# 8.2 DIAGNOSING AND FORECASTING INFLIGHT ICING ENVIRONMENTS USING ADWICE

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## 1. INTRODUCTION

In the atmosphere supercooled liquid water (SLW) exists as droplets in clouds and precipitation at subfreezing temperatures down to –40°C. If supercooled droplets get in contact with aircraft, they freeze and the resulting ice accretion may lead to a significant modification of aircraft aerodynamics up to the point of uncontrolled flight. Supercooled large droplets (SLD) with radii greater than 30µm are extremely hazardous in that respect. Instead of freezing immediately at the location where they hit the aircraft, SLDs freeze slowly by flowing around larger parts of the wing and cover even unprotected areas of the aircraft with ice.
The safest way to carry out a flight and the recommended practise would be to avoid the icing conditions. However for meteorological services this requires the forecast of supercooled liquid water content (SLWC) in cloud, cloud drop-size distribution, and complete ice microphysics model scheme. Since the forecast quality of SLW as numerical model data still is insufficient to completely rely on that model output for forecasting aircraft icing, other methods are in use and still under development. They rely on algorithms which deduce the potential icing threat from measured (mainly radiosonde ascents) or forecast (numerical models) distributions of temperature and humidity. In addition to these data sources new developed methods use more model data like the moist convection and apply weather observations (weather type, clouds).
To improve icing forecasts at the German Weather Service (DWD), ADWICE, the **A**dvanced **D**iagnosis and **W**arning system for aircraft **IC**ing **E**nvironments, has been developed in joint cooperation of the DLR (Deutsches Zentrum für Luft- und Raumfahrt), and the Institut für Meteorologie und Klimatologie (IMUK) at the University of Hannover (Tafferner et. al., 2002 and Leifeld, 2004).

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## 2. ADWICE – DATA AND METHODOLOGY

ADWICE provides forecast and diagnosis of inflight-icing hazards by newly developed algorithms using model data of the Lokal-Modell (LM) of the DWD (Doms and Schättler, 1999), weather observations and radar data. The developed algorithms potentiate to classify the weather and cloud situation into four different icing scenarios, which make it possible to deduce drop-size distribution including SLD-potential in order to determine icing severity.

### 2.1 TYPICAL ICING WEATHER SITUATIONS WITH SIGNIFICANT SLD POTENTIAL

SLDs exist as precipitation droplets as well as cloud droplets. To define icing scenarios for ADWICE first different weather situations have to be investigated where SLDs are likely to exist.
SLDs as precipitation droplets originate from two different mechanism:

1. Precipitation particles falling through a melting layer become liquid, and get supercooled in the subfreezing layer underneath. This is the formation mechanism of supercooled raindrops. If they reach the surface without evaporating entirely and the surface temperature still is subfreezing they are called freezing rain.

2. The second mechanism to produce SLDs as precipitation droplets is the formation by condensation-collision-coalescence process, called the warm rain process. Before cloud droplets reach precipitation size the cloud droplets grow to sizes of SLDs. If the growing process is going on, the supercooled large cloud droplets reach

drizzle size, they will fall out of the cloud because of the weight and fall as precipitation droplets towards the surface. This precipitation mechanism is likely in flat stratiform clouds with cloud top temperatures not colder than –12°C. If these supercooled drizzle drops reach the ground without evaporating entirely and the surface temperature still is subfreezing they are called freezing drizzle.

In addition to freezing precipitation and SLDs in stratiform clouds, SLDs are likely in towering cumulus (TCU) and cumulonimbus clouds too. High updrafts, windshear and turbulence force the collision-coalescence process in these clouds. Due to high upwinds in convective clouds SLDs can be found even at temperatures down to –40°C.

## 2.2 ICING SCENARIOS FOR ADWICE

Up to this point we discussed weather situations with SLDs as precipitation droplets: the supercooled raindrops and the supercooled drizzle droplets. And we have found that SLDs are likely in towering convection as well as in flat stratiform clouds.

For these weather/cloud situations icing scenarios are defined. The scenario **freezing** represents the situation where supercooled raindrops will form, the **stratiform** scenario represents the stratiform cloud situation with SLDs as well as the situation that these SLDs grow to drizzle size and leave the cloud as supercooled precipitation droplets. The third icing scenario **convective** represents all convective clouds with at least 3000m of vertical expansion.
All other clouds and weather situations that will not belong to one of these three SLD scenarios may hazardous to aircraft too and are all classified by an icing scenario called **general**. The only requirement for this scenario is the existence of clouds at temperatures between 0°C and -20°C.

Typical vertical profiles of temperature and dewpoint as prototypes are dedicated to the defined icing scenarios.

