2.4 Nowcasting Winter Weather at Munich Airport

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The WxFUSION concept can also be extended to handle winter weather conditions. Of particular importance here is the occurrence of in-flight and ground icing conditions at an aerodrome. Data from surface observations of precipitation type and intensity, of surface conditions (dry, liquid, frozen), of hydrometeor observations within clouds, and of aircraft observations of temperature and humidity can be fused. Work is underway to combine existing in-flight icing algorithms with the additional data sources available to build a corresponding winter weather module within WxFUSION.

Introduction

Airport operations in winter are significantly impacted by weather conditions such as snow fall, freezing rain and drizzle, and low ceiling and visibility. Delays and cancellation of flights are often resulting from these weather conditions. Runways and taxiways must be kept free of or cleared from snow and ice and aircraft have to be de-iced before take-off. Planning and conduct of aircraft traffic flow on the ground and in the air can be significantly impacted through these procedures. During the recent winters 2009 and 2010 European air traffic has been significantly disrupted by winter weather as has been the case for two major hubs shortly before Christmas in December 2010: 200 flights at Frankfurt on a single day (17.12.2010) and an almost complete still stand at London Heathrow. The photographs in Figure 1 are two examples from 30 November 2010 at Frankfurt airport and on 22 December 2010 at Berlin Tegel after heavy snow fall (left) and snow together with rain (right).

Figure 1. Winter weather impacting airport operations: Frankfurt on 30.11.2010 (left) and Berlin Tegel on 22.12.2009 (right)

In order to gain understanding of the impact of winter weather conditions on airport operations a meeting was held at Munich airport with representatives of Munich airport operations, air traffic control, local office of the German weather service and DLR institute of Atmospheric Physics on 17 December 2007. The outcome of the meeting can be compressed into the following user requirements:

Of particular interest for all stakeholders is the short-term forecasting, or nowcasting, of:

- Onset, duration and type of precipitation,
- Icing at the surface,
- Freezing fog,
- Aircraft icing at ground,
- Visibility.

The Deutsche Flugsicherung (DFS) reported in the meeting that there are 20-30 winter weather days at Munich airport and 70-90% of all delays are weather related (summer and winter). Therefore, the objective of the work package “Winterwetter” within the DLR project “Wetter & Fliegen” was to develop a winter weather nowcasting system that provides users with 0-2 hour nowcasts of the winter weather conditions described above. The following paragraphs describe the concept of the system and show first results from individual measurement platforms.

The nowcasting Concept

The task “nowcasting of winter weather at Munich airport” can be approached by a stepwise procedure:

- Check which MET data are available at the airport and within the TMA
- Analysis: combine MET data to determine winter weather conditions hazardous to aviation at every observation site within the TMA and represent these hazards by winter weather objects (WWO)
- Nowcasting: use calculated trends at observation sites within the TMA to determine changes in weather conditions at the airport
- Use forecast data from numerical model for early warning

In the following, these points are addressed.

Available data at Munich Airport

Figure 2 shows schematically the available data at and around Munich airport which can be used for the analysis of winter weather conditions. We have to distinguish in-situ data, remote sensing data and derived products.

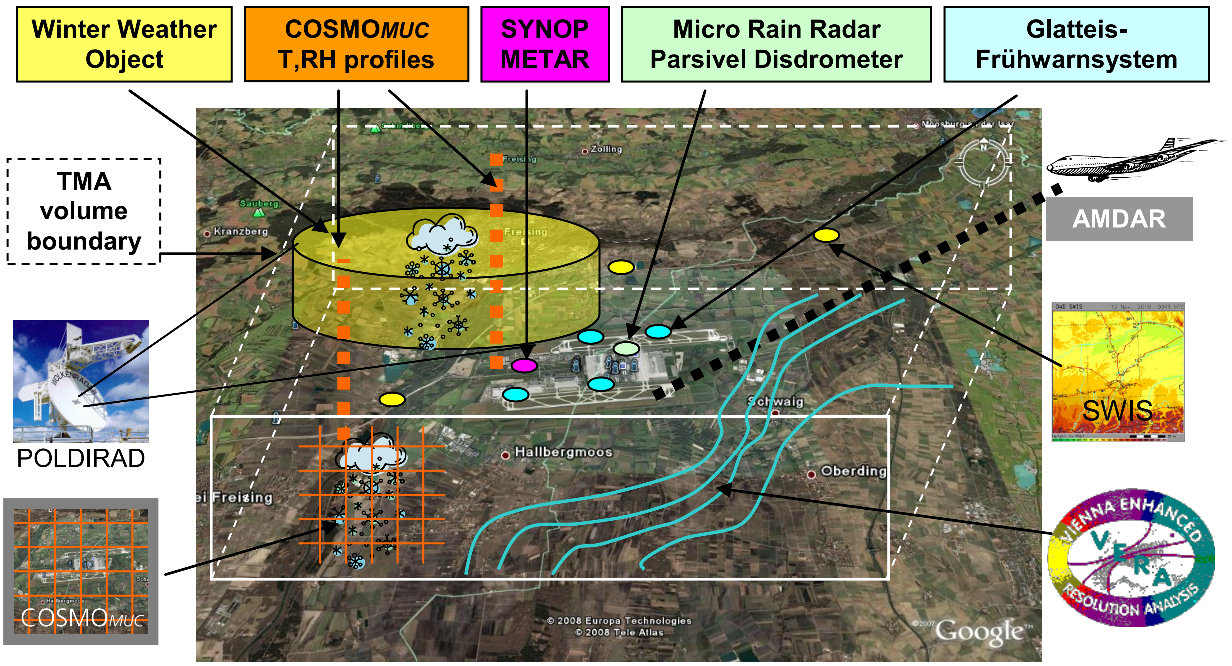

Figure 2. Available MET data at and around Munich airport

SYNOP & METAR data are reported hourly from station 10870 (München Flughafen) and cover up to 90 different parameters, including besides standard observations like pressure, wind, temperature and humidity, also cloud cover, cloud height and type, precipitation amount and type, various soil temperatures and ground state. These data therefore give valuable information also on winter weather conditions like e.g. observation of freezing rain, frozen surface, etc.

