ISSN 1024-8560, Atmospheric and Oceanic Optics, 2014, Vol. 27, No. 1, pp. 100–105. © Pleiades Publishing, Ltd., 2014.
Original Russian Text © V.V. Zuev, A.P. Shelekhov, E.A. Shelekhova, A.V. Starchenko, A.A. Bart, N.N. Bogoslovsky, S.A. Prokhanov, L.I. Kizhner, 2014, published in Optica Atmosfery i Okeana.

OPTICAL INSTRUMENTATION

Measurement–Calculation Complex for Monitoring and Forecasting Meteorological Situations at Airports

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Received March 24, 2013

Abstract—We describe the measurement and calculation complex for monitoring and forecasting the meteorological situation at airports, which comprises MTP-5PE meteorological temperature profiler, WXT520 Vaisala Weather Transmitter, main and remote terminals for managing the complex, network data storage, two high-resolution meteorological models, server, and SKIF Cyberia cluster at Tomsk State University. The paper presents the results of monitoring and forecasting the atmospheric temperature profile and surface wind speed and direction, pressure, humidity, and temperature for the previous winter, when different extreme weather events were observed in Bogashevo airport. It is shown that the measured and calculated vertical temperature profiles in the lower part of the atmospheric boundary layer show high level of qualitative and quantitative agreement of results.

DOI: 10.1134/S102485601401014X

INTRODUCTION

Monitoring and forecasting the altitudinal behavior of air temperature and temperature variations, especially the behavior of inversion layers and isothermal regimes, are urgently needed from the viewpoint of meteorological support of aeronavigation. The lower atmospheric layer is characterized by considerable altitudinal and daily variations; therefore, monitoring and forecasting performed based on the radio radar and pilot-balloon measurement facilities do not meet the requirements regarding the spatiotemporal resolution. High-quality requirements in the altitude range 0–1000 m are satisfied by the MTP-5PE meteorological temperature profiler (a version with extended temperature range and high resolution), which can be used to display the thermal structure of the lower 1-km atmospheric layer and to study its time dynamics [1–5]. The MTP-5PE profiler underlies the measurement–calculation complex for monitoring and forecasting the meteorological situation at airports. In addition to the temperature profiler, the complex comprises a Vaisala Weather Transmitter WXT520, main and remote terminals for managing the complex, a network data storage, two high-resolution meteorological models [6–9], a server, and the SKIF Cyberia cluster of Tomsk State University (TSU).

This paper describes the measurement–calculation complex for forecasting unfavorable situations at Bogashevo airport; furthermore, it presents measurements of the atmospheric temperature profiles and surface wind speed and direction, pressure, humidity, and temperature (for December 2012, when weather in the airport was anomalously cold and, for January 2013, when there was a thaw, i.e., when temperature rose to 0° and higher), as well as the results of numerical forecast obtained using these models.

1. MEASUREMENT–CALCULATION COMPLEX FOR FORECASTING UNFAVORABLE SITUATIONS AT THE AIRPORT

The measurement–calculation complex consists of two parts. The measurement part (henceforth, the measurement complex) consists of a MTP-5PE meteorological temperature profiler and a Vaisala Weather Transmitter WXT520, which are connected to a terminal with Internet access. The measurement complex is installed at the airport in immediate proximity to the runway. In addition to meteorological models used for numerical weather forecast, the calculation part of the complex (henceforth, calculation complex) also includes a server, a network data storage, and the SKIF Cyberia cluster (62 TFlops).

1.1. Measurement Complex

The MTP-5PE meteorological temperature profiler is designed for remote measuring the atmospheric temperature profile in the altitude range from the level of instrument installation to 1000 m [1–3]. The profiler consists of a measuring block, temperature sensor, supply unit, and base for mounting the instrument.

The measuring block comprises a receiver of atmospheric thermal radiation, scanning device with stepper motor, reflector mirror, sensor for pointing the reflector, and meteorological protector with radiolucent window. The atmospheric thermal radiation is received from different directions by mechanically turning the reflector mirror, installed geometrically coaxially with motionless receiver antenna. The atmospheric radiation, proportional to the temperature for every direction, is sent to receiver input and converted to direct-current voltage at the receiver output. Amplified signal is received at the input of microprocessor board, connected to notebook computer. A special software is used to convert the measured signal to atmospheric temperature profile, archived on notebook computer, which is located at Bogashevo airport.

The Vaisala Weather Transmitter WXT520 is designed for measuring the six most important weather parameters, i.e., surface wind speed and direction, liquid water precipitation, atmospheric pressure, temperature, and relative humidity. It is a totally integrated device without movable constituent parts, and its measurements are archived on notebook computer. The terminal for working with measuring instruments equipped with Internet access consists of notebook computer and 3G modem.

