -6°C (below 27 to 21°F)	0:08 - 0:13	0:14	0:08 - 0:14	0:05 - 0:08	0:05 - 0:09	0:04 - 0:06		
below -6 to -10°C (below 21 to 14°F)	0:06 - 0:10	0:11	0:06 - 0:11	0:04 - 0:06	0:04 - 0:07	0:02 - 0:05		
below -10°C (below 14°F)	0:05 - 0:09	0:07	0:04 - 0:07	0:02 - 0:04				

NOTES
1 Type I fluid / water mixture must be selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 To determine snowfall intensity, the Snowfall Intensities as a Function of Prevailing Visibility table (Table 40) is required.
4 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
5 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
6 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
7 Heavy snow, ice pellets, moderate and heavy freezing rain, small hail and hail.

CAUTIONS
- These holdover times apply to aircraft with critical surfaces constructed predominantly or entirely of aluminum materials that have demonstrated satisfactory use of these holdover times.
- The responsibility for the application of these data remains with the user.

EXAMPLE: light snow, -8 C Holdover-time= 6-11 minutes

The fluids, practical science

Transport Canada Holdover Time Guidelines **Winter 2017-2018**

TABLE 4: GENERIC HOLDOVER TIMES FOR SAE TYPE II FLUIDS

Outside Air Temperature[1]	Fluid Concentration Fluid/Water By % Volume	Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets[2,3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3°C and above (27°F and above)	100/0	0:55 - 1:45	0:25 - 0:50	0:35 - 1:05	0:25 - 0:35	0:07 - 0:45	CAUTION: No holdover time guidelines exist
	75/25	0:25 - 0:55	0:15 - 0:25	0:15 - 0:40	0:10 - 0:20	0:04 - 0:25	
	50/50	0:15 - 0:25	0:05 - 0:10	0:08 - 0:15	0:06 - 0:09		
below -3 to -14°C (below 27 to 7°F)	100/0	0:30 - 1:05	0:15 - 0:30	0:20 - 0:45[7]	0:15 - 0:20[7]		
	75/25	0:25 - 0:50	0:08 - 0:20	0:15 - 0:25[7]	0:08 - 0:15[7]		
below -14 to -18°C (below 7 to 0°F)	100/0	0:15 - 0:35	0:06 - 0:20				
below -18 to -25°C (below 0 to -13°F)	100/0	0:15 - 0:35	0:02 - 0:09				
below -25°C to LOUT (below -13°F to LOUT)	100/0	0:15 - 0:35[8]	0:01 - 0:06[8]				

NOTES
1 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I fluid when Type II fluid cannot be used.
2 To determine snowfall intensity, the Snowfall Intensities as a Function of Prevailing Visibility table (Table 40) is required.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, small hail and hail.
7 No holdover time guidelines exist for this condition below -10°C (14°F).
8 If the LOUT is unknown, no holdover time guidelines exist below -25°C (-13°F).

CAUTIONS
- The responsibility for the application of these data remains with the user.

Example: light snow , - 8 C Holdover time = 100% = 15-30 min.
= 75% = 08-20 min.

The fluids, practical science

Transport Canada Holdover Time Guidelines — Winter 2017-2018

TABLE 20: GENERIC HOLDOVER TIMES FOR SAE TYPE IV FLUIDS

Outside Air Temperature[1]	Fluid Concentration Fluid/Water By % Volume	Freezing Fog or Ice Crystals	Very Light Snow, Snow Grains or Snow Pellets[2,3]	Light Snow, Snow Grains or Snow Pellets[2,3]	Moderate Snow, Snow Grains or Snow Pellets[2]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3°C and above (27°F and above)	100/0	1:15 - 2:40	2:00	1:10 - 2:00	0:35 - 1:10	0:40 - 1:30	0:25 - 0:40	0:08 - 1:10	
	75/25	1:25 - 2:40	2:00	1:15 - 2:00	0:40 - 1:15	0:50 - 1:20	0:30 - 0:45	0:09 - 1:15	
	50/50	0:25 - 0:50	0:40	0:25 - 0:40	0:10 - 0:25	0:15 - 0:30	0:09 - 0:15		
below -3 to -14°C (below 27 to 7°F)	100/0	0:20 - 1:35	1:20	0:45 - 1:20	0:25 -	0:25 - 1:20[7]	0:20 - 0:25[7]		
	75/25	0:30 - 1:10	1:40	0:45 - 1:40	0:20 - 0:45	1:05[7]	0:15 - 0:25[7]		
below -14 to -18°C (below 7 to 0°F)	100/0	0:20 - 0:40	0:40	0:20 - 0:40	0:06 - 0:20				
below -18 to -25°C (below 0 to -13°F)	100/0	0:20 - 0:40[8]	0:20[8]	0:09 - 0:20[8]	0:02 - 0:08[8]				
below -25°C to LOUT (below -13°F to LOUT)	100/0	0:20 - 0:40[8]	0:20[8]	0:06 - 0:20[8]	0:01 - 0:06[8]				

NOTES
1 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I fluid
2 To determine snowfall intensity, the Snowfall Intensities as a Function of Prevailing Visibility table
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, small hail and hail (Table 39 provides allowance times for ice and small
7 No holdover time guidelines exist for this condition below -10°C (14°F).
8 If the LOUT is unknown, no holdover time guidelines exist below -22.5°C (-8.5°F).

CAUTIONS
- The responsibility for the application of these data remains with the user.

De- and anti-icing give a small takeoff time window: rwy has to be available & cleared !

Example: light snow , - 8 C **Holdover time = 100% = 45 - 80 min.**
= 75% = 45 – 100 min.

Aircraft treatment: old style

https://jalopnik.com/how-and-why-we-de-ice-aircraft-before-takeoff-1657914108

State of the Art !

State of the Art !

15-Minute
de- & anti-Icing
for
747
in Denver

4 trucks…
READY & WAITING
to go to work

We need sufficient de-icing capacity to handle ALL planned flights

Case : a flight to frozen

Frankfurt - 2013

Anticipation

Am Frankfurter Flughafen geht nichts mehr

Gefrierender Regen hat den Flugbetrieb in Frankfurt am Main lahmgelegt. Seit 16 Uhr 20 können die Maschinen weder abheben noch landen. Der Verkehr an Europas drittgrösstem Luftdrehkreuz kommt zum Erliegen.

20.1.2013, 18:25 Uhr

Eine Maschine wird am Sonntag, 20. Januar 2013, am Flughafen in Frankfurt a. M.

MEISTGELESEN IM RESSORT

Die Schweiz friert am kältesten Morgen dieses Winters
13.2.2018, 06:30 Uhr

Pfadfinderin verkauft schachtelweise Kekse neben Marihuana-Laden
13.2.2018, 10:16 Uhr

Der schiefe Turm von San Francisco

20 JAN 2013 - but not known to pilots

Anticipation

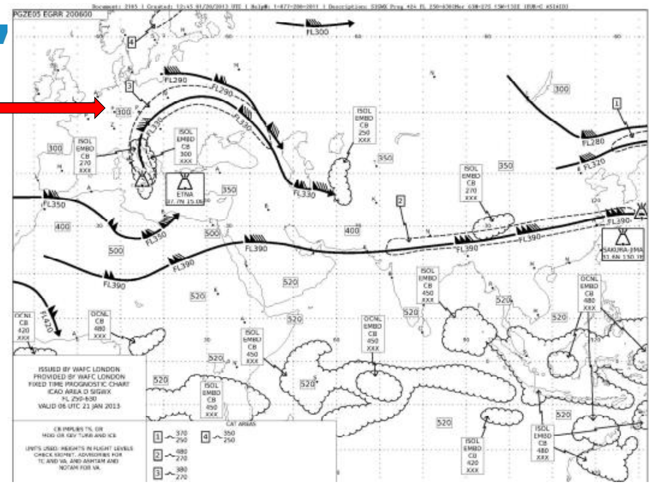
TAF EDDF 201700Z 2018/2124 05006KT 6000 -SN SCT008 BKN015
PROB40
TEMPO 2018/2020 4000 FZRA BKN008
TEMPO 2020/2105 2000 SN VV003
TEMPO 2105/2110 1200 -SN BR BKN002
BECMG 2105/2107 VRB03KT
TEMPO 2110/2124 4000 -SN BR BKN008

Anticipate severe winter weather for landing at approx. 06:00z ??

Not from this forecast, for a landing at 06z.

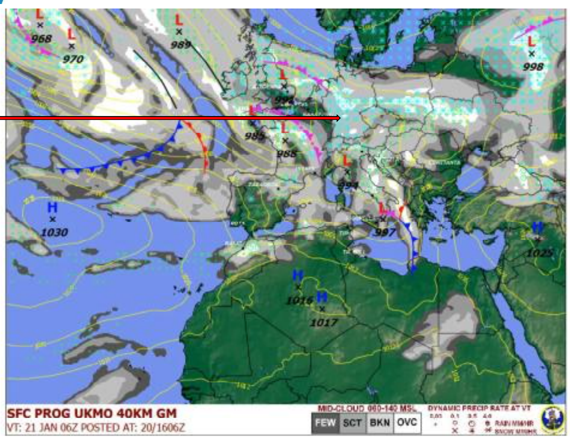
EDDF

No snow in this chart….



Anticipation

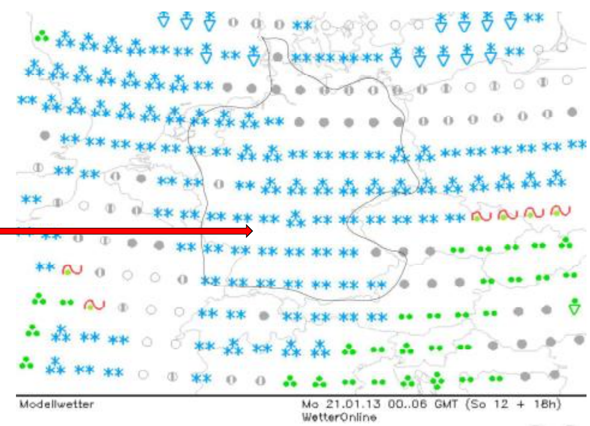
EDDF



NOT APPROVED FOR USE IN AVIATION

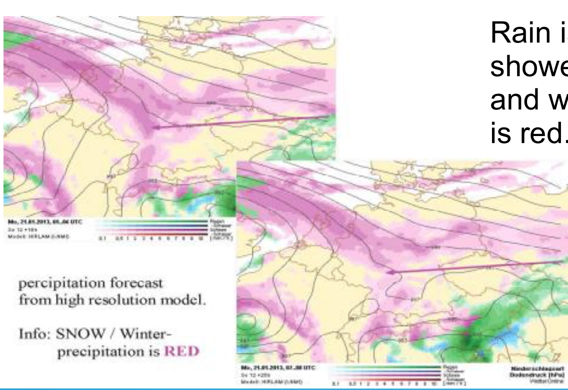
Anticipation

EDDF



NOT APPROVED FOR USE IN AVIATION

Anticipation



Rain is green, showers are blue, and winter weather is red.

NOT APPROVED FOR USE IN AVIATION

Anticipation

```
.D-ABVW ---- DLH757       21JAN13 0654Z
ATIS FRA

ARR-ATIS EDDF Z METAR 210650
EXPECT ILS  APCH RWY 25L
RWY 25L
RWY COND RWY 25L AT TIME 0620 3MM WET
SNOW CONTAMINATION 100 PERCENT BA TDZ 1
MID 22 END 20 TWYS AND APRON SLIPPERY ,
USE CAUTION , RWY EXITS SLIPPERY ,
TRL 70
ATTN WEATHER WRNG VALID UNTIL 1000 SNOW
1 CM
21004KT
2700
-SN FEW001 BKN003
TM01 DPM01
QNH998 QFE985
TREND TEMPO SN
```

ATIS confirmed forecast weather conditions.

Note WRNG: 1cm SNOW in 3 hours !

AIRPORT WAS OPEN, BUT ARRIVAL- AND DEPARTURE RATE WAS SET TO 0 (ZERO)

Anticipation

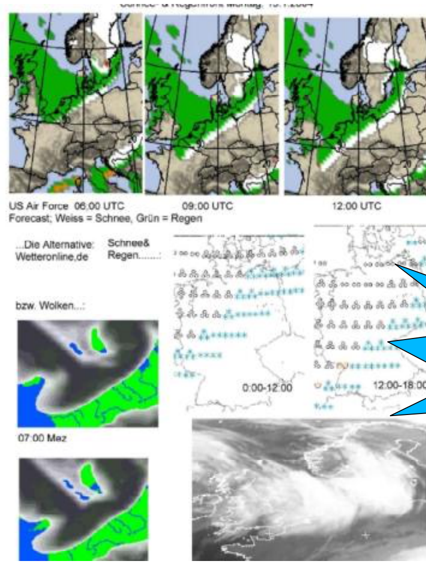
Mother

Nature

is

stronger.

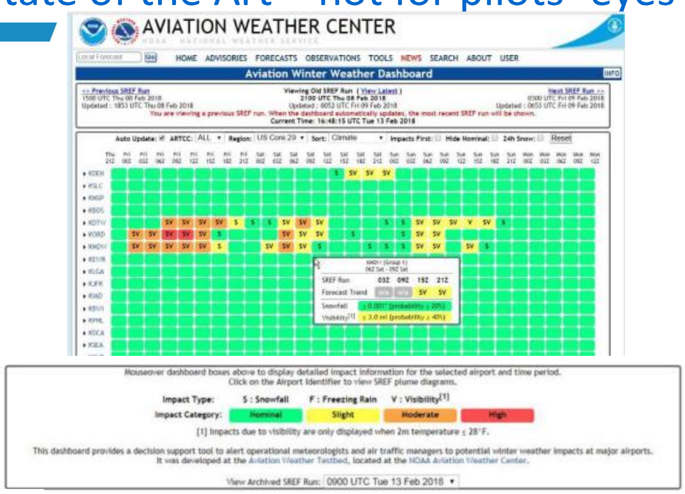
ACCEPT IT –
and ANTICIPATE



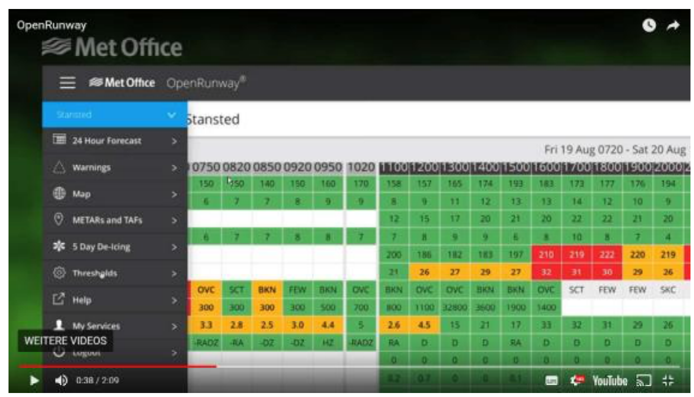
Conclusion:

We need better, timely info on airport and runwy status, availability .

State of the Art – not for pilots´ eyes

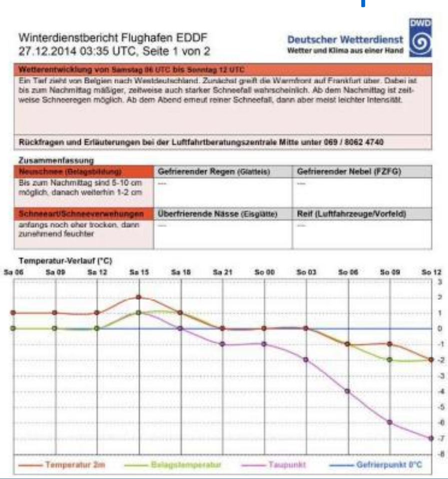


State of the Art – not for pilots´ eyes



Source: MetOffice video https://www.metoffice.gov.uk/aviation/openrunway

State of the Art – not for pilots´ eyes

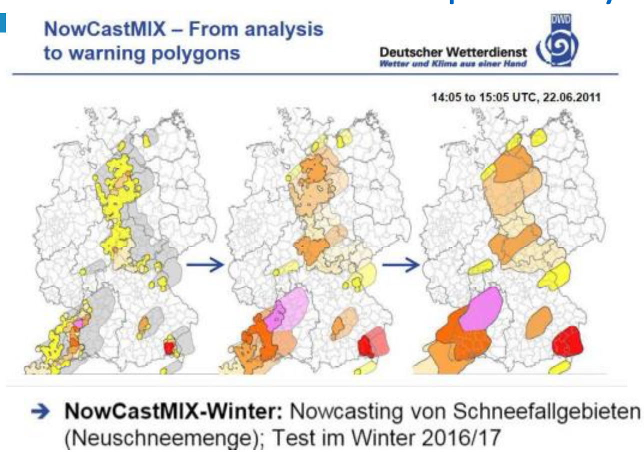


https://www.dwd.de/DE/forschung/wettervorhersage/met_fachverfahren/met_arbeitsplatz/ninjo/omedes_node.html

State of the Art – not for pilots´ eyes

https://www.dwd.de/DE/forschung/wettervorhersage/met_fachverfahren/met_arbeitsplatz/ninjo/omedes_node.html

State of the Art – not for pilots´ eyes



http://docplayer.org/35817479-Luftfahrtkundenforum-2016-herzlich-willkommen.html

http://slidegur.com/doc/1775113/folie-1---copernicus

Probabilistic :State of the Art ?

Source: AccuWeather

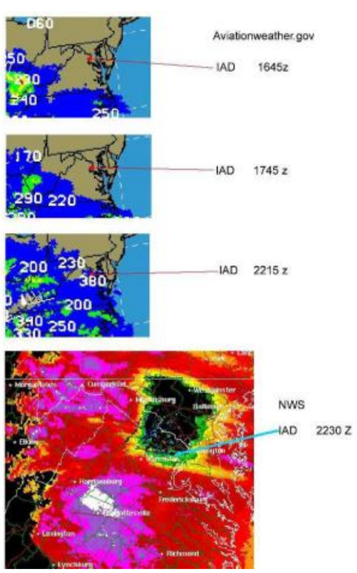
State of the Art – not for pilots´ eyes

The information pilots need is already available !

We have to get it into the papers, into the cockpit .

Source: MeteoFrance

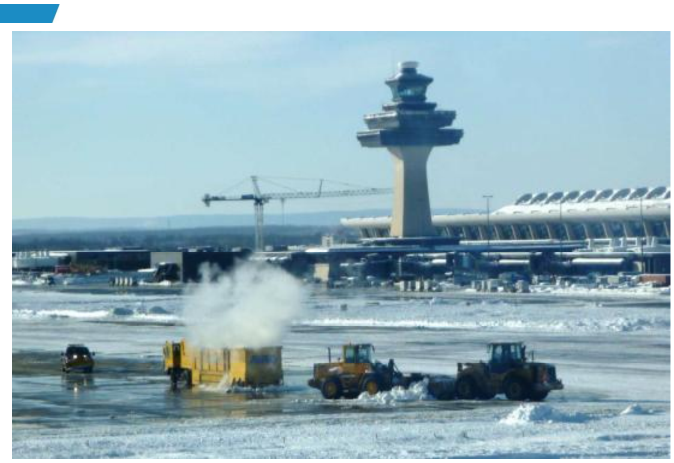
Just Snow !



almost snowed –in

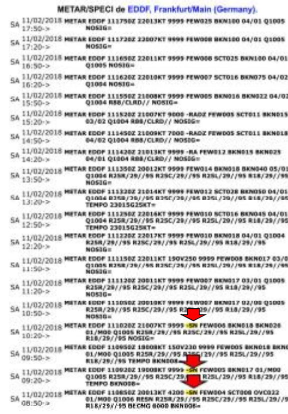
at Washington-Dulles international airport

Snowdragon @ work



´´private´´, commercial WX…does it help ?

Airport weather Frankfurt : commercial weather company UBIMET



3 snowflakes in the morning.

And the result ?

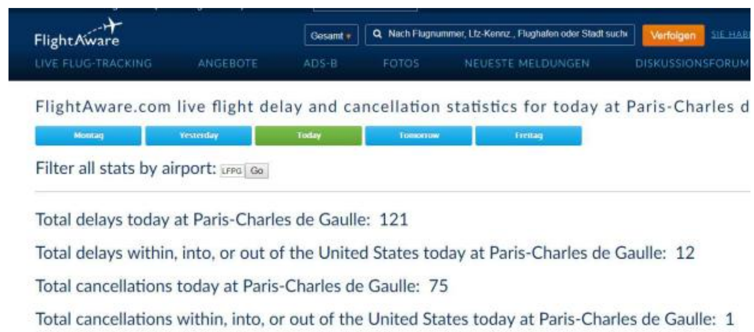
Still 1hr + delay in the

late afternoon

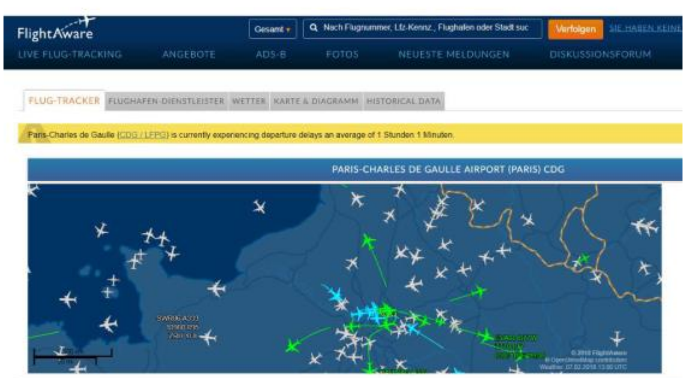
Either the wx-information or the use of the wx-information needs to improve.

https://www.ubimet.com/

High-Tech European Approach to snow….
Sensors in runways drive de-icing models, de-icing trucks have GPS & datalink, and surface-treatment is done according to measured needs & documented in real time. Looks great on paper…..



1 : 01 Hrs delay, average



Snowed-in JFK: January, 2018

World's biggest passenger jet forced to land at small New York airport thanks to blizzard

- Singapore Airlines Flight 26 from Frankfurt, Germany, was bound for JFK.
- The winter storm has diverted dozens of flights.
- The passengers are disembarking at Stewart, and the airline said it is working to provide ground transportation for them.

Source: CNBC

We need better coordination !

The Port Authority said normal coordination broke down.

Mother

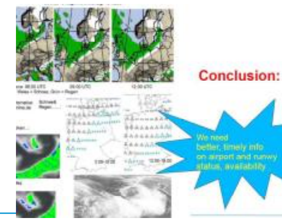
Nature

is

stronger.

ACCEPT IT –
and ANTICIPATE

Elements for improved airport operations in winter



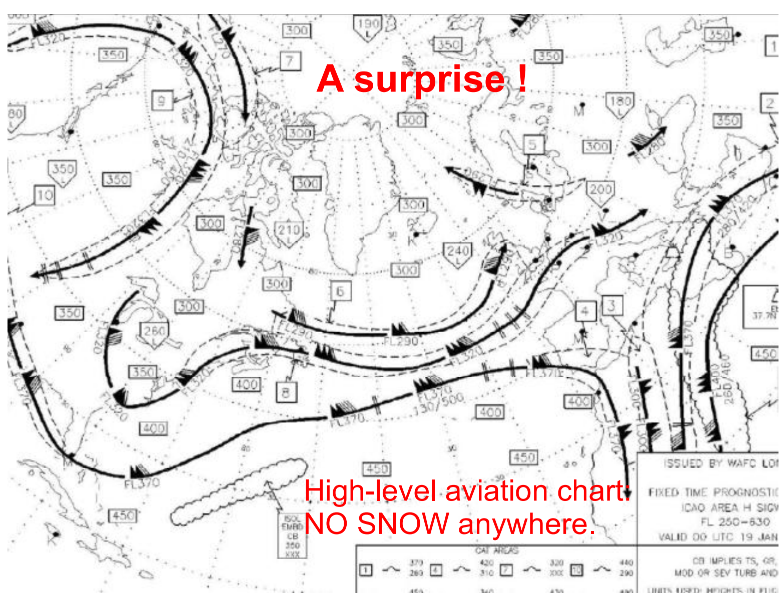
Conclusion: We need accurate forecasts on
- rwy direction
- rwy change
- rwy availability
- rwy status / future: TALPA code

Thank you for your attention.

Klaus Sievers
Klaus.Sievers@VCockpit.de

Additional case

Case 2: a near surprise in New York , 2009



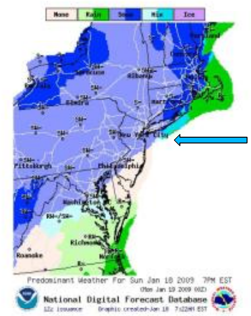
A surprise !

Destination:
KJFK/JFK NEW YORK JOHN F. KENNEDY
SA 181351 06004KT 2SM -SN BKN016 OVC024 M03/M07 A3008=
FT 181123 1812/1918 VRB05KT 4SM -SN OVC035
TEMPO 1813/1815 2SM -SN OVC025
FM181500 20009KT 4SM -SN OVC025
FM181800 19007KT P6SM VCSH SCT025 OVC035
TEMPO 1818/1820 BKN025 OVC035
FM190500 28005KT P6SM SCT035 OVC050=

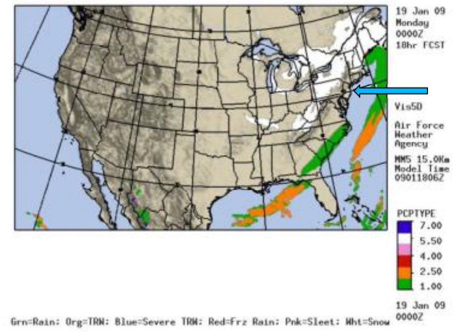
Forecast for landing at 19., 00z: NO SNOW

Flying to New York

A surprise !