Special sensors installed in the run and taxiways record the temperatures of the near ground air, of the surface and the soil, furthermore the precipitation type, pressure, wind velocity and freezing temperature. The sensors form the hardware part of the so-called “Glatteisfrühwarnsystem – **GFS**”, an icing early warning system. It determines freezing conditions which are used to optimize the use of de-icing chemicals.

In addition to these sensors at the airport, surface conditions of roads around the airport are also evaluated by the Strassenwetterinformationssystem **SWIS** (Street Weather Information System), operated by the German weather service. Measurements include air temperature, humidity, wind velocity and direction, visibility range und precipitation amount. Similar to the sensors within the airport area SWIS sensors measure surface and soil temperature, humidity and water film on the road and in addition the salt content during the winter period.

The **Micro Rain Radar** (MRR-2) is a small low-power vertical-looking Doppler radar operating at 24 GHz. It measures the velocity spectra of falling raindrops. Raindrop size distribution and rain rate are estimated as vertical profiles. A narrow spectra with low fall speeds indicates snow, a broad spectra with higher fall speeds indicates rainfall. For further information see www.metek.de.

The **Parsivel optical disdrometer** measures size and fall speed of particles with a narrow laser beam. Fall speed and size distribution is used to estimate rain rate and precipitation type. For further information see http://www.ott-hydrometry.de. The photograph in Figure 3 (left) shows these two instruments, the observation site is indicated on the right.

Figure 3. Observation instruments at Munich airport operated by DLR, foto: Parsivel (left), micro-rain radar (right), observation site indicated by green dot in right Figure.

The Polarimetric Doppler Weather Radar **POLDIRAD** is operated for research since 1986 jointly with the DLR Institute of High Frequency Technology. The main characteristics of the C-band system comprise the polarisation agility for transmitting, the dual-channel receiving, the Doppler capability and the real time processing and display. A selection of two parameters out of the following are available for real time display: reflectivity factor for each polarisation of choice; the differential reflectivity; and the depolarisation ratio for a selected polarisation, especially the linear depolarisation ratio; or the circular depolarisation ratio; the Doppler velocities; and the Doppler spectral widths for both receiving channels. Time series products as the differential propagation phase will be available in real time soon. The radar can be used to estimate the dynamical and the connected microphysical cloud structures and their developments with their lifetimes. Snow, graupel, hail and rain can be distinguished. It is such of great value in order to reveal winter weather precipitation in real time.

AMDAR (Aircraft Meteorological Data Relay) data are reported from aircraft during flight. Data transmitted are temperature and humidity besides others. Together with pressure recordings, geographic position data and time information vertical profiles of these data can be constructed. These soundings thus provide useful information on inversion layers, cloud layers and possible icing zones.

Besides these in-situ data, forecast data from the **COSMO*MUC*** derivative of the COSMO-DE model of the DWD (COSMO, 1998) are available within the Terminal Manoeuvring area (indicated as **TMA** volume boundary) of the airport; see Section 2.5 for a description of that model.

Vienna Enhanced Resolution Analysis (**VERA**) is a objective, automatic analysis procedure for meteorological parameters over complex terrain developed by the University of Vienna (Steinacker et al., 1997). It is able to resolve mesoscale structures caused by topography by including meteorological a priori knowledge in the analysis. The scheme is used for both error detection and correction, and interpolation of irregularly distributed data onto a regular grid. The emphasis is put on the transfer of information from data sparse to data rich areas. For this purpose the so called “fingerprint technique” is used. It adjoins additional orographic information to the measurements. The error detection mode checks the single measurements concerning their spatial physical plausibility and calculates correction suggestions where necessary. The method runs independently from any first guess or model field. For the use in Wetter & Fliegen VERA has been installed at DLR/IPA over a domain with reduced size covering southern Germany. For winter weather the analysis system can provide information on surface temperature and humidity, observed precipitation and especially fronts, where the exact position, movement, strength is of great importance for timely warning and model forecast verification. Figure 4 shows an example of analysed surface temperature. The 0° C contour run close to the airport MUC, dividing colder near ground air to the northeast from warmer temperatures to the southwest. Such information could be quite valuable when there is precipitation in the area, thus allowing the estimate of possible freezing conditions at the ground.

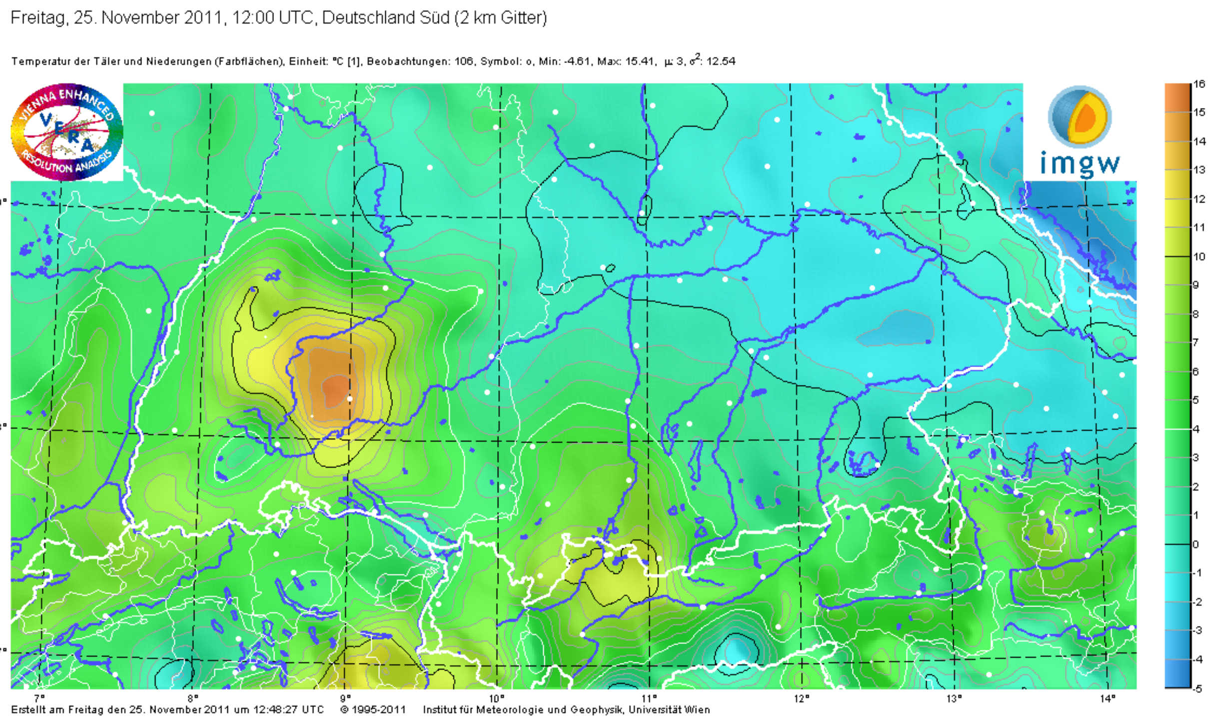

Figure 4. Vienna Enhanced Resolution Analysis: Temperature of valleys and low lands on 25/11/2011.