1.2. Calculation Complex

The measurement–calculation complex includes two meteorological models with user-friendly interfaces. These models are used for regular calculations on a supercomputer, with a subsequent archival of calculation results in network data storages. The server of the calculation complex collects data from instruments, installed at Bogashevo airport and maintains the data on a network storage. Also, the server interacts with the TSU SKIF Cyberia cluster to prepare for and perform labor-consuming calculations.

The information recourses used in the measurement–calculation complex also include an ftp server of the Hydrometeorological Center of Russia, on which real-time medium-range forecasts based on the PLAV global model for Tomsk, Novosibirsk, and Kemerovo regions are put daily. These data are transferred to the server and saved to network storage.

The data are transferred from the airport to the server of the computer complex using a notebook computer with a 3G modem located at the airport, as well as via Internet in real time. The measurement complex is managed (instruments are switched on and off, data are rapidly inspected and transferred, and programs are restarted) remotely via Internet.

2. MEASUREMENTS

We consider the measurements of meteorological parameters at Bogashevo airport, Tomsk on December 13, 2012 and January 26, 2013, which were days with substantially different synoptic and weather conditions.

The synoptic situation in the period of December 11–17, 2012 in Tomsk was characterized by anomalously low air temperature, which sometimes dropped below –40°C [10]. These conditions were due to a powerful anticyclone that dominated vast territory, at the center of which (in Urals) the sea-level pressure was higher than 1050 hPa. The pressure at the airport (Fig. 1a) gradually increased throughout December 13, 2012 from 1011 to 1016 hPa, which was 3–8 hPa larger than the climatic norm for December (the pressure increase indicates that anticyclone developed on), the humidity increased from 58 to 68%, the temperature increased from –33 to –42.7° (according to Vaisala WXT520 data) and to –43.8°C (according to MTP-5PE data); the predominately northerly–northeasterly wind grew from 0 to 2.5 m/s, which corresponds to dry, very cold, and almost windless weather. This day was characterized by classical daily variations in air temperature (with the maximum at 16:00 LT and minimum at 08:00–10:00 LT) and relative air humidity (opposite to the temperature behavior).

The period of January 23–27, 2013 was characterized by much higher air temperatures (–6...+2°C) compared to climatically average temperatures [10]. This situation was due to the supply of warm and humid maritime tropical air. The powerful southwestern transport on AT-850 map indicates that air masses arrived from Caspian and Aral Seas. During January 26, 2013, the pressure, humidity, temperature, and wind (Fig. 1b) varied, respectively, in the ranges: 976–989 hPa, 52–91%, –6...+2°C, and 2–20 m/s, which corresponds well to the synoptic situation on the given day, i.e., advection of warm air until 14:00–15:00 LT (decreasing pressure, rising temperature, high (more than 80%) humidity), passage of cyclone, and advection of cold air toward the end of the day (rapidly increasing air pressure, decreasing temperature and humidity, and strong and gusty wind) [10].

Figures 2 and 3 show the daily variations in the altitude temperature profiles: Figures 2a and 3a correspond to December 13, 2012; and Figures 2b and 3b correspond to January 26, 2013. Figures 2a and 3a show that the temperature inversion was throughout December 13, 2012. The inversion layer encompassed all 1-km layer until 11:00 LT. The temperature increased most strongly in the lower 100–150-m layer. The temperature increase was slower at higher altitudes, air was either isothermal or showed minor temperature decrease up to the altitude of 350–400 m, and then temperature again increased with altitude. The intensity of the inversion was 7–10°C. The inversion layer became somewhat thinner (as thin as 700–800 m) after 11:00 LT. The intensity of the inversion was 6–11°C in this period of time, with a daily maximum of 12°C.

