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Remote sensing of potential aircraft icing areas

Vladimir V. Zuev[* a, b, c], Daria P. Nakhtigalova[a, d], Alexander P. Shelekhov[a], Evgeniya A. Shelekhova[a], Nikolay A. Baranov[e], Lubov I. Kizhner[b]
[a]Institute of monitoring of climatic and ecological systems SB RAS, 634055, Tomsk, Akademichesky ave., 10/3; [b]National Research Tomsk State University, 634050, Tomsk, Lenin ave., 36; [c]National Research Tomsk Polytechnic University, 634050, Tomsk, Lenin ave., 30; [d]West Siberian Branch FSBI "Aviamettelecom Roshydromet" 630099, Novosibirsk, Deputatskaya st.1; [e]Institution of Russian Academy of Sciences Dorodnicyn Computing Centre of RAS, 119333, Moscow, Russia, Vavilov st., 40

ABSTRACT

Remote sensing technique of detection of potential aircraft icing areas based on temperature profile measurements, using meteorological temperature profiler, and the data of the Airfield Measuring and Information System (AMIS-RF), was proposed, theoretically described and experimentally validated during the field project in 2012 - 2013 in the Tomsk Bogashevo Airport. Spatial areas of potential aircraft icing were determined using the RAP algorithm and Godske formula. The equations for the reconstruction of profiles of relative humidity and dew point using data from AMIS-RF are given. Actual data on the aircraft icing for the Tomsk Bogashevo Airport on 11 October 2012 and 17 March 2013 are presented in this paper. The RAP algorithm and Godske formula show similar results for the location of spatial areas of potential icing. Though, the results obtained using the RAP algorithm are closer to the actual data on the icing known from aircraft crew reports.

Keywords: aircraft icing, profile, temperature, relative humidity, dew point temperature

1. INTRODUCTION

Aircraft icing is one of the most complex weather events, which largely affects the security and regularity of flights. Icing is an in-flight accretion of ice on different parts of the aircraft in the clouds, fog, rain or wet snow. It is well known that aircraft icing most frequently occurs at low temperatures in supercooled pure drop clouds; and in the area of freezing rain, sleet, drizzle and etc. under the clouds. Aircraft icing occurs comparatively rarely via direct sublimation of water vapor at low temperatures [1 – 3].

Currently, the monitoring of weather conditions that induce icing is carried out at the aerodromes of Russia twice a day using radiosounding as well as the pilot reports of occasional icing. This data acquiring interval may be insufficient for objective control over the meteorological situation due to the high daily variability of temperature fields in the atmosphere. To decrease the data acquiring interval we use the remote sensing technique, which allows to determine the temperature profile for the lower atmosphere and to measure its temporal dynamics with high spatial and temporal resolution.

The remote sensing technique of spatial areas of potential aircraft icing based on the temperature profiles, obtained from meteorological temperature profiler MTP-5PE [5, 6], and the data of the Airfield Measuring and Information System (AMIS-RF), described in the paper, was proposed, theoretically described and experimentally validated during the field projects in 2013-2014 in the Tomsk Bogashevo Airport [6]. The second part of the article presents the theoretical description of the method of detection of potential aircraft icing areas using the RAP algorithm [3] and Godske formulae [1, 2]. The third part contains the analysis of the actual meteorological conditions at the Tomsk Bogashevo Airport on 11 October 2012 and 17 March 2013. Time and dates are in Coordinated Universal Time (UTC). The fourth part of the article presents the validation of the proposed method. The main conclusions are given in the summary.

* vvzuev@imces.ru; phone +7-382-2-492-232; http://www.imces.ru/en

21st International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, edited by G. G. Matvienko, O. A. Romanovskii, Proc. of SPIE Vol. 9680, 96806Q
© 2015 SPIE · CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2205762

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2. THEORETICAL DESCRIPTION OF THE METHOD

Potential icing detection is determined using the RAP algorithm and Godske formula [1−3].