Fusion of Observation Data into Weather Objects Representing Hazards to Aviation

A certain winter weather phenomenon, like e.g. freezing precipitation, can be thought of a certain volume of air within which this phenomenon can be observed. Various observations, like the ones described above, are suited for describing one or the other attribute of that phenomenon, as e.g. the surface temperature, the precipitation type. With no doubt the actual weather phenomenon can be determined more precisely when data from various sensors are combined (Tafferner et al., 2008). It is therefore advisable to think of such volumes as weather objects with certain inherent attributes. Such an approach has already been successfully implemented for nowcasting thunderstorms (Forster and Tafferner, 2009; also Forster and Tafferner this volume). For our purposes, a winter weather object at a certain location, e.g. an airport, can be defined through the following parameters:

- a vertical column of air consisting of several layers
- issued time
- valid time
- next update time
- layer description, e.g.:
  - Snow: upper and lower boundary with intensity: light, moderate, severe
  - Rain: upper and lower boundary with intensity: light, moderate, severe
  - Freezing rain: upper and lower boundary
  - Freezing drizzle: upper and lower boundary
- surface conditions
- trends, e.g. intensity increasing, change to melting, etc.

This first approach addresses only the threats to aviation related to precipitation processes. In the future, further ingredients could be taken into account like wind, visibility, ceiling.

A winter weather object (WWO) is shown schematically as yellow cylinders in Figures 2 and 5. From the definition it is obvious that the object can have several different hazard layers. In Figure 5 this is exemplified within the yellow idealized object:

- there is a near surface layer with temperatures above freezing up to about 800 mb (ref. sounding to the left) which contains rain drops;
- a second layer from H1 to H2 (about 800 to 660 mb) contains supercooled droplets which result from melting of snow and ice within the "warm nose", the the layer with positive temperatures between about 660 and 600 mb;
- on top there is a precipitating cloud layer with mixed type particles up to the radar height of precipitation (Ht).

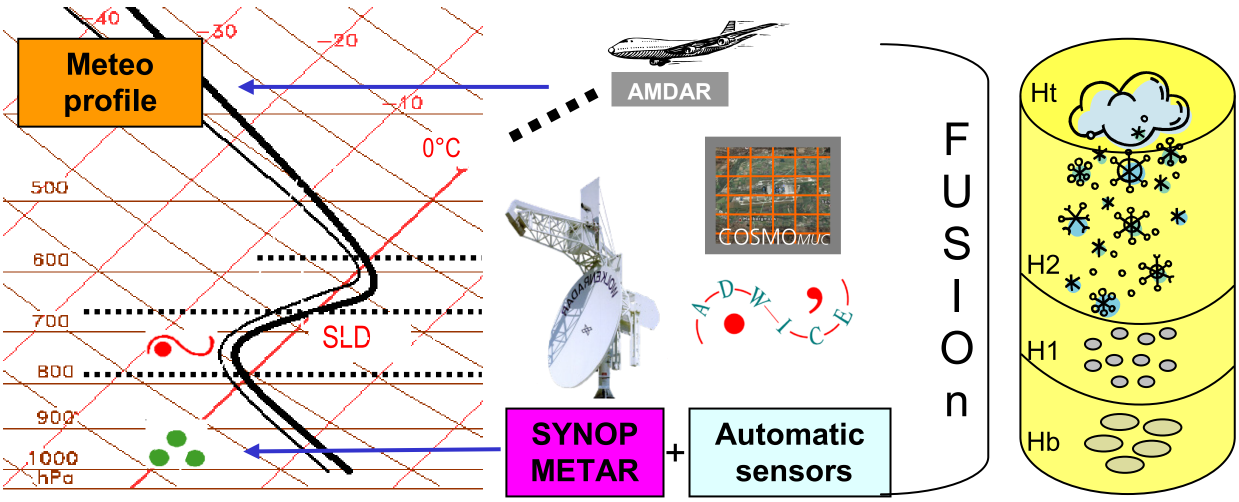

Figure 5. Fusion of data into an object

In Figure 5 various data sources are shown symbolically which would allow deriving the weather object. SYNOP and automatic sensors (e.g. from GFS) allow to determine the surface conditions, in this example rain with temperature above zero. The temperature/humidity sounding can be provided from

COSMO*MUC* model or AMDAR data, or constructed from both depending on data availability (esp. as regards to AMDAR humidity observations). POLDIRAD observes the precipitation height and is able to determine the hydrometeors within the cloud through its polarimetric capability and related algorithms. ADWICE – the Advanced Diagnosis and Warning System for Icing Environments - (Tafferner et al., 2003; Leifeld, 2004) uses the information of reported weather at the ground together with the soundings of temperature and humidity and radar measurements to determine the icing threat to aircraft in flight.

Figure 6 illustrates schematically the current algorithm for the diagnostic product which is run operationally at DWD (DWD - Luftfahrt, 2003). Starting from weather observations of SYNOP and of radar reflectivity from the European radar composite of DWD icing scenarios “freezing”, “convective” or “stratiform” are determined over the domain of the COSMO-EU model which covers roughly the area of Middle Europe. Forecast profiles of temperature and humidity from this model allow to calculate the vertical structure and extent of the icing scenarios (“3-D DIP” in the Figure). Another scenario “general” is added if temperature and humidity profiles are within certain thresholds even when not supported from ground observations. Note that within ADWICE not only precipitation is considered but also the occurrence of super-cooled droplets in general, e.g. in stratiform clouds which can pose a hazard to aircraft especially when residing for a longer time within this clouds as is the case during holding pattern. A graphical depiction of the diagnosed icing product is seen on the right. Coloured regions indicate different icing threats on flight level 65. A detailed description of both the diagnostic and prognostic icing algorithm can be found in Leifeld (2004).

