EXPLORATORY RESEARCH

Report of method to improve nowcasting with direction-dependent forcing fields

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PNOWWA

PROBABILISTIC NOWCASTING OF WINTER WEATHER FOR AIRPORTS

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Abstract

This document describes the quantified effect of mountains and sea to the snowfall observed at airports of Helsinki, Stockholm, Oslo, Rovaniemi and München, based on studies of radar images. Proposals how to improve the forecast quality by nowcasting by extrapolation and numerical weather prediction are made.

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Abbreviations

DIW	De-icing Weather index
DIW_e	De-icing Weather index based on radar extrapolation
DIW_T	De-icing Weather index based on TAF forecasts
DIW_M	De-icing Weather index based on HIRLAM model
DLR	German Aerospace Center
DWD	German Meteorological Service
EDDM	Munich airport
EFHK	Helsinki airport
EFRO	Rovaniemi airport
ESSA	Stockholm airport
ENGM	Oslo airport
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
HIRLAM	High-resolution Limited Area Model
HR	Hit Rate
LOWS	Salzburg airport
NWP	Numerical Weather Prediction
PNOWWA	Probabilistic Nowcasting of Winter Weather for Airports
RX	operational radar precipitation composite from DWD weather radars
TAF	Terminal Aerodrome Forecast
WP	Work Package

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Executive Summary

When airflow comes over open sea or over the mountains, snowfall is more difficult to forecast than in other situations. The predictability is worse for all studied methods: extrapolation of radar images (which is the subject of PNOWWA), but also for TAF forecasts written by human forecasters, and for numerical weather prediction models. However, even a simple radar-based method outperforms the other two data sources in very short forecasts.

To quantify the mountain effect, especially the one of the Alps considering the Munich and Salzburg airport, flow properties were analysed. Cold frontal systems were observed to be retarded when approaching the Alps leading to long-lasting precipitation events. Other systems did cross the area and the Alps without any sustainable modification. It was found that the flow properties expressed by the wind profile and the Froude number were different for the two regimes.

To improve nowcasting for airports in the vicinity of sea or mountains several techniques are possible, most promising are the combination of nowcasting and numerical weather prediction. High resolution NWP with improved cloud and precipitation microphysics will considerable improve forecasts even at short time span, further improvements can be achieved by the assimilation of advanced radar observations into NWP models.

1 Introduction

Nowcasting methods for the temporal range of 0 to 1 or 2 hours are typically based on extrapolation of current and past observations and trends. Numerical weather forecast in this short time range is often not sufficient stable due to spin-up effects in the model. Experience and observations by forecasters show that in certain situations nowcasting methods are not as reliable as in other situations. Adverse situations are convective weather situations where developments of deep convection can happen within 10 or 20 minutes. The scope of this report is to investigate situations where the atmospheric flow is influenced by topographic features. In particular we will consider the effects of nearby sea and mountains on the forecast quality for selected airports.

This study consists of three parts: the first two parts consider the quantitative effect of sea and orography on forecasts using a nowcasting system which was developed for SESAR1, and was run on additional periods. The third part of this study aims to estimate the dynamical effect of cold frontal systems approaching the Alps. Finally, improvements for nowcasting are made.

2 Methods

2.1 Quantitative studies on sea and mountain effects

For the quantitative studies on the effect of sea and mountains for the airports Helsinki, Stockholm, Rovaniemi and Oslo we use forecasts of DIW, de-icing weather (cf. Table 1), which is an index getting values 0-3 describing the temporal effort for de-icing aircraft at ground. For the comparison, DIW index is calculated in three ways:

- DIW_e - Extrapolating the movement of radar echoes using the method described by Andersson and Ivarsson (1991)
- DIW_T – from TAF forecasts
- DIW_m – from HIRLAM numerical weather prediction model forecasts

The references and the verification methods were selected to be familiar for aviation forecasters and end users, to produce material to raise their interest in nowcasting.

Table 1. The DIW classes and meteorological thresholds used.

DIW=3, severe	DIW=2, medium	DIW=1, light	DIW=0, no need for de-icing
Freezing rain/drizzle			
Heavy snow or sleet, visibility cased 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		
		Risk for frost formation on the plane surface. Temperature between -3….+1 and humidity over 75%	
			All other cases

Nowcasts were calculated every 15 minutes in steps of 15 minutes for valid times up to 180 minutes. The temporal resolution of model and TAF forecasts is 60 minutes. Radar images are available every 15 minutes.

The verification parameter used here is Hit rate HR – how many forecasted cases were observed in the right DIW class. The higher HR will be, the better will be the forecast.

The ‘sea effect’ was studied at two coastal airports: Helsinki-Vantaa (EFHK, Finland), 13-16 km from the coast and Stockholm Arlanda (ESSA, Sweden), 30-80 km from the coast. Location of airports is shown in Fig.1. Days were counted as sea effect days if at 850 or at 925 hPa was from the sector (120° – 220°) in Helsinki and from (10° – 180°) in Stockholm. In most days the direction of the flow varies with time; the flow was considered coming from the sea when it remained in the sector at least two hours.