2.1 The RAP algorithm

For the RAP algorithm [3], the spatial areas of potential icing are determined by the inequalities

$$-16^{\text{o}}\text{C} \le T(z) \le 0^{\text{o}}\text{C} \tag{1}$$

and

$$R_H(z) \ge 63\% \tag{2}$$

where $T(z)$ and $R_H(z)$ are temperature and relative humidity at the altitude z.

2.2 The Godske formula

For the Godske formula [1, 2] the temperature vertical profiles and dew point temperature, which characterize the humidity, allow to calculate the spatial area of potential icing by the equation

$$T(z) \le -8 \cdot \{T(z) - T_d(z)\} \tag{3}$$

where $T_d(z)$ is the dew point temperature at the altitude z.

2.3 Humidity profile reconstruction

Relative humidity profile $R_H(z)$ is reconstructed using data on the cloud bottom height H and surface relative humidity $R_{H,0}$ from AMIS-RF.

$$R_H(z) = \begin{cases} R_{H,0} + \dfrac{100 - R_{H,0}}{H} z, & z \le H \\ 100, & \text{в облаках} \end{cases}. \tag{4}$$

Calculation of the dew point temperature profile $T_d(z)$ is based on the measured values of the temperature profile $T(z)$ and the results of the relative humidity profile reconstruction $R_H(z)$ using the formula

$$T_d(z) = \frac{B_1\left[\ln\left(\dfrac{R_H(z)}{100}\right) + \dfrac{A_1 T(z)}{B_1 + T(z)}\right]}{A_1 - \ln\left(\dfrac{R_H(z)}{100}\right) - \dfrac{A_1 T(z)}{B_1 + T(z)}}, \tag{5}$$

where $A_1 = 17.625$ and $B_1 = 243.04°\text{C}$ [7].

Equations (1) - (5) are the theoretical basis for the proposed method of remote sensing of potential aircraft icing areas using the meteorological temperature profiler and AMIS-RF. The temperature profile may be obtained from the meteorological temperature profiler MTP-5PE with high spatial and temporal resolution. The cloud bottom height H and relative surface humidity $R_{H,0}$ are measured by the AMIS-RF devices. This method allows us detect the spatial areas of potential aircraft icing in a supercooled pure drop cloud; in the area of freezing rain, sleet, drizzle etc. under the clouds, and also for direct sublimation of water vapor.

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3. ANALYSIS OF THE METEOROLOGICAL CONDITIONS AT THE TOMSK AIRPORT

Figures 1 and 2 depict surface temperature (solid curve), relative humidity (dotted curve), dew point temperature (dashed curve) for 11 October 2012 and 17 March 2013, according to AMIS RF. Air temperature on 11 October 2012 at the Tomsk Bogashevo Airport fell to -6° C (2100 - 2200 UTC) and rose to + 2° C (0800 - 1100 UTC). Dew point temperature for this period was below -5° C and the relative humidity was 60% and more (see Fig. 1).

Surface air temperatures on 17 March 2013 in the Tomsk Bogashevo Airport ranged from -2° C to -6° C, minimum values were recorded in the period 0000-0100 UTC (morning hours, local time) and maximum between 0800 - 2200 UTC (afternoon and evening). Dew point deficiency during the day does not exceed 2° C, relative humidity ranged from 80 to 100% (see Fig. 2).

