Enhanced ADWICE Diagnosis of In-Flight Icing Risk by the Use of COSMO-EU Gridded MSG Satellite Data

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Motivation: Aircraft In-Flight Icing

Aircraft icing is a rare but very hazardous phenomenon because it has a direct impact of the aircraft's performance.

Distortion of airflow around the wing

Reduction of lift and air speed

Disruption of control by locking devices

Fig. 1: DLR Dornier-228 research aircraft after the encounter of icing conditions.

Forecasting In-Flight Icing

Aircraft icing can be traced back to supercooled liquid cloud, drizzle and rain drops which are in a metastable state and freeze immediately after the collision with the aircraft's surface. The icing intensity is equivalent to the accumulation rate of ice and depends on three meteorological parameters:

Ambient Air Temperature → **Good forecast quality by NWP models**

Liquid Water Content → **Poor forecast quality by NWP models [2]**

Droplet Size Spectrum → **Not predicted by operational NWP models**

Therefore aircraft icing cannot be predicted adequately by NWP models. In the 1990s, so-called expert systems were developed to identify regions with an aircraft icing risk.

The German aircraft icing warning system ADWICE (***A**dvanced **D**iagnosis and **W**arning System of Aircraft **Ic**ing **E**nvironments*) was developed in 1998 in joint cooperation between Deutscher Wetterdienst (DWD), German Aerospace Centre (DLR) and the Institute of Meteorology and Climatology Hannover [3]. Today ADWICE consists of a forecasting and a nowcasting part:

Prognostic Icing Algorithm
ADWICE PIA

- is run at 03 and 15UTC each day
- uses input data of the German NWP model COSMO-EU
- Result: Prognostic Icing Product (PIP)

Diagnostic Icing Algorithm
ADWICE DIA

- is run every hour
- uses the PIP, observational data and input data of the German NWP model COSMO-EU
- Result: Diagnostic Icing Product (DIP)

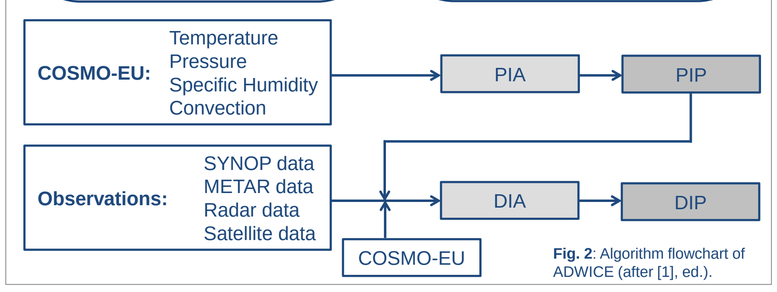


Fig. 2: Algorithm flowchart of ADWICE (after [1], ed.).

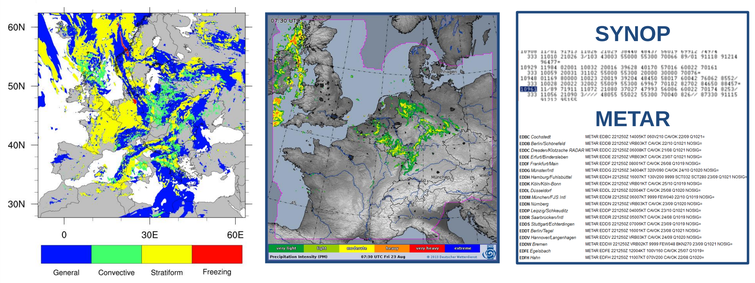
The new DIA-SAT Algorithm

The former diagnostic part of ADWICE was upgraded for the implementation of METEOSAT Second Generation (MSG) satellite data. The PIP of the relevant hour is first merged with SYNOP, METAR and radar data, resulting in the DIP.