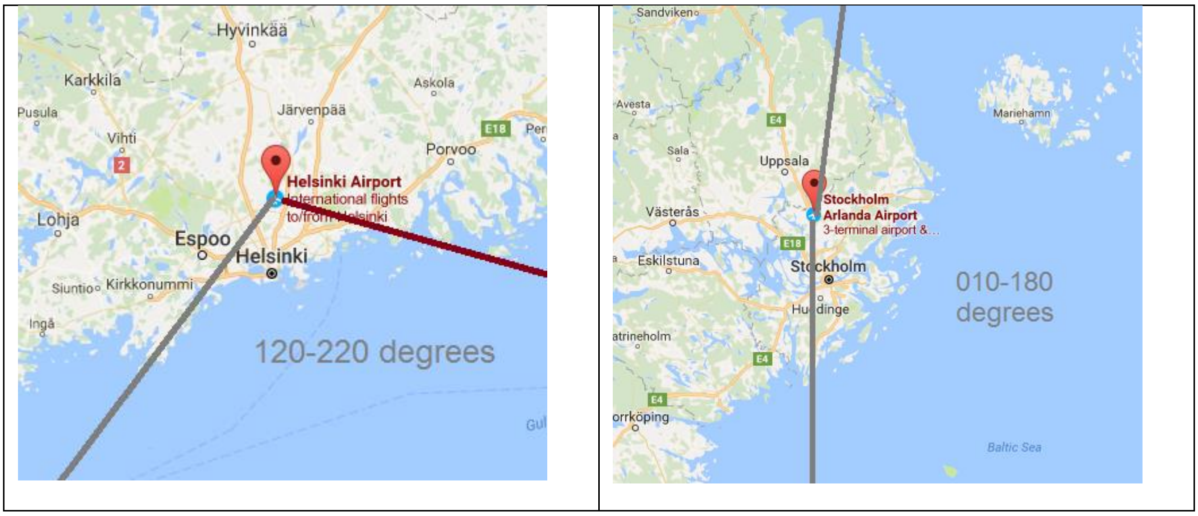

Figure 1. The sectors considered “sea” at Helsinki (left) and Stockholm (right).

The ‘orographic effect’ was studied using the SESAR1 methods at two airports: Rovaniemi (EFRO, Finland) and Oslo Gardemoen (ENGM, Norway). Location of the airports is shown in Figure 2. Days were counted as orographic effect days if at 850 or at 925 hPa (in the case of EFRO also 950 hPa was taken into account, as the terrain and height differences are rather low there) was from the sector (180° – 250°) in Rovaniemi and from (80° – 180°) in Oslo. In most days the direction of the flow varies with time; the flow was considered coming from the valley when it remained in the sector at least two hours.

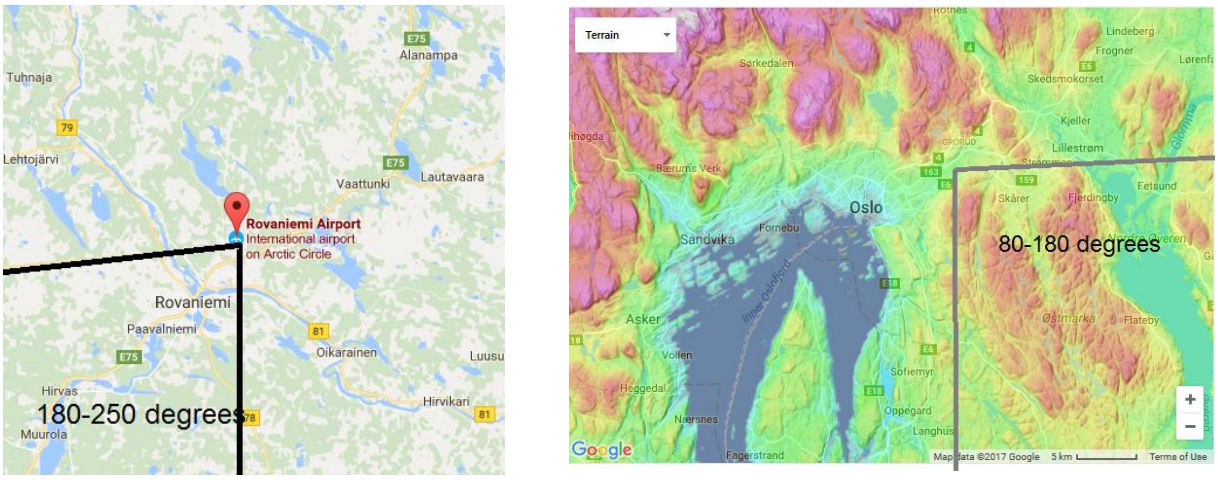

Figure 2. The sectors considered "mountains" at Rovaniemi (left) and Oslo (right).

2.2 Dynamical studies on mountain effects

It is observed that cold fronts can either be delayed when approaching the Alps, other systems cross the Alpine Foreland and the Alps without delay, and even acceleration can be observed for fronts passing along the Alpine Foreland (e.g. Schumann, 1987 and Volkert et al., 1991). Delayed systems can generate long-lasting (up to a few days) continuous rain or snow fall events. Numerical weather forecast can forecast the behaviour on a long term basis. However, nowcasting for a time horizon of one to three hours extrapolation techniques are more favourable because numerical models need some spin-up time. Radar-based extrapolation techniques will fail in case of non-linear propagation speed due to delay or acceleration.

For the airport of Munich (EDDM, Germany) and Salzburg (LOWS, Austria) the behaviour of cold fronts approaching from North and Northwest was investigated. Figure 3 shows the location of both airports relative to the Alps. Munich is about 75 km from the first mountains, whereas Salzburg is located directly at the mountain chain.

22 events during the winters 2013/14 to 2016/17 were investigated using radar images and radio soundings. The events were manually classified in events where the frontal passage over the Alpine Foreland was delayed or retarded and events where the cold fronts passed the Alps without noticeable delay. Wind profiles and flow properties were analysed to find controlling parameters and to describe dependencies on nowcasting.