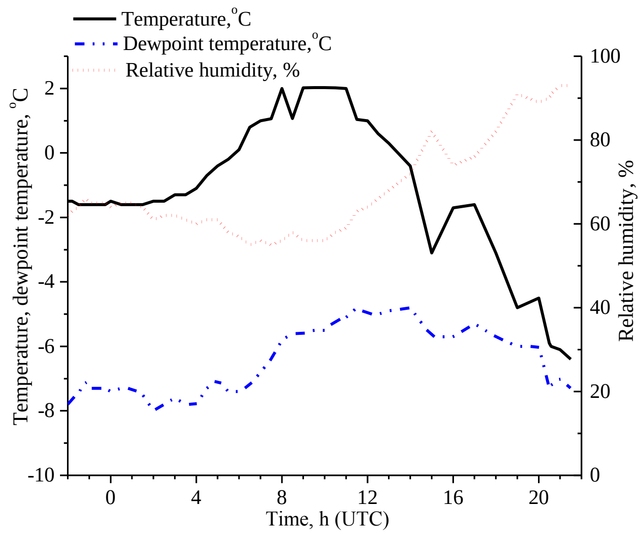

Figure 1. Surface temperature (solid curve), relative humidity (dotted curve) and dew point temperature (dashed curve) on 11 October 2012, according to the AMIS RF.

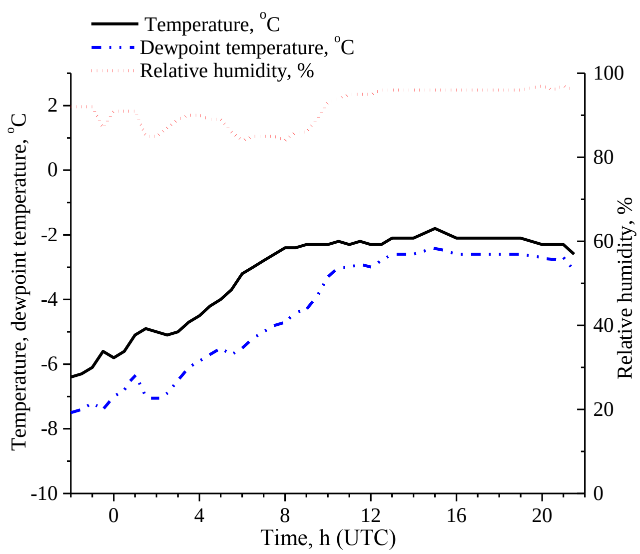

Figure 2. Surface temperature (solid curve), relative humidity (dotted curve) and dew point temperature (dashed curve) on 17 March 2013 according to AMIS-RF.

Diurnal variations of cloud bottom height according to AMIS-RF are shown in Figures 3 and 4. The cloud bottom height on 11 October 2012 fell to 800 m, and rose to 6900 meters. From 0000 UTC to 0730 UTC the bottom layer of clouds did

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not exceed the height of 1000 m (see. Fig. 3). During 1700-2100 UTC (nighttime, local time) the cloud bottom was at the altitude of 1200 m. The cloud bottom height during 17 March 2013 did not exceed 700 m, and in some cases was observed at 70-80 m (see Fig. 4).

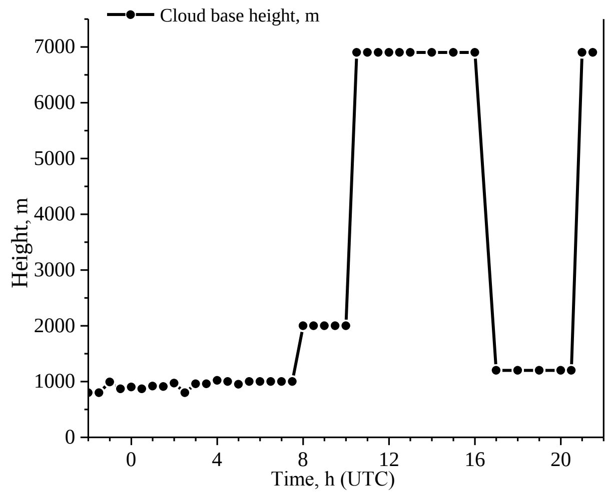

Figure 3. Daily variations of the cloud bottom height on 11 October 2012 according to the AMIS-RF.