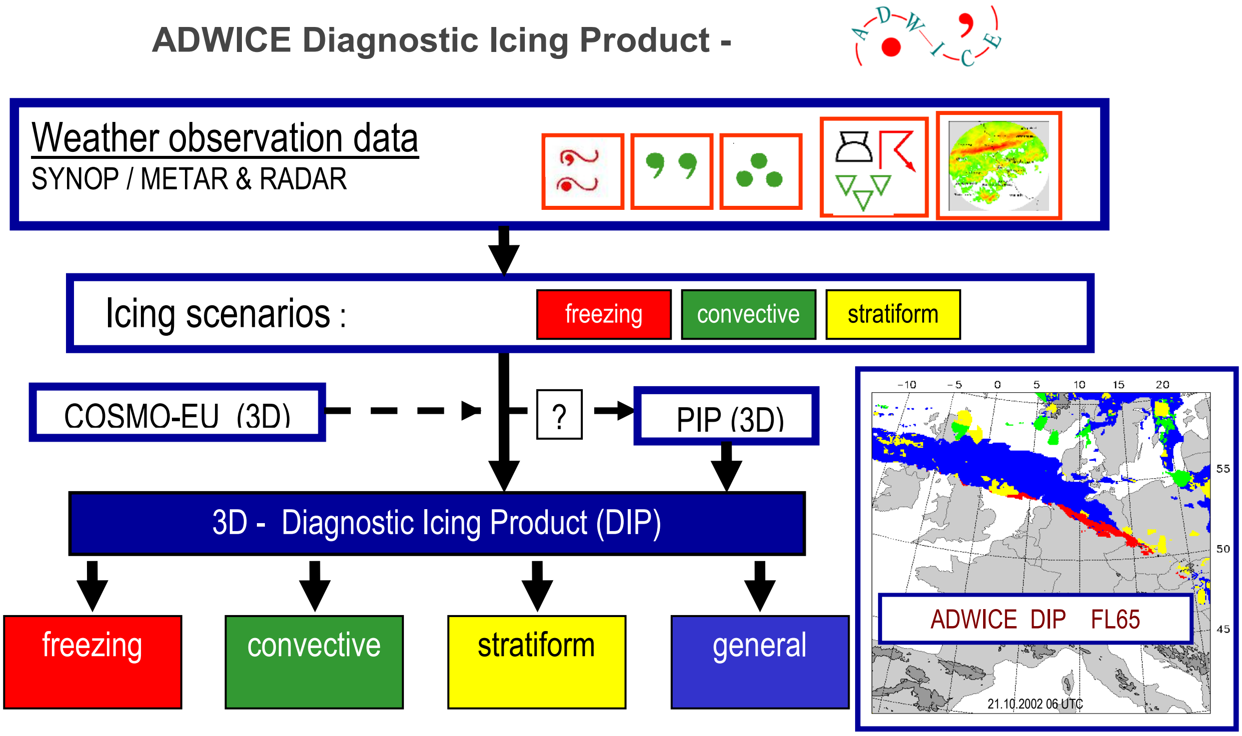

Figure 6. Data flow diagram of ADWICE algorithm for diagnostic icing product.

Up to date, ADWICE only uses radar reflectivity for the analysis. However, the quite useful polarimetric radar information and the measurements of the micro rain radar can be included in the analysis. This will be part of a data combination algorithm. It will be based on fuzzy logic which allows that the ‘ingredients’, i.e. the information contents of the various observations can be weighted and contrasted to each other using physical concepts and experience to derive the actual weather state as precisely as possible. This work is carried out within the frame of a doctoral thesis (Keis, 2010).

Nowcasting: Extrapolating Winter Weather Conditions in Time and Space

Close to actual time, air traffic control and airport operations require exact weather information as it makes a great difference whether the precipitation during the next hour will be rain, freezing rain or snow. Quite different operations have to be set into place like the planning and conduct of runway and airport road clearing, of aircraft deicing, of aircraft traffic flow on the ground and in the air. This is why users chose the nowcasting of winter weather conditions at first place when asked what they need most.

For nowcasting icing & snow conditions for the airport one has to consider weather changes due to advection of air with different characteristics and, especially demanding, possible changes resulting from precipitation and cloud physics processes which can occur within short time spans at the observation site. For capturing both of these effects an approach is followed where WWOs are determined at the various observation sites around the Munich airport where both SYNOP and polarimetric radar data are available. Changes in WWOs around the airport can then provide guidance for the expected change at the airport. Figure 7 demonstrates this approach.