Public and US Air Force charts show snow...



A surprise !

Actual at 00:35z: light snow, scatterd 800ft,
Braking action advisories in effect
((meaning: it´s very slippery. No BA coefficients given !))

19JAN09 0035Z
ATIS JFK

JFK ATIS INFO U 0028Z SPECIAL. 00000KT
3/4SM -SN SCT008 OVC013 00/M03 A2981 (
TWO NINER EIGHT ONE). APPROACH IN USE
ILS RY 4R. ILS RY 4L. DEPG RY 4L, SW
DEPS EXPECT RY 31L KK 10700 FT AVBL.
NOTAMS... BA ADZYS IN EFCT. AS DEE EX
SYSTEM OPE RATIONAL. ALL AIRCRAFT
OPERATE TRANSPONDERS WITH MODE CEE ON
ALL TAXIWAYS AND RU NWAYS. READBACK ALL
ASSIGNED ALTITUDES. READBACK ALL RWY
HOLD SHORT INSTRUCTION S. IN THE
INTEREST OF NOISE ABATE MENT PLEASE USE
ASSIGNED RY. ...ADVS YOU HAVE INFO U.

CONTRACT ACTIVE

PNOWWA
Probabilistic Nowcasting of Winter Weather for Airports

Surveys
Interviews

Rudolf Kaltenboeck *(Austro Control)*
H. Juntti, E. Saltikoff *(FMI)*

PNOWWA Workshop Vienna
27-28 Feb 2018

SESAR JOINT UNDERTAKING

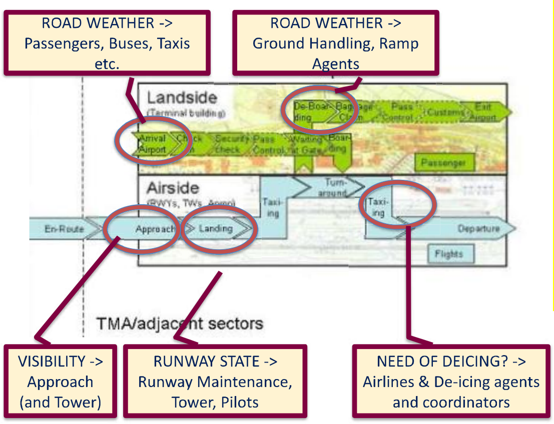
Founding Members

Content

1. Potential PNOWWA users
2. PNOWWA survey
3. Interviews
4. Summary




Winter Weather influencing to the Total Airport Management (TAM)



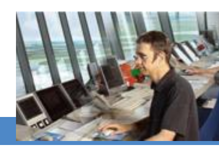
TAM
- create an environment enabling airport partners to maintain a joint plan – the Airport Operations Plan
- get full CDM (Collaborative Decision Making) benefits
  - efficiency in airport
  - enhanced use of airport resources
- Extent time horizon from tactical to pre-tactical and strategic phases.

https://www.eurocontrol.int/eec/public/standard_page/EEC_News_2006_3_TAM.html

Survey

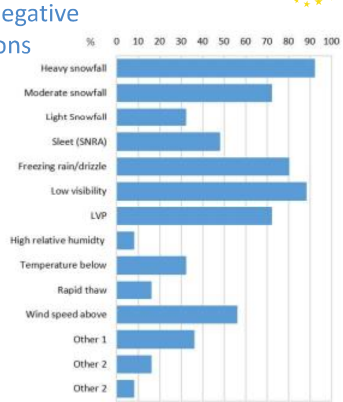
different user groups:
- ATM (TWR, APCH)
- airline operations, pilots
- de-icing
- runway maintenance
- ground handling
- transportation (public and private)

airports
- large (hub) – small (charter)
- Austria, Germany, Denmark, Finland, Norway, Turkey and Switzerland



Survey (web-based)
Airport user opinions– highest negative impact affecting airport operations

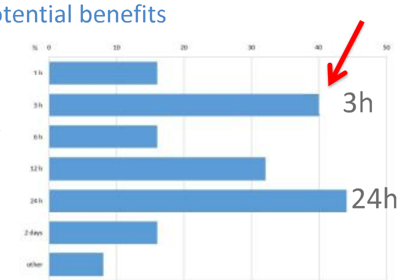
1. Heavy snowfall
2. (low visibility)
3. Freezing rain and drizzle
4. LowVisibilityProcedere
5. Moderate snowfall
6. Wind speed above
7. Sleet



the type of winter weather affecting negatively to airport operation (PNOWWA survey)

Survey (web-based)
Airport user opinions for probabilistic winter weather forecasts – potential benefits

- Helps to make objective decisions
- When cost-loss ratios are known it can be used in decision support
- Positive attitude to probabilistic forecasts
- Need for lead time 3 and 12-24 hours products

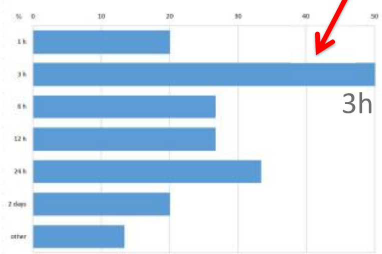


Useful lead time for warning of critical weather for all responses (PNOWWA survey)

Survey (web-based)

Airport user opinions for probabilistic winter weather forecasts – potential benefits

- Helps to make objective decisions
- When cost-loss ratios are known it can be used in decision support
- Positive attitude to probabilistic forecasts
- Need for lead time 3 and 12-24 hours products

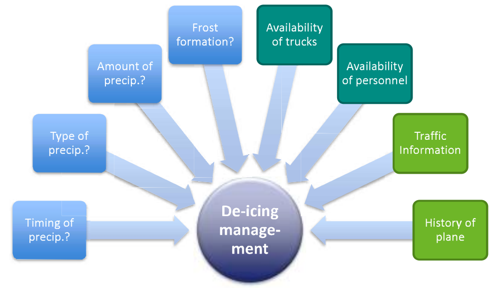


Useful lead time for warning of critical weather for **ATM/Airport maintenance** group (PNOWWA survey)

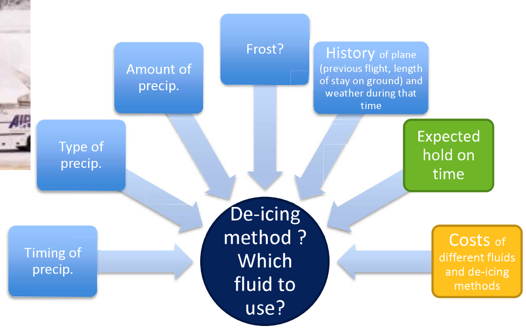
De-icing management

De-icing of aircraft=

1. Snow and ice removal
2. Prevention of ice and snow accretion on plane (-hold over time)

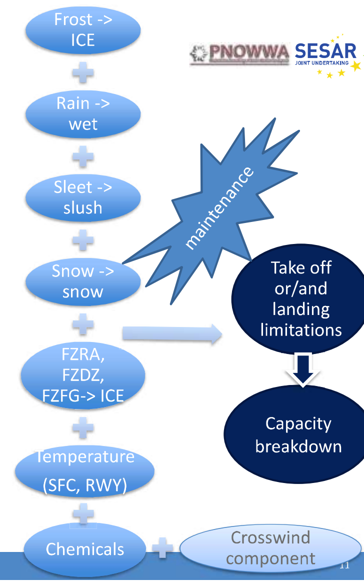


De-icing on airline's perspective



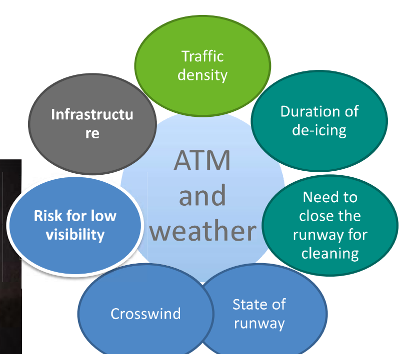
Runway Maintenance

Keep runway in safe conditions. Best friction conditions are achieved



Air Traffic Management / Tower

What's happening in de-icing or runway maintenance influences to ATM, too. Add to that a Low Visibility will change landing procedures and can even prevent that.



Interviews

- probabilistic forecast might be used especially for preventive actions – e.g. FZRA
- usable in decision making process (eliminating human errors and bias) - objective
- different weighting of probabilistic information depending from air traffic
- defining threshold values triggering maintenance procedures
- individual parameters for each airport / different stakeholders for demonstration
- PROB more relevant at big hubs
- forecasting of ordinary winter events (not only rare events as strong snow fall)
- arrival rate – depending from likelihood ???
- Pilots using already PROB in TAF
- Probability forecast used for planning (e.g. truck refueling, actions depent on traffic load ,flight planning)
- human forecast/interaction prevered
- operational procedere/workflow well established
- considering of safety aspects
- use of low probability events (e.g. in case of incident)
- complex interaction of different airport operations

Interviews

- seamless forecast system 0-24/72h
- all weather parameters
  - FG or DRSN/BLSN
  - Ceiling / LVP
  - Summer – thunderstorms, wind shift

- layout
- easy handling (mobile app)
- development of KPI (key performance indicators) and development of new procedures
- training

Interviews
Key Performance Indicator

- Complex interaction – stakeholder
- Traffic
- Workload
- Environment
- Economic
- Delays
- Pre-runway-conditions (chemicals, runway- temperature, ….)
- Safety aspects

Conclusions

- most potential for probabilistic weather forecasts to help render decisions
- +SN/FZRA, but forecasting daily winter weather (not focus an rare events only)
- lead time 3h/24h – stakeholder dependent
- seamless forecast – one all weather product
- layout (decission support)
- handle low probability
- implementation in CDM ?

PNOWWA … Probabilistic Nowcasting of Winter Weather for Airports

http://pnowwa.fmi.fi

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

Funded by: TAKE OFF bmvit FFG

Weather impact analysis based on elaborate air traffic simulations

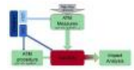
PNOWWA Workshop
27-28 February 2018, Vienna, Austria

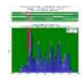
Martin Steinheimer, Carlos Gonzaga-Lopez, Christian Kern, Markus Kerschbaum, Lukas Strauss
austro CONTROL

Kurt Eschbacher, Martin Mayr, Carl-Herbert Rokitansky
UNIVERSITÄT SALZBURG

SICHERHEIT LIEGT IN DER LUFT

Outline





- The Motivation
  - Why are we doing it…
- The Method
  - How are we doing it…
- The Tool
  - What do we use to do it…
- A Case Study
  - What we do in action…
- The Outlook
  - What are we doing next…

The Motivation

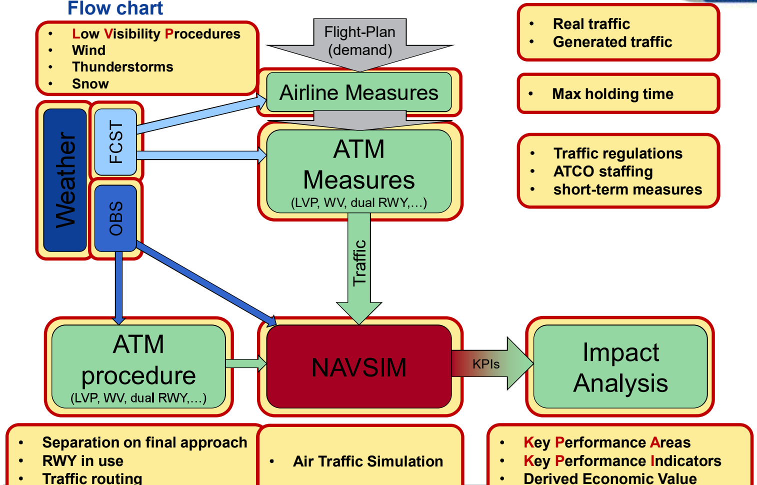
Weather impact on Air Traffic Management

- Weather especially wind, thunderstorms and low visibility have big impact on airport capacity
- Weather cannot be changed but accurate forecasts help to be prepared and to minimize weather impact
- Project objective: Quantify weather impact to identify mitigation potentials
- Weather impact in numbers:
  - Vienna International airport:

Delays LOWW ARR Oct. 2015 - Mar. 2016			
	minutes	min/flight	percentage
Weather	66 214	0,59	89%
Total	74 121	0,66	

The Method

Weather impact analysis
Flow chart



Weather impact analysis
Methodology

- Cost matrix based on air traffic simulations

Weather event occurs in simulation

Weather event does NOT occur in simulation

		Observed	
		Yes	No
Action taken	Yes	***COST**hit*	***COST**false alarm*
	No	***COST**missed*	***COST**none*

Reduced traffic according WX-FCST

full traffic

Weather impact analysis
Challenges

- Not everything can be readily measured in terms of money, e.g.:
  - ATM workload
  - safety
- Optimization criteria are contradictory, e.g.:
  - trade-off between maximizing capacity and optimizing workload
  - trade-off between optimizing workload and minimizing flight delays
  - etc…
- Different stakeholders (ANSP, airlines, airports,…) prioritize optimization criteria differently
  - e.g. ATM workload is not airlines' first priority
- To quantify the impact on the overall air traffic management system all stakeholders' requirements must be considered and balanced

The Tool

NAVSIM / AMAN
Air traffic simulation

- Detailed simulation of arrival procedures
  - Simulation is initialized with traffic at STAR endpoints
  - Weather (wind, LVP, TS) is realistically considered
  - Detailed performance analysis based on various KPIs

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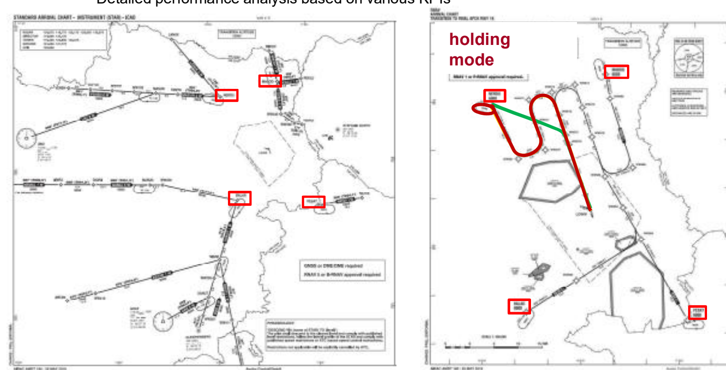
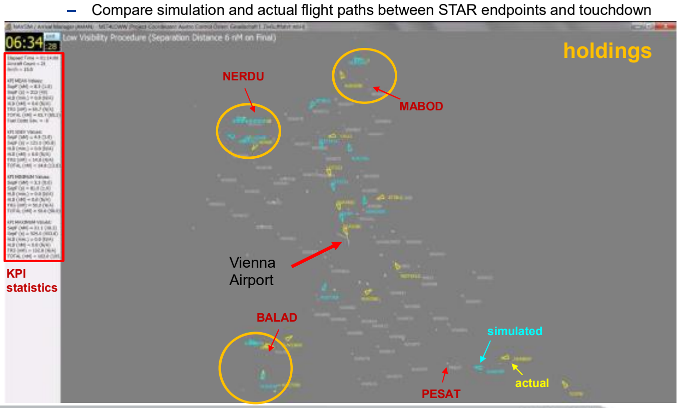
Note: NAVSIM ATM/ATC/CNS Tool developed by Mobile Communications Research & Development Forschungs GmbH in co-operation with USBG



NAVSIM / AMAN
Validation

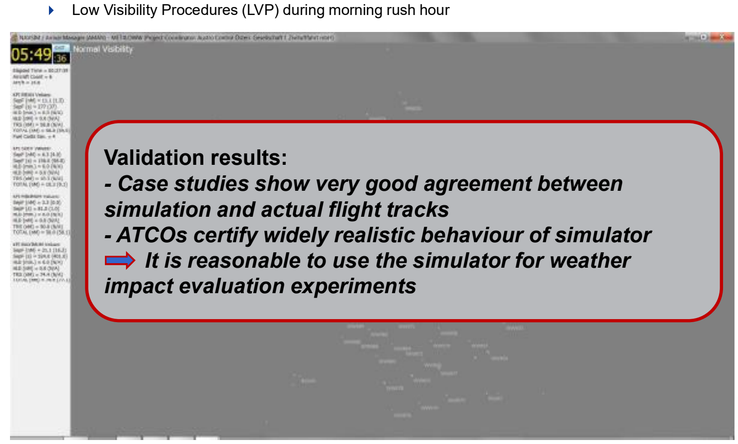
- Compare actual flight path to simulated flight path
  - Simulation is initialized with actual traffic at STAR endpoints
  - Compare simulation and actual flight paths between STAR endpoints and touchdown



yellow: CPR; blue: simulated

NAVSIM / AMAN
Validation - video

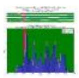
- Low Visibility Procedures (LVP) during morning rush hour



Validation results:
- Case studies show very good agreement between simulation and actual flight tracks
- ATCOs certify widely realistic behaviour of simulator
⇨ It is reasonable to use the simulator for weather impact evaluation experiments

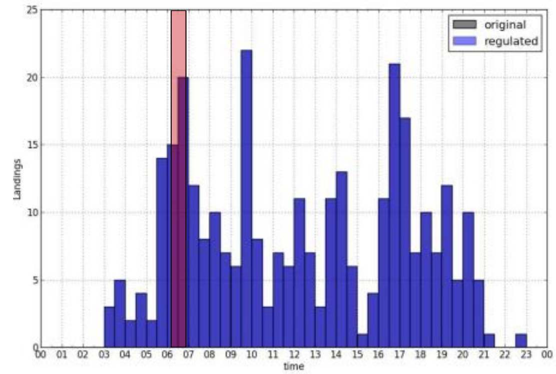
yellow: CPR; blue: simulated

A Case Study



Case study
Runway closure – synthetic example

- Arrival runway is closed for 45 minutes during morning peak



Case study
Runway closure – synthetic example

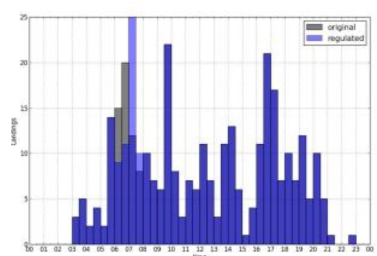
- Cost matrix scenarios were simulated:
  - n: No RWY closure and none forecasted **No action taken.**
  - f: No RWY closure, but forecasted **Action taken.**
  - m: RWY closure, but not forecasted **No action taken.**
  - h: RWY closure and forecasted **Action taken.**

		Observed	
		Yes	No
Action taken	Yes	*h*	*f*
	No	*m*	*n*

Case study
Runway closure – synthetic example

- No action taken
  - No traffic regulation applied
  - Average possible maximum holding time: 20 minutes
- Action taken
  - Traffic regulated
    Regulation issued at 05:00:
    06:10 to 06:55: acceptance rate 0
  - Average possible maximum holding time: 30 minutes

Simplified assumptions:
- in m case regulation would be applied once event happens
- in f case regulation would be cancelled once event does not happen



Case study
Runway closure – synthetic example

KPIs:
2.5 hours
75 flights

	n	f	m	h
Diversions	0	0	15	3
Trackmiles / flight	64.3	70.8	67.8	84.5
Holding time [min]	46	71	239	291
Holding time / flight [min]	0.62	0.95	3.19	3.89
Regulated delay [min]	0	823	0	823
Regulated delay / flight [min]	0	11	0	11
Regulated delay cost [€]	0	19,710	0	19,710
ARR delay cost [€]	0	1,630	10,090	20,060
Diversion cost [€]	0	0	70,500	13,500
Total cost [€]	0	21,340	80,590	53,270
Total cost / flight [€]	0	285	1,075	710

- Cost estimates based on:
  - Delay costs:
    A. Cook, G. Tanner, *European airline delay cost reference values, updated and extended values*. Version 4.1, https://www.eurocontrol.int/publications/european-airline-delay-cost-reference-values (2015).
  - Diversions:
    Standard Inputs for EUROCONTROL Cost-Benefit Analyses. Edition Number: 7.0. Edition Date: November 2015

Case study
Runway closure – synthetic example

- How do results relate to weather forecasts?
  - Cost / Loss ratio can be derived from cost matrix – important when using probability forecasts
  - Together with contingency table of specific forecast the forecast value can be derived
- Other insights from this analysis method
  - Impact of different actions can be evaluated
  - Decision processes and weather forecasts can be aligned

Cost matrix:

		Observed	
		Yes	No
Action taken	Yes	*53,270 €*	*21,340 €*
	No	*80,590 €*	*0 €*

Forecast contingency table:

		Observed	
		Yes	No
Forecasted	Yes	*hit*	*false* alarm
	No	*missed*	Correct *negative*
		o = h + m	1 - o

Cost / Loss ratio in this example: 0.44

The Outlook

Outlook
What happens next…

- Consolidating results
  - Low visibility procedures
  - Thunderstorms in approach sectors
  - Distance based vs. time based vs. weather dependent separation
  - RWY closure
- **End of project workshop: 11 April 2018**
- Proposal for follow up project is underway
  - Includes flight planning expertise to refine cost estimates
  - Focus on how probability forecasts can be integrated in ATM decision making
  - Evaluate what ATM decisions can be improved by probability forecasts
  - Evaluate available probabilistic weather forecast systems
  - Holistic view on the ATM-System (Airlines + Airport + ATC)

Funded by

TAKE OFF bmvit FFG

TAKE OFF is an initiative of the Federal Ministry of Transport, Innovation and Technology (BMVIT) and is managed by the FFG

Contact:

- Air Traffic Simulator

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- MET + ATM Evaluation

  Dr. Martin Steinheimer
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  Austro Control GmbH
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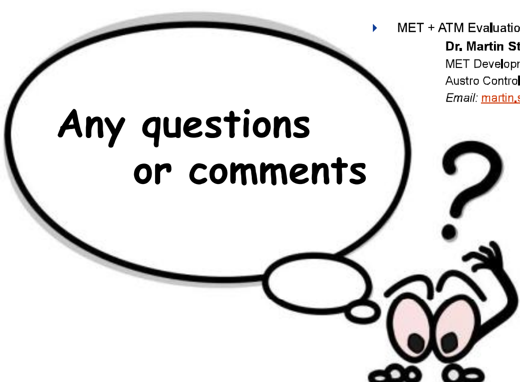


Summary what we have learnt from stakeholders in Finland

Heikki Juntti, Finnish Meteorological Institute (FMI)

PNOWWA (Probabilistic Nowcasting of Winter Weather for Airports)

SESAR JOINT UNDERTAKING

Founding Members

Stakeholders

Pilot user feedback - Helsinki

- After the first winter feedback asked, few answers got
- Before second winter season it was organized meeting with users, where it was discussed about the scientific demonstration, collected opinions and informed about the feedback mechanisms
- During winter 2017-2018 it is conducted special interviews with APOC after heavy snow days.
  - 24.1.2018
  - 1.2.2018

Proposal of user -> Rate of snow mm/15 min, when it is cm/h in most previous applications

Probability of accumulation class was changed to exceedance probabilities after first winter, because users felt is more appropriate to them.

Pilot user feedback - Rovaniemi

- After first winter feedback asked, only two answers got
- During winter 2017-2018 it is conducted special interviews with maintenance head during snowing days 24.-25.1.2018.

In next slides it is combined user opinions and ideas about PNOWWA scientific demonstration and winter weather needs they have based on all feedback got in Finland during 2016-2018.

Availability of demo product

- Delivery system by web page worked well.
- Automatic update cycle is necessary in that kind of product. That was useful feature in demonstration
- Possibility to follow weather situation development via mobile phone would be wished to operative product. That must be taken into account in deployment phase

Layout of demo product

There is a lot of information, but…

- Layout is complicated, a lot of numbers, which update very often.
- Layout doesn't attract to use product – in most days conventional sources of information were used
- Also opinions if It should be more useful to user colours describing the severity of weather instead of prob. value as we did.

Likelihood matrix would be most appropriate

Green 0-20%	< 1 mm/15 min
Yellow 30-50%	1-5 mm/15 min
Red 60-100%	> 5 mm/15 min

Content of demo product

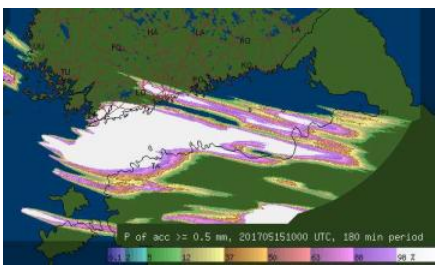
- Exceedance probability was preferred to class probabilities as we did during second winter
- **Thresholds** needs further discussions with users. Different users have different opinions
- **Fog and drifting snow** phenomena shall be included to tower product
- **24 hour product** was wished, too (bellow one possible example for that)

Meteorological quality of demo product

- Demo product was used only occasionally. **Users felt conventional sources of information more convenient** and used them. So users opinions of MET quality are not clear – yet it is easy verify independently (as it is done – see my previous presentation).
- Individual comment from the case when **product decrease the strength of precipitation too much and too early (EFHK 1.2.1018)**.

Usability of demo product

- Poor in the form it is now.
- Users like to see snow area movement and estimations also on map.
- Table type of product is appropriate to machine-machine systems. Products to humans shall include more visualisations and probably also option to interact with meteorologist



Other aspects risen

- **Climatology** of snow accumulation is needed. How often different classes happens at different airports? In mm/h, mm/3 h, mm/12 h, mm/24 h
- Most of benefits of that type of product would be gained **at runway maintenance** duty.
- **Departing traffic** will benefit more than arriving for now-casting, because by CDM they got information about possible take of time. (if there is limitations at capacity in near future)
- Tower will need more **12-24 h forecast** than 3 hour nowcast.