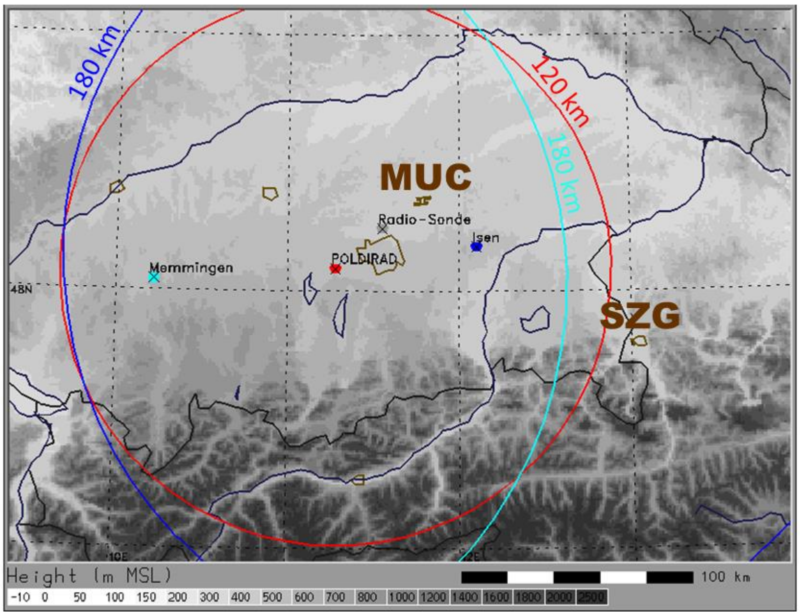

Figure 3. Location of the airport Munich (MUC) and Salzburg (SZG) in the Alpine Foreland. Circles denote maximum range of weather radars Memmingen (DWD), POLDIRAD at Oberpfaffenhofen (DLR), and Isen (DWD). Also shown is the location of the release of the radio sondes at Munich-Oberschleißheim.

3 Quantitative Studies

3.1 Effect of sea

The ‘sea effect’ was studied at two coastal airports: EFHK (Helsinki-Vantaa, Finland), 13-16 km from the coast and ESSA (Stockholm Arlanda, Sweden), 30-80 km from the coast. Location of airports if in Fig.1.

The study period was 1.2.2015 to 31.3. 2015 and 1.12. 2015 to 29.2.2016 in Stockholm, and 1.2.2015 to 31.3. 2015 and 1.12. 2015 to 31.3.2016 in Helsinki. In Stockholm 63 days were classified as sea effect days, in Helsinki 89 days.

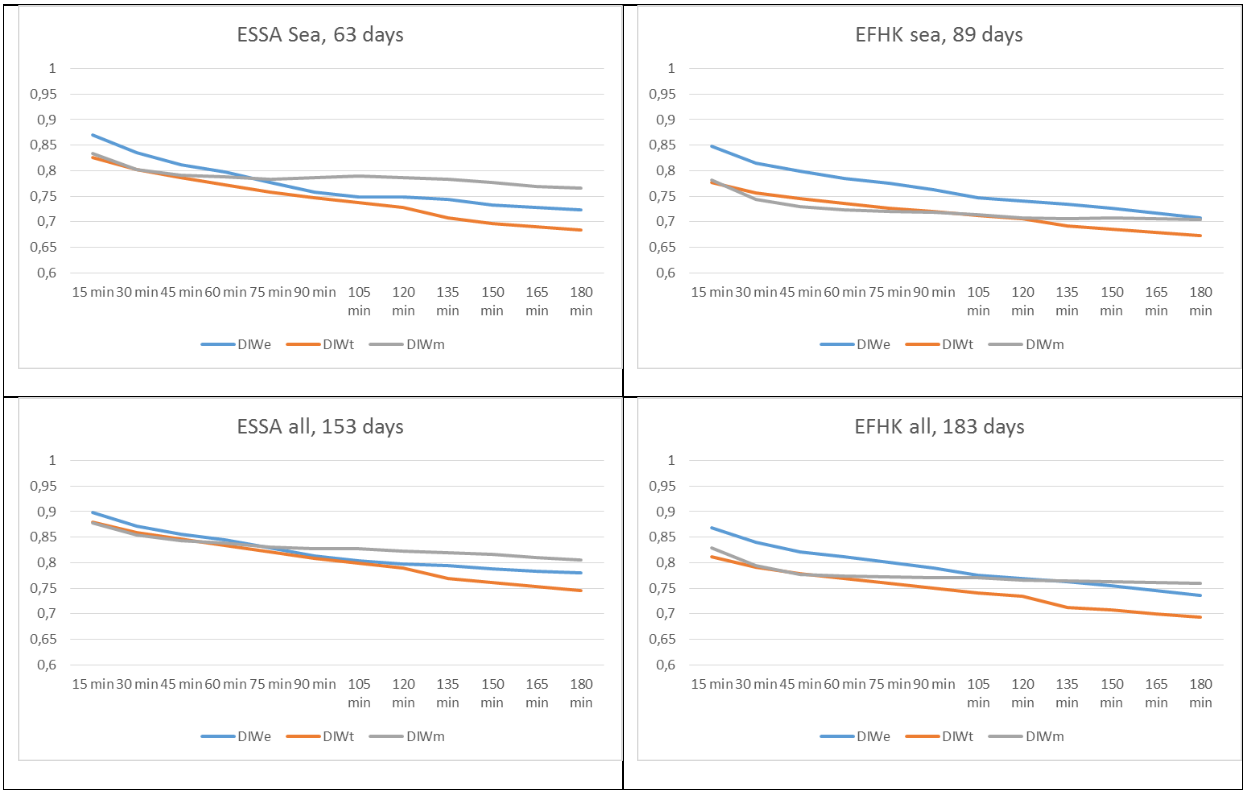

Figure 4. Hit ratios of DIW index based on extrapolation (blue), TAFs (red) and model (grey); for sea effect (upper panels) and all cases (lower panels), in Stockholm (left) and Helsinki (right) airports. Note the vertical axis is from 0.6 to 1.