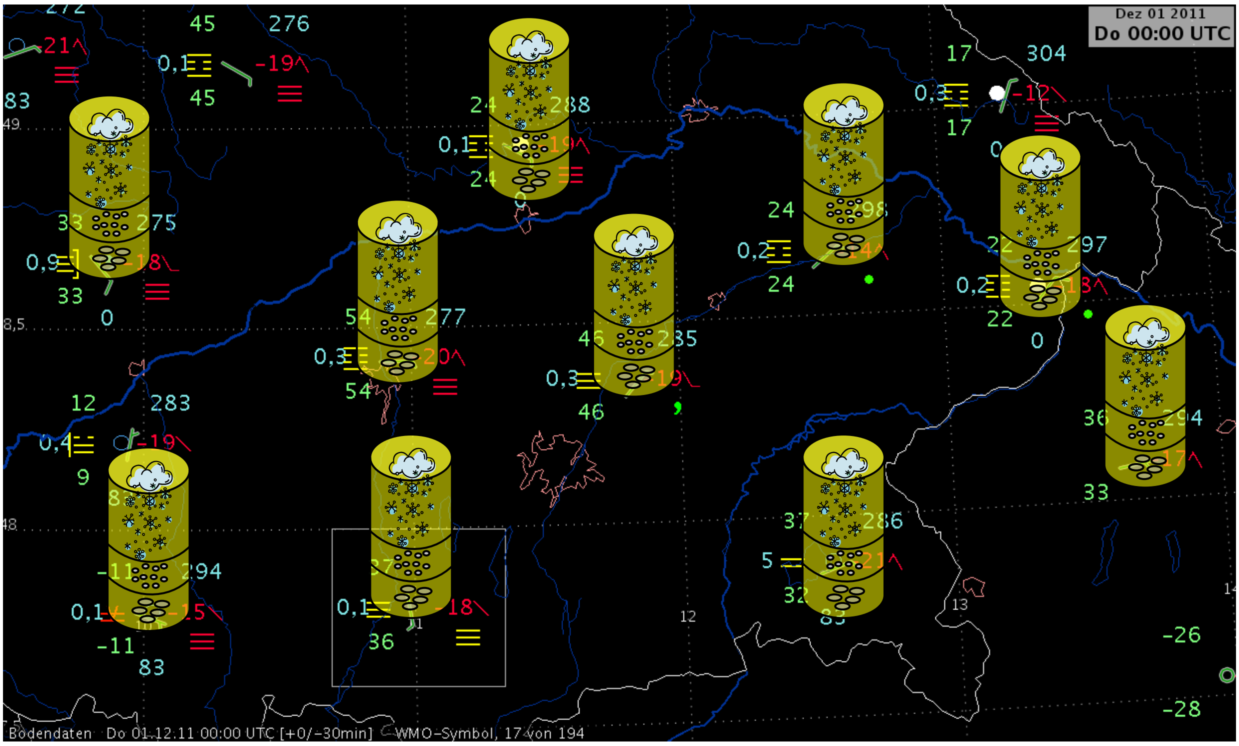

Figure 7. SYNOP stations within the TMA MUC together with winter weather objects

At every SYNOP observing station within the TMA a WWO is determined as described above using surface observations, polarimetric radar data and temperature/humidity forecast soundings from the COSMO-DE model. Note that only at MUC airport (in the centre of the Figure) AMDAR data are available for the soundings, too. For nowcasting winter weather hazards at MUC the following approach is proposed:

1) Determine WWO from observed data and forecast soundings at every observation site;
2) Calculate trends in surface parameters, e.g. temperature, humidity at the airport;
3) Use forecast temperature/humidity soundings at the airport from COSMO*MUC*;
4) Determine weather trend at the airport from observed weather at upstream stations at earlier time which can then be used to take into account advection;
5) By fuzzy logic, combine upstream weather changes with estimated trend at the airport to nowcast winter weather conditions up to 2 hours.

From data availability at Munich airport, points 1 to 5 can be updated every 30 minutes, also the calculation can be performed quite fast in order to not produce unnecessary delays.

Forecasting for Early Warning

For forecasting winter weather beyond the nowcasting range up to about 24 hours or more, one can rely on operational forecast models like COSMO-DE. Although numerical models have achieved remarkable progress during the last years in forecasting the overall weather state, e.g. the surface pressure distribution or whether it will rain or not, winter weather phenomena like freezing rain or drizzle, or light or heavy snow fall result from the subtle interplay of various factors, like the vertical distribution of temperature and humidity, cloud cover and type, snow cover, soil moisture and the composition of the atmosphere with aerosols which again influence cloud and precipitation processes. The situation gets even more complicated as these processes result from instabilities which are triggered by small changes in the atmospheric parameters, e.g. whether the temperature at the ground or through a certain depth of the atmosphere is slightly above or below 0° C. In order to better estimate the future atmospheric state ensemble models as mentioned above give better guidance than a single model run. Combined quantities like ensemble mean, spread and others allow estimating probabilities which can be used for advanced planning. Here output of the KENDA ensemble model from DWD can be used in future to provide this probability information.

First Results

Several winter weather events which occurred in 2010 have been selected as example cases for first studies. In the following some results from algorithm development and local measurements are presented, all of which are necessary steps in setting up the nowcasting procedure as described in the previous chapter.

Installation of ADWICE at DLR

The operational ADWICE algorithm run at DWD consisting of diagnostic and prognostic parts has been installed at DLR. However, in contrary to DWD the higher resolution COSMO-DE model output is used at DLR instead of COSMO-EU output as in the operational version. In a first step, it is evaluated whether this can already bring improvements. Figure 8 demonstrates these differences.

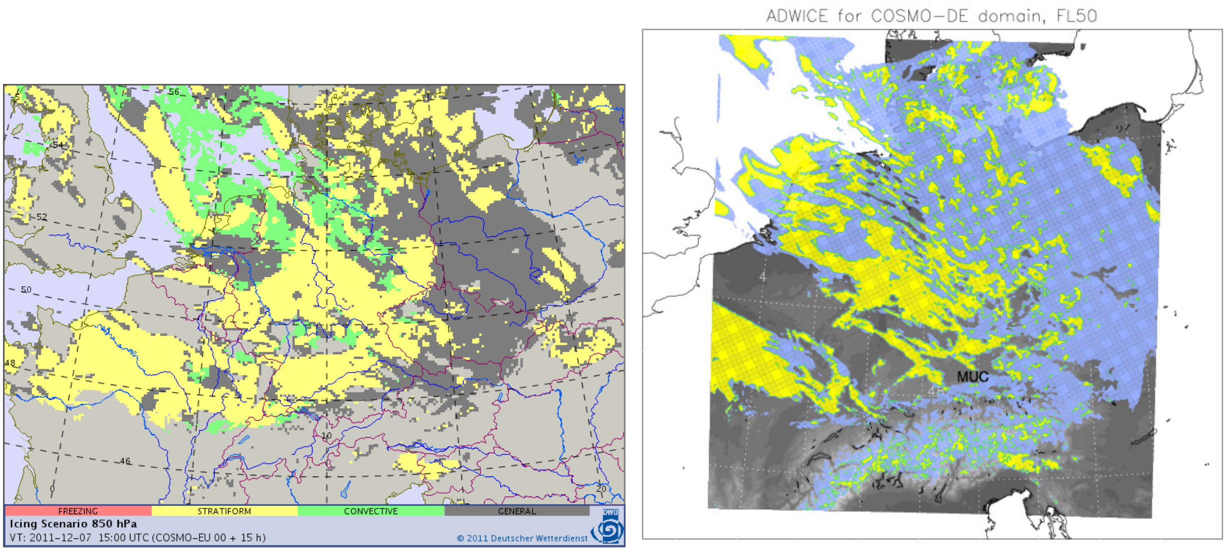

Figure 8. ADWICE forecasts for flight level 50 using COSMO-EU output left, COSMO-DE output right.