Conclusions of stakeholders feedback

- Table type product could be most appropriate to automatic decision making systems (machine to machine).
- To humans visualization and option to interaction with other human is needed, too.
- It could be useful to discuss how probabilistic information is used in automated decision making systems and how in human generated systems? There can be differences between these.
- Winter weather nowcast products shall be available also by mobile phone.
- All weather parameters influencing to airport capacity shall be implemented to product
- More experiments together with users is needed to verify the meteorological reliability and usability of winter weather information in users point of view.

PNOWWA Probabilistic Nowcasting of Winter Weather for Airports

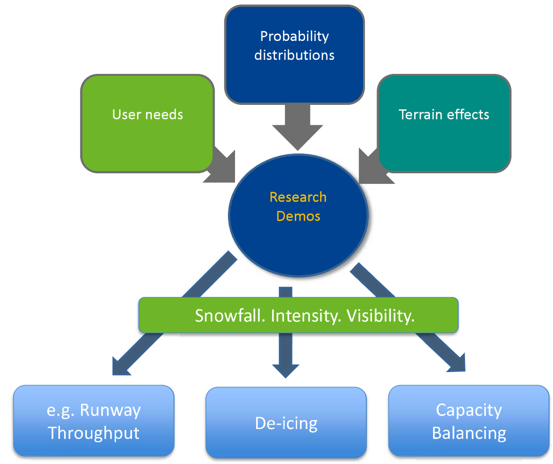
Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

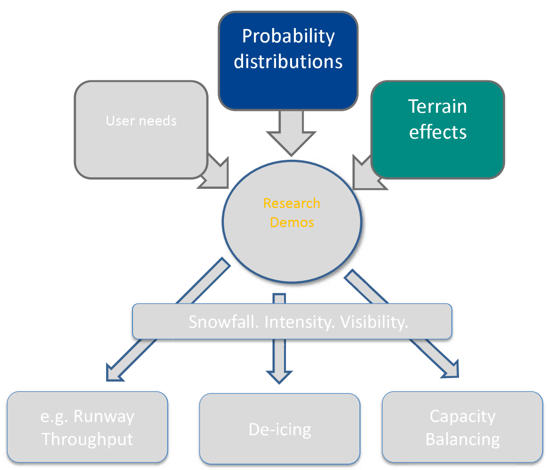
Winter Weather Nowcasting – Effects of Sea and Mountains PNOWWA – WP3

Martin Hagen – DLR Oberpfaffenhofen, Germany
Elena Saltikoff, Finnish Meteorological Institute (FMI)
Seppo Pulkkinen, FMI
Annakaisa von Lerber, FMI
Martin Steinheimer, Austro Control

PNOWWA Goals



PNOWWA Goals



PNOWWA WP 3 – Overview

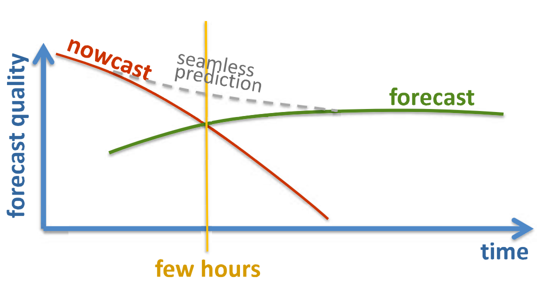
Objectives

- Improving the nowcasting of snowfall intensity
- Assessing predictability of motion-vector nowcasting
- Increasing understanding of effect of mountains and sea to the snowfall intensity

Nowcasting - Forecasting

Nowcasting: 0 – 1(2)(3) hours (depending on weather situation)
radar/satellite extrapolation techniques

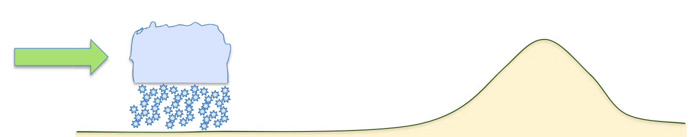
Forecasting: some hours – several days
numerical weather forecast



Effect of Mountains and Sea

Mountains have an influence on atmospheric flow

Advection in flat areas, minor temporal evolution are expected.



Effect of Mountains and Sea

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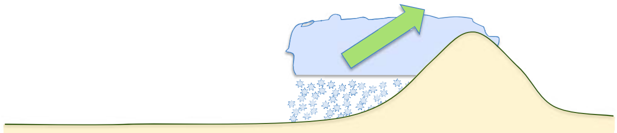


When approaching mountains:
airmass is lifted, humidity condenses, clouds and precipitation intensify, clouds and precipitation is blocked by mountains.

Effect of Mountains and Sea

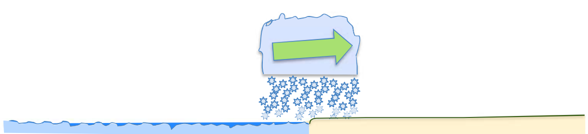
Transition from sea to land

Advection over sea, minor temporal evolution are expected.

Effect of Mountains and Sea

Transition from sea to land

Advection over sea, minor temporal evolution are expected.



When moving over land:
lake effects in winter: warm sea (continuous source of moisture), cold land, cold air

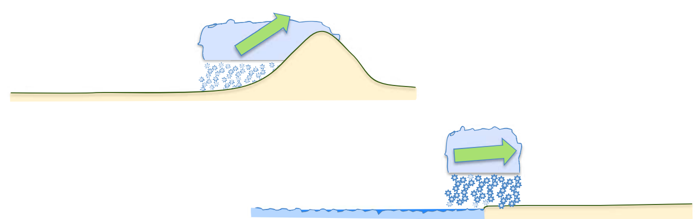
slight lifting by shoreline, slow down of motion (increased surface friction), change of moisture fluxes

Effect of Mountains and Sea

Nowcasting of precipitation fields

Nowcasting techniques by extrapolation of radar images assume linear motion and minor temporal evolution of the cloud- or precipitation system.

Any deviation from linear motion will introduce nowcast errors.



Statistical analysis of predictability

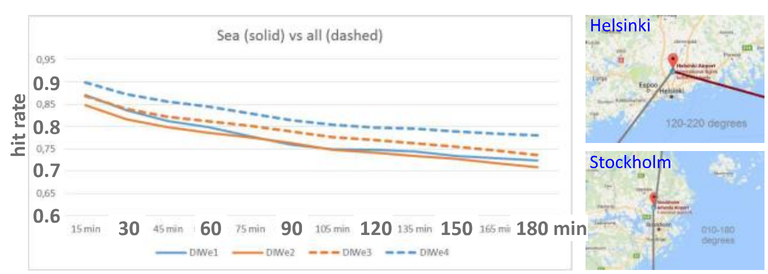
Study the winter weather products developed for SESAR1 de-icing validation campaign:

- to see, if the quality of the forecasts at certain airport depends systematically on the flow direction
- to see, if the "unpredictable sectors" can be linked to underlying terrain such as sea or mountains

Statistical analysis of predictability – Effect of Sea

Influence of sea on predictability for Stockholm and Helsinki.

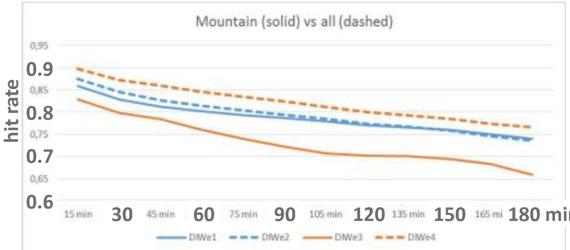
Forecast quality is lower for precipitation systems arriving from Sea.

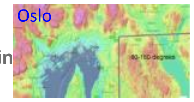


Stockholm Helsinki Helsinki Stockholm
from Sea from all directions

Statistical analysis of predictability – Effect of Mountains

Influence of mountains on predictability for Rovaniemi and Oslo
Forecast quality is lower for precipitation systems with flow affected by mountainous areas





Rovaniemi
Mountain / all directions

Oslo
Mountain / all directions

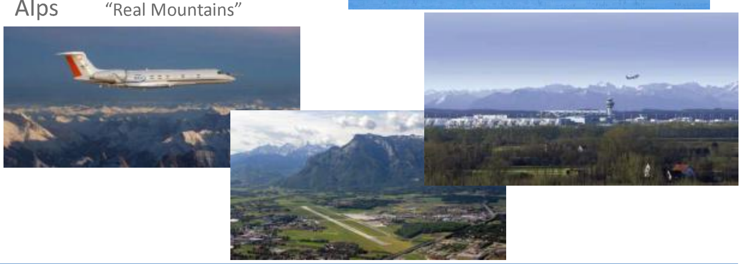
Mountain Effects

Low Scandinavian mountains

Mountain Effects

Low Scandinavian mountains

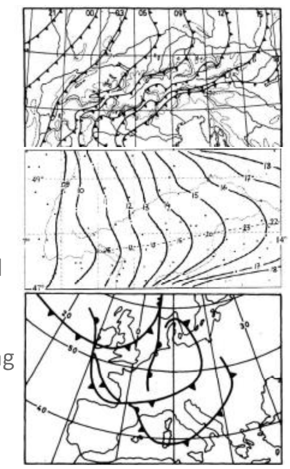
Alps "Real Mountains"



Orographic Effects on Cold Fronts

The Alps considerable influence the weather in the region around the Alps.

- Frontal systems can be
  - retarded / delayed
  - accelerated along Alps
  - passage without any delay
- Nowcasting by extrapolation is impeded in these situations due to the non-linear propagation of frontal systems
- Retarded precipitation systems and cyclogenesis can generate long lasting continuous rain or snow fall events (2-3 days!)



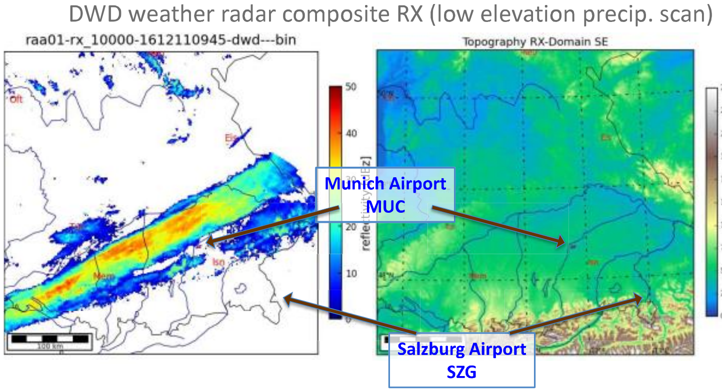
Steinacker, 1983 in Schumann, 1987

Volkert et al., 1991

Schumann, 1987

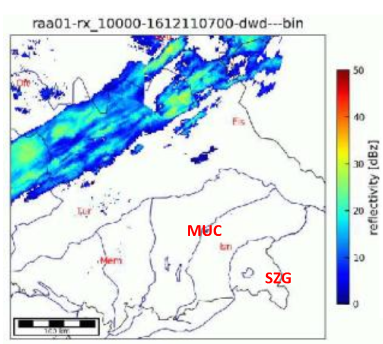
Orographic Effects on Cold Fronts

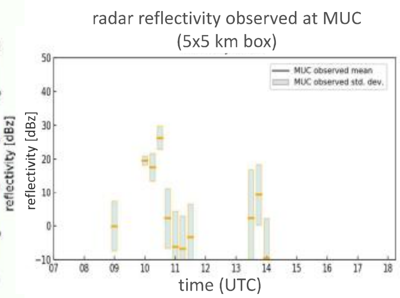
- Example of cold-front crossing Alpine Foreland (11 Dec. 2016)
  DWD weather radar composite RX (low elevation precip. scan)



Orographic Effects on Cold Fronts

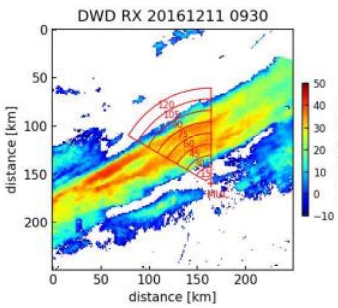
- Example of cold-front crossing Alpine Foreland (11 Dec. 2016)

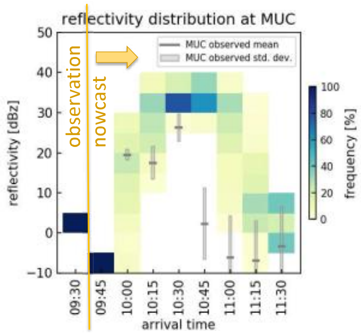




Nowcasting of Cold Front

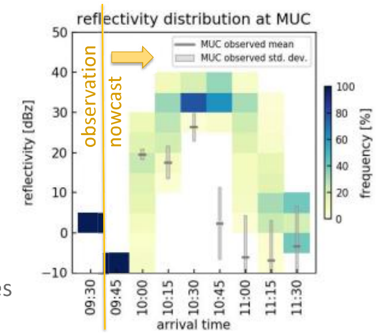
- Example of cold-front crossing Alpine Foreland (11 Dec. 2016)
- Andersson&Ivarsson nowcasting method
  speed and direction given from forecast / tracking / radio sondes





Nowcasting of Cold Front Weather

- Example of cold-front crossing Alpine Foreland (11 Dec. 2016)
- Andersson&Ivarsson nowcasting method
  speed and direction given from forecast / tracking / radio sondes
- translation of reflectivity
  to more practical quantities
  - snow accumulation
    dry / wet snow
  - de-icing weather index
  - visibility
- with considerable
  uncertainty due to large
  variability of snow properties



Nowcasting of Cold Front Weather

- Example of cold-front crossing Alpine Foreland (11 Dec. 2016)
- Andersson&Ivarsson nowcasting method
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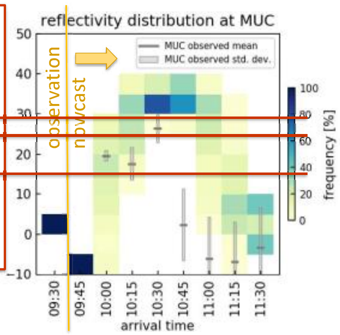
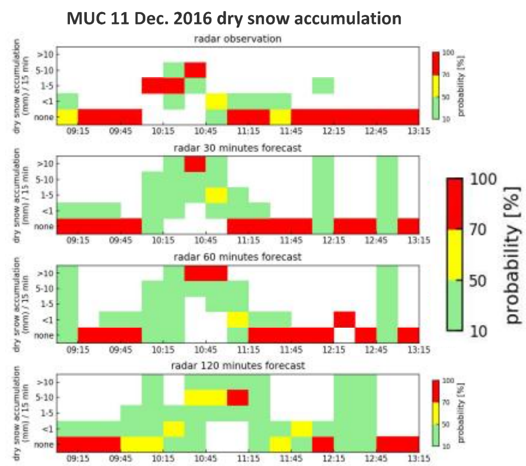
- translation of r
  to more practi
  - snow accur
    dry / wet sr
  - de-icing we
  - visibility
- with considera
  uncertainty du
  variability of snow properties

dry snow

> 1cm/15min acc.
< 600 m visibility
DIW 3
0.5-1; <1500; 3
<0.5; <3000; 2
< 0.1cm/15min acc.
> 3000 m visibility
DIW 0



Nowcasting of Cold Front Dec. 2016



Nowcasting of Cold Front Dec. 2016

Deterministic evaluation of nowcast using the most probable weather class

dry snow accumulation mm / 15 min

30 minutes forecast

forecast \ observation	none	<1	1-5	5-10	>10
none	13	0	0	0	0
<1	0	0	0	0	0
1-5	0	1	1	0	0
5-10	0	0	0	0	0
>10	0	0	1	1	0

60 minutes forecast

forecast \ observation	none	<1	1-5	5-10	>10
none	11	0	1	0	0
<1	2	0	0	0	0
1-5	0	0	0	0	0
5-10	0	0	0	0	0
>10	0	1	1	1	0

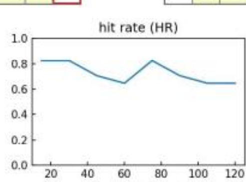
120 minutes forecast

forecast \ observation	none	<1	1-5	5-10	>10
none	[illegible]	0	1	[illegible]	[illegible]
<1	2	0	1	0	[illegible]
1-5	0	0	[illegible]	0	0
5-10	1	1	0	1	0
>10	[illegible]	[illegible]	0	0	0

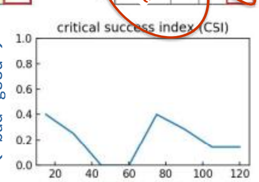
zeros missed hits false

$$HR = \frac{hits + zeros}{total}$$

$$CSI = \frac{hits}{hits + false + missed}$$

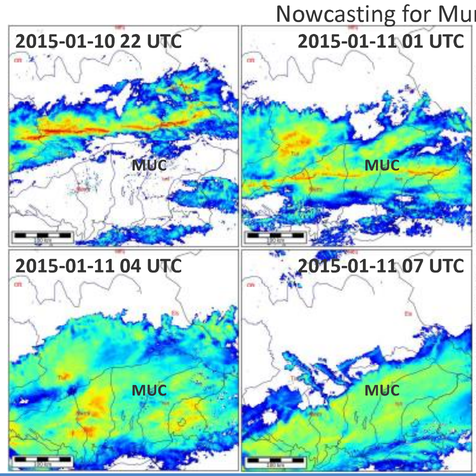


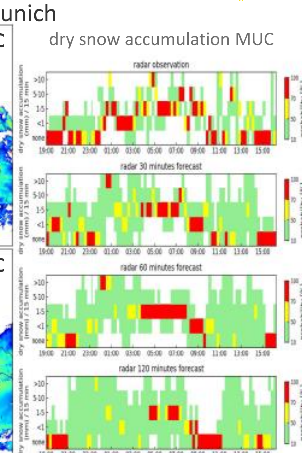
← bad good →



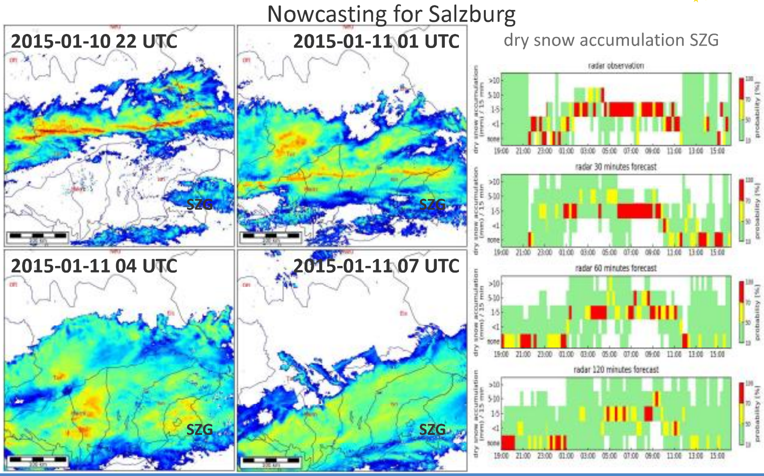
Nowcasting of Cold Front Jan. 2015

Nowcasting for Munich





Nowcasting of Cold Front Jan. 2015

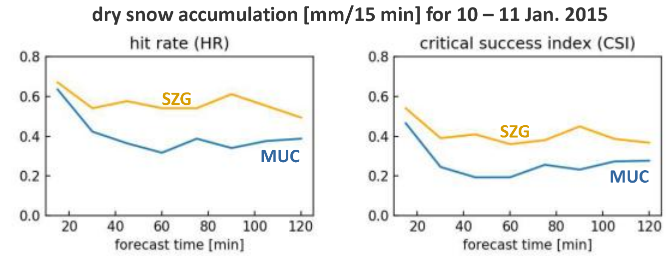


Nowcasting of Cold Front Jan. 2015

Development of long lasting precipitation system over the Alpine Foreland (~ 22 hours).

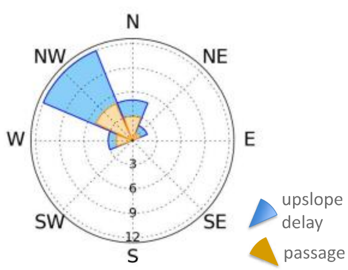
Prevailing north-westerly flow:

- Salzburg within precipitation system
- Munich close to the edge of precipitation field



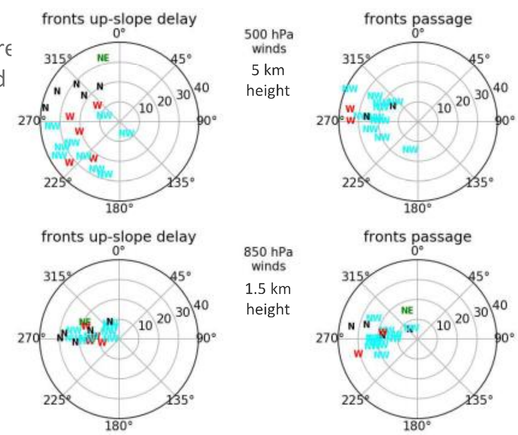
Orographic Effects of the Alps

- 22 cold-front events lasting between 8 and 46 hours from winters 2013/14 to winter 2016/17 were analysed
- prevailing flow direction from NW
- most case show a clear signal of delay/upslope enhancement (50%) or undisturbed passage (50%)



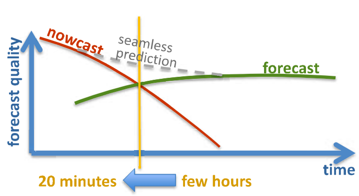
Orographic Effects of the Alps

- observed winds (radio sondes) are often not related to motion of precipitation systems
- cyclogenesis can impede extra-polation for longer time periods



Conclusions and Outlook

- Radar extrapolation techniques can provide probabilistic nowcast of winter weather elements.
- Probabilistic nowcast provides the user with information on the likelihood of the occurrence of winter weather elements.
- Information that there will be no precipitation is valuable
- Nowcasting of complex orographic motion and precipitation patterns can be improved by advanced numerical weather prediction
  - high resolution / nesting
  - frequent update
  - radar data assimilation
- data fusion
- seamless prediction



Winter Weather Nowcasting – Effects of Sea and Mountains
PNOWWA – WP3

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

Potential for follow up projects

Heikki Juntti
Elena Saltikoff, Finnish Meteorological Institute (FMI)

PNOWWA (Probabilistic Nowcasting
of Winter Weather for Airports)

SESAR JOINT UNDERTAKING

Founding Members

Potential for follow up projects

In PNOWWA we have identified opportunities
to further utilize **probability forecasts** at the airports.

So far we have limited us to **airport operations** and **winter weather.**

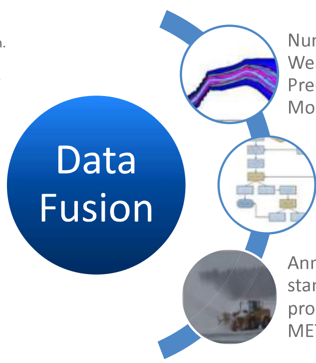
It could be considered to invove also

- **Convective weather (thunderstorms)**
- **En-route**
- **Network planning**

Potential for follow-up projects

as identified in PNOWWA Surveys

PNOWWA is S2020 Fundamental Explonatory Research. To reach higher maturity levels, more work is needed



Numerical Weather Prediction Models (EPS)

Special models (road, fog, DRSN, …)

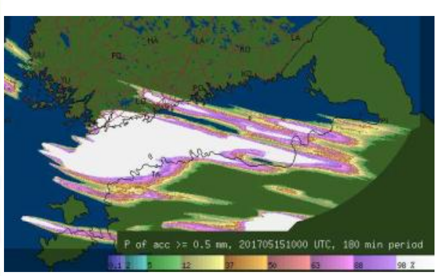
Annex III standard products (TAF, METAR, …)

Winter weather needs and opportunities

- A need for **3h** and **24h** forecasts is seen in the survey.
- Are these **separate** use cases,
  or is there a need to generate a **seamless** merger ?
- In PNOWWA we focused on providing **numbers**.
  Many stakeholders want to understand a bit more, so **visual** presentation should be developed.

