Case study on a cloud layer with heavy icing

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***Abstract*—A pilot of a military aircraft reported heavy icing in terminal control area of Kuopio Airport at Jan 28 2009 08:35 UTC between between 10 000 ft and 14 000 kft (3000 m and 4300 m MSL). Based on sounding data heavy icing conditions were created by an altocumulus or an altostratus with cloud base 2900 m, cloud top 4100 m MSL and cloud top temperature between -25...-26°C. The supercooled liquid water content is estimated to be about 0.55 g/m^3 using adiabatic assumption and cloud water to cloud ice ratio to be at least 10:1 using satellite data. These values suggest that only light to moderate icing conditions were present at the cloud layer. It is possible though that cloud layer may have contained large supercooled drops. Otherwise, the icing conditions were overestimated by the aircraft pilot as pilot reports of icing are highly subjective by their nature.**

I. INTRODUCTION

It is well known (Fig. 1) that the probability of a cloud layer in temperatures below -20°C to contain only supercooled liquid water (SLW) is less than 10 % and supercooled cloud layers, which contain ice crystals, are likely to glaciate quite rapidly [1]. Consistently with this the general rule of thumb amongst the aviation forecasters in the Finnish Meteorological Institute (FMI) is that icing is not usually forecasted at all to occur in a cold cloud layers below -20°C temperature.

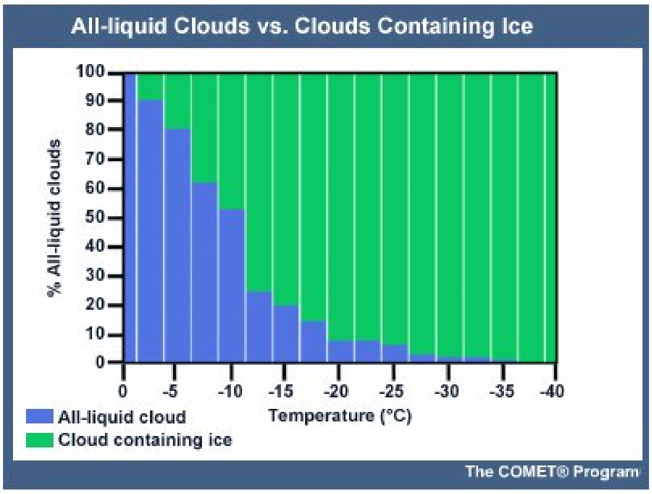

Fig. 1. Percentage of cloud phase (liquid/mixed) as a function of temperature [1].

However a military aircraft reported (Table I) heavy icing in terminal control area of Kuopio Airport (EFKU TM) on Jan 28 2009 08:35 UTC between between 10 kft and 14 kft (3000 m and 4300 m MSL).

TABLE I
ORIGINAL PILOT REPORT MESSAGE (WXREP) DESCRIBING THE ICING CONDITIONS EXPERIENCED BY A MILITARY AIRCRAFT ON 28 JAN 2009 AT EFKU TM.

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UKY118 280846 •
GG EFCCYMYX
280846 EFKUYMYX
UAFI31 EFKU 280835
WXREP
F18 REP HVY ICE BTN FL100-140 AT EFKU TM
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Reported heavy icing conditions took place quite high, in a middle level cloud layer with temperature significantly below -20°C. Thus, there is clear discrepancy between the forecasting rule of thumb and the reported icing contion.

II. RELEVANT DATA

A. *Atmospheric Sounding*

In Fig. 2, Jyväskylä atmospheric sounding at 28 Jan 2009 6 UTC is presented. Jyväskylä is 128 km to SW from EFKU TM. Time difference between the sounding and aircraft icing report is 2 and 35 minutes. Differences in time and location are bearable because the cloud layer was very widespread and long-lasting (see section B. Satellite imagery).

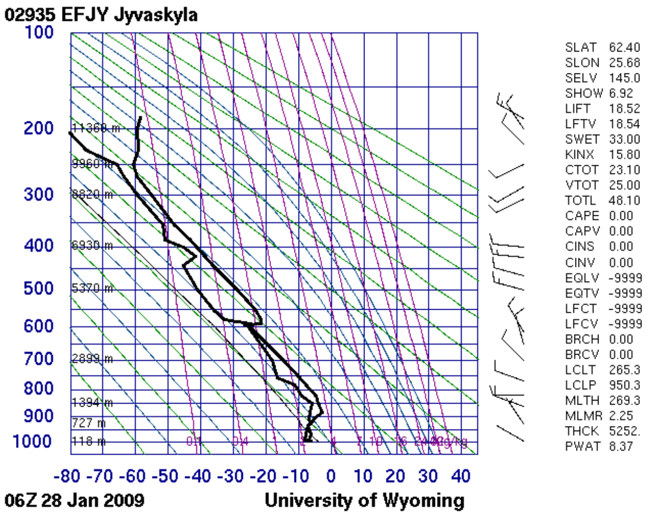

Fig. 2. Atmospheric sounding at Jyväskylä 28 Jan 2009 at 6 UTC.