Comparisons between extrapolation, TAF and model-based forecasts are shown in figure 4. In all cases DIWe was better than the other nowcasting methodologies in the beginning, although the margin was small. Regarding the whole period, in ESSA DIWe was best only for the first 45 minutes, in EFHK 105 minutes. In sea effect days DIWe was best for the the first 75 minutes, in EFHK for the whole 3-hour period. The fact that EFHK is nearer the coast than ESSA might have had some effect on the results.

Effect of predictability is shown in figure 5. The results using all the participating methods are worse than average, when flow is from sea. In Stockholm, the sea makes a larger difference than in Helsinki. Stockholm airport is further away from the sea than Helsinki, but the open sea area is wider.

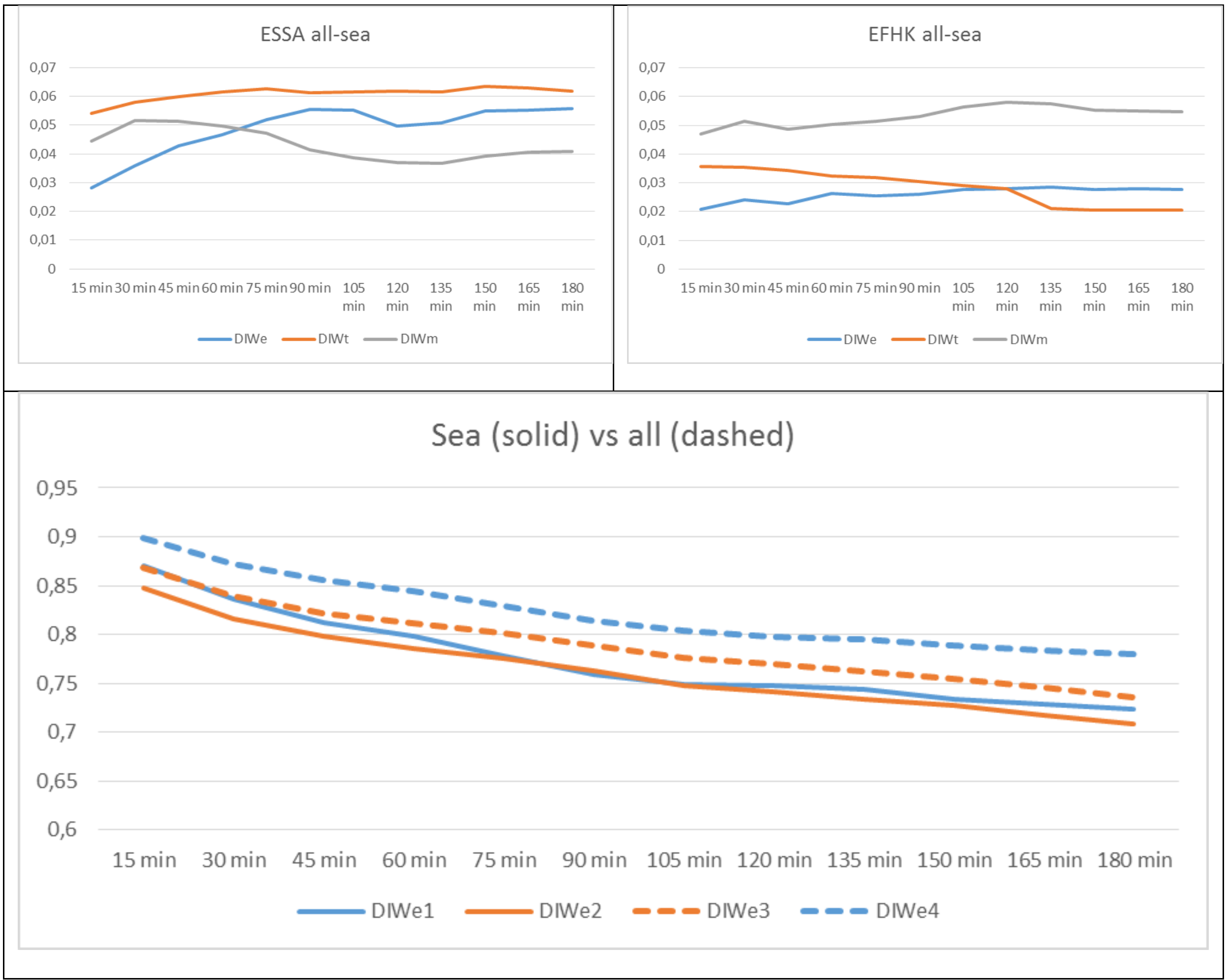

Figure 5. Difference in hit ratios in all cases vs. sea effect cases (upper panels, colours as in figure 2), and a summary figure showing the extrapolation performance in Helsinki (red) and Stockholm (blue).

3.2 Effect of mountains

The orographic effect was studied at two airports: Rovaniemi EFRO and Oslo Gardemoen ENGM. Days were counted as orographic effect days if at 850 or at 925 hPa (in the case of EFRO also 950 hPa was taken into account, as the terrain and height differences are rather low there) was from the sector (180 – 250) ° in Rovaniemi and from (80 – 180) ° in Oslo. In most days the direction of the flow varies with time; the flow was considered coming from the valley when it remained in the sector at least two hours.

The study period was 1.2.2015 to 31.3. 2015 and 1.12. 2015 to 29.2.2016 in Oslo and 1.2.2015 to 31.3. 2015 and 1.12. 2015 to 31.3.2016 In Rovaniemi 107 days were classified as orographic effect days, in Oslo 31 days.