Notable differences are seen in the extent of the yellow areas which render the icing scenario "stratiform" in both Figures. Calculated from the output of the COSMO-EU model (left) these areas are much larger especially over Germany as compared to the ADWICE forecast from DLR which is calculated from COSMO-DE output (right). The too large icing fields in the operational version are well known as a problem referred to as "overforecasting". It appears that the use of COSMO-DE output is a step in the right direction, although more testing is required and results have to be verified against independent data sources.

Use of AMDAR Data

At the airport AMDAR data relayed from descending aircraft can replace the forecast soundings of temperature and humidity from the COSMO model. The benefit is demonstrated in Figure 9. Forecast temperature and dew point temperature from the COSMO-DE model are shown as black lines, crosses mark measured temperature and dew point from descending aircraft. The pink lines are lines fitted to the measurements. Whereas the temperature curves from both AMDAR and forecast show close resemblance, especially within the range 0° to -20° C degrees which is the preferred range where icing is most probable, there is a large difference in the dew point temperatures. Under the precondition that the measurements are correct, the forecast icing zone indicated as blue bar on the right is correctly dismissed by using the observation data (no respective bar). Further evaluations in this direction will be conducted together with POLDIRAD measurements and surface observations.

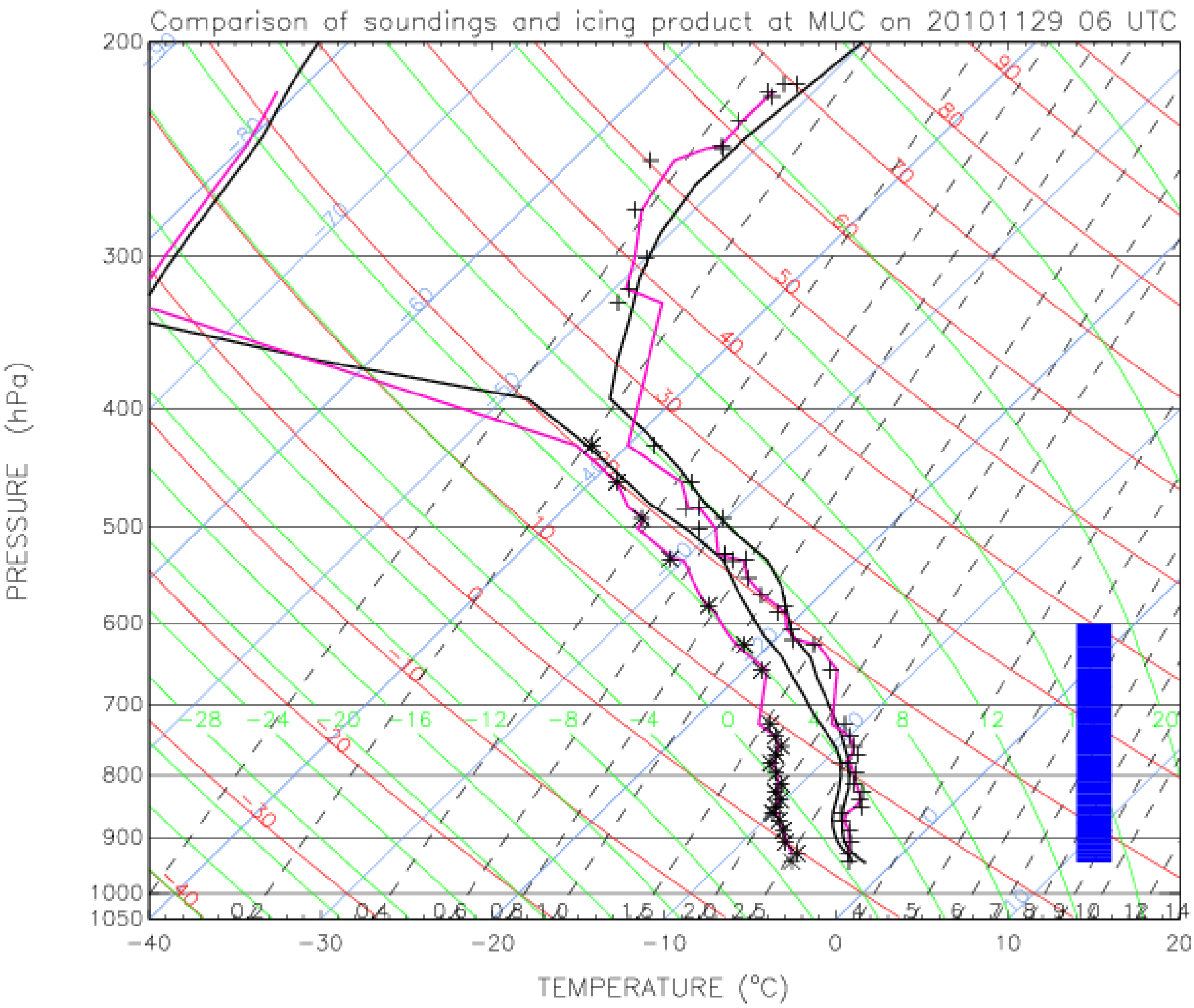

Figure 9. Comparison of forecast (black curves) and measured (pink) soundings of temperature and humidity for 29 November 2010 06 UTC. The blue vertical bar on the right indicates the ADWICE icing range as forecast by COSMO-DE.

Use of Polarimetric Radar Data

Figure 10 shows measurements from a winter time snow front which is detected as a line signal in the POLARIMETRIC reflectivity data (left). From the corresponding polarimetric information the hydrometeors can be determined as indicated in the right Figure. Clearly the possibility to distinguish between snow and rain provides a quite useful information for winter weather nowcasting as it helps in decision making at the airport, e.g. snow clearing on runways, as well as for de-icing procedures and warnings of in-flight icing threat.