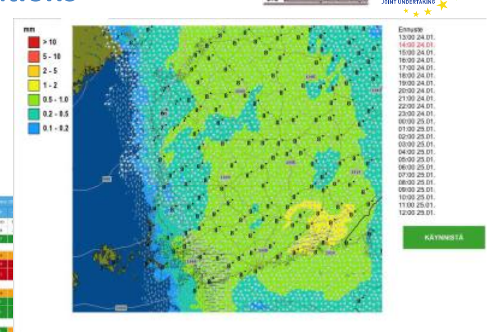
Possible visualizations

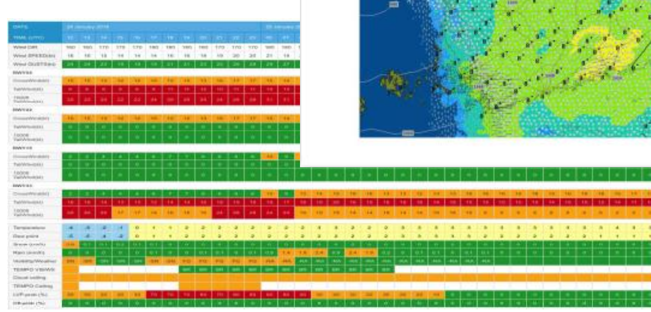
FEW HOUR FORECAST: Point forecast + radar extrapolation animations



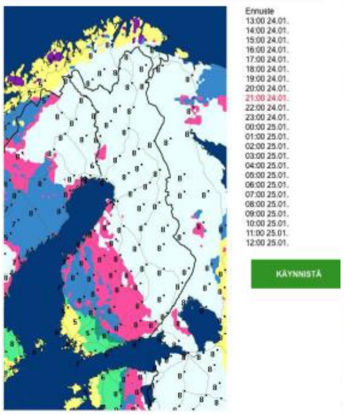
Possible visualizations

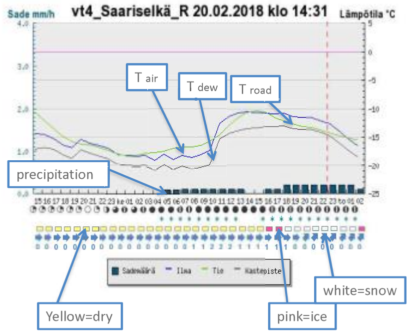
**1 DAY FORECAST:
Point forecast +
NWP PRECIPITATION
animation**





1 DAY FORECAST: Point forecast + ROAD/RUNWAY animation



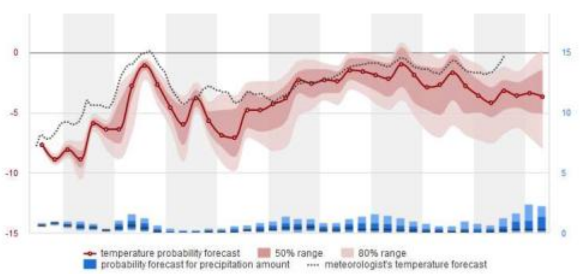


ICY ROAD
PARTLY ICY
FROST ON ROAD
SLEET ON ROAD
SNOW ON
WET ROAD
MOIST
DRY ROAD

Probability of Hurricane route

Probability forecasting with computer models: EPS

Instead of making a single forecast of the most likely weather, a set (or **ensemble**) of forecasts is produced. 50 or 100 forecasts are run from slightly different start information, and then probabilities can be calculated from their distribution.



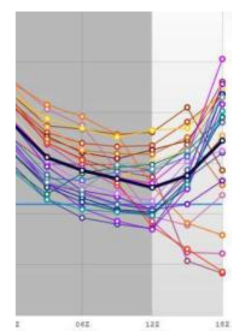
Example of ensemble of 20 members

16 forecasts say ”warmer”

4 forecasts say ”colder”

We can say ”warmer with 75% certainty”

Or we can give intervals or averages.



Potential of specialist models

Some parameters have very large differences in small scale.

This could be improved by running special models at one point

Some of these are ”ready to use”, others need research.

Such as

- Road model for runway state
- Fog model
- Snow model (for drifing snow)

Data merging in visualization

PNOWWA methods, based on radars, do not forecast e.g. fog.

However, fog forecasts are already part of TAF.

Visualization could be added:

VIS decreased by snow	0-15 min	15-30 min
VIS less than 600 m	0	0
VIS less than 1500 m	0	0
VIS less than 3000 m	0	0
VIS over 3000 m	100	100

Draft for how TAF could be illustrated

TOWER (UPDATED 2018-02-06 09:00:00 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 less than 1500 m	0	0	0	0	0	0	0	0	0	0	0	0	0
VIS less than 3000 m	0	0	0	0	0	0	0	0	0	0	0	0	0
VIS over 3000 m	100	100	100	100	100	100	100	100	100	100	100	100	100
Fog in taf	NIL				TEMPO				PROB30				

-Technically it is possible to split TAF in to pieces and take part of as a part of other product. For example freezing precipitation, fog etc. .
-A human has investigated a a lot of MET material before making TAF – why not use that expertise also in other products?

-> by MET data fusion new and better products can be produced, but that needs more research

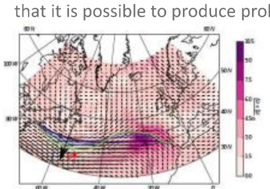
Probabilistic weather forecast -> influence to aeronautical procedures at airport?

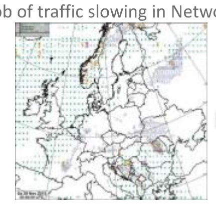
- Adverse winter weather -> capacity of airport decreases -> flights are typically 1-3 hours late.
- Generally the need of stakeholders are know -> better products by MET data fusion to serve users better
- Machine to machine products
- Products to Humans
- Optimal MET services to increase the accuracy of timing in CDM
- Optimal MET observational network to support services

Co-operation needed between MET and airport stakeholders

Probabilistic weather forecast -> influence enroute and network traffic?

- In SESAR H2020 Exploratory Research Project: TBO-Met (Meteorological Uncertainty Management for Trajectory Based Operations) it is investigated the effects of probabilistic wind and convection forecasts to trajectory planning and sector demand analysis.
- PNOWWA results can be used to convection forecasts, too
- FMI has developed winter weather index indicating the influence of winter weather to the capacity of individual airports. (SESAR LSD Toplink). Based on that it is possible to produce prob of traffic slowing in Network level, too


From TBO-Met poster



TOPLINK winter weather index example

There exists many ways how winter weather research can be continued in future projects.

There is numerous ways available to show weather information to aviation industry in more informative form than we do now.

PNOWWA Probabilistic Nowcasting of Winter Weather for Airports

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

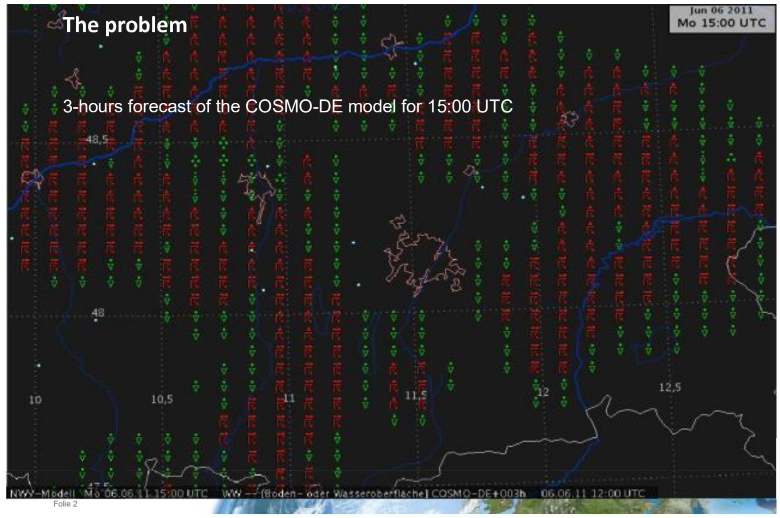
Founding Members

PNOWWA Workshop, 27-28 February 2018 in Vienna, Austria

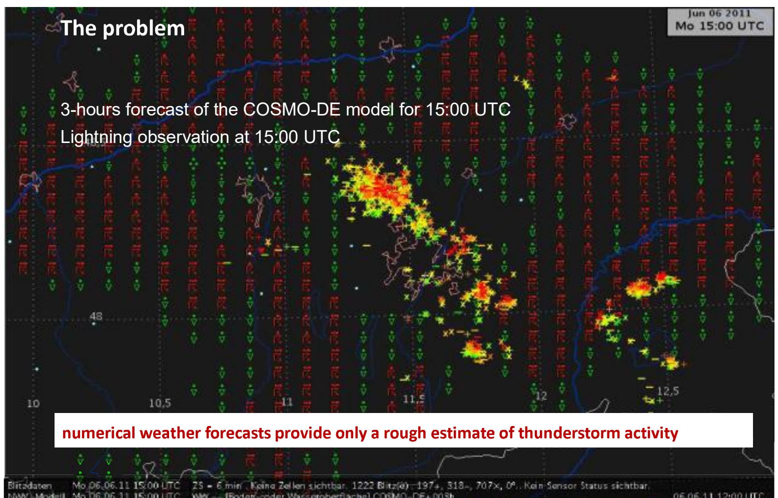
Nowcast and forecast of Cumulonimbus
Rad/Cb-TRAM, Cb-LIKE, fuzzy logic

Thomas Gerz
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt
DLR Oberpfaffenhofen

The problem



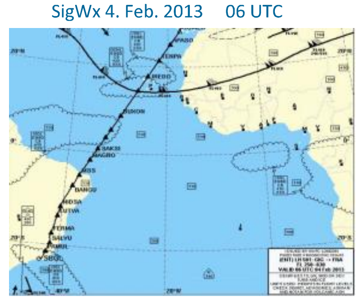
The problem



The Problem

Weather charts from NWP provide only a rough estimate of thunderstorm activity

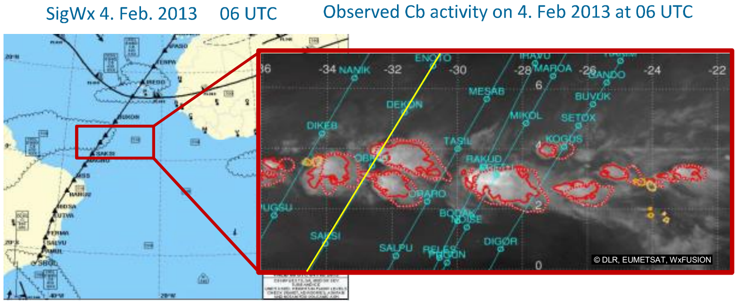
SigWx 4. Feb. 2013 06 UTC



The Problem

Weather charts from NWP provide only a rough estimate of thunderstorm activity

SigWx 4. Feb. 2013 06 UTC Observed Cb activity on 4. Feb 2013 at 06 UTC



The Problem for end users (aviation)

- MET-Products not tailored, not on time, often too complex
- Forecast lead time and update rate not adjusted to the disruptive MET event

Improvement of forecast quality for end users (aviation)

Necessary steps:

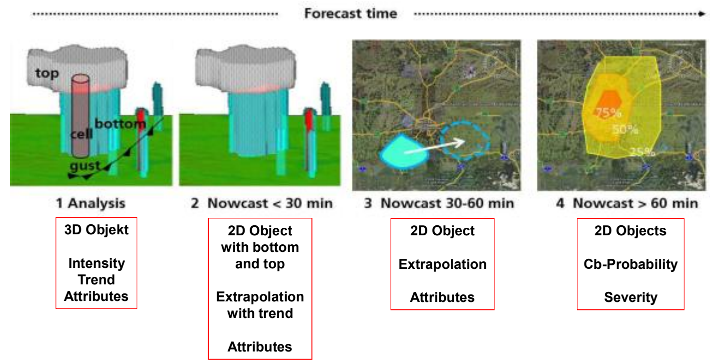
- Understanding physics and the underlying processes

- Analysis: Best guess of the actual wea... ...ject identification
- Nowcast: Extrapol... ...displacement
- Forecast: NWP i... ...assessment and combination of relevant parameters

Seamless prediction

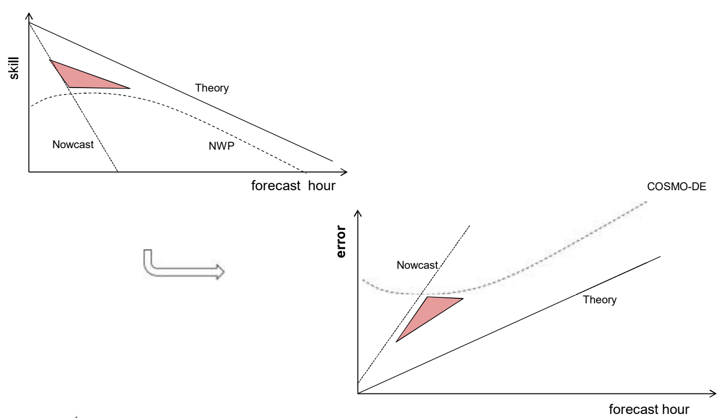
- Tailoring of the MET products to the user's needs – unambiguous, easy to interpret
- From MET info to MET impact

Seamless prediction



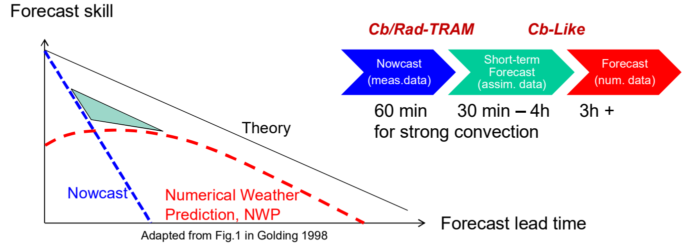
Decrease of descriptive detail over forecast time

Improvement of all-over forecast skill

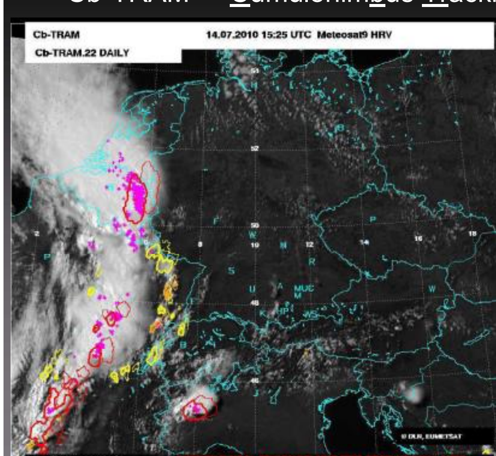


From nowcast to forecast

For seamless prediction of air-traffic-relevant phenomena



Cb-TRAM - Cumulonimbus Tracking and Monitoring



Using MSG (SEVIRI) data:
WV 6.2 IR 10.8
IR 12.0 HRV
for deriving top contours

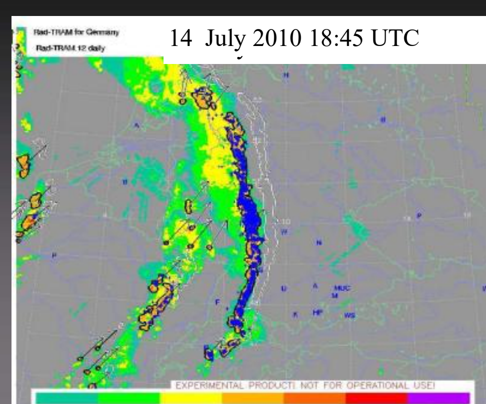
Detection stages:
1: Convection Initiation (CI)
development in HRV
IR 10.8 cooling
2: Rapid development
WV 6.2 rapid cooling
(> 1K/15min)
3: Mature storms
T 6.2 - T 10.8
HRV texture

Lightning (LINET)

Extrapolation up to 60 min
(here 30 minute nowcast plotted)

Description: Zinner et al., 2008,09 & 13

Rad-TRAM - Radar Tracking and Monitoring



Using European precip. radar composit (DWD):
37 dBZ reflectivity
for deriving bottom contours

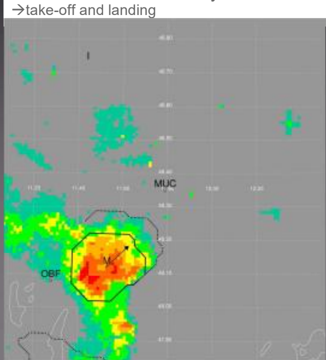
- detected contours in black
- 60 min nowcast in white
- moving direction by arrows

lightning obs. superimposed (LINET by nowcast GmbH)

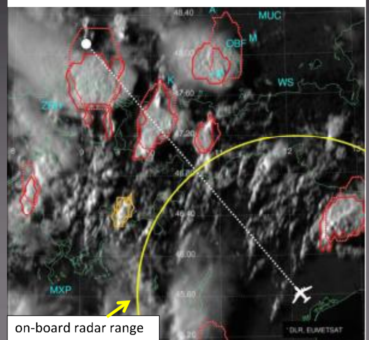
Use cases

Cb-TRAM: objects for aircraft en-route, encountering thunderstorms
Rad-TRAM: objects for airports / air traffic control when thunderstorms approach

Bottom: Rad-TRAM
weather radar data analysis
→take-off and landing



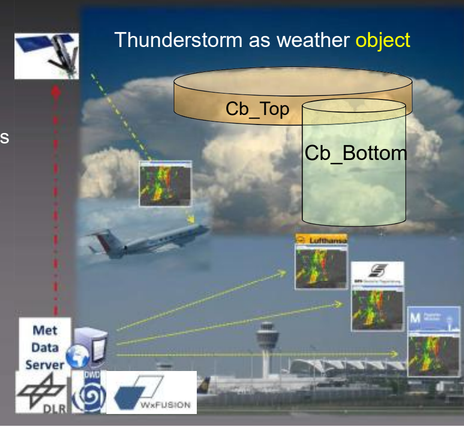
Top: Cb-TRAM
satellite data analysis
→en-route



Use cases

Cb-TRAM: objects for aircraft en-route, encountering thunderstorms
Rad-TRAM: objects for airports / air traffic control when thunderstorms approach

Thunderstorm warnings
- near-real time, on time
- update every 5/15 minutes
- forecast up to 60 minutes
- precise in space and time
- easy to interpret
- simultaneous for all: pilots, AOC, ATC, ATM, airports

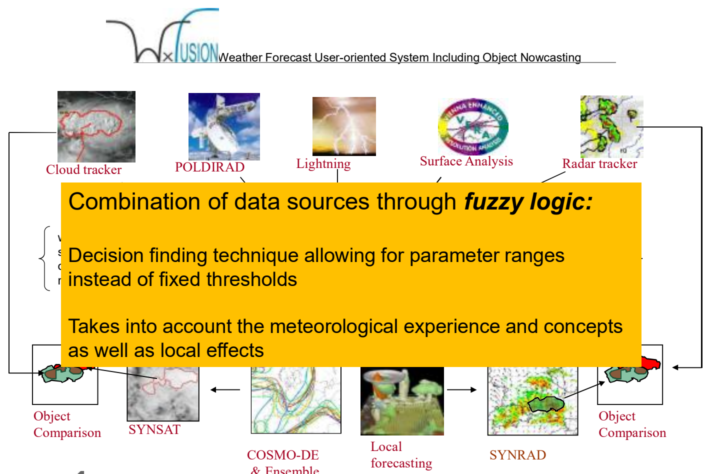


Issue:
- Nowcast of thunderstorms up to 1 hour is not sufficient for ATM purposes
- ANSP (Eurocontrol Maastricht) require at least 3 hours for planning purposes
- NWP alone (standard model output) is not reliable in forecasting Cb
- Seamless prediction chain required for continuity, consistency and reliability

DLR's approach:

⇒ Combination of all available and relevant data for assessment and prediction

⇒ **Cb-LIKE**



Combination of data sources through ***fuzzy logic:***

Decision finding technique allowing for parameter ranges instead of fixed thresholds

Takes into account the meteorological experience and concepts as well as local effects

Cb-LIKE - Likelihood of thunderstorms

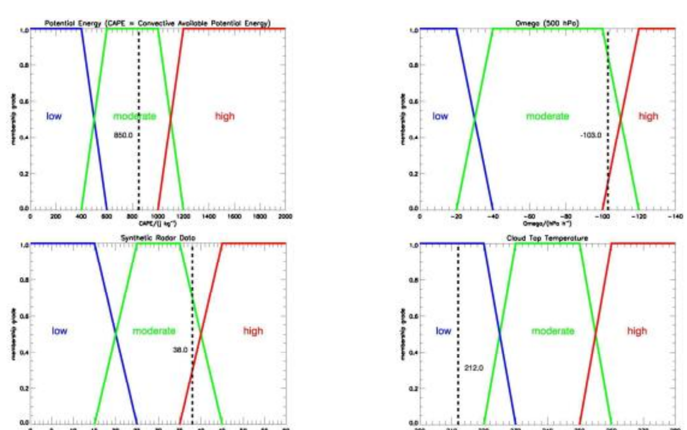
- extension of Cb nowcasting scale to short-term forecasting scale
- use of model output data (COSMO-DE)
- selection of the best member from an ensemble forecast
- combination of four model output quantities using fuzzy logic approach
  - vertical velocity, omega
  - convectively available potential energy, CAPE
  - synthetic radar data, SYNRAD
  - cloud top temperature, CTT

Parameter	x-Bereich	Fuzzy-Input Sets	Überlappung
		nied.: 0 bis 600 J/kg	400 bis 600 J/kg
Temperatur an Wolkengrenze (IR 10.8)	200 bis 280 K	nied.: 200 bis 230 K mod.: 220 bis 260 K hoch: 250 bis 280 K	220 bis 230 K 250 bis 260 K
Radarreflektivität	0 bis 60 dBZ	nied.: 0 bis 25 dBZ mod: 15 bis 45 hPa/h hoch: 35 bis 60 hPa/h	15 bis 25 dBZ 35 bis 45 dBZ

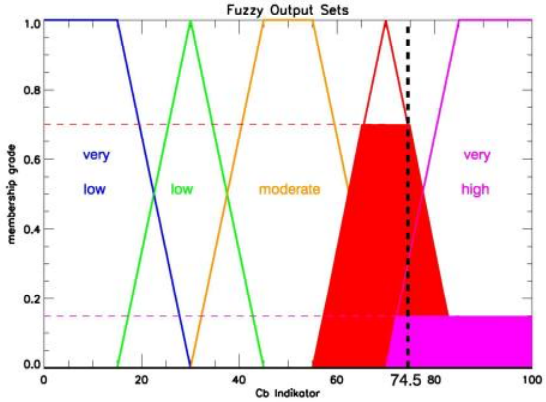
M. Köhler 2015: Cb-LIKE Cumulonimbus Likelihood: Thunderstorm forecasting with fuzzy logic. Subm. to Meteorologische Zeitschrift

M. Köhler 2015: Dissertation an der Ludwig-Maximilians-Universität München

Determination of thunderstorm intensity by fuzzy logic

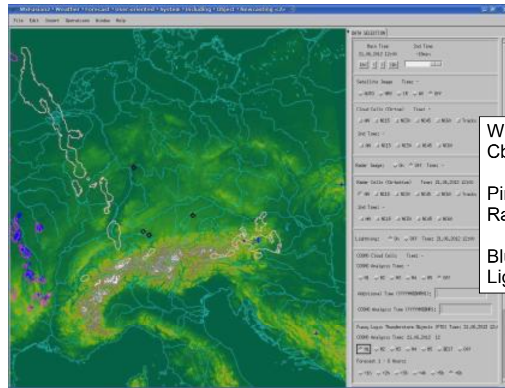


Determination of thunderstorm intensity by fuzzy logic



Cb likelihood forecasts up to 6 hrs: Cb-Like
Fuzzy logic combination of CAPE, 500 hPa vertical velocity, synthetic satellite and radar data from the DWD COSMO-DE model

Cb 6 hrs forecast for 21 June 2012 18:00 UTC



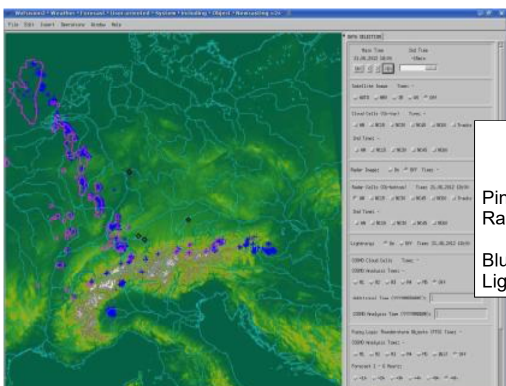
White contours:
Cb probability > 50%

Pink contours:
Rad-TRAM cells

Blue crosses:
Lightning data (LINET)

Cb likelihood forecasts up to 6 hrs: Cb-Like
Fuzzy logic combination of CAPE, 500 hPa vertical velocity, synthetic satellite and radar data from the DWD COSMO-DE model

Cb observation 21 June 2012 18:00 UTC



Pink contours:
Rad-TRAM cells

Blue crosses:
Lightning data (LINET)

Translation of "likelihood" into "probability"

Indikator	Mittleres FAR	Gewitterwahrscheinlichkeit
20	0,47	53 %
30	0,40	60 %
40	0,35	65 %
50	0,21	79 %
60	0,18	82 %
70	0,14	86 %
80	0,10	90 %

Summary:
Improvement of forecast quality for end users (aviation)

Necessary steps:

- Understanding physics and the underlying processes

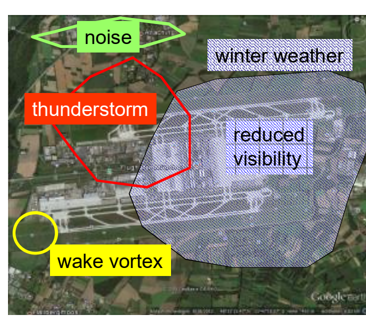
- **Analysis:** Best guess of the actual w... ...bject identification
- **Nowcast:** Extrapol... ...displacement
- **Forecast:** NWP i... ...assessment and combination of relevant parameters

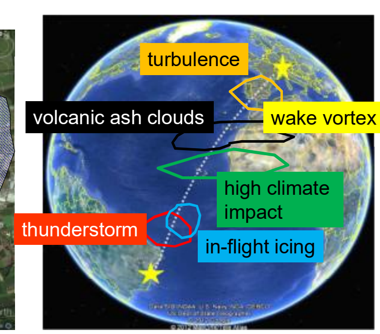
Seamless prediction

- **Tailoring** of the MET products to the user's needs – unambiguous, easy to interpret
- From MET info to MET impact