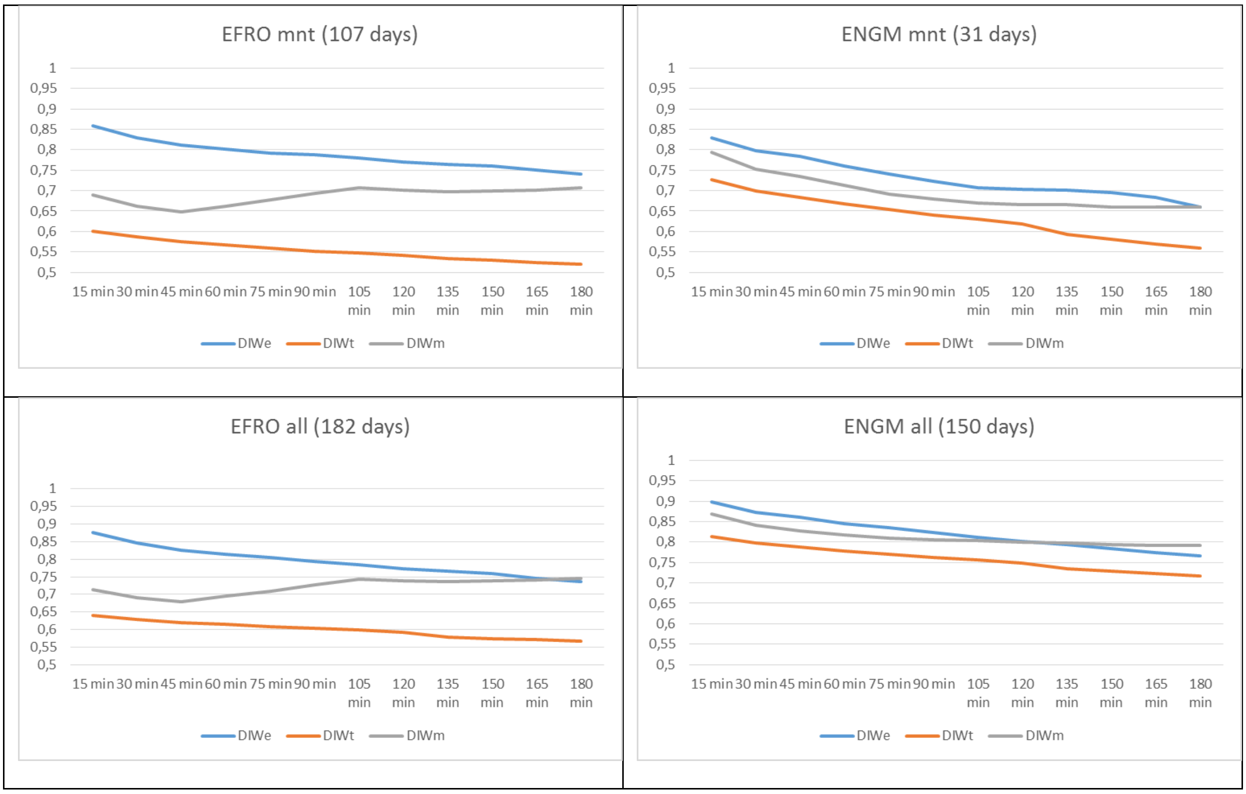

Figure 6. Hit ratios of DIW index based on extrapolation (blue), TAFs (red) and model (grey); for mountain flow (upper panels) and all cases (lower panels), in Rovaniemi (left) and Oslo (right) airports. Note the vertical axis is from 0.5 to 1.

In almost all the situations, the radar-based extrapolation method (DIWe) was slightly better than the others. Only in average of all cases for the 2-3 h model forecasts outperformed the radar extrapolation. In orographic situations DIWe was best for the whole 3-hour period. Almost 60% of cases in Rovaniemi were classified as orography-effected class, and hence the differences to all-cases average were small. On the other hand, in Oslo only 20% of the cases were in the orography class. The difference was in Oslo 0.07 in short forecasts and 0.10 in longest forecasts.