## 2.3 PROGNOSTIC ICING ALGORITHM (PIA)

The prognostic icing algorithm (PIA) of ADWICE is based on numerical model data from a Lokal Model (LM) of the German Weather Service with model extension covering Europe, a horizontal resolution of 7km, and 36 vertical layers. The algorithm is started twice a day, at about 03 UTC and 15 UTC, the time when new model data are available. The maximum icing forecast time depends on the model and is limited to 48 hours using LM data.
In order to find similar weather and cloud situations in model data like the ones defined in the icing scenarios, PIA compares all vertical profiles of temperature and dewpoint simulated by the numerical model with the ones defined in the scenarios. Further on PIA checks moist convection in the LM in order to find convective situations with towering convection or even cumulonimbus clouds.
If simulated profiles show the same structure as the defined profiles from the icing scenarios or the extend of the parametrized moist convection reaches at least 3000m one of the four icing situation in model data is found.

## 2.4 DIAGNOSTIC ICING ALGORITHM (DIA)

The diagnostic icing algorithm is based on observational data from weather observing stations (SYNOP, METAR), weather radar data as well as numerical data from the LM. In a first step the weather and cloud observations are assigned to the corresponding gridpoints of the LM. Gridpoints between two neighbour stations get the weather and cloud information from the station which is nearest to the gridpoint. If the distance between gridpoint and synoptic station exceeds 70km no information will be assigned for this gridpoint. The density of observation stations in Europe is so high that only some few gridpoints get no observational data.

The second step using the assigned observational information regarding weather and clouds is to attribute all gridpoints one of the four defined icing scenarios as a first guess information. To do so the algorithm needs three dimensional data to give the first guess information a vertical structure.
E.g. freezing rain is observed and the radar composite shows an echo. This information is enough to attribute the icing scenario freezing to the corresponding gridpoints of the observation

station as a first guess information. To find the vertical extend of supercooled rain three dimensional model data are used to allocate the base of the expected melting layer. In other cases model data are used to search for the cloud top of a stratiform layer, to get the height of some temperature thresholds or to get the base and the top of convective activity.

Weather radar data are used similar to the observational data reported by meteorological stations. Conventional weather radar systems do detect precipitation size particles, thus radar data can be used as important additional information to confirm the observational data or to have an information at gridpoints where no observational data are available. Further on the echo intensity is used to estimate whether the precipitation particles result of the icephase process, so it is snow or rain, or they maybe are formed by the warm-rain process, so it is drizzle.
In ADWICE radar echoes of values greater than 19dBZ suggest that precipitation particles are raindrops or snowflakes but not drizzle.

### HOW DOES DIA REDUCE MODEL ERROR

If model data differ from observed weather the algorithm checks the model data at the surrounding grid columns in order to correct small model errors. In a case where a freezing rain band moves faster than the simulated band, the observational data differ from model data. To get the right vertical information like the base of the melting layer for this observation the algorithm checks model data from neighbour gridcolumns in order to find the expected structure and relocate the information from one of the neighbour gridcolumns to the grid column where model data is wrong.
The diagnostic icing algorithm uses surface observations of precipitation (SYNOP, METAR or RADAR) and has therefor an big advantage over the forecast algorithm which is based only on model data. The forecast algorithm checks the simulated moisture in order to make a decision whether there is precipitation or not. This information is very important to identify freezing rain situations or stratiform clouds with SLD or even drizzle droplets in model data.
The diagnostic icing algorithm is able to overrule possible wrong simulated moisture in upper levels.

In addition cloud information is provided by SYNOP data too. Whenever cloud cover less than 4/8 is observed no icing in the vertical column above the observing station is assigned. In a similar way, the information of cloud base is used to limit the icing in cloud to gridpoints above the reported cloud base with the exception of supercooled precipitation (icing scenarios freezing and stratiform).

### 2.5 ICING INTENSITY

To calculate an expected icing intensity for all types of aircraft is very difficult. Two different types of aircraft flying into the same icing conditions will receive different forms and amounts of ice accretion.
Beside the classification of the weather/cloud situation into four different icing scenarios, ADWICE estimates universal icing intensity based on an estimation of liquid water content. The liquid water content is calculated by a parcel method using simulated relative humidity data. This method already was integrated in the first version of ADWICE (Tafferner et. al., 2002).
Estimating icing intensities for all aircraft still is an ongoing development.

## 3. CONCLUSIONS

ADWICE provides diagnostic and prognostic products of inflight icing hazards. The system uses model data of the LM as well as observational data (SYNOP, METAR, RADAR) in order to classify the weather/cloud situation into four different icing scenarios called freezing, stratiform, convective and general.
Products of icing intensity are available but there still is great need of ongoing development.
Of particular advantage for ADWICE are the grid resolution of the LM and the density of the observation stations in Middle Europe in particular in Germany.
In near future ADWICE will be used operationally at the German Weather Service. Feedback information from users and of a validating phase will route the future development steps.

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