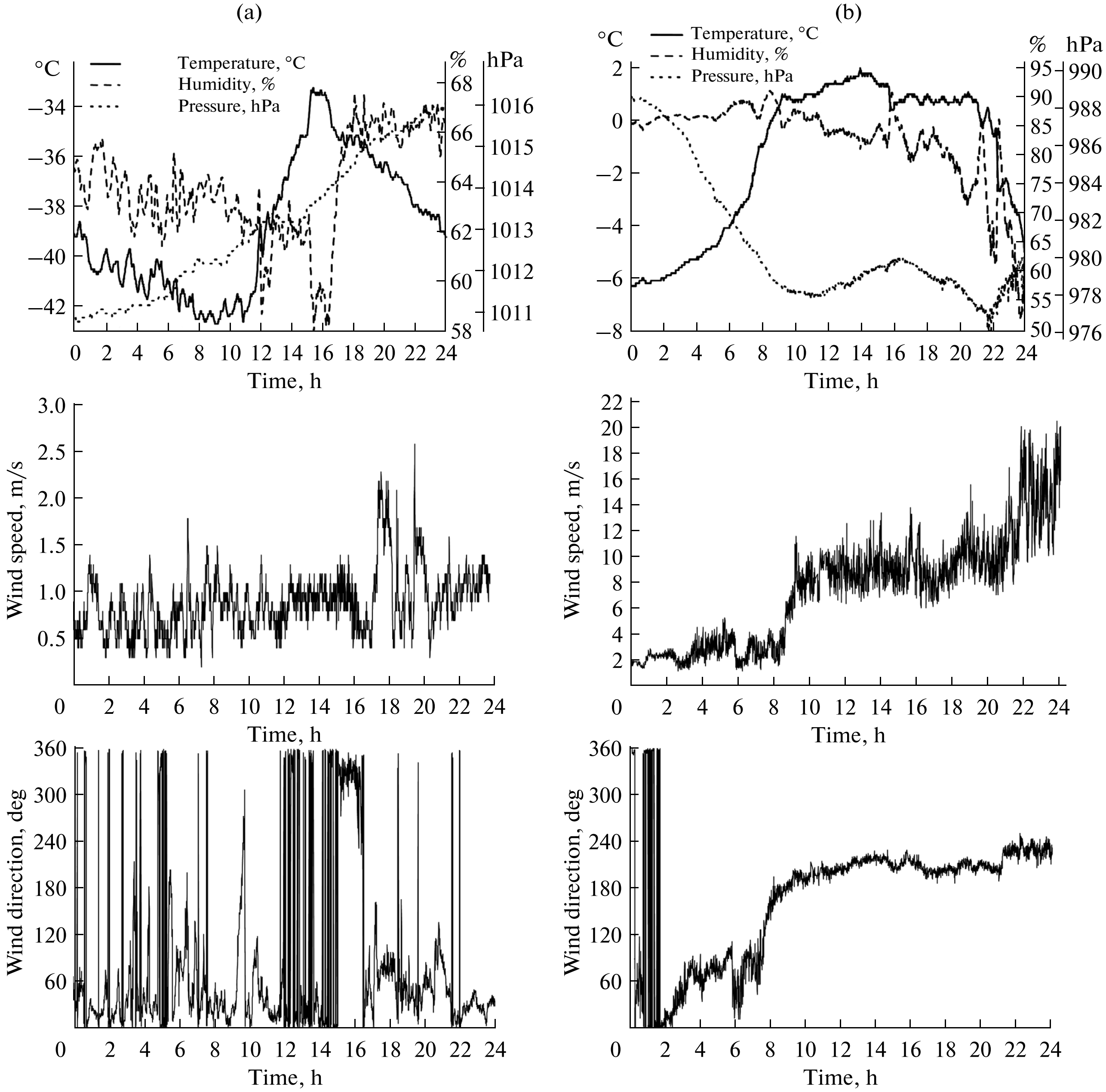

Fig. 1. Daily variations in the surface values of meteorological parameters: (a) on December 13, 2012 and (b) on January 26, 2013.

From about 14:00 to 16:00 LT, due to a minor daytime heating, there had been an elevated inversion with the lower boundary as low as 50 m. This situation is characteristic for an exceptionally stable weather, favoring a strong pollution of the atmosphere.

According to data from AMIS-RF Airport meteorological information-measurement system, there were haze and fog at the airport throughout the day, with the visibility range as low as 650 m (from 05:00 to 13:00 LT on December 13 and at night on December 14), which was even lower than the weather-related minimum visibility range (800 m) for the Tomsk airport. Simultaneously, there was a fog in Tomsk, with the visibility range as low as 200 m [10].

An intense inversion in the lower layer may lead to a change in flight conditions (need to significantly speed up the engine revolution and to increase the fuel consumption). It is considered that, when the temperature is 10°C higher than standard, the rate of climbing of aircraft decreases by 10–20%, and the time of climbing increases by 6–10%. Therefore, it can be concluded that the intense and thick inversion, which