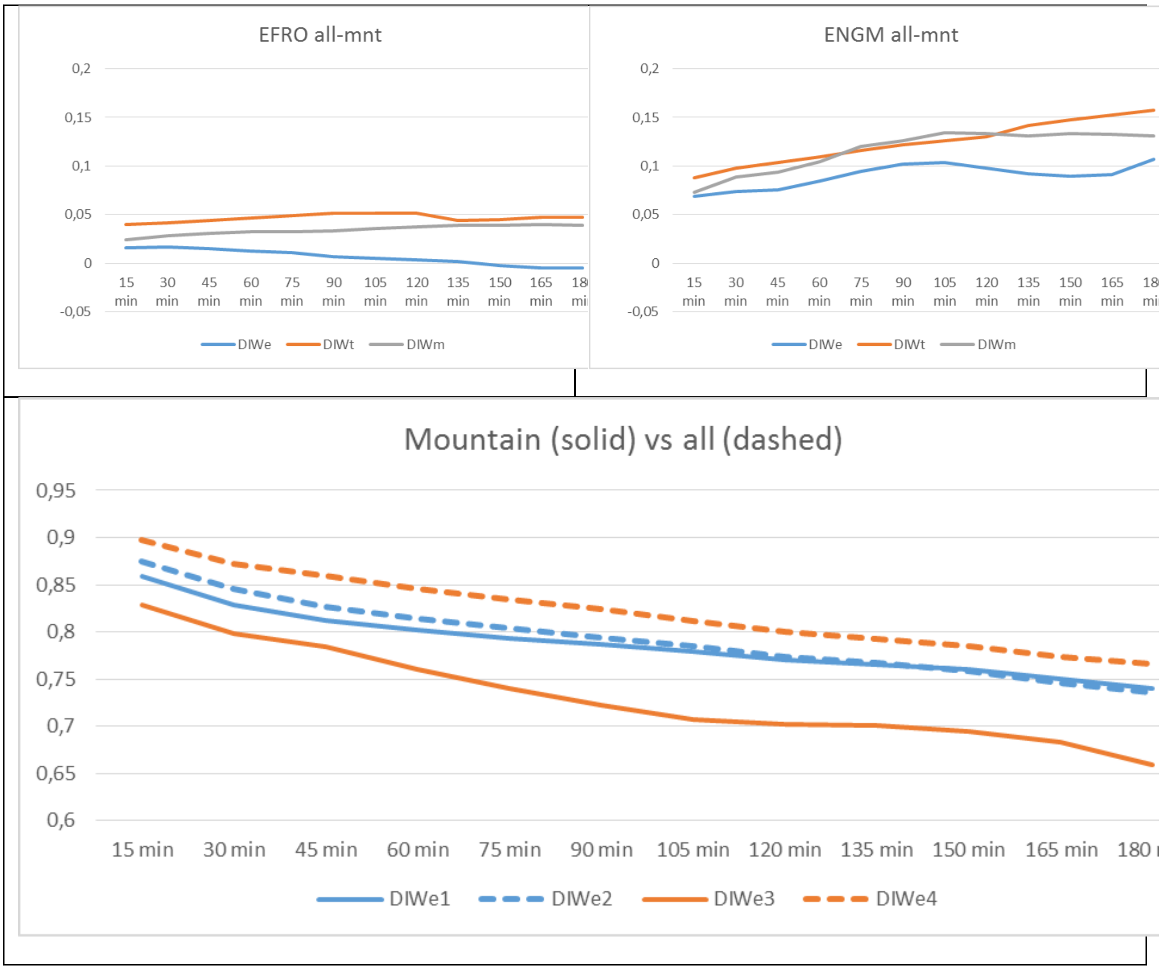

Figure 7. Upper panels. Absolute difference in hit ratio between all cases and sea effect cases. Colours as in Fig 2.), and a summary figure showing the extrapolation performance in Oslo (red) and Rovaniemi (blue).

4 Dynamical studies

The orography at Rovaniemi and Oslo has shown to affect the predictability, to investigate the effects of larger mountain chains to airports along the northern slopes of the Alps were included in the study. For the airport of Munich (EDDM) and Salzburg (LOWS) the behaviour of cold fronts approaching from North and Northwest was investigated.

The goal of this task is to investigate effects controlling the behaviour of cold fronts. Cold front passages in Southern Germany during winter (December – March, plus April 2017) 2013/14 to 2016/17 were examined using synoptic weather maps and the national radar composite (product RX) of the German Meteorological Service (DWD). 49 events were observed during that four winter seasons. 22 of them were investigated in more detail.

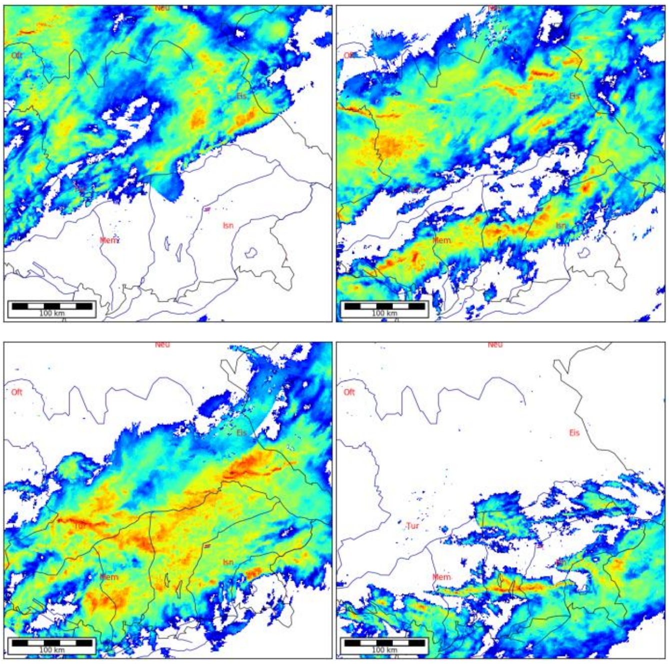

Figure 8. 3-hourly radar images of a frontal system passing South-Eastern Germany without major delay from 16 UTC on 19 until 00 UTC on 20 December 2014.

To increase the number of samples both situations with rain and snowfall at ground were considered. In about half of the cases the fronts did pass the Alpine Foreland without noticeable delay (cf. figure 8), whereas the other cases showed considerable delay of the frontal motion leading to long lasting precipitation events (cf. figure 9). The duration of the events was between 8 and 46 hours.