ADWICE PIP
3D Icing Scenarios

European Radar Composite
Reflectivity

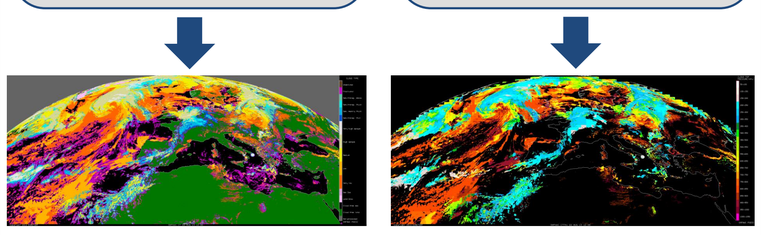
SYNOP / METAR
cloud base, significant weather



Afterwards, MSG cloud observations are used to reduce the over-diagnosis and to identify icing regions which were not found by the other data sources. The used MSG products are:

Cloud type and cloud phase
for distinguishing between
→ cloudy and cloud free areas
→ ice and liquid clouds

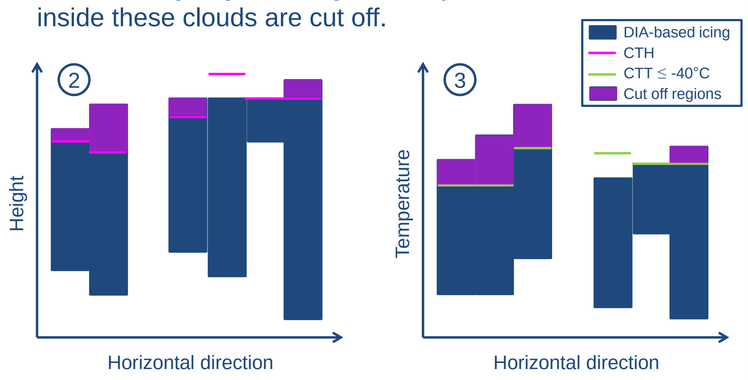
Cloud Top Height and Cloud Top Temperature
for deriving explicitly supercooled clouds and their height



Reduction of Over-Diagnosis

The reduction of the DIP over-diagnosis is done in three ways.

1. Grid columns identified as *cloud free* by the satellite, but as *icing risky* by ADWICE DIA, are cut off from the DIP because they are now interpreted as *icing free*.
2. DIP-based icing areas are cut off which lie above the satellite derived cloud top height.
3. The cloud top temperature product allows to identify too cold clouds. Icing regions diagnosed by ADWICE DIA which lie inside these clouds are cut off.

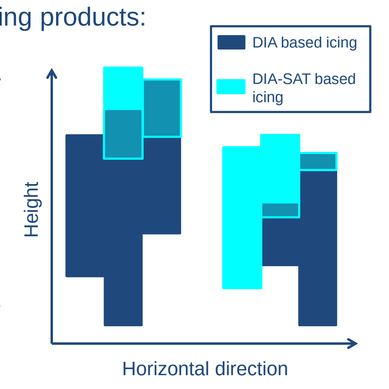


Satellite based icing detection

The additional identification of icing areas based on satellite data is executed with the following products:

→ cloud type for finding cloudy regions
→ cloud phase for finding liquid clouds
→ cloud top temperature to find supercooled clouds

The new detected icing areas are added to the DIP.



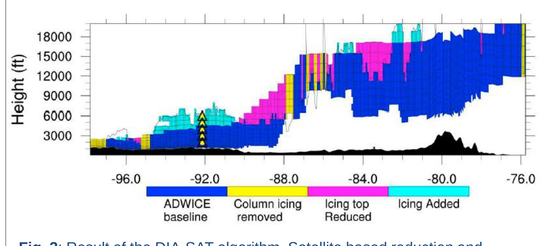


Fig. 3: Result of the DIA-SAT algorithm. Satellite based reduction and addition areas are shown. The yellow triangles are highlighting icing observations from a pilot, sent via pilot report during climb (taken from [4]).

Result: DIA-SAT

Figure 3 shows the combination of satellite based reduction and addition of icing areas in the former DIP (blue).