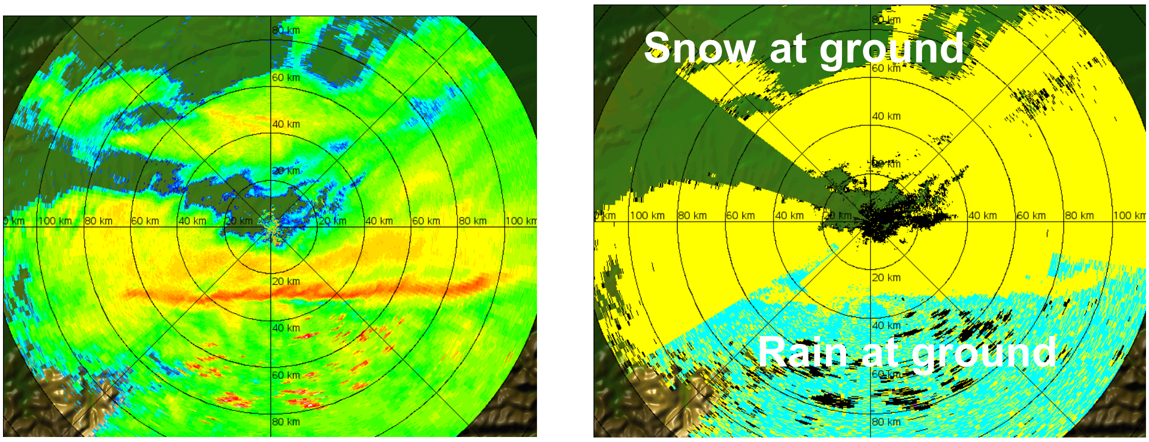

Figure 10. Snow front approaching from north towards Alps (line in left Figure) as detected by DLR POLDIRAD Alps on 21 November 2008 1330 UTC. Snow and rain areas can be distinguished through polarimetric capability.

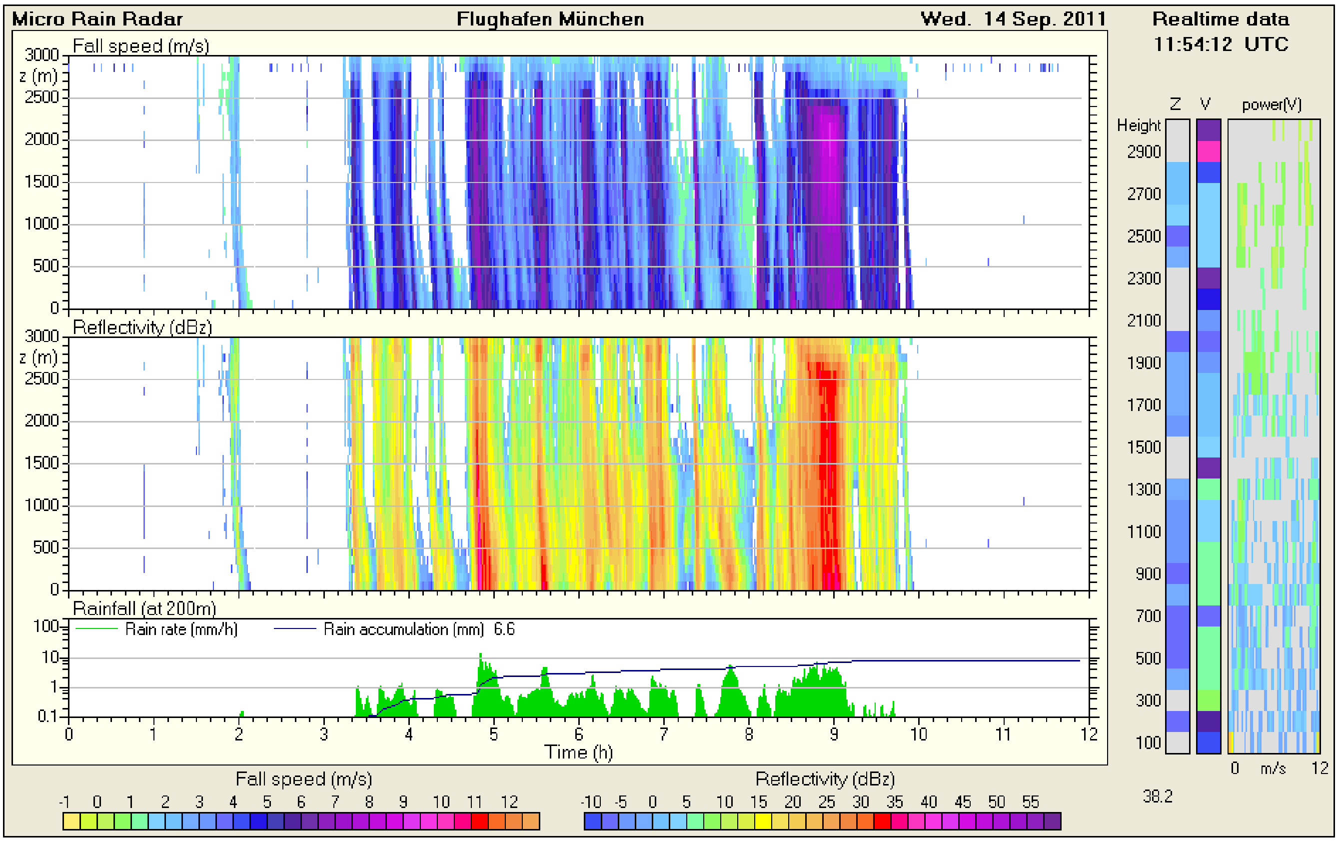

Figure 11. Measurements of the micro rain radar at Munich Airport on 14 September 2011

Use of Other Local Data

The Micro Rain Radar and the Parsivel instrument allow to observe precipitation events at the airport in real time and to provide relevant information on winter weather threats like the precipitation strength, the size and type of hydrometeors, the accumulated precipitation and the actual weather. Figure 11 shows a measurement example on 14 September 2011 with hydrometeor fall speed, reflectivity and accumulated rain fall. Figure 12 shows corresponding measurements from the Parsivel instrument. Note that also actual weather (ww) is determined from the measurements automatically. The droplet size provides useful information for estimating the icing intensity, in particular when super-cooled large droplets (SLD, range 40 – 400 µm) are detected.