Rad-TRAM, Cb-TRAM
Cb-LIKE

The multi-hazards for aviation



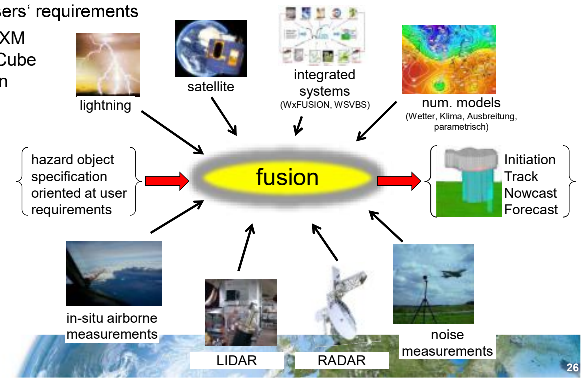


Safe, efficient, and sustainable aviation
Proposal: „5D MET Advisory“

- Provision, distribution and integration of complex information on different hazards or sensitive areas in a standardised form with interfaces to different users (ATC, ATM, AOC, crews in flight, APOC) (WXXM / SWIM)
- Presentation of the (weather) hazard as a (weather) object
- Is it doable ?
- Which hazards are “cooperative” (w.r.t. a standardisation) ?
- The **5D MET Advisory** approach

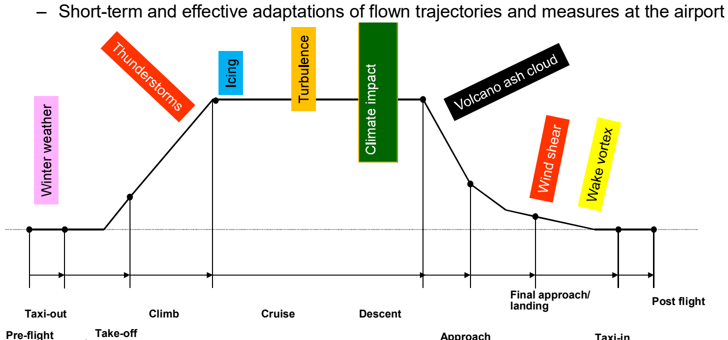
5D MET Advisory

- **Working principle:** Monitoring, seamless and continuous prediction, and fusion of data
- Considering different temporal and spatial scales
- Combining output of different approaches, algorithms, and measurements
- Modelling the region of the hazard or the environmentally sensitive zone as objects according to the users‘ requirements
- Coding acc. to WXXM for SWIM / 4d-WxCube in SESAR/NextGen



5D-MET Advisory:
an integrated advisory for weather, climate and disruptive events

- 5D MET Advisory shall provide standardised data on hazards which are enablers for
  - Planning of optimised flight routes (ATFM) and sectors (TAM) w.r.t. weather, climate, disruptive events, … well in advance
  - Short-term and effective adaptations of flown trajectories and measures at the airport



Meteorological Uncertainty Management for Trajectory Based Operations — TBO-Met

PNOWWA workshop

Prof. Damián Rivas
Project Coordinator

Austro Control, Vienna, 27-28 February 2018

Founding Members

TBO-Met

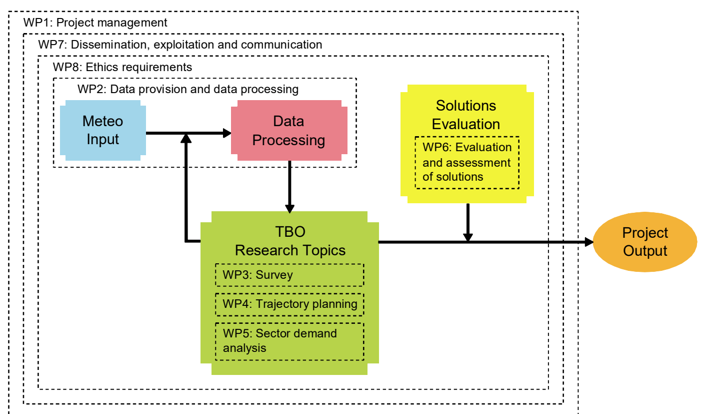
SESAR 2020 Exploratory Research
(01 June 2016 - 31 May 2018)

CONSORTIUM

Outline

1. **Project overview**
2. Robust trajectory planning (pre-tactical)
3. Storm avoidance (tactical)
4. Sector demand analysis (pre-tactical and tactical)
5. Validation
6. Final comments

Project Overview



Project overview

- **3 research topics:**
  - robust trajectory planning
  - storm avoidance
  - sector demand analysis
- **8 technical problems**

	Input	Trajectory analysis	Traffic analysis	Validation
Mid term	100%	100%	100%	40%
Short term	100%	100%	100%	20%
	WP2	WP4	WP5	WP6

Overall:
about 90%

Meteo input

- **ECMWF-EPS** -- Meteo data used:
  - wind speeds, U, V;
  - air temperature, T
- **GLAMEPS (multimodel)** -- Meteo data used:
  - convective precipitation, CP;
  - Total Totals index, TOTALX
- **AEMET Nowcast 2D_NAC** -- (based on radar reflectivity; 10 min nowcast steps; 0, 10, …, 60 min lead time)

  Meteo data used:
  - latitude and longitude of the rectangle limits of the convective cell, LAT_N, LAT_S, LON_E, LON_W;
  - latitude and longitude of the center of the convective cell at lead times 0, …, 60 min, LAT00,…,LAT60, LON00,…,LON60

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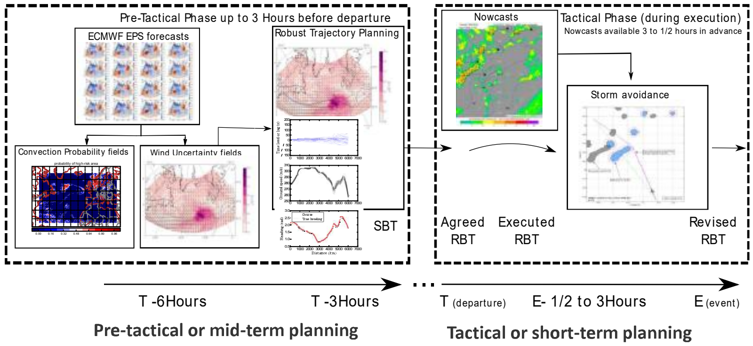
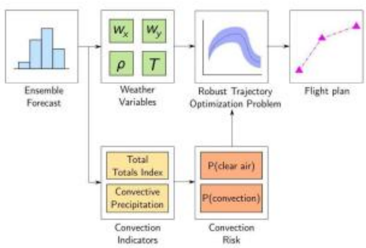
Robust trajectory planning - Overview

Objective: To analyze trade-offs between efficiency and predictability of 4D trajectories under meteorological uncertainty within the envisioned TBO operational concept.



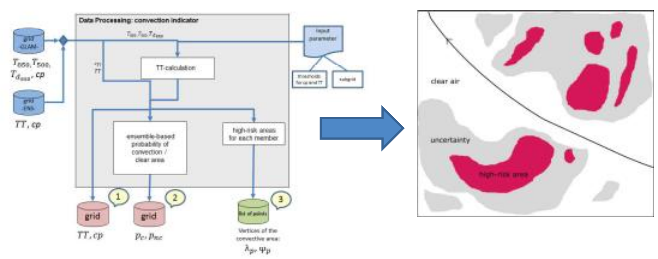
Methodology

- Uncertainty due to winds and convection (EPS forecast)
- Approach: **Robust Optimal Control**
- Cost funcion: expected time + **p** time dispersion + **cp** convective risk



$$\min\left[\frac{1}{n}\sum_{j=1}^{n} t_j(r_f) + p(t_{f,max} - t_{f,min}) + cp\int_0^{r_f} p_c(\lambda,\phi)dr\right]$$

Processing of NWP Model Forecasts (EPS) for pre-tactical trajectory prediction



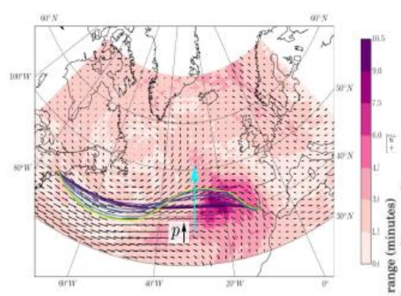
Similarly for wind components and air temperature

Probability of convection

The ensemble-based probability of convection is the fraction of ensemble members with values above given thresholds TT_H and CP_H for all TT and CP of the ensemble members (thresholds: TT_H approx. 50; CP_H = 0)

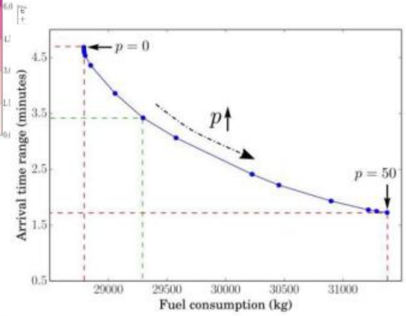
$$p_c = \frac{N_c}{N} \quad \text{with } N_c = \sum_{i=1}^{N} i\text{, where } (TT_i > TT_H) \wedge (cp_i > cp_H)$$

Robust Trajectory Optimization considering Uncertain Winds

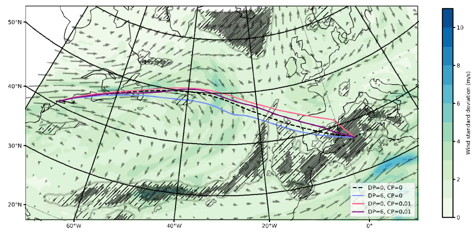


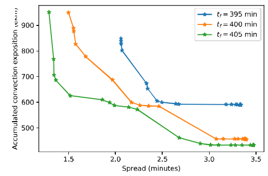
3 minutes reduction in time uncertainty flying the most predictable trajectory (p = 50), with 2500 kg of extra fuel burnt.

Description:
- A330 from NY to Lisbon
- Flying at constant M=.82 and FL380
- 20th of January, 2016
- 200 hPa level ensemble Forecast



Robust Trajectory Optimization considering Uncertain Winds and Convection





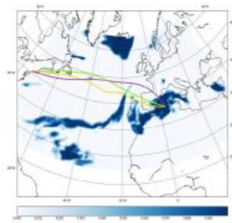
Description:
- A330 from NY to Argel
- Constant M=.82 and FL380
- 19th of December, 2016
- 200 hPa level EPS

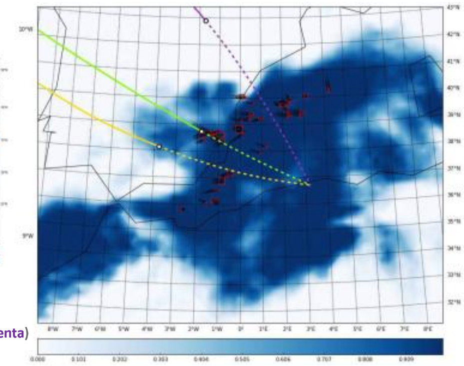
Optimal trajectories for p/cp values: dashed, p=0, cp=0; blue, p=6, cp=0; red, p=0, cp=0.01; brown, p=6, cp=0.01
Color contour scale indicates wind uncertainty.
Dashed regions indicate regions of convective exposure.

Reducing the exposure to convection to one-half implies to increase the time dispersion from 1.5 to 3.5 min

Pareto frontiers for different average flight times

Robust Trajectory Optimization considering Uncertain Winds and Convection





Three planned trajectories:
- Min exposure to convection (magenta)
- Min fuel (green)
- Max Predictability (yellow)

Polygons represent storms at different time instants (red-actual time; black 10-20-30-40-50-60 min look-ahead times).
The white dot in the trajectories represents the actual time .

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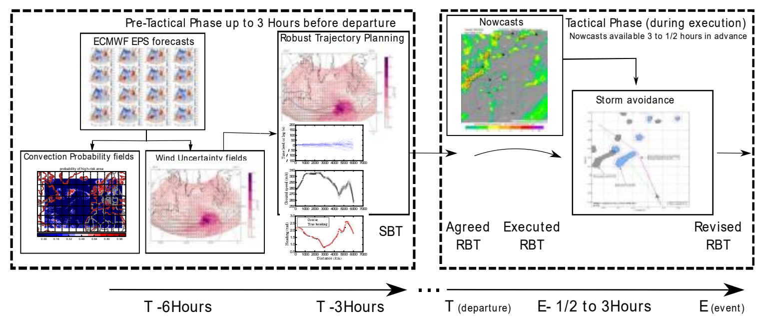
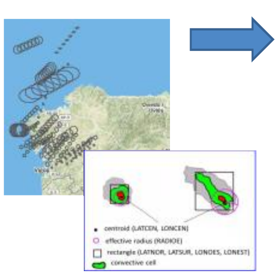
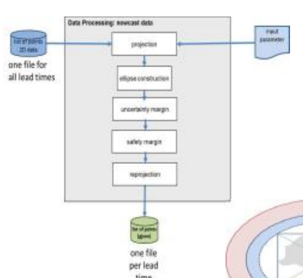
Recap

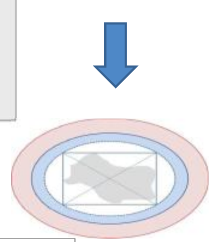


Trajectories planned (with more/less exposure to convective areas) should be flown, but may potentially encounter storms

Processing of Nowcast Data for Tactical Trajectory Prediction

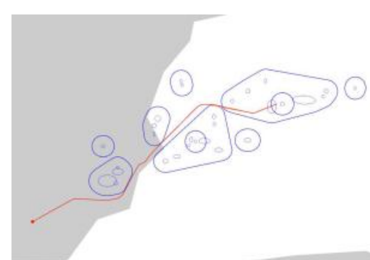






Input:
Outline of Convective Cell as Ellipse with Uncertainty Margin (light blue) and Safety Margin (light red)

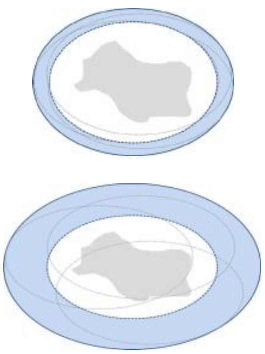
Tactical Trajectory Prediction: DIVMET



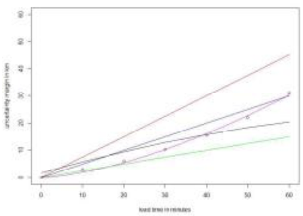
Animation of trajectory prediction with nowcasts (lead times 0 – 40 min)

Modelling of Storm Uncertainty

Random elliptic Storm Cells
within Uncertainty Margin

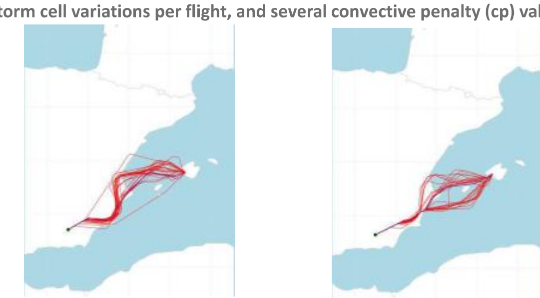


Lead-Time dependent
Uncertainty Margins



Deviation Routes as Input to Sector Demand Analysis

DIVMET calculated Deviation Routes for 350 Flights, considering
31 storm cell variations per flight, and several convective penalty (cp) values.



cp=0.005 cp=0

2016/12/19, 06:20; Safety Margin: 10NM; Uncertainty Margin by AEMET

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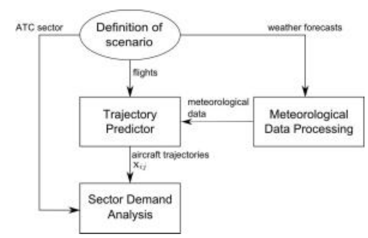
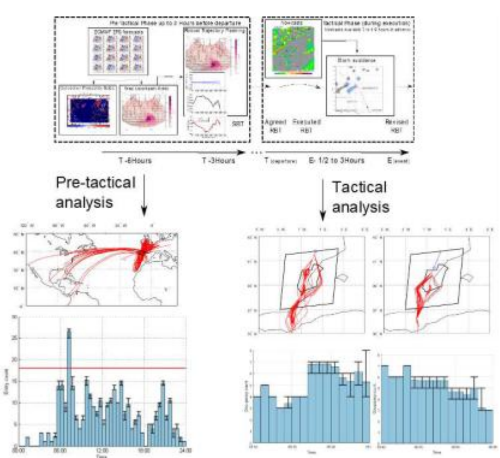
Sector Demand Analysis



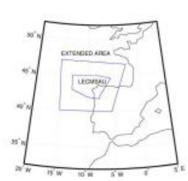
Main elements:
- Definition of scenario (ATC sector, flights, and weather forecasts),
- Meteorological data processing,
- Trajectory predictor,
- Analysis, based on statistichal characterization of
  - entry and exit times, and
  - entry and occupancy counts.

Applications



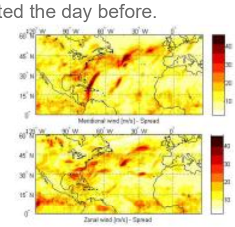
Pre-tactical analysis (I)

Sector demand predicted for a whole day, when predicted the day before.

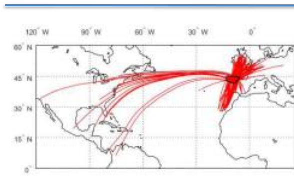


ATC sector

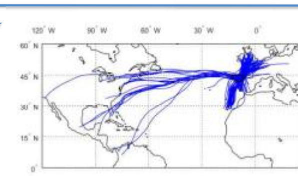
328 Flights



Weather forecast (EPS)



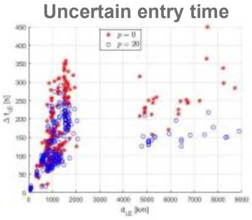
Trajectories for minimum flight time (p=0)



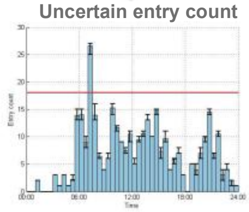
Trajectories with reduced time dispersion (p=20)

Pre-tactical analysis (II)

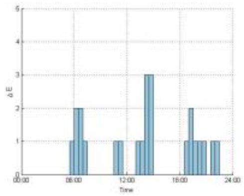
Uncertain entry time



Uncertain entry count

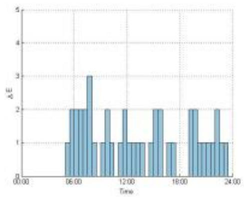


Dispersion



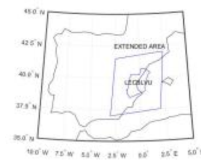
p = 20

Dispersion can be reduced



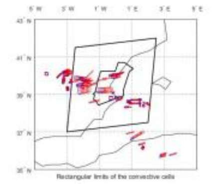
p = 0

Tactical analysis (I)



ATC sector

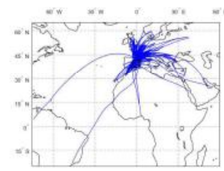
257 Flights



Weather forecast (EPS & Nowcasts)

Trajectories for minimum flight time (cp=0)

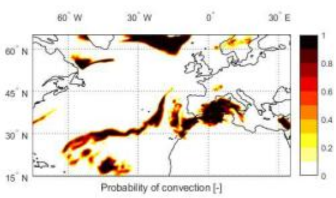
Reference Trajectories



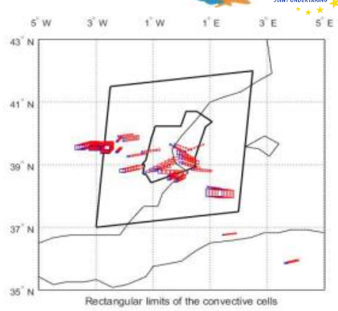
Trajectories with reduced convection risk (cp=0.005)

Tactical analysis (II)

Meteo data



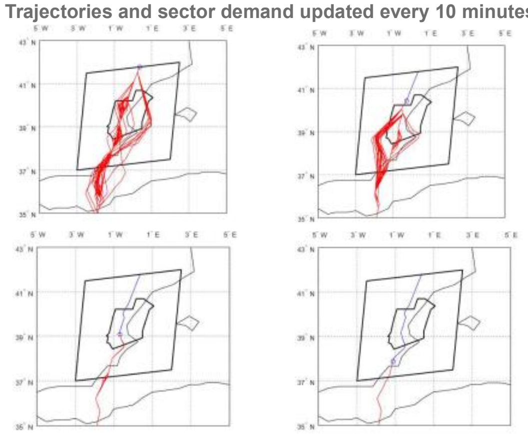
ECMWF-EPS released at 00:00, 19/12/16, forecasting horizon 6 hours.



AEMET Nowcast released at 06:00, 19/12/16; detected storm cells (blue), and forecasted for 10, 20, 30, 40, 50, and 60 minutes (red)

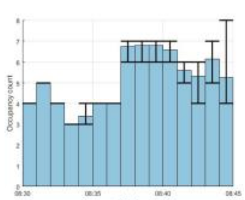
Tactical analysis (III)

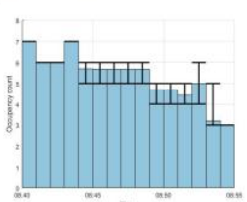
Trajectories and sector demand updated every 10 minutes



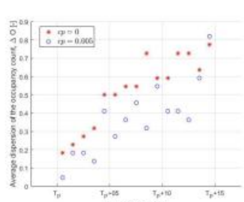
Deviation trajectories

Tactical analysis (IV)





Uncertain occupancy count



Dispersion is reduced

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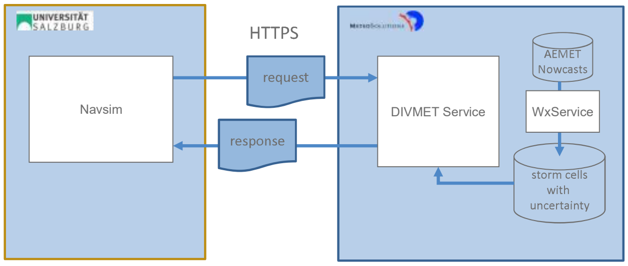
2. Robust trajectory planning (pre-tactical)
3. Storm avoidance (tactical)
4. Sector demand analysis (pre-tactical and tactical)
5. **Validation**
6. Final comments

Simulation of real world: NAVSIM

- **Installation of DIVMET as a Service**
- **Linking DIVMET to NAVSIM**



Validation scenarios

VS1: to validate the **robust flight-planning** concept considering only **wind uncertainties**

VS2: to validate the **robust flight-planning** concept considering both **wind uncertainties and convective risk**

VS3: to validate the **robust short-term flight planning** concepts considering the **uncertain evolution of storms**

VS4: to validate the **sector-demand prediction at pre-tactical level** considering only **wind uncertainties**

VS5: to validate the **sector-demand prediction at tactical level** considering both **convective risk and the uncertain evolution of storms**

Set of flights in VS1, VS4

Set of flights in VS2, VS3, VS5

Outline

1. Project overview
2. Robust trajectory planning (pre-tactical)
3. Storm avoidance (tactical)
4. Sector demand analysis (pre-tactical and tactical)
5. Validation
6. **Final comments**

Project maturity

	Input	Trajectory analysis	Traffic analysis
Mid term	**EPS**	**TP/Opt Control**	**1 sector**
Improvement/ Expansion	Calibration	Improved TP	Multi sector (network level)

	Input	Trajectory analysis	Traffic analysis
Short term	**Nowcast**	**DIVMET**	**1 sector**
Further research/ Expansion	Probabilistic nowcast	Improved DIVMET	Sector reconfiguration

References

Robust Aircraft Trajectory Planning under Wind Uncertainty using Optimal Control. D. González-Arribas, Manuel Soler, and Manuel Sanjurjo. *Journal of Guidance, Control, and Dynamics, Vol. 41 (3), 2018, pp. 673-688. https://doi.org/10.2514/1.G002928*

Wind-Based Robust Aircraft Route Optimization using Meteorological Ensemble Prediction Systems. D. González-Arribas, Manuel Soler, and Manuel Sanjurjo. *6th SESAR Innovation Days (SID), 2016. Available at Open-Aire.*

Robust Optimal Trajectory Planning under Uncertain Winds and Convective Risk. Daniel González-Arribas, Manuel Soler, Javier García-Heras, Manuel Sanjurjo-Rivo, Ulrike Gelhardt, Juergen Lang, Daniel Sacher, Thomas Hauf, and Juan Simarro. *ATM/CNS EIWAC Conference 2017. In review for "Air Traffic Management and Systems III - Selected papers of the 5th ENRI international workshop, 2017", Springer.*

Sector demand analysis under meteorological uncertainty. Alfonso Valenzuela, Antonio Franco and Damián Rivas. *7th European Conference for Aeronautics and Space Sciences (EUCASS), 2017.*

Effects of Reducing Wind-Induced Trajectory Uncertainty on Sector Demand. Alfonso Valenzuela, Antonio Franco, Damián Rivas, Javier García-Heras and Manuel Soler. *7th SESAR Innovation Days (SID), 2017.*

Effects of Weather Uncertainty in Sector Demand at Tactical Level. Alfonso Valenzuela, Antonio Franco, Damián Rivas, Daniel Sacher, Javier García-Heras and Manuel Soler. *8th International Conference for Research in Air Transportation (ICRAT), 2018.*

2nd International Workshop on Meteorology and Air Traffic Management

UNIVERSITÄT SALZBURG

University of Salzburg, Austria
3-4 May 2018

Suported by SESAR
Project TBO-Met

European Commission

HORIZON 2020

Meteorological Uncertainty Management for Trajectory Based Operations — TBO-Met

PNOWWA workshop

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

SESAR JOINT UNDERTAKING

ATM4E Stakeholder Webinar
Climate-optimized trajectories
1 February 2018

Exchange with stakeholders on to summarize knowledge, provide guidance and technical insights and discuss research and implementation requirements.