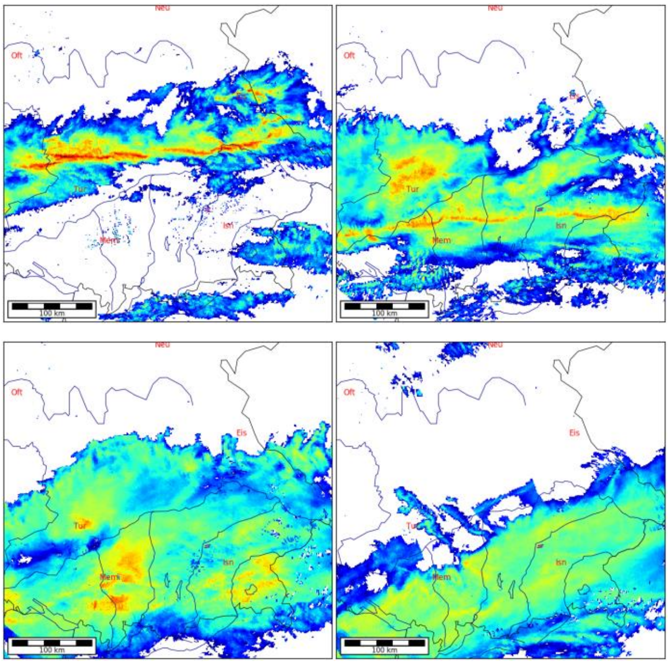

Figure 9. 3-hourly radar images of a frontal system passing South-Eastern Germany with delay and enhancement at the Alps from 22 UTC on 10 to 07 UTC on 11 January 2015.

Figure 10 shows the distribution of the events in relation to the approaching direction of the frontal systems. To find relations between flow and behaviour the wind profile as measured by the radio sonde München-Oberschleißheim (app. 20 km South-West of Munich airport) was investigated. Shown in figure 11 are the wind direction (direction from which the wind is blowing) at two pressure levels. 850 hPa corresponds to about 1500 m MSL, corresponding to about 800 m above the Alpine Foreland and thus describing the flow at lower levels beneath the Alpine mountains. 500 hPa corresponds to about 5500 m MSL, thus describing the large scale flow over the Alps. Radio sondes are released twice a day at 00 and 12 UTC. All available soundings (46) for the 22 events are used. The events are grouped into upslope delay and passage events.

However, there is no clear relation between the propagation direction of the fronts and the wind direction at the 850 and 500 hPa level (about 1000 m above the Alpine Foreland and 2 km above the main ridge). This is mainly caused by the fact that during winter when the tropopause is low the Alps act as a major obstacle and cause a considerable distortion of the atmospheric flow. Especially during those conditions which were classified as up-slope or delay often low pressure systems develop in the Alpine region causing long-lasting precipitation and no more distinctive motion characteristics. It also should be considered that on the pre-frontal side the flow is parallel to the front, i.e. a front approaching from North-West will have south-westerly flow ahead of the front.

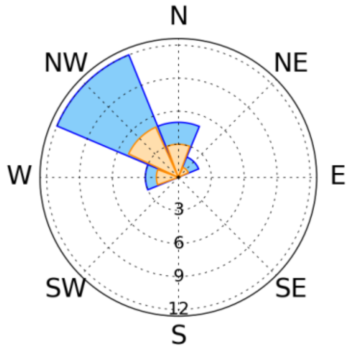

Figure 10. Approaching direction of cold fronts in winter for the Munich/Salzburg region, Blue: total number of events; orange: number of events being delayed/blocked by the Alps.

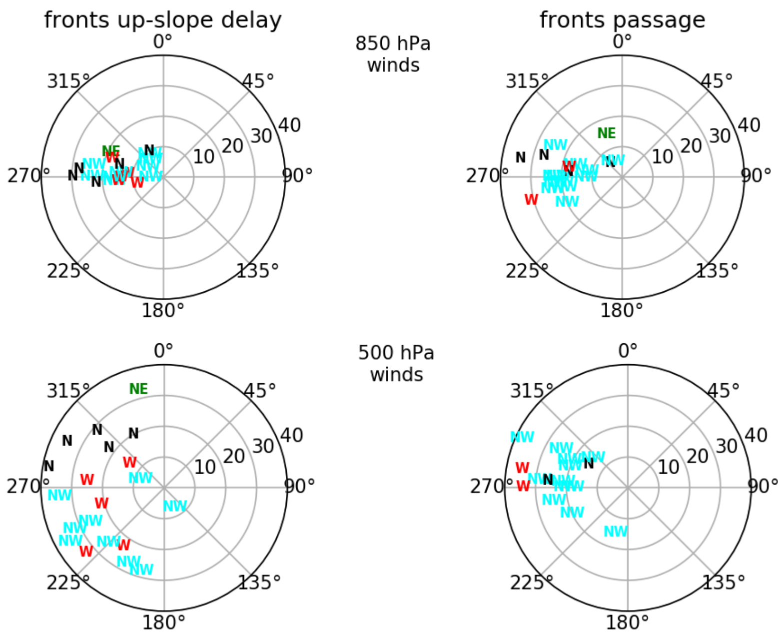

Figure 11. Wind direction for two levels (top row: 850 hPa; bottom row: 500 hPa) for situations with up-slope/delay and passage (left column: up-slope/delay; right column: passage) of 22 cold fronts events during winter. Labels (and colours) indicate the approaching direction of the frontal systems.

Schumann (1987) investigated the behaviour of frontal systems in relation to the Alps with idealized numerical studies. Assuming a two-dimensional flow he found that the front is strongly retarded if the kinetic energy is too small to let the cold air climb over the mountain. He found that the dimensionless Froude number (e.g. Smith, 1979) describes whether a front (i.e. the cold air) is able to climb over the mountains or is retarded.

The Froude *Fr* number describes the ratio between gravity forces (i.e. atmospheric stability) expressed as the Brunt–Väisälä frequency *N* and momentum forces expressed by the speed of the flow.

$$Fr = \frac{U}{NH}$$

where U is a characteristic speed of the flow, H a characteristic height of the mountain. The Brunt–Väisälä frequency is computed using the vertical gradient of the virtual potential temperature of the lower atmosphere between the two standard levels 925 and 700 hPa. 925 hPa corresponds to the height of the Alpine Foreland, and 700 hPa corresponds to about 3000 m MSL, the average height of the Alps in Germany and Western Austria. For the characteristic speed, the wind speed at 850 hPa is used, and the characteristic height is set to 2000 m, the height of Alps above the Alpine Foreland.