The sounding data shows that there really was a middle level cloud layer (altocumulus or altostratus) present with cloud top temperature (CTT) of -25.5°C at height of about 600 hPa. The cloud layer is approximately between 2900 m and 4100 m MSL and it is situated below a 4°C temperature inversion. In this middle level cloud layer the aircraft experienced and reported the icing conditions. In the middle level cloud layer the environmental lapse rate is equal or greater than the moist adiabatic rate thus the conditions are neutral or slightly unstable. The airmass near the surface is close to isothermal and above isothermal layer there is an inversion of about 3°C with inversion top at 1100 m MSL.

Liquid water content (LWC) can be approximated using adiabatic assumption [2] and the data provided by the Jyväskylä sounding. Approximation gives a LWC value of 0.55 g/m^3. Comparing this to the values in the Table II suggests that only moderate to light icing conditions were present in the cloud layer as threshold value of 0.6 g/m^3 separates these two categories.

It must be noted that the calculation of LWC is sensitive to the determination of the cloud layer base which is not very exactly definable from the atmospheric sounding data. Choosing a lower cloud base height would result in a greater LWC value .

TABLE II

The relation between SLWC values and icing categories [3].

LWC vs Icing Severity

Icing Category	LWC (g/m^3)
Trace	< 0.1
Light	0.11 - 0.6
Moderate	0.61 - 1.2
Severe	> 1.2

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B. Satellite data

The presence of the middle level cloud layer one day before the time of the WXREP can be seen in the NOAA18/AVHRR-satellite image, Fig. 3. The black square shows the location of EFKU TM.

There was some high level clouds (white) visible north of EFKU TM. These high level clouds show also that there was a decaying upper low present. In addition, some low level liquid clouds (yellow) south of EFKU TM can be seen. The approaching middle level cloud layer (white blueish) can be seen SW of EFKU TM covering the western part of Finland and the Bay of Bothnia.

Fig. 4 presents the NOAA18/AVHRR-satellite image taken roughly at the same time as the WXREP was submitted. Now the middle level cloud has advected from Western Finland and is covering the whole Southern and Central Finland. The middle level cloud layer is very well visible in the satellite image because the absence of the high level clouds .

By comparing figures 3 and 4 it can be said that not much transformation has happened at the top of the middle level cloud. The smoothness and the colouring is very similar between images.

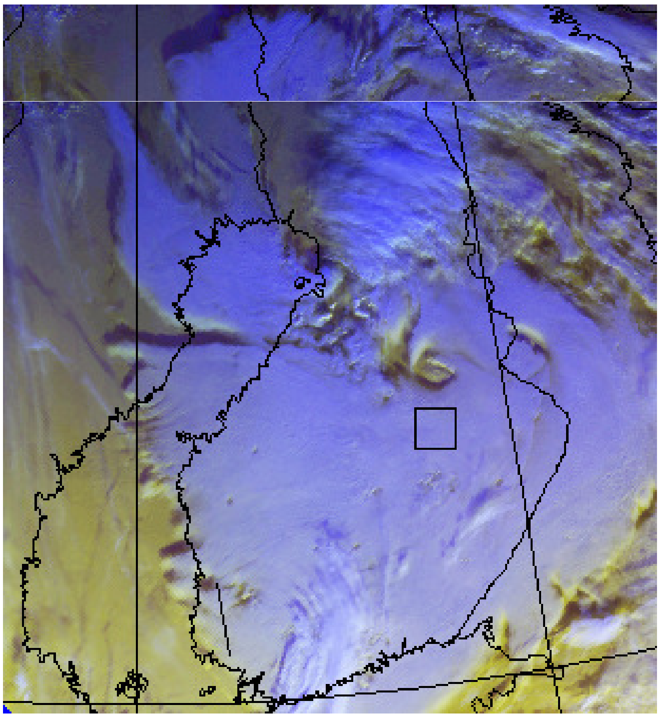

Fig. 4. As in Fig. 3 but at 28 Jan 2009 09:14 UTC. Approximate CloudSat track on 28 Jan 2009 between 11:18:29 UTC and 11:18:44 UTC is marked with black line in the SW part of Finland.