SESAR JOINT UNDERTAKING

Founding Members

ATM4E

DLR

ATM4E Air Traffic Management for Environment

Webinar
Thursday, February 1st, 2018
13:00-15:00 (CET time)

ATM4E project explores the feasibility of a concept for environmental assessment of ATM operations centered on environmental change functions. The two year research project will complete implementation in May 2018 and has successfully achieved its key milestones so far.

ATM4E is working towards the objective to enable climate-optimized trajectories in the future air transport system. The project aims at defining a conceptual assessment framework for the deployment of the produced environmental change functions involving environmental performance indicators. Additionally, a roadmap is under development with recommendations and an implementation strategy for the environmental optimization of aircraft trajectories.

Effective communication with stakeholders and aviation experts is key when working toward the environmental optimisation of air traffic operations in the European airspace. This webinar will be a great opportunity to summarize the acquired knowledge, provide guidance and technical insights and discuss research and implementation requirements to enable, encourage and accompany stakeholders in the implementation of the necessary steps and actions that would need to be taken to ultimately introduce environmentally-optimized flight operations in European airspace.

Agenda:
13:00 ATM4E *Concept for climate-optimized routing* — ***Sigrun Matthes***
13:30 *Climate-optimal trajectories over Europe: A case study* — ***Ben Lührs***
14:00 *Lesson learnt on implementation of MET service* — ***Keith Shine***
14:30 *Open discussion and next steps*

SESAR JOINT UNDERTAKING

Founding Members

This project has received funding from the SESAR Joint Undertaking under grant agreement No 699395 under European Union´s Horizon 2020 research and innovation programme.

DLR

ATM4E Stakeholder Webinar Participants

ATM4E SESAR JOINT UNDERTAKING

ATM4E Steering Committee
Ben Lührs, TU Hamburg
Sigrun Matthes, DLR
Ling Lim, MMU
Keith Shine, Univ. Reading
Feijia Yin, TU Delft

Volker Grewe, TU Delft / DLR
Florian Linke, TU Hamburg /DLR

Stakeholder Webinar Participants

Tatjana Bolic	Univ.Trieste/SJU
Rachel **BURBIDGE**	Eurocontrol
Laurent **Cavadini**	Eurocontrol
Luca **Crecco**	SESAR JU
Alexandra **Covrig**	Airport Regions
David **Batchelor**	SESAR JU
Andrew **Booth**	Rolls-Royce
Alain **Bourgin**	DGAC
David **Brain**	Eurocontrol
James **DEELEY**	NATS
Robin **Deransy**	Eurocontrol
Nathalie **Guitard**	ACNUSA
Oleksandra **Hrasko**	UkSATSE
Kay **Köhler**	UBA, Germany
Marina **Kousoulidou**	European Commission
Alexander **Kuenz**	DLR
Laura **LONZA**	European Commission
Paul Madden	Rolls-Royce
Miguel **MARTI VIDAL**	European Commission
Corinne **Marizy**	Airbus
Manfred **MOHR**	IATA
Jarlath **Molloy**	NATS
David **MARSH**	Eurocontrol
Alessandro **Prister**	SESAR JU
Matteo **Prussi**	European Commission
Olivier **PENANHOAT**	SAFRAN
Herbert **Puempel**	WMO
Mischa **Repmann**	firstclimate
Frédérique **RIGAL**	Airbus
Thomas **ROETGER**	IATA
Peter **Swann**	Rolls-Royce
Rainer **von Wrede**	Airbus
Urs **Ziegler**	FOCA

ATM4E approach for identifying climate-optimal aircraft trajectories

ATM4E Air Traffic Management for Environment

Sigrun Matthes
DLR, Institute Atmospheric Physics, Oberpfaffenhofen
Coordinator ATM4E (SESAR 2020, Exploratory Project)

Volker Grewe, Keith Shine, Florian Linke, Benjamin Lührs, Feijia Yi, Stavros Stromatas and ATM4E Team

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ATM4E

http://www.atm4e.eu/

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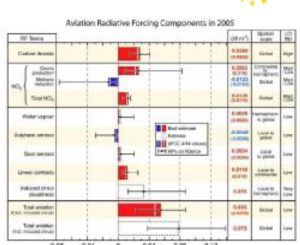
Aviation climate impact CO_2 and non-CO_2 effects

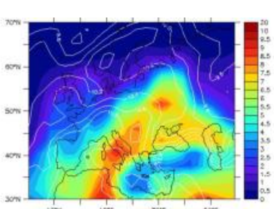
ATM4E SESAR JOINT UNDERTAKING

Climate impact of aviation emissions (direct & indirect effects)

- **CO_2**, black carbon (soot) - direct
- Nitrogen oxides **NO_x** (O_3, CH_4)
- **Contrail cirrus** and H_2O
- soot (AIC, aviation induced cloudiness)



Lee et al., 2010 (IPCC)



Ozone production efficiency pf NO_x emissions, 18 Dec, 250 hPa (EMAC)

Climate impact of **non-CO_2 emissions** depends on

- time and position of aircraft
- actual weather conditions (processes, transport pathways, temperature, humidity)
- background concentrations

⇒ **Climate optimized trajectories avoid sensitive regions**

Aviation climate impact CO_2 and non-CO_2 effects

ATM4E SESAR JOINT UNDERTAKING

Climate impact of aviation emissions (direct & indirect effects)

- **CO_2**, black carbon (soot) - direct
- Nitrogen oxides **NO_x** (O_3, CH_4)
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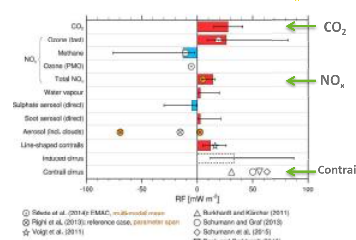
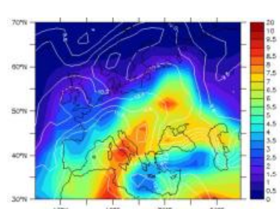


Grewe et al., 2017, updating Lee et al., 2010 (IPCC)



Ozone production efficiency pf NO_x emissions, 18 Dec, 250 hPa (EMAC)

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- background concentrations

⇒ **Climate optimized trajectories avoid sensitive regions**

ATM4E

Environmental-optimised trajectories

- Aviation is concerned by environmental impact of its operations. **Aviation climate impact** is caused by CO_2 and non-CO_2 emissions, comprising contrails, nitrogen oxides impacting ozone and methane, water vapour, etc.
- However, during flight planning currently emission information is available, but no **environmental impact information** is available.
- **ATM4E**, Exploratory Research project **SESAR 2020** (2016-2018)
- **Main objective** of the ATM4E project is to explore the feasibility of a concept for environmental assessment of ATM operations working towards environmental optimisation of air traffic operations in the European airspace.

Matthes et al., 2012
Grewe et al., 2014a,b

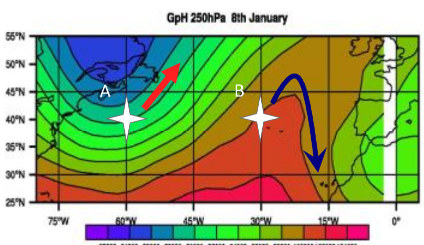
Interface between environmental impact and ATM via Environmental Change Functions

How to make available information on environmental impact for flight planning.

Founding Members

How to generate such information?

Evolution of aircraft NO_x at two different locations



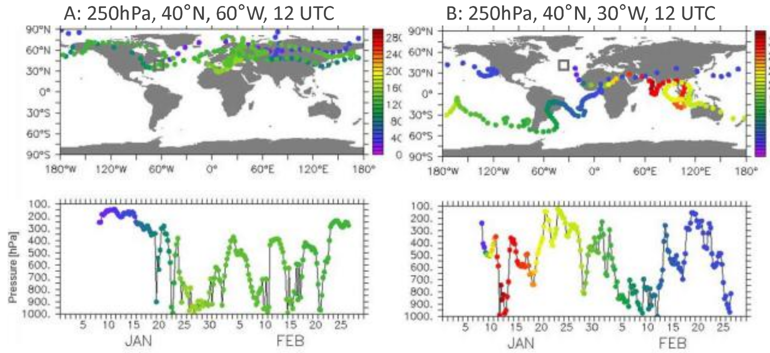
Frömming et al., 2011, 2018

What happens if an aircraft emits NO_x at location A compared to location B?

Using a Lagrangian approach in a chemistry climate model EMAC to study photochemical processes and climate impact

Climate chemistry model (EMAC)

Evolution of O_3 [ppt] following a NO_x emission



Frömming et al., 2011, 2018

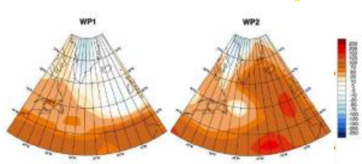
Depending on location of emission ozone formed during weeks after emission can be high (here: 30°W) and lower (here: 60°W)

Environmental Change Functions ECFs

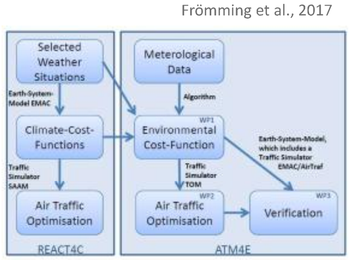
- The key step in ATM4E is to **relate** readily-available **meteorological data** to these existing detailed CCFs to allow the rapid generation of new CCFs (algorithmic CCFs) for specific (forecast) weather situations

  ⇒ **Advanced MET information**

- Integration of **environmental impact information** via Meteorological interface to **SWIM infrastructure** (format, architecture) to make it available during flight planning.

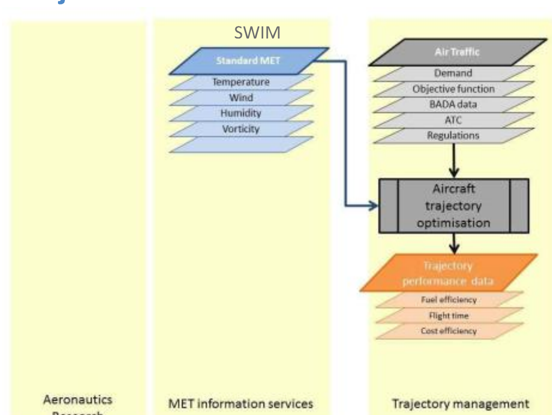


Frömming et al., 2017

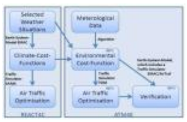


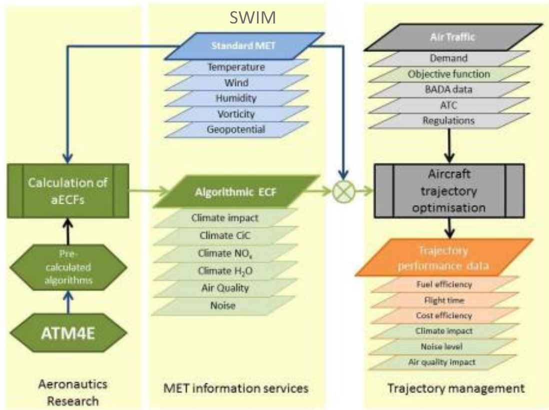
Air traffic management for environment: SESAR/H2020-Project ATM4E

Current situation



Air traffic management for environment: SESAR/H2020-Project ATM4E



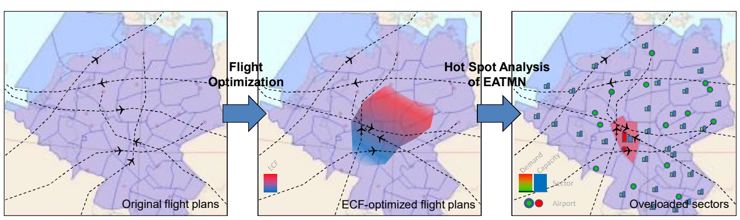


Contribution of ATM4E

Environmental-optimized routing impact on ATM changes in air traffic flows

Environmental-optimized routing impact on ATM changes in air traffic flows

- To **optimize trajectories** to minimize the environmental impact of an air traffic sample in the European airspace
- To **analyze ATM network implications** (hot spots) resulting from environmental optimized routing

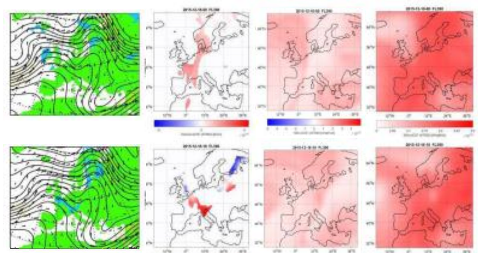


Using ECFs for flight planning

Objective function with **economic** and **environmental** elements

$$\mathcal{J} = c_Y \cdot \mathrm{COC}(t_{\mathrm{mission}}, m_{\mathrm{fuel,mission}}) + \int_{t_0}^{t_f} \sum_i (c_{\Psi,i} \cdot \mathrm{ECF}_i(\mathbf{x},t) \cdot r_i)\, \mathrm{d}t$$

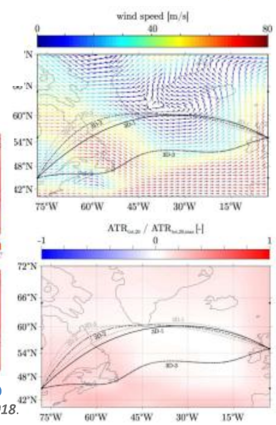
Synoptical situation	Contrail	H_2O	NO_x
GpH, wind	*T, RH, OLR*	*Pot. Vort.*	*GpH, T*



	10^{-12} K/km	10^{-15} K/kg fuel	10^{-12} K/kg NO

Irvine and Shine, 2018; Matthes et al. 2017, Van Manen and Grewe, 2018.

Algorithmic Climate change function (ECF) given as average temperature response in case study (250 hPa)

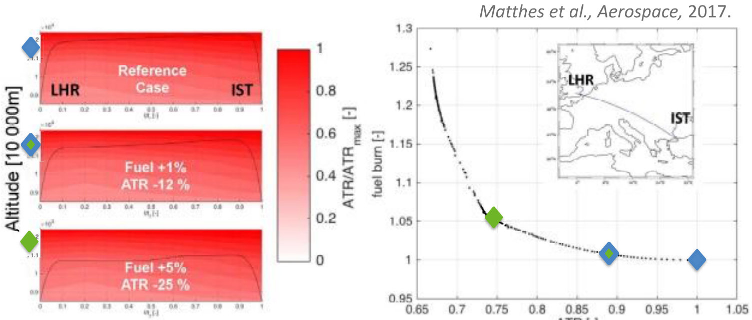


Trajectory optimisation (TOM) by Linke, Lührs, Niklaß

Environmental Optimization of Aircraft Trajectories

Using advanced MET service ECF to identify Pareto front for use case climate optimized trajectories

Matthes et al., Aerospace, 2017.



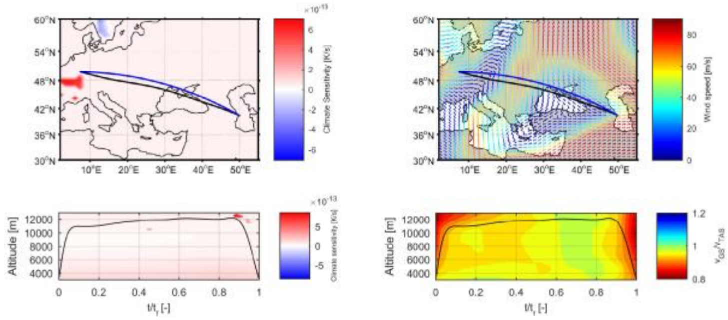
Trajectory optimisation assesses climate impact simultaneously with fuel burn.

ATM delivers economic and environmental performance – Pareto Front

How do environmentally optimized trajectories look like?

2 Sample optimization results – Route 1

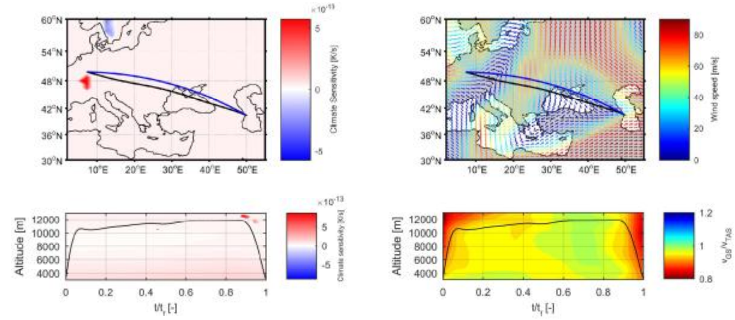
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 0.0 %
ΔATR: - 0.0 %

2 Sample optimization results – Route 1

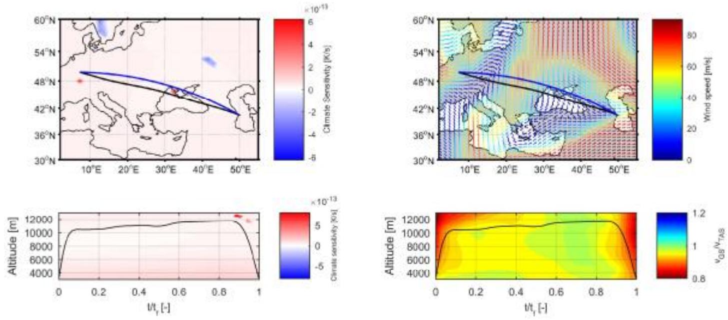
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 0.5 %
ΔATR: - 11.2 %

2 Sample optimization results – Route 1

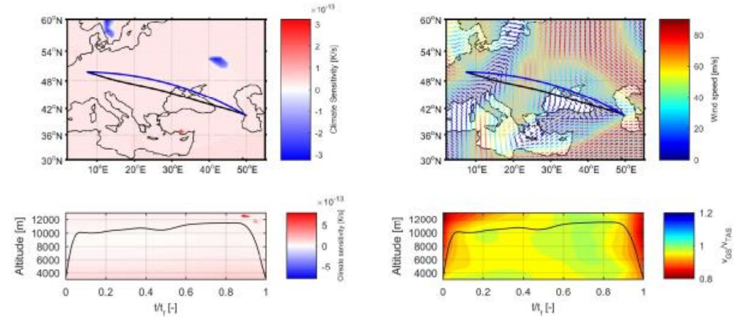
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 1.0 %
ΔATR: - 16.0 %

2 Sample optimization results – Route 1

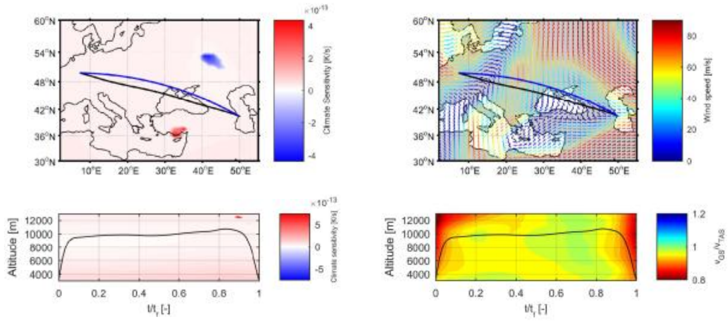
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 2.0 %
ΔATR: - 22.1 %

2 Sample optimization results – Route 1

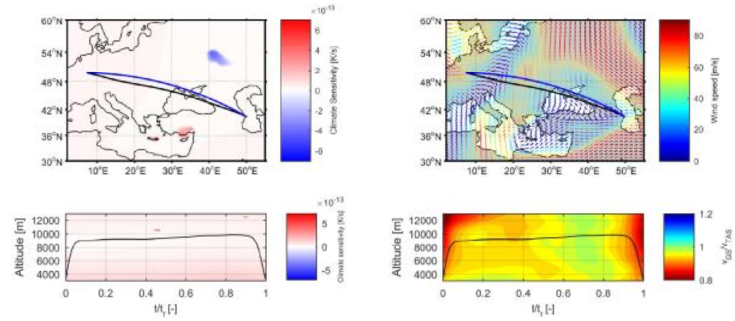
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 5.0 %
ΔATR: - 32.9 %

2 Sample optimization results – Route 1

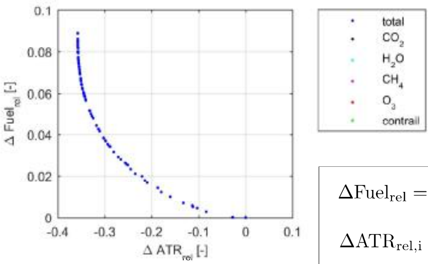
UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



ΔFuel: + 8.8 %
ΔATR: - 35.8 %

2 Sample optimization results – Route 1

UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



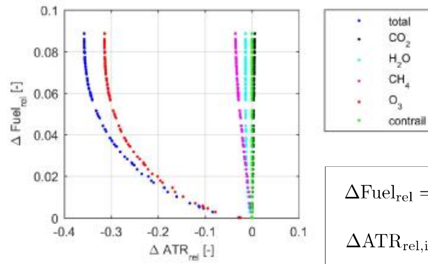
$$\Delta \mathrm{Fuel}_{\mathrm{rel}} = \frac{m_{\mathrm{Fuel}} - m_{\mathrm{Fuel,ref}}}{m_{\mathrm{Fuel,ref}}}$$

$$\Delta \mathrm{ATR}_{\mathrm{rel,i}} = \frac{\mathrm{ATR_i} - \mathrm{ATR_{i,ref}}}{\mathrm{ATR_{total,ref}}}$$

i ∈ CO_2, H_2O, CH_4, O_3, contrails

2 Sample optimization results – Route 1

UBBB (Baku, Azerbaijan) – ELLX (Luxembourg)



$$\Delta \mathrm{Fuel}_{\mathrm{rel}} = \frac{m_{\mathrm{Fuel}} - m_{\mathrm{Fuel,ref}}}{m_{\mathrm{Fuel,ref}}}$$

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2 Sample optimization results – Route 1

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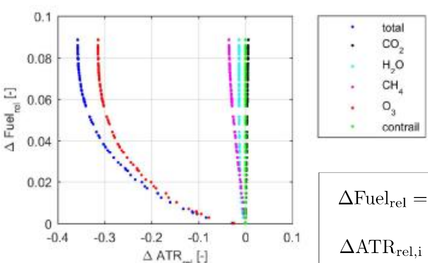

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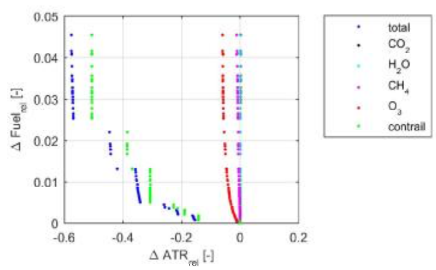
$$\Delta \mathrm{ATR}_{\mathrm{rel,i}} = \frac{\mathrm{ATR_i} - \mathrm{ATR_{i,ref}}}{\mathrm{ATR_{total,ref}}}$$

i ∈ CO_2, H_2O, CH_4, O_3, contrails

Climate impact reduction driven by emitting NO_x in less climate sensitive regions

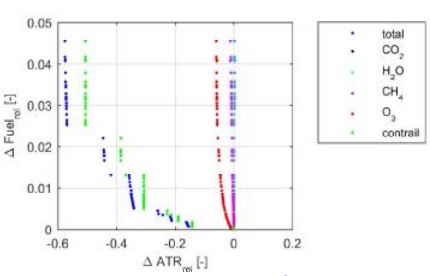
2 Sample optimization results – Route 7

EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



2 Sample optimization results – Route 7

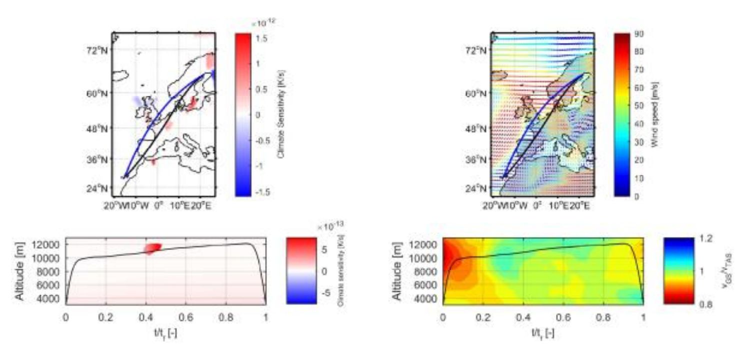
EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



Climate impact reduction driven by contrail avoidance

2 Sample optimization results – Route 7

EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)

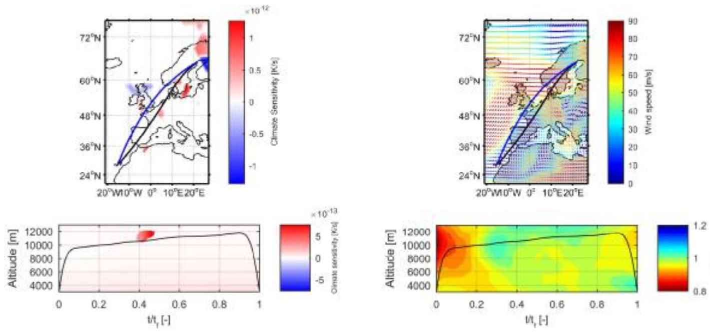


ΔFuel: + 0.0 %

ΔATR: - 0.0 %

2 Sample optimization results – Route 7

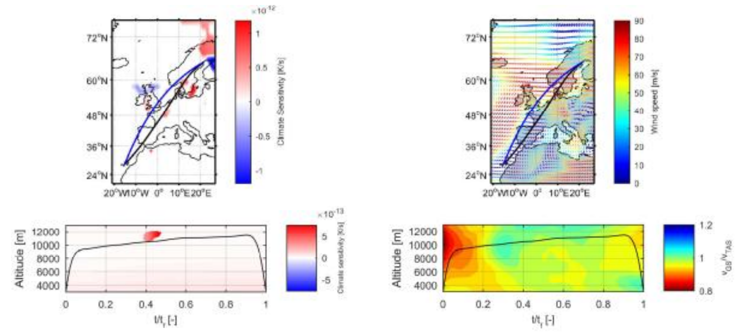
EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