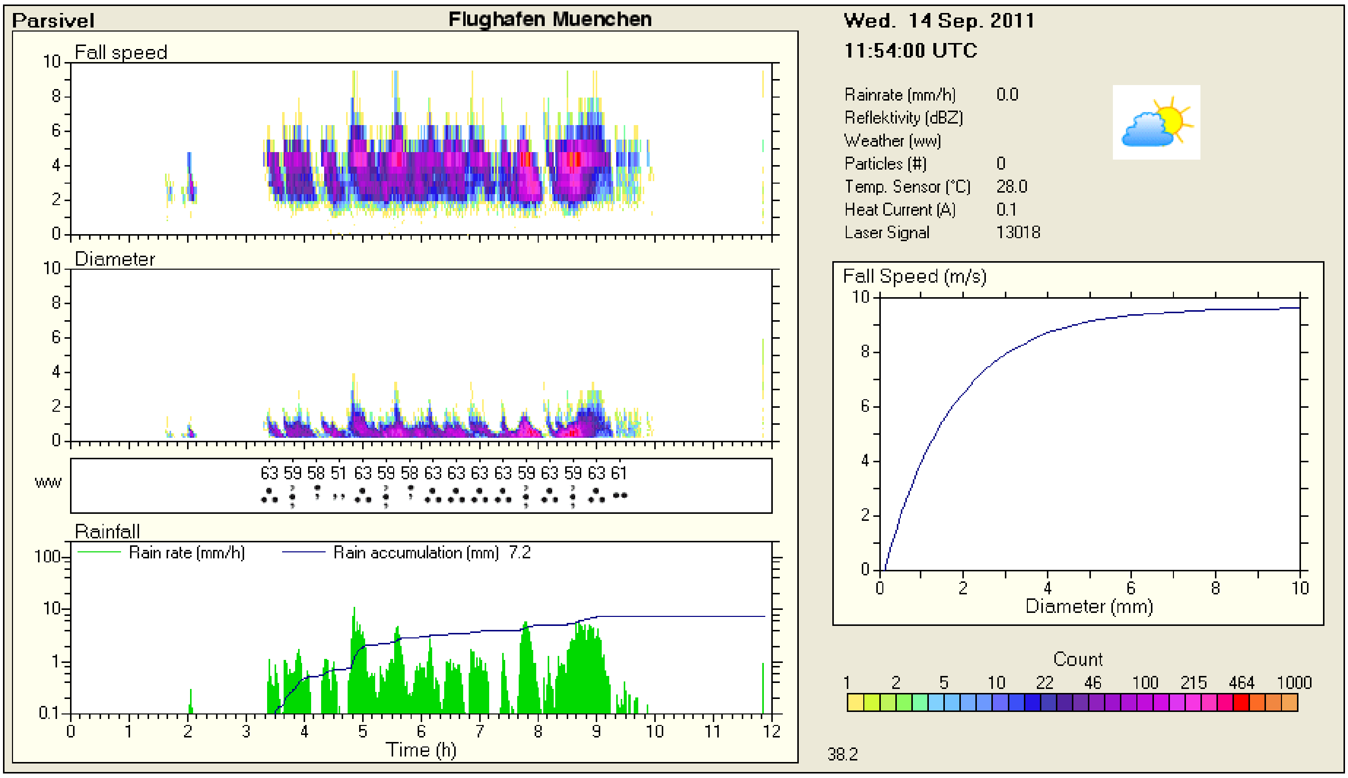

Figure 12. Measurements of the Parsivel instrument at Munich Airport on 14 September 2011

Outlook

During the winter 2011/12 cases where winter weather influences airport operations at MUC will be gathered and evaluated as regards to icing and snow fall conditions. All local observations and POLDIRAD measurements will be used to further develop the nowcasting system in the sense described above. It is expected that the experience gained from many winter weather cases will enable the build-up of a fuzzy logic procedure which can improve the nowcasting of winter weather and thus provide a reliable source of information for decision making at the Munich airport.

References

COSMO, 1998: Consortium for small scale Modeling: http://www.cosmo-model.org/content/model/documentation/core/default.htm

DWD – Luftfahrt, 2010: ADWICE Vereisungsprognosen für den europäischen Luftraum – Leitfaden zur Nutzung und Interpretation der Produkte –. DWD Abteilung Flugmeteorologie, 31.03.2010

Forster, C., and A. Tafferner, 2009: An integrated user-oriented weather forecast system for air traffic using real-time observations and model data, Proceedings of the European Air and Space Conference (CEAS), Manchester, UK, 26 - 29 October 2009

Keis, F., 2010: Nowcasting von Winterwetter am Münchner Flughafen und Umgebung durch Verbindung von Beobachtungs-, Fernerkundungs- und Modelldaten. Ph.D. work in progress at Institut für Physik der Atmosphäre, DLR

Kober K., Tafferner T. 2008: Tracking and nowcasting of convective cells using remote sensing data from radar and satellite, Meteorol. Zeitschrift, 1 (18), 75 - 84.

Leifeld, C., 2004: Weiterentwicklung des Nowcastingsystems ADWICE zur Erkennung vereisungsgefährdeter Lufträume, Berichte des Deutschen Wetterdienstes Nr. 224, Offenbach am Main, 118 S.

Steinacker, R., W. Pöttschacher, M. Dorninger, 1997: Enhanced Resolution Analysis of the Atmosphere over the Alps Using the Fingerprint Technique. Annalen der Meteorologie, 35, 235- 237

Tafferner, A., Hagen, M., Keil, C., Zinner, T. and Volkert, H., 2008, Development and propagation of severe thunderstorms in the upper Danube catchment area: Towards an integrated nowcasting and forecasting system using real-time data and high-resolution simulations, Meteorology and Atmospheric Physics, 101, 211-227, DOI 10.1007/s00703-008-0322-7

Tafferner, A. , Hauf, T. und Leifeld, C. und Hafner, T. und Leykauf, H. und Voigt, U. (2003) ADWICE - Advanced Diagnosis and Warning System for Aircraft Icing Environments. Weather and Forecasting, 18 (2) , 184-203

Zinner, T., H. Mannstein, A. Tafferner, 2008: Cb-TRAM: Tracking and monitoring severe convection from onset over rapid development to mature phase using multichannel Meteosat-8 SEVIRI data. – Meteor. Atmos. Phys. 101, 191–210, DOI 10.1007/s00703-008-0290-y.