Figure 12 shows the Froude number for the 46 soundings during the 22 events. Frontal systems showing upslope delay in general have lower Froude numbers than frontal systems passing over the Alps. A Froude number below unity indicates that the air flow is stratified stable with a slow speed and the mountain is relatively high. This results in flow blockage or delay of the motion. For $Fr > 1$, the flow is stronger or the stability is less or the mountain is lower, in this case the flow will be over the mountain. However, the exact value of the Froude number depends on the assumption about the characteristic height of the mountain and the pressure levels for the estimation of characteristic speed and the Brunt-Väisälä frequency.

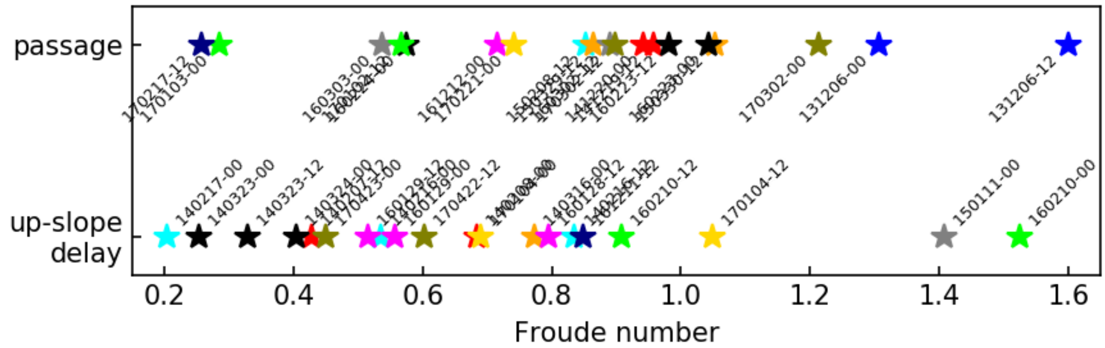

Figure 12. Froude number computed from the soundings at Munich-Oberschleißheim (see text for details). The different colours indicate the different events and the numbers indicate the date and time of the soundings.

In general the representativeness of the soundings is limited due to their low temporal resolution. Frontal systems are imbedded in large scale synoptical systems, thus the local wind and temperature profile will not always resemble the flow properties which control the behaviour of the frontal system approaching the Alps.

5 Towards the improvement of nowcast

Nowcasting for airports in the vicinity of open sea or mountains is hindered by the fact that extrapolation or numerical weather prediction gives larger uncertainty than for airports where synoptical patterns are less affected by topographic features. It is the nature of atmospheric processes that under certain conditions the evolution of precipitation can take place in short times or that the assumption of a quasi-linear propagation is affected by topographic features (e.g. Foresti and Seed, 2015). The effect of the Alps on cold frontal systems has shown that certain mechanisms exist which control the motion of precipitation systems.

Several possibilities do exist that have potential to improve the nowcast for airports close to open sea or mountain ranges:

- Under the aspect of probabilistic nowcasting one of the options is to consider increase or lower the probability of the occurrence of precipitation at a certain location in situation where the atmospheric flow is coming from or going towards certain sectors.
- One aspect which is currently hardly considered in nowcasting by extrapolation is the description of the life-cycle of precipitation systems. Currently there are some initiatives to consider this for convective precipitation cells: often cells are at the end of their life and should not be extrapolated for more than 15 or 30 minutes; under certain atmospheric conditions the life-time of cells is only in the order of 30 to 60 minutes. The later also increases the likelihood that new cells develop somewhere in the region.
- With the continuous improvement of numerical models, higher spatial resolution, more often initiation the quality of NWP will improve and the gap between nowcasting by extrapolation and NWP forecasts will get smaller. Higher resolution NWP is also able to describe and thus consider more aspects of precipitation microphysics and their reaction on underlying topographic features (Hagelin et al., 2014).
- Improved understanding of precipitation physics and the enhancements of radar networks with dual-polarization and Doppler capabilities brings new possibilities of radar data assimilation into NWP thus being able to continuously update NWP forecast and then providing better forecasts even for short time ranges.

The aforementioned options and other possible options are towards an improved combination of nowcasting techniques and numerical weather prediction and will in future tend to close the gap between nowcast and forecast.

6 Conclusions

The effect of sea and mountains on nowcasting of winter weather for nearby airports has been found to be more unreliable than for airports where no such influences do exist. Reasons for this behaviour can be found in additional influence of open sea on precipitation microphysics by the release of moisture and often a different surface temperature than over nearby land. The influence by mountains is seen by the distortion of the low-level flow. This is even more pronounced in the vicinity of the Alps, here the mountain chain has a considerable influence on the flow and easily can affect even synoptic scale systems like cold fronts or low pressure systems. This can lead to long lasting precipitation in the Alpine Foreland where for the situation of snow large amounts of snow can accumulate in several hours or even days.

By advanced nowcasting techniques adapting forcing fields or the consideration of the life-cycle of the precipitation systems an improvement of the nowcasting techniques can be achieved. However, promising research shows that by the improvement of numerical weather prediction models forecasting precipitation systems can be improved and the gap between nowcasting by extrapolation and NWP can be closed. The advantage of NWP is that it can consider large scale flow pattern and microphysical evolution. However, this advantage is only possible with high resolution NWP (horizontal resolution in the range of 1 – 2 km) and detailed cloud and precipitation microphysics. Further improvement of short term forecast and nowcasting can be achieved by the assimilation of radar observations in NWP. Modern radar systems provide much more information that reflectivity only.

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