ΔFuel: + 0.5 %
ΔATR: - 34.2 %

2 Sample optimization results – Route 7

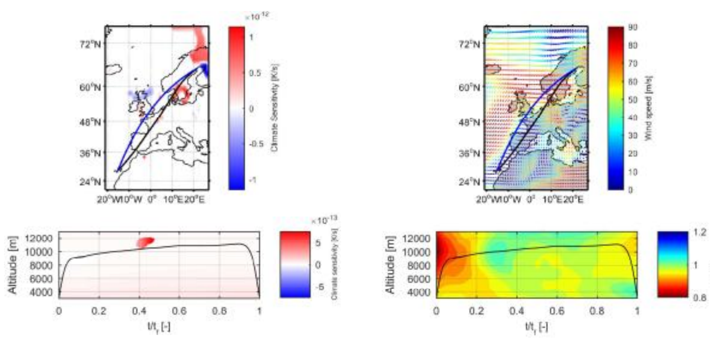
EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



ΔFuel: + 1.0 %
ΔATR: - 35.0 %

2 Sample optimization results – Route 7

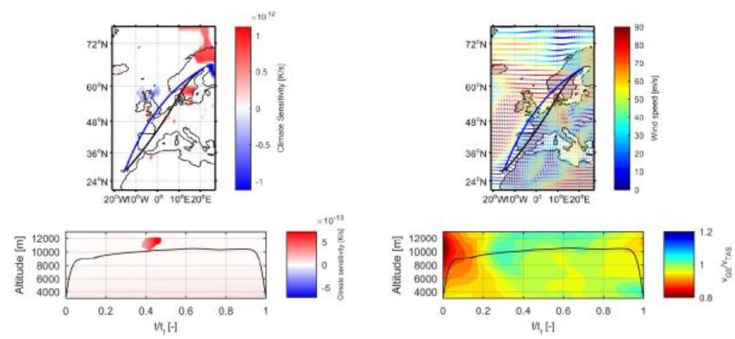
EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



ΔFuel: + 2.0 %
ΔATR: - 44.4 %

2 Sample optimization results – Route 7

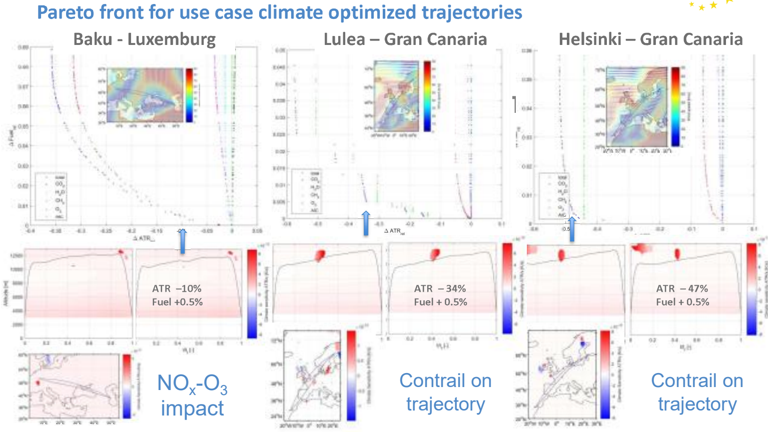
EPSA (Lulea, Sweden) – GCLP (Gran Canaria, Spain)



ΔFuel: + 4.5 %
ΔATR: - 57.6 %

Case Study – Climate optimisation

Using advanced MET service as algorithmic ECFs to identify Pareto front for use case climate optimized trajectories

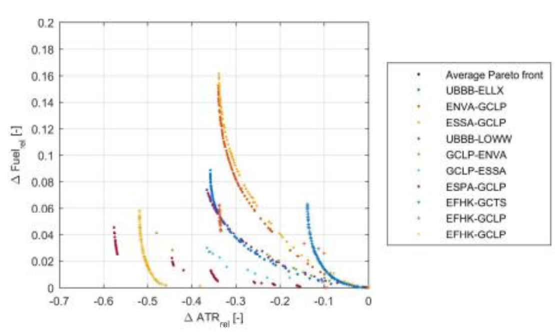


Trajectory optimisation assesses climate impact simultaneously with fuel burn.

ATM delivers economic and environmental performance (Case study 19 Dec 2015)

2 Estimation of the overall potential

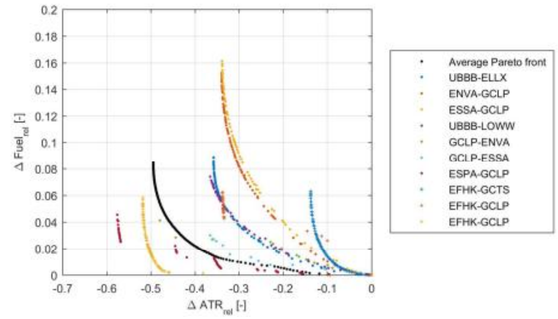
- Combination of individual pareto fronts
- Absolute ATR and fuel changes are considered
- Optimization using integer linear programming approach



Average Pareto front for the top 10 routes (black) estimated based on the individual Pareto fronts of each route (colored). Red circles indicate the point on each individual Pareto front which leads to minimum ATR impact when an overall fuel penalty of 5% is accepted (see black circle on average Pareto front)

2 Estimation of the overall potential

- Combination of individual pareto fronts
- Absolute ATR and fuel changes are considered
- Optimization using integer linear programming approach



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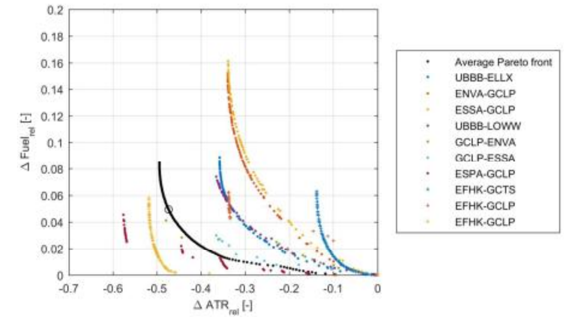

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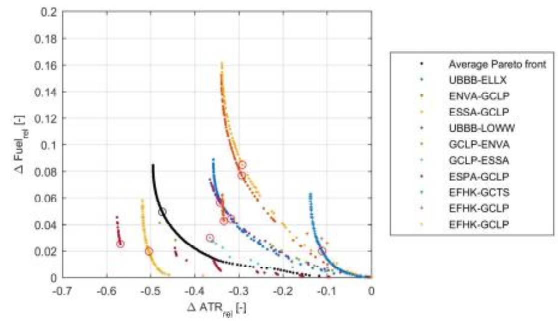

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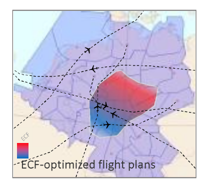
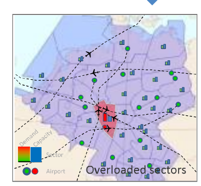
Outlook

- Further **analysis** of the **optimization results**
  - **Huge amount of data** (more than 1,000,000 optimized trajectories (100 per route), 700 GB)
  - Estimation of the **overall potential** for all routes
  - Study the **contribution of each species** for potential climate impact savings
  - Study **changes in routing**
- Analyse **ATM network implications**
  - **Hotspot analysis**
  - Identification of **imbalances**



Hotspot analysis

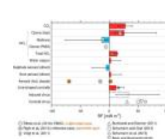


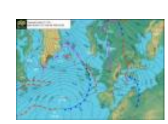
Lesson learnt on implementation of climate-optimized routing

Founding Members

Some issues for post-ATM4E research – atmospheric science

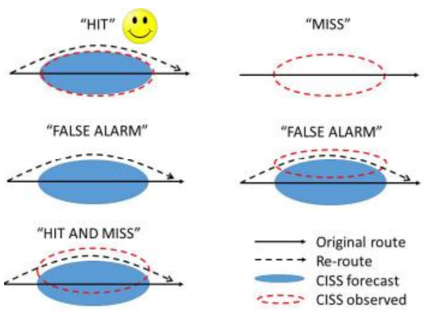
- What **complexity** of aECFs can be handled in an operational system?
- aECFs need to be produced for more world regions
- Can we incorporate **scientific uncertainties** in the aECF concept to provide a basis for robust decisions or for no-regret measures?
- Are weather forecast data sufficiently **accurate** and how can **uncertainties** be incorporated in an operational system?
- How dependent are claimed benefits on **aircraft type**? Will these be affected by **future** aircraft/engine developments?
- We need to **explore the impact** of other components at the frontiers of current research. e.g., the effect of aviation soot and sulphate emissions on cloud properties, the role of cruise level emissions on air quality, the consequence of re-routing on turbulence encounters etc





The meteorological forecasting problem – an example

- Re-routing (horizontally and/or vertically) to avoid a **predicted** contrail formation area, only results in benefit if contrail formation areas are well predicted
- Other outcomes could lead to unnecessary extra fuel use, and/or flying through unpredicted contrail formation areas
- Hence, we must evaluate the quality of weather forecasts to ensure that they are fit for purpose and to understand uncertainties

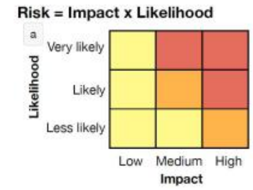


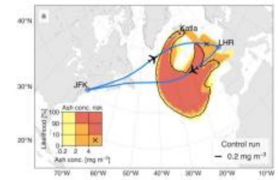
CISS = Cold ice supersaturated region
i.e. a region where persistent contrails can occur

Figure courtesy of Emma Irvine, Univ of Reading

Coping with forecast (and other) uncertainty

- Future implementation might follow developments in volcanic ash forecasting by using a risk matrix approach
- Weather forecast agencies often now produce an **ensemble** of likely forecasts rather than a single "best guess"
- Hence the **likelihood** of contrail formation can be given in probabilistic terms and the strength of the predicted climate effect represents the **impact**
- Other ECFs uncertainties could be incorporated - might favour **night-time** contrail avoidance?
- The final decision on re-routing is then made on the basis of a combination of **likelihood** and **impact**





Figures courtesy of Andrew Prata and Helen Dacre, University of Reading

Some issues for post-ATM4E research – ATM and other issues

- **Consistency** with other developments in ATM management
- **How robust** are our choices of alternative aircraft trajectories to aECFs uncertainties?
- Is the framework **flexible** enough to incorporate advances in aECFs?
- How do we **demonstrate** that benefit of re-routing has been achieved, and what is expected? Who audits and how? What are the key performance indicators? Benefit on a flight-by-flight basis, or fleet-wide and time-averaged basis?
- **Political decisions** – which metrics are used to compare $CO_2$and non-CO_2 climate effects?
- **Political decisions** – how are climate/noise/local air quality impacts weighted against each other, especially in trade-off situations? (e.g. longer flights → more fuel/higher weight → impact of emissions on local air quality and possible breaches of noise curfews)

Concluding comments

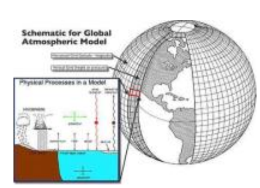
- ATM4E, REACT4C and other national projects have demonstrated the **feasibility of environmentally-optimised** routing. They have also highlighted many issues that would be faced in any operational implementation
- Additional costs of re-routing could be tolerable given appropriate **financial and political drivers**
- Some uncertainties are considerable, but current knowledge is sufficient to make **informed decisions**; any operating framework needs to be **flexible** enough to incorporate both the uncertainties and advances in knowledge
- We estimate that **a system could be operational by 2030** if the necessary intermediate steps are successful
- A possible future step could be a **"live" trial**: no aircraft would be re-routed, but the system could be tested to examine possible re-routing options. A post-mortem (using actual rather than forecast weather data) would assess whether **projected benefits** during flight planning would have been realised in practice

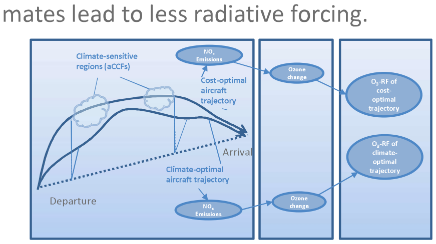
Verification of environmental benefit by environmental-optimized flight planning relying on algorithmic ECFs

Founding Members

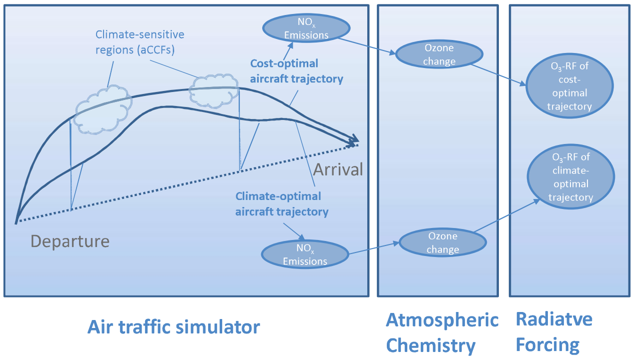
Verification of algorithmic Climate Change Functions

- Implementation of aCCFs in an Chemistry-Climate Model, which includes an Air Traffic Simulator
- Compare cost-optimal with climate optimal (aCCFs) trajectories
- Verify that aCCFs estimates lead to less radiative forcing.





Verification approach
Earth-System Modell

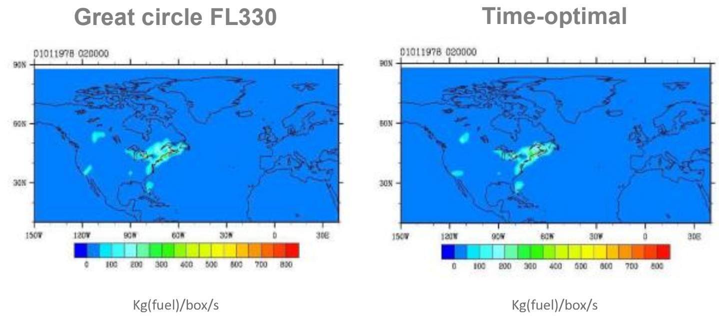


Yin et al. (2018)

Verification of Environmental Benefit

Using comprehensive global chemistry-climate model EMAC and routing module: AirTraf

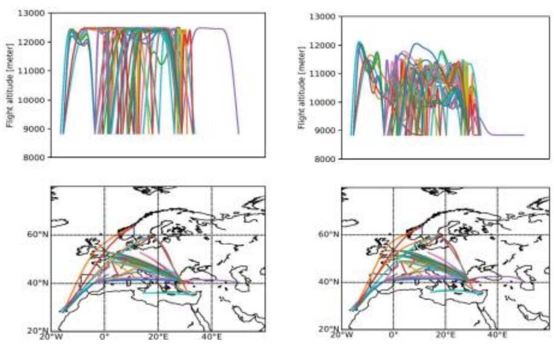
Yamashita et al., GMD, 2016.



Atmospheric model uses algorithm based Environmental change functions.

We will focus on the European Airspace in the ATM4E project

Verification in Earth-System Model
Simulated Traffic Flow over Europe

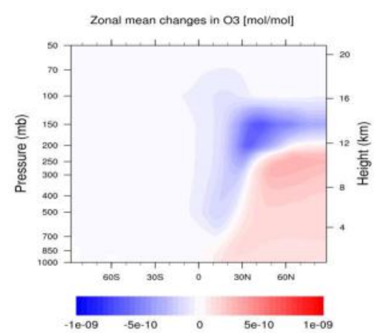


Cost optimal

aCCF optimal

Yin et al. (2018)

Verification in Earth-System Model
Impact of aircraft trajectory changes on atmospheric composition and climate



Yin et al. (2018)

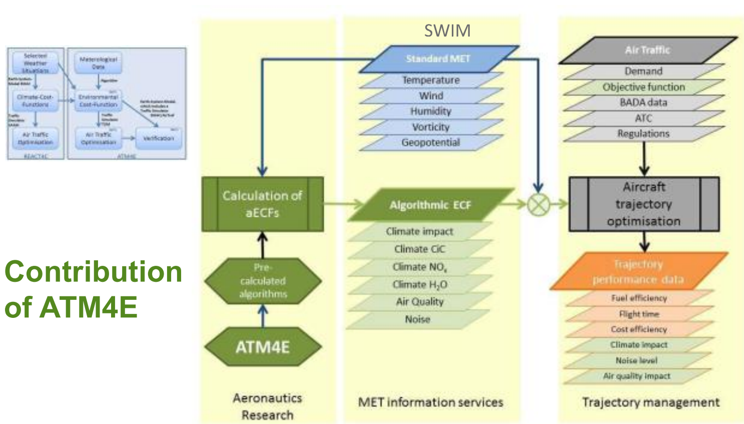
Aviation-induced ozone changes compared for **climate-optimal** (NO_x-O_3) versus **cost-optimal** trajectory optimisation

Largely reduced ozone concentration at higher altitudes.

2.2% reduced climate impact

Air Traffic Management for Environment

Contribution of ATM4E



Summary and Conclusion

Environmentally-optimized flight planning

- **Environmental change functions (ECFs)** as advanced MET Service establish an interface between climate change knowledge and ATM
- **Use cases for climate-optimised trajectories** rely on advanced MET service for providing information on climate impact of aviation emission
- **Algorithmic ECFs** derived from complex climate chemistry simulations allow to derive climate change functions from standard MET information
- Communication on a **roadmap on implementation** considering necessary steps and actions **to introduce environmentally-optimized flight operations** has started involving research, service providers, manufacturers and airspace users
  - Stakeholder Workshop, ILA, April 2018, Berlin
- **Performance indicators** are proposed in order to be able to assess and demonstrate environmental benefits on climate impact mitigation.

Matthes, S.; Grewe, et al. A Concept for Multi-Criteria Environmental Assessment of Aircraft Trajectories. Aerospace 2017, 4, 42.

Grewe, V.; Matthes, S.; et al. Feasibility of climate-optimized air traffic routing for trans-Atlantic flights. Environ. Res. Lett. 2017, 12, 034003.

Environmental impact assessment and optimization of aircraft trajectories

Sigrun Matthes, DLR

→ Case study for Europe

→ Lesson learnt on MET service implementation

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

Summary and Conclusion

Environmentally-optimized flight planning

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- **Performance indicators** are proposed in order to be able to assess and demonstrate environmental benefits on climate impact mitigation.
- **Stakeholder Workshop, ILA, April 2018, Berlin**
  - *Identify key issues to present and discuss with regards to implementation*

ATM4E Air Traffic Management for Environment Stakeholder Event

Wednesday, April 25, 2018
13:00-16:00 (CET time)

ATM4E is working towards the objective to enable **climate-optimized trajectories** in the future air transport system. The project aims at defining a conceptual assessment framework for the deployment of the produced environmental change functions involving environmental performance indicators. Additionally, a roadmap is under development with recommendations and an implementation strategy for the environmental optimization of aircraft trajectories.

Effective communication with stakeholders and aviation experts is key when working toward the environmental optimisation of air traffic operations in the European airspace.

This Stakeholder Event will be a great opportunity to summarize the **acquired knowledge**, provide **guidance** and technical insights and discuss research and implementation requirements to enable, encourage and accompany stakeholders in the implementation of the **necessary steps** and actions that would need to be taken to ultimately introduce environmentally-optimized flight operations in European airspace.

See you in Berlin at ILA 2018!

This project has received funding from the SESAR Joint Undertaking under grant agreement No 699395 under European Union´s Horizon 2020 research and innovation programme.

Environmental impact assessment and optimization of aircraft trajectories

Sigrun Matthes, DLR

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

Objective ATM4E

Environmentally-optimized flight planning

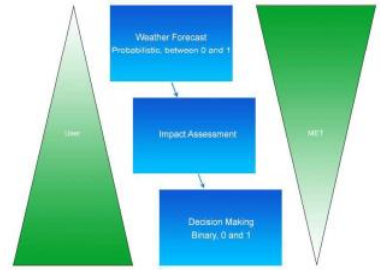
- The project aims at **integrating existing methodologies for assessment of the environmental impact of aviation**, in order to evaluate the implications of **environmentally-optimized flight operations** to the European ATM network, considering climate, air quality and noise impacts.
- A modelling concept for climate-optimisation which has been developed in a feasibility study for the North Atlantic **will be expanded to a multi-dimensional environmental impact assessment**, covering climate, air quality and noise.
- Different **traffic scenarios (present-day and future)** will be analysed to understand the extent to which environmentally-optimized flights that are planned and optimized based on multi-dimensional environmental criteria (assessment) would **lead to changes in air traffic flows and create challenges for ATM**.
- These findings will be used **to prepare a roadmap** compliant with SESAR2020 principles and objectives which would consider the necessary steps and actions that would need to be taken **to introduce environmentally-optimized flight operations** on a large scale in Europe.

ATM4E [ref DoA]

From weather forecast into impact in ATM: Capacity Modeling for Controller Workload Evaluation and Optimization of Staff Planning at RTC

Billy Josefsson (LFV),
Tatiana Polishchuk (Linköping University, LIU),
Christiane Schmidt (LIU),
Valentin Polishchuk (LIU),
Igor Kos (Croatia Control, CCL)
Alen Sajko (CCL)

Weather Forecast is the first step



- ✓ Process from weather forecast into decision making
- ✓ Very important step – impact assessment
- ✓ Combination of weather forecast and traffic forecast (traffic demand)

Weather Forecast and Impact Assessment

Snow forecast:
- ✓ Total amount: 0.1 cm or 3 cm?
- ✓ Intensity: In 1/4 hour or 3 hours?
- ✓ Probability: 40% or 95%?

Impact:
- ✓ Traffic: 1 aircraft or 40 aircrafts in 1 hour?
- ✓ Complexity of traffic: ground movement, extra traffic?

Decision in ATM:
What kind of decision making on is needed to mitigate the weather related impact?

Remote Tower Center in Sweden

- ✓ LFV + SAAB (within SESAR Joint Undertaking)
- ✓ RTC in Sundsvall: operates 2 airports remotely + 5 Swedavia airports in development
- ✓ LiU works in a close collaboration with LFV

Photo from the visit in November 2016

Remote Tower Concept

- ✓ Provides ATS remotely to small airports
- ✓ Replaces local tower with cameras and sensors
- ✓ Increases efficiency: HR and ATS costs are split between several airports

KODIC 2016-2017: personnel planning at RTC

How are RTC personnel **shifts** organized?

Time "in position", scheduled breaks
workload from several airports
endorsements and trainings
24/7 operation

Automation required!

RTC ATCO shift scheduling problem

Input:

One-day flight schedules for 5 Swedavia airports (in 2016)

Output:

Optimal assignment of controllers to RTC airports per hour

Formulated as MILP (mixed-integer linear program)

Constraints

General for RTC:

- ✓ Max # movs per controller
- ✓ Max # airports per controller
- ✓ All open hours and all movements are to be covered

SHIFT-specific:

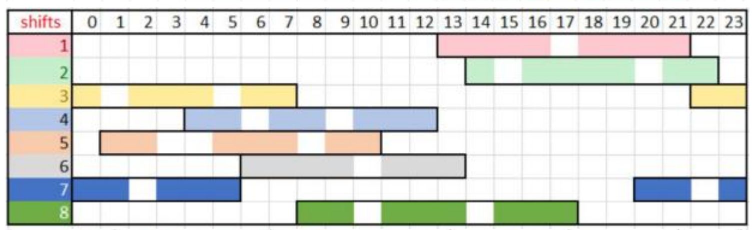
- ✓ Time at work
- ✓ Max hours "in position"
- ✓ Breaks: durations, max cont. time w/o break
- ✓ Endorsements
- ✓ Conflict avoidance
- ✓ ... (controller-specific)

Objectives

- ✓ Minimize total # controllers at RTC
- ✓ Minimize average # controllers per airport
- = Minimize average # endorsements per controller
- ✓ Minimize the # of assignment switches

Minimize average # controllers per airport

19-Oct-16	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
AP1	0	0	0	0	2	0	0	2	1	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0
AP2	1	1	2	3	4	9	10	7	5	3	2	5	7	4	5	10	8	7	6	8	8	2	0	2
AP3	1	0	2	1	6	5	2	6	4	3	5	4	2	5	6	4	6	8	6	4	3	1	2	2
AP4	0	0	0	0	2	3	3	3	2	1	2	3	2	2	2	4	3	3	0	2	0	0	0	0
AP5	0	0	0	0	3	2	0	4	3	1	2	1	0	2	4	3	2	2	1	2	0	1	0	0



Total #. of ATCOs	Av. # of ATCOs per airport	Av. # endorsements per ATCO	Av. time in position	Av. time at work	COP
8	3.4	2.13	7.5	9.38	0.8

ATCO WORKLOAD

✓ ATCOs perform in a ***multitask environment***

✓ The importance of assessment of controller mental workload was reported in many of our projects

Mental workload - limitation on number of tasks a human can perform during a certain period of time

Complexity measures influencing workload: the number of aircraft in a sector, voice messages, radar screen clicks etc...

New workload factors appear in connection with the emerging technologies (CPDLC, RTC).