Verification of DIA-SAT

Methodology

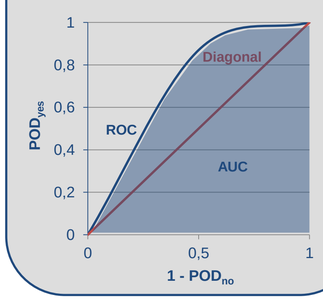
Probability of Detection

The ADWICE icing diagnosis is compared to pilot reports (PIREP) about icing observations over the US.

		PIREP Icing Observation	
		Yes	No
DIP	Yes	Hit (H)	False Alarm (FA)
	No	Miss (M)	Correct Rejection (CR)

$$POD_{yes} = \frac{H}{H + M}, \quad POD_{no} = \frac{CR}{CR + FA}$$

Creation of ROC-Curve and calculation of *Area Under* ROC *Curve* (AUC) value



Volume Efficiency

PIREPs with the information "no icing" are very rare because pilots are used to report dangerous phenomena. Therefore especially the number of *False Alarms* is not reliable so that POD_{no} is not reliable as well.

The Volume efficiency is a metric used to quantify the relationship between POD_{yes} and the icing volume from an icing diagnosis.

The amount of icing which a diagnosis produces is expressed as the volume percentage:

$$Vol\% = 100 \cdot \frac{Vol_{ice}}{Vol_{tot}}$$

The volume efficiency is the ratio of POD_{yes} in percentage form, devided by the volume percentage of icing.

$$Voleff = \frac{100 \cdot POD_{yes}}{Vol\%}$$

Case Study

Within a winter time period (February 2nd to 9th, 2010) PIREPs with an icing information were collected over the US and compared to the ADWICE diagnosis from the old ADWICE DIA algorithm and the new ADWICE DIA-SAT algorithm.

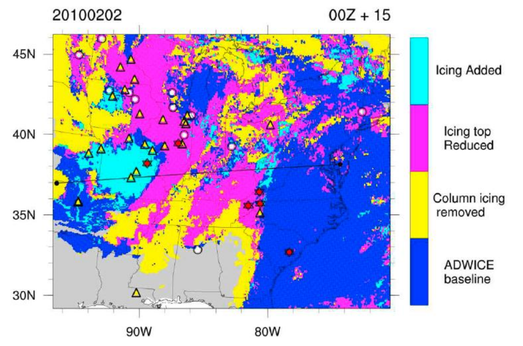


Fig. 4: Changings in the old ADWICE DIA diagnosis (blue) due to satellite information. The circles are highlighting "no icing" PIREPs whereas the triangles and stars are highlighting "light" respectively "moderate or greater icing" PIREPs (taken from [4]). The figure shows the situation for February 2nd, 2010 at 15UTC.

Skill Scores		ADWICE DIA	ADWICE DIA-SAT	Difference
Near PIREP	POD_{yes}	0.879	0.898	within error
	POD_{no}	0.229	0.215	within error
	AUC	0.554	0.556	within error
Overall	Vol%	17.6%	14.4%	-17.7%
	Vol_{eff}	5.11	6.51	+27.4%

The application of satellite products results in a reduction of greater than 17% in average icing volume percentage across the validation period while maintaining an excellent POD_{yes} against positive icing PIREPs. The increase in volume efficiency is a considerable step change over the former ADWICE DIA system and demonstrates the potential of satellite based icing products in contributing to the increase of icing warning accuracy while reducing inappropriate over-diagnosis.

References

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[3] Tafferner A., T. Hauf, C. Leifeld, T. Hafner, H. Leykauf and U. Voigt, 2003. ADWICE: Advanced Diagnosis and Warning System for Aircraft Icing Environments. *Weather and Forecasting*, **18**, 184-203.

[4] Tendel J., 2013. *Warning of In-Flight Icing Risk through Fusion of Satellite Products, Ground Observations and Model Forecasts.* Dissertation, Leibniz Universität Hannover, 117 S.

A paper is planned in the journal *Meteorological Applications* (RMS) for 2014.

This poster can be found on

http://www.muk.uni-hannover.de/download/free/forschung/hauf/CUS_2014_Poster_Roloff.pdf

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