More exact satellite information on the middle level cloud layer can be obtained using the NASA Earth Science Data [4]. The following values over EFKU TM were measured at 28 Jan 2009 09:22 UTC by the MODIS AQUA instrument [5]:

- liquid water path 35.2 g/m^2
- optical thickness 8.3
- effective particle radius 6.9 μm,
- CTT -26°C
- cloud phase: mixed.

The CTT of MODIS corresponds very well to the CTT of the atmospheric sounding (Fig. 2). Effective particle radius suggests that there were no supercooled large droplets (SLD, radius > 25 μm) present at the cloud top level.

a)

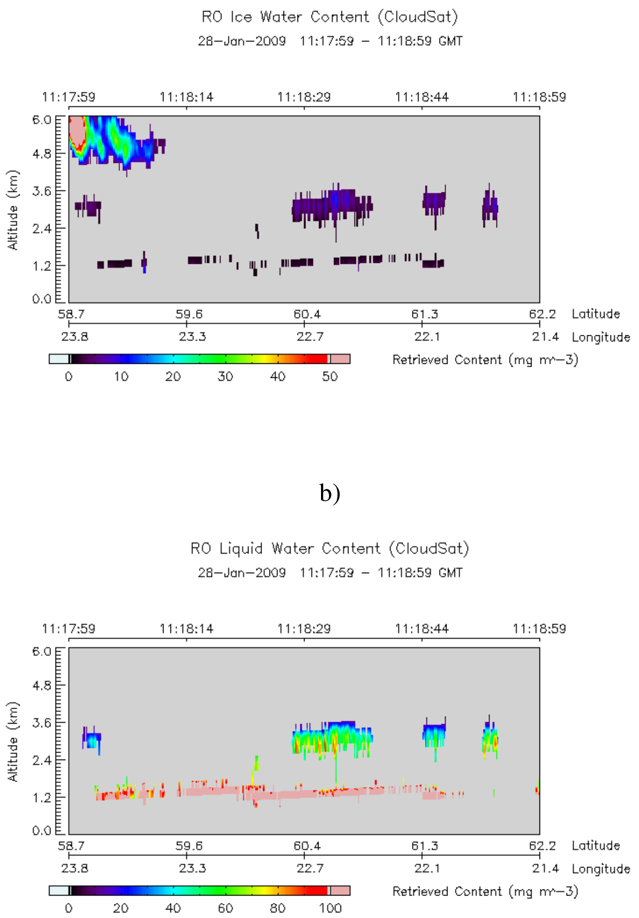

Fig. 5. a) Ice water and b) liquid water content measured by CloudSat [6].

Some estimates on the relative content of cloud liquid water and cloud ice water can be obtained using CloudSat data [6]. The CloudSat flew over the very SW part of Finland 28 Jan 2009 between 11:18:29 UTC an 11:18:44 UTC. The CloudSat surface track is marked in Fig. 4. The measurements of cloud liquid water and ice content can be seen in Fig. 5 a) and b).

The middle level cloud can be seen just below the height of 3.6 km. The data suggests for cloud liquid water content a value of over 90 mg/m^3 and for cloud ice water content a value of around 10 mg/m^3. Thus the water to ice ratio is about 10:1. It can be argued that the CloudSat data is not applicable in this case as measurement track is over 380 km away from the EFKU TM and the time difference to the WXREP is over 3 hours. Also the CloudSat measurement track is on the very edge of the layer of the middle level cloud. Some entrainment of cloudy air and unsaturated air outside the cloud layer has happened prior to the CloudSat measurement.

C. Surface observations

Many weather observation stations In Finland reported snow and some stations even freezing drizzle (FZDZ) on the 28th of Jan 2009 at 06 UTC. Thus some SLD must have been present in the atmosphere, but those drops may have formed in the middle or in the low level cloud layers.

III. Conclusions

From the data presented in this paper, it is clear that there were no or very little seeding from the high clouds to the middle level cloud that produced icing conditions. A clean continental airmass [7] may have been formed at the height of the middle level cloud due to the snow precipitation. The middle level cloud layer persisted a very long time so the collision coalescence process had time to work. There might have been even some production of SLW because of weak rising motion due to the weakening upper low nearby and the slight moist unstable conditions. These findings suggest that there might have been some SLD present in the middle level cloud.

On the other hand the cold temperatures and satellite measurements do not suggest the presence of the SLD, also quite low SLWC values are probable. Thus it is possible that the icing conditions were overestimated by aircraft pilot as a pilot reports of icing are highly subjective by their nature.

It is also clear that the -20°C threshold for not to forecasta and/or nowcast icing is not very good. The icing conditions must be analyzed also at lower temperatures. Satellite data can provide crucial information in analysing and nowcasting these rare icing events.

IV. Acknowledgment

Fig. 5 a) and b) presented in this paper were produced with the Giovanni online data system, developed and maintained by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

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