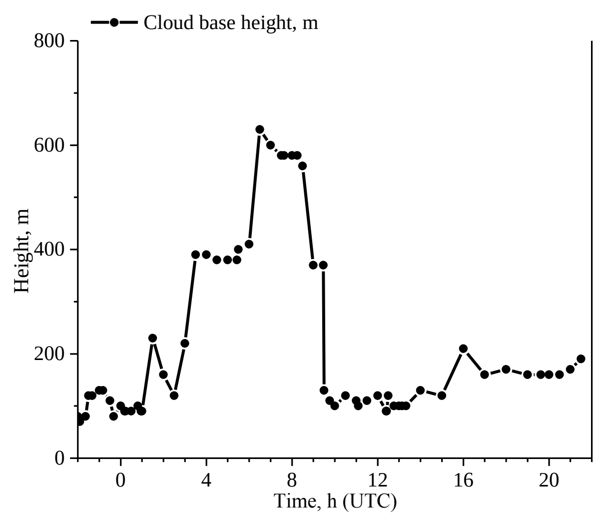

Figure 4. Daily variations of cloud bottom height on 17 March 2013 according to AMIS-RF.

Daily variations of the temperature profile are shown in Figures 5 and 6, respectively, for 11 October 2012 and 17 March 2013. Diurnal measurements of the thermal profiles for the lower (1 kilometer) layer of the atmosphere at the Tomsk Bogashevo Airport using profiler MTP-5PE showed considerable temperature variations with altitude and time in this layer.

Air temperature on 11 October 2012 was decreasing to a height of 600 m and then the decrease slowed down to a slight fall at 600-1000 m. The minimum temperatures were about -9° C at altitudes of 700-1000 m from 0000 to 0100 UTC. During the day, in the period from 0830 to 0930 UTC, the temperature increased to + 2° C it the ground layer up to 100 m.

In the morning (0000 to 0400 UTC) on 17 March 2013, there was an increase in air temperature starting from 500 m. In the daytime, evening and nighttime (0600 to 2200 UTC) the temperature profile from the ground to 1000 m corresponded to the normal vertical gradient. Minimum temperature -11° C was observed at 400-500 m from 0000 to 0200 UTC. Maximum temperatures were recorded at night (1200 to 2000 UTC) on the heights to 150 meters at around -2°C.

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On the base of the analysis of weather data we can conclude that the atmospheric state observed on 11 October 2012 and 17 March 2013, could induce aircraft icing. According to pilot reports on 11 October 2012 moderate icing was observed in the clouds at an altitude of 1000 m in the morning (0000-0030 UTC). Moderate icing was recorded on 17 March 2013 in the period from 0000 to 0230 UTC in the clouds, from 0815 to 1000 UTC in the clouds at altitudes ranging from 700 m to 2000 m and from 1106 UTC to 1300 in the clouds and precipitation at altitudes from ground to 2400 m.

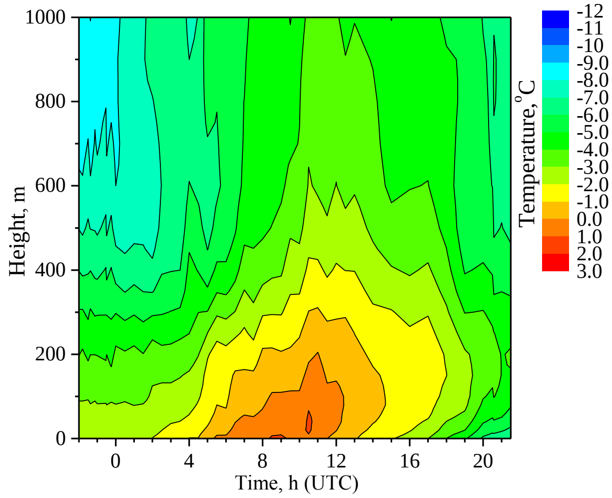

Figure 5. Daily temperature profile variations on 11 October 2012 (data obtained from MTP-5PE).