A generic single quantity for workload measurement is missing

Capacity Modeling for controller workload evaluation at RTC Arlanda

According to LFV Operations, IFR traffic accounts for only ~40% of the workload

Other important aspects:

- **ground traffic movements**
- **bad weather conditions**
- **VFR and extra traffic movements**

are to be included into the optimization framework for RTC personnel planning

Phase 2: Statistical analysis and probabilistic modeling

Study how bad weather conditions (e.g. **snow**, fog, low visibility) influence controllers workload - **weather related impact assessment**

Input:
- ✓ Statistical weather data (snow, fog, low visibility)
- ✓ Statistical traffic data
- ✓ Staffing solutions at individual tower

Output:
- ✓ "Red spots" - quantify the correlation between adverse weather and workload problems in ATM

Even more…

Our interests:
- TMA optimization (routes + sectorization): KPIs, uncertainties due to weather
- ATC Security (unexpected events)
- UTM routing methods and rules of the game LVP, capacity modeling

Weather impacts everything!

What do we offer:
- Strong team: algorithmic approach (math background, LIU) + constant support from Operations (LFV)
- Working tools: models, methods, techniques, knowledge base (validated in Sweden, looking for expansion to European scale)
- Other partners: CroControl, Eurocontrol, DLR Braunschweig

THANK YOU!

Appendix 2 Presentations at the Webinar

PNOWWA* Webinar on Nowcasting of Snow

11:30 Snow nowcasts with extrapolative methods. Case studies and lessons learned.

E. Saltikoff , S. Pulkkinen and M.Hagen. WP2 and WP3

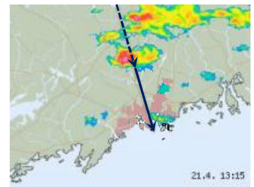
Founding Members

Nowcasting with extrapolation of radar images in PNOWWA

Common principle:

Time= distance/speed

Example:



storm 75 km away,

moving 50 km/h

arrives in 90 minutes

15	30	45	60	75	90	105	120	135	150	165

…..dry………….. snow...maybe

Task split in two

- Calculate the motion vectors and their uncertainty
- Move the radar image with the vectors, assess uncertainty

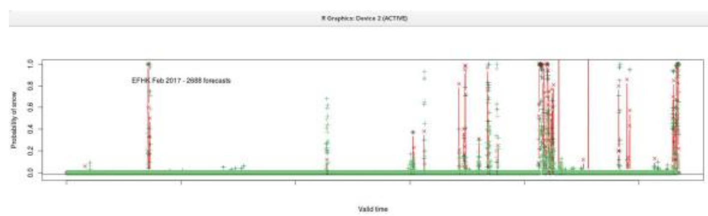
In PNOWWA we have tried three methods for both.

- Simple one from 1990s (Andersson & Ivarsson 1991)
- Operational one from Finnish Met Institute (Hohti et al 2000)
- New ones in research (Proesmans et al, Pulkkinen et al.)

- References:

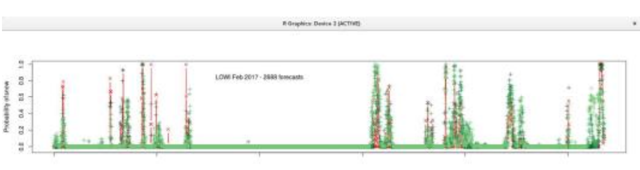
- Andersson T, Ivarsson K (1991) A model for probability nowcasts of accumulated precipitation using radar. J Appl Meteorol 30:135–141 DOI: http://dx.doi.org/10.1175/1520-0450(1991)030<0135:AMFPNO>2.0.CO;2
- Hohti H., J. Koistinen, P. Nurmi, E. Saltikoff, K. Holmlund , (2000) Precipitation Nowcasting Using Radar-Derived Atmospheric Motion Vectors. Proceedings of ERAD – the First European Radar Conference. Bologna, Italy.
- Proesmans, M. L. Van Gool, E. Pauwels, and A. Oosterlinck (1994): Determination of optical flow and its discontinuities using non-linear diffusion, in *3rd European Conference on Computer Vision*, ECCV'94, 1994, Vol. 2, pp. 295–304.
- Pulkkinen S., J. Koistinen, A-M Harri (2016): Consistency-Driven Optical Flow Technique for Nowcasting and Temporal Interpolation ERAD the 9th European Radar Conference

The simple one was used in first demos, and it performed quite well !

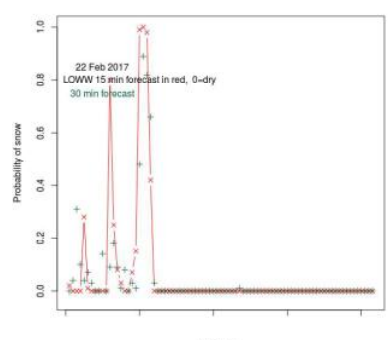


EFHK
Red: Observations (15 minutes)
Green shades: 30-120 min forecasts

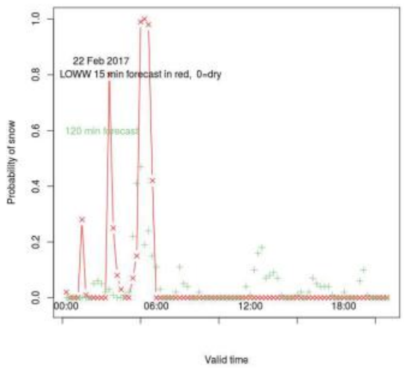
LOWI



30 min forecasts are usually brilliant

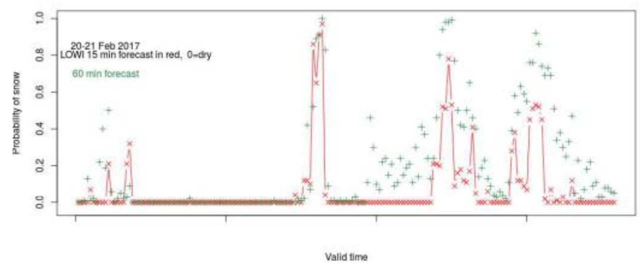


Longer forecasts have often small probabilities for snow that never comes



The "probabilistic observation" is the frequency of radar pixels over a threshold indicating snowfall at the airport. It can be seen as indicator of how large fraction of the first 15-minutes period it is snowing.

60 minutes shows some skill



This was validation radar to radar

Radar to airport has still challenges:

- Radar only sees snow which is falling from the clouds
- Visibility may be low also for drifting snow
- ..or fog

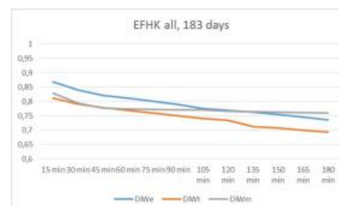
- For operational use, we recommend merging this with TAF for DRSN and FG

Have we compared to models ?

Feb-March 2015, Dec 2015 - Feb 2016, 183 days

Radar better than model for 2 hours

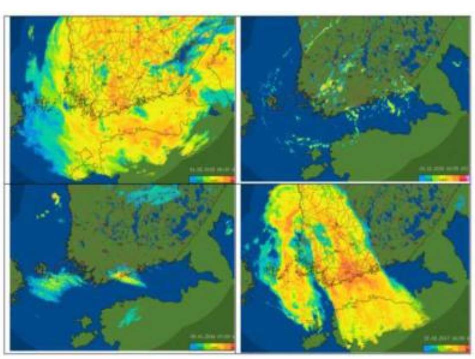
(Parameter Deicing weather DIW, verified as Hit rates HR)



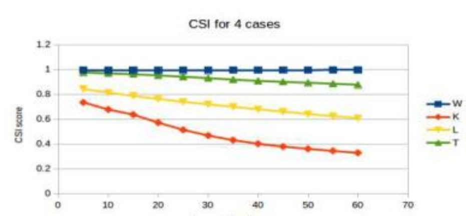
Blue: Radar
Gray: TAF
Red: Model

Verification scores with the new systems

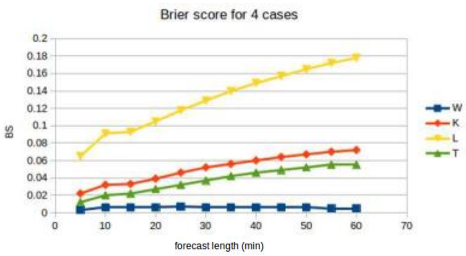
Wide
Showers
Lake-effect
Front



CSI Critical success index: Wide is easiest to forecast, showers (K) most difficult



Brier score also



Come see us at
Sesar Innovation Days in Belgrad

Pulkkinen et al: Improving snow nowcasts for airports

…and also the papers by Juntti et al. and Harri et al.

PNOWWA Probabilistic Nowcasting of Winter Weather for Airports

Thank you very much for your attention!

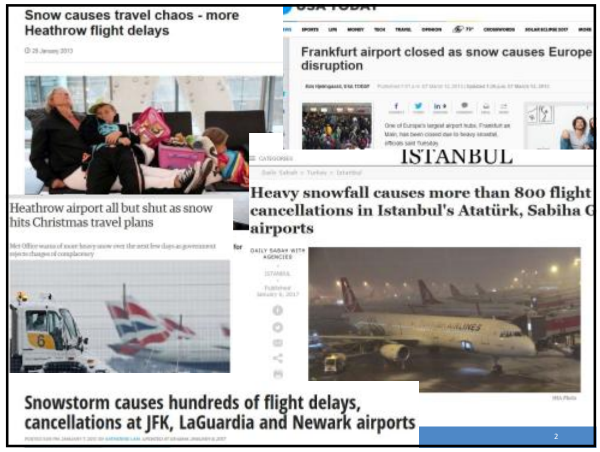
This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699221

Synthesis of user needs for Probabilistic Nowcasting of Snow at the Airports

Heikki Juntti
Task 5 leader in PNOWWA, Finnish Meteorological Institute

Rovaniemi 4th October 2017

SESAR JOINT UNDERTAKING



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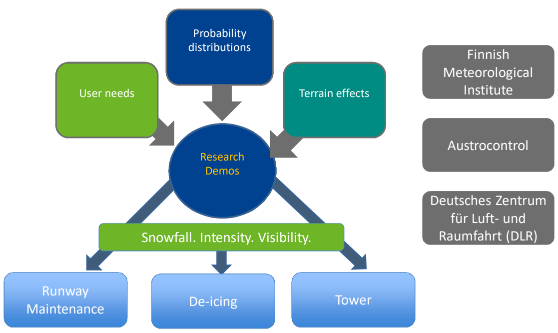
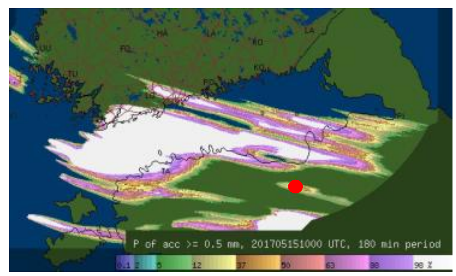
PNOWWA = Probabilistic Nowcasting of Winter Weather for Airports



PNOWWA

Nature of weather forecast is PROBABILISTIC



2 hour probability forecast for over 0.5 mm 3 hour precipitation

Time -> min	+15	+30	+45	+60	+75	+90	....	120
Prob of snow	20	0	40	80	60	0		50

Airport users opinions for probabilistic winter weather forecasts – potential benefits

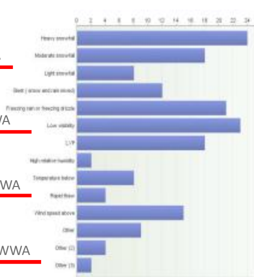
- Helps to make objective decisions
- When cost-loss ratios are known it can be used in decision support
- Positive attitude to probabilistic forecasts
- Need for lead time 3 and 12-24 hours products

Useful lead time for warning of critical weather for all responsens (PNOWWA survey)

PNOWWA

Airport users opinions– highest negative impact affecting on airport operations

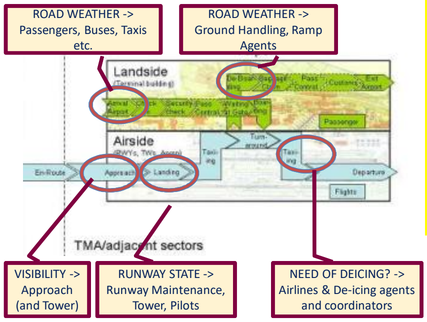
1. Heavy snowfall ← PNOWWA
2. (low visibility)
3. Freezing rain and drizzle ← PNOWWA
4. Moderate snowfall ← PNOWWA
5. Wind speed above
6. Sleet ← PNOWWA



the type of winter weather affecting negatively to airport operation (PNOWWA survey)

PNOWWA

Winter Weather influencing to the Total Airport Management (TAM)

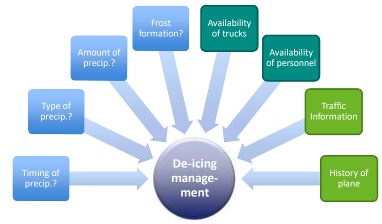


TAM
- create an environment enabling airport partners to maintain a joint plan – the Airport Operations Plan
- get full CDM (Collaborative Decision Making) benefits
  - efficiency in airport
  - enhanced use of airport resources
- Extent time horizon from tactical to pre-tactical and strategic phases.

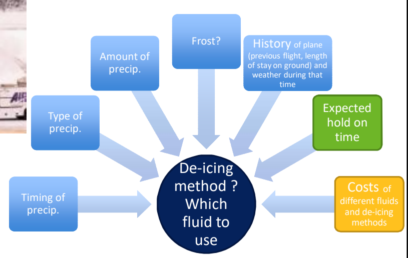
https://www.eurocontrol.int/eec/public/standard_page/EEC_News_2006_3_TAM.html

De-icing management

De-icing of aircraft=
1. Snow and ice removal
2. Prevention of ice and snow accretion on plane (-hold over time)

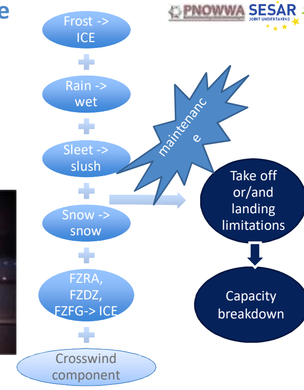


De-icing on airline's perspective



Runway Maintenance

Keep runway in safe conditions. Minimum friction conditions are achieved



Air Traffic Management / Tower

What's happening in de-icing or runway maintenance influences to ATM, too. Add to that a Low Visibility will change landing procedures and can even prevent that.

PNOWWA Scientific demo 2017

- On line service with automatic update
- Tailored products to:
  - Runway maintenance
  - De-icing agents
  - Tower
- Probabilities of the weather categories defined with users are used to individual users
- Forecasted parameters:
  - Accumulation of DRY snow
  - Accumulation of WET snow
  - Probability of freezing rain
  - Probability of freezing of wet runways
  - De-icing weather type (categories dependent on the time of individual plane de-icing duration
  - Decrease of visibility CAUSED BY SNOW (fog or mist outscored)

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SESAR
JOINT UNDERTAKING

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Probability, uncertainty and forecast skill

Marko Laine, FMI
PNOWWA webinar 2017-10-04

What is probability

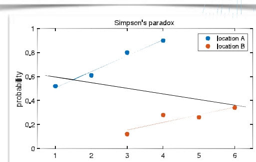
- ”The probability that it rains tomorrow is 20%”
- **Classical interpretation** as long run frequencies. Relevant for simple, repeatable (and deterministic) events, like a tossing of coin or gambling.
- Probability as a (subjective) measure of degree of belief, aka the **Bayesian interpretation**.
- When talking about a single future event, there is no direct frequentistic interpretation. In most cases, **we use probability to quantify uncertainty.**
- Weather and climate are complicated phenomena. We need a notion of chaos and **predictability.**
- [Mathematically, probability is finite and additive measure, defined for a set of events. No philosophical disputes here.]

Difficulties with probabilities

- Probabilities, especially conditional probabilities, can fool our intuition.
- ”Thinking, Fast and Slow” by Daniel Kahneman:
  - People overestimate rare probabilities.
  - Adding more information, makes the scenario more plausible.
  - Risk policies are difficult, as we tend to avoid immediate losses.
- Simpson’s paradox. Change in the background assumptions, e.g. different climatologies.

Probability of thunderstorm in Helsinki tomorrow at 12.

Choose between:
A. sure gain of $ 240
B. 25% chance to gain $ 1,000
and 75% chance to gain nothing



Uncertainty in forecasts

- Natural variability of weather. **Climatology** as the historical distribution.
- **Forecast skill** is reduction of uncertainty with respect to a reference/trivial forecast.
- NWP models have uncertainties and inaccuracies for several reasons.
  1. Limited number or observations to initialize the model.
  2. Model resolution does not allow to resolve all important spatial and temporal scales.
  3. Uncertainty in the model parameterizations.
- Uncertainty quantification is done by using statistical probability distributions.

How to make probability forecasts

- Probabilities for an event based on **an ensemble of predictions** from NWP models.
- **Statistical post-processing** of NWP output from a single model run or the output of ensemble-based NWP.
- By **analysis of historical weather and climate data** to yield statistical relationships between currently observable predictors and the future observations of interest.
- Meteorologist **subjective interpretation** of NWP forecasts and other information.

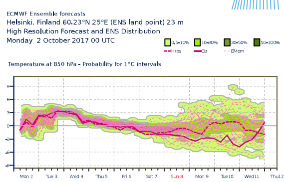
Probability forecasts

”There is 20% probability for rain exceeding 5 mm, tomorrow between 9 —12 AM, at Kumpula, Helsinki.”

- The meteorologist best opinion (but might fear feedback for false negatives).
- Of 50 ENS forecast members, 20% had heavy rain (but might not be calibrated).
- Of 5 different deterministic models, 1 forecasted rain (but they all use the same observations).
- In October, it usually rains 20% of the days in Helsinki (no skill).

Ensemble forecasts

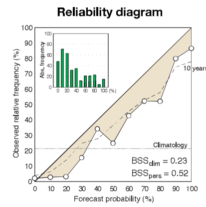
- Run the same forecast model with **perturbed initial conditions.**
- Probability 20% means that 10 out of 50 ensemble members predict more than 5mm of rain to fall at the specified location in the defined period.
- ENS system has to be tuned to match **predictability** and model's inaccuracies.
- Ensembles have to be **calibrated** to correct the spread and remove biases.

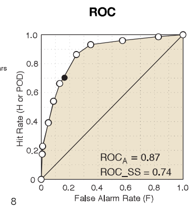


How to verify probabilities

- When we do **repeated** probability statements, they can be verified by using actual observations. The forecasted probabilities have to match the observed frequencies (reliability). Several statistics and diagrams are used.

Reliability and ROC diagrams of one year of Probability of Precipitation forecasts. The reliability curve (with open circles) indicates strong over-forecasting bias throughout the probability range.





The ROC curve is constructed on the basis of forecast and observed probabilities leading to different potential decision thresholds. The black dot represents the single value ROC when using 50% treshold (H=0.7; F=0.17).

Figures by Pertti Nurmi.

Decisions with probabilities

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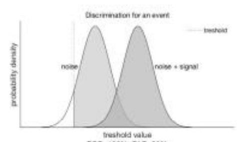

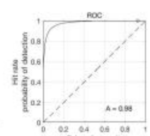

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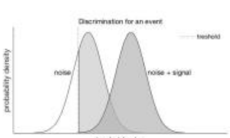

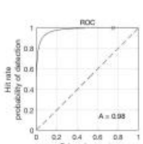

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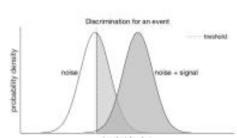

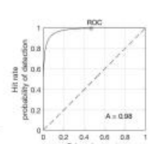

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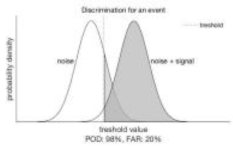

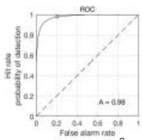

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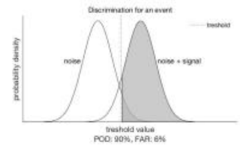

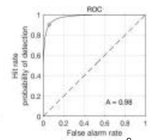

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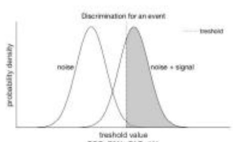

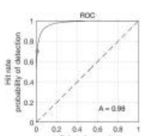

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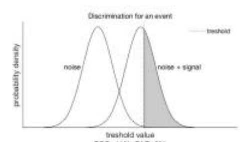

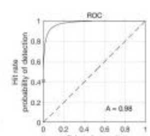

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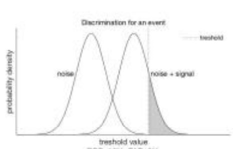

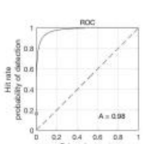

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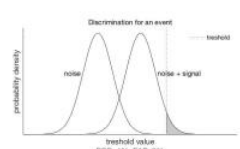

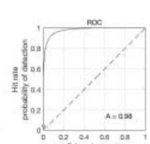

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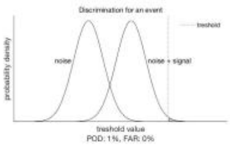

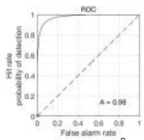

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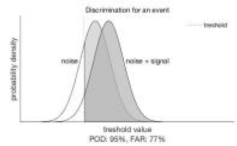

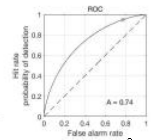

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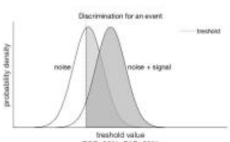

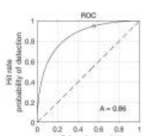

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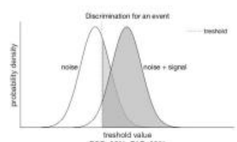

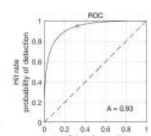

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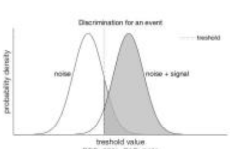

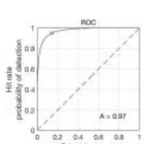

	observed	not observed
forecasted	OK (hit)	false positive
not forecasted	false negative	OK

Decisions with probabilities

- A probability forecast includes a numerical expression of uncertainty about the quantity or event being forecast.
- Uncertainty means risks of wrong decisions. We want to avoid false positive and false negative predictions and want the risks for the both to be small.
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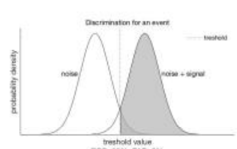

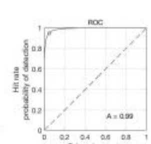

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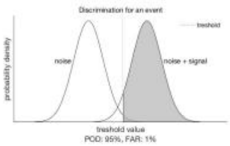

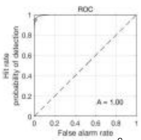

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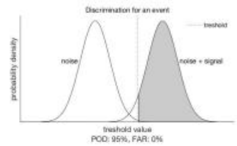

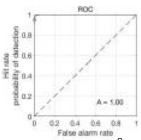

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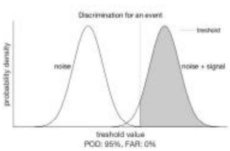

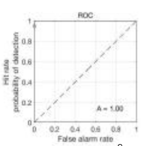

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Why probability forecasts

- To quantify the uncertainties related to forecasts.
- To better handle risks associated with different actions.
- ”We want to be 95% sure that in the next 30 years the water level will rise more than 1 m from the average less that 2 times.”
- To educate the public about uncertainties in forecasts.
- To have better verification measures, e.g. which account for the predictability.

This is the last slide! Thank you!

Appendix 3 Abstract for TBO-MET Workshop

Provision of probabilistic nowcasts (PNOWWA project)

Heikki Juntti, Ari-Matti Harri, Elena Saltikoff, Seppo Pulkkinen, Harri Hohti,
Finnish Meteorological Institute Helsinki / Rovaniemi, Finland Firstname.lastname@fmi.fi

The S2020 ER Project PNOWWA (Probabilistic Nowcasting of Winter Weather for Airports) is a joint effort of Finnish Meteorological Institute in Finland, DLR in Germany and Austro Control in Austria. The 24-month project started in April 2016.

The PNOWWA project will produce methods for the probabilistic short-term forecasting of winter weather and enable the assessment of the uncertainty in the ground part of 4D trajectories. Probabilistic forecasts could be used in ATM applications to support operational planning in surface management and ATM decision making, thereby increasing airport capacity, shortening delays and promoting safety.

PNOWWA will demonstrate 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 are conducted both offline and online at the. An extensive user consultation will analyze needs to ensure products are suitable to be integrated in various applications on the ATM side. The adjustment to user needs will cover the most relevant parameters (visibility, intensity and snow depth) and operationally important thresholds of the selected parameters (e.g. heavy snowfall).

An online survey and face-to-face interviews were used to map the needs of probabilistic winter weather forecasts at airports. We focused on three user groups: runway maintenance, de-icing and TWR control. The demo forecasts were also given for the meteorologist serving these groups.

In the first demonstrations, very simple methods were used to determine the movement. As a first guess, method described by Andersson and Ivarsson, using 850 hPa winds from weather prediction model was used. Other more sophisticated methods will be used during the second demonstration in the coming year.

The quantitative verification results are still pending, but we have a few cases and some end-user feedback. Based on that demo has shown areas for further development and highlighted the importance of discussions between MET and ATM to found the optimum products to be most valuable for ATM.

Web pages of project are: http://pnowwa.fmi.fi

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	40	40	40	30
VIS over 3000 m	0	0	0	40	70	60	60	50	60	70	70	70	70