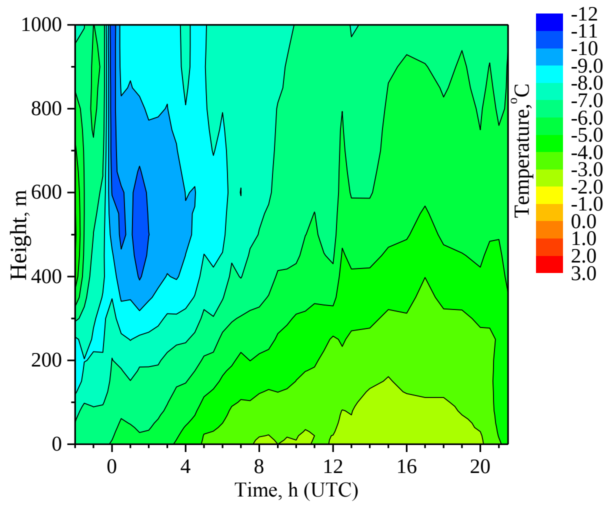

Figure 6. Daily temperature profile variations 17 March, 2012 (data obtained from MTP-5PE).

4. METHOD VALIDATION

Figures 7 - 10 show the results of calculation of spatial areas of potential aircraft icing, based on the data obtained at the Tomsk Bogashevo Airport, for the RAP algorithm and Godske formula. Gray, green, and blue colors show the spatial areas of potential aircraft icing, white color marks areas where weather conditions are not conducive to icing. The blue color corresponds to the spatial areas of potential icing in the clouds, green - in snow showers. The red shading denotes the spatial area of actual icing, reported from the aircrafts during the considered period. Calculated possible icing areas

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are fully consistent with the analysis of the actual atmospheric situation: icing is possible both in the clouds and precipitation and in their absence as it was on 11 October, 2012 and 17 March, 2013. The RAP algorithm and Godske formula give similar results for the location of the actual spatial icing areas. Figures 9 and 10 show that the results of calculations by the Godske formula for the period from 11.06 UTC to13.00 UTC do not coincide with the reported weather data at altitudes from 0 to about 50 m. For this period of time the RAP algorithm adequately describes aircraft icing at altitudes from 0 to 1000 m. Thus, the results obtained from the RAP algorithm, better agree with the actual data on the icing from pilot reports.

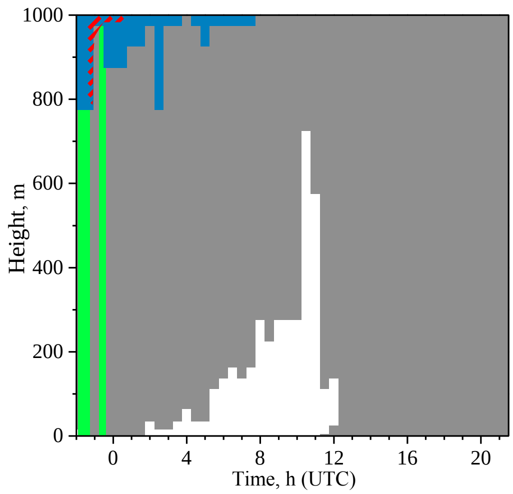

Figure 7. Spatial areas of potential aircraft icing on 11 October, 2012, the RAP algorithm.

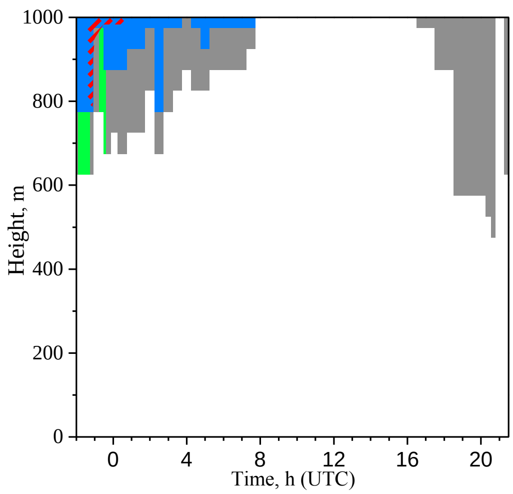

Figure 8. Spatial areas of potential aircraft icing on 11 October, 2012, the Godske formula.

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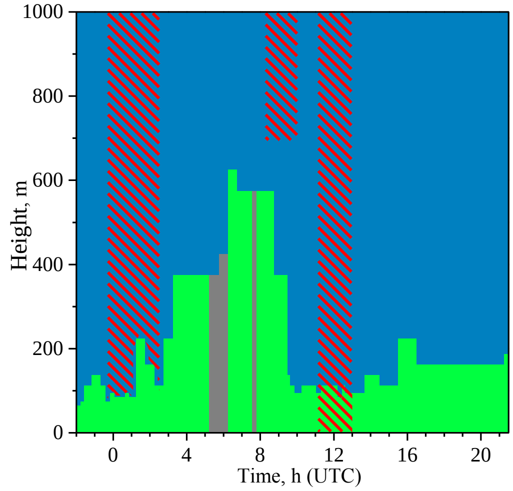

Figure 9. Spatial areas of potential aircraft icing on 17 March, 2013, the RAP algorithm.

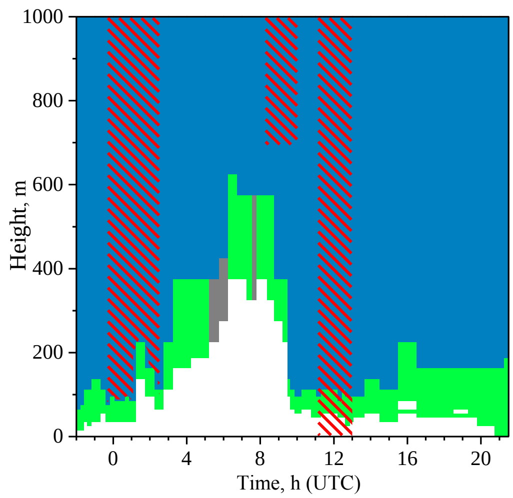

Figure 10. Spatial areas of potential aircraft icing 17 March, 2013, the Godske formula.

CONCLUSIONS

Remote sensing technique of detection of potential aircraft icing areas based on temperature profile measurements, using meteorological temperature profiler and the data of AMIS-RF, was proposed, theoretically described and experimentally validated during the field project in 2012 - 2013 in Tomsk Bogashevo Airport. Spatial areas of potential aircraft icing were determined using the RAP algorithm and Godske formula.

The temperature profile was measured by meteorological temperature profiler MTP-5PE with high spatial and temporal resolution for altitudes from 0 to 1000 m. The cloud bottom height and surface relative humidity used for humidity profile reconstruction were measured by devices of AMIS-RF. The proposed method allows us to determine the spatial areas of potential aircraft icing in supercooled pure drop clouds; and within freezing rain, sleet, drizzle and etc. under the clouds, and for the case of direct sublimation of water vapor.

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Calculated potential aircraft icing areas are fully consistent with the analysis of the actual atmospheric situation: icing is possible both in the clouds and precipitation and in their absence as it was on 11.10.2012 and 17.03.2013. The RAP algorithm and Godske formula give similar results for the location of the actual spatial icing areas. The results of calculations by the Godske formula for the period from 1106 to 1300 UTC 17 March, 2013 UTC do not coincide with the reported weather data at altitudes from 0 to about 50 m. For this period of time the RAP algorithm adequately describes aircraft icing at altitudes from 0 to 1000 m. Thus, the results obtained from the RAP algorithm, better agree with the actual data on the icing from onboard.

According to [4, 5], the profiler MTP-5PE is capable to measure the temperature profile to the height of 1000 m with a spatial resolution of 10, 25 and 50 m and with intervals of 5 minutes. Scheduled time of measurements at the aerodrome is 30 minutes, but depending on the changing weather conditions and air traffic control request more frequent meteorological observations are possible. Thus, the use of meteorological temperature profiler MTP-5PE together with data from AMIS-RF with high spatial and temporal resolution allows monitoring of meteorological conditions that contribute to aircraft icing.

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