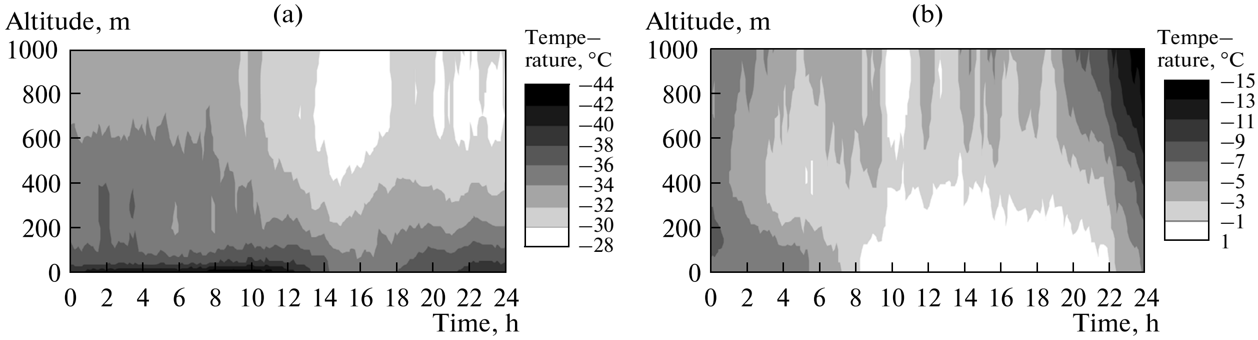

Fig. 2. Daily variations in altitude temperature profile: (a) on December 13, 2012 and (b) on January 26, 2013.

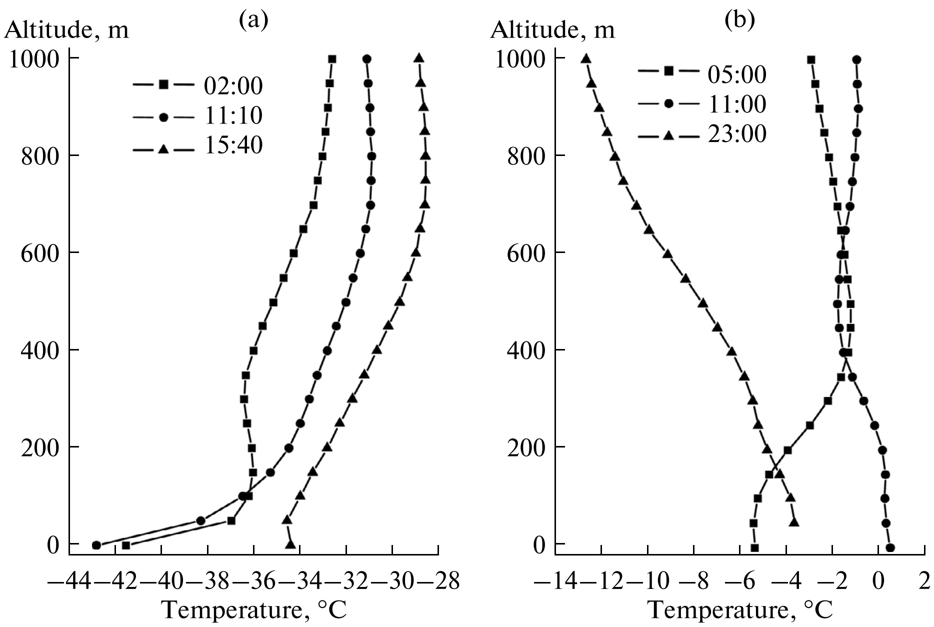

Fig. 3. Dynamics of temperature profile: (a) on December 13, 2012 and (b) on January 26, 2013.

was observed during the day in 1-km layer, was significant for aircraft flights. We note that an inversion acts to increase the probability of strong vertical wind shear, which complicates takeoff and landing of aircrafts.

It can be seen from Figs. 2b and 3b that, at the beginning of the day, until 08:00 LT, there is an elevated inversion with the lower boundary gradually subsiding from 200 m to the surface as thick as 200–400 m and as intense as 4°C. From 09:00 to 14:00, the inversion layer is lifted to higher heights, its lower boundary is as high as 500 m, its thickness increases to 300–400 m, and its intensity remains low and changes from 0°C (isothermal regime) to 1.5°C. The inversion broke up in the second half-day. It can be seen from the temperature profile that the daily behavior of the temperature is distorted (it starts to rise at 00:00 LT and has no well-defined morning minimum); the temperature increases until 14:00 LT, which is confirmed by synoptic data and weather conditions.

Based on the temperature profiles, which were analyzed using weather conditions and synoptic situation, we can state that the vertical temperature profile was the result of arrival of warm air until approximately 18:00–20:00 LT with minor daily variations. After 20:00 LT, the temperature gradually decreases, starting from higher atmospheric levels (around 1000 m). Colder air gradually subsides. Toward the end of the day, the temperature decreased to –6°C, and to –14°C at high altitudes of measurements.

In all periods of observations considered here, there was a danger of the icing of both runway and aircrafts. Work [5] reports that the danger of runway icing is maximal when negative temperatures in the atmospheric layer change to positive ones with altitude. Rain Showers (snow, and rain at 15:00 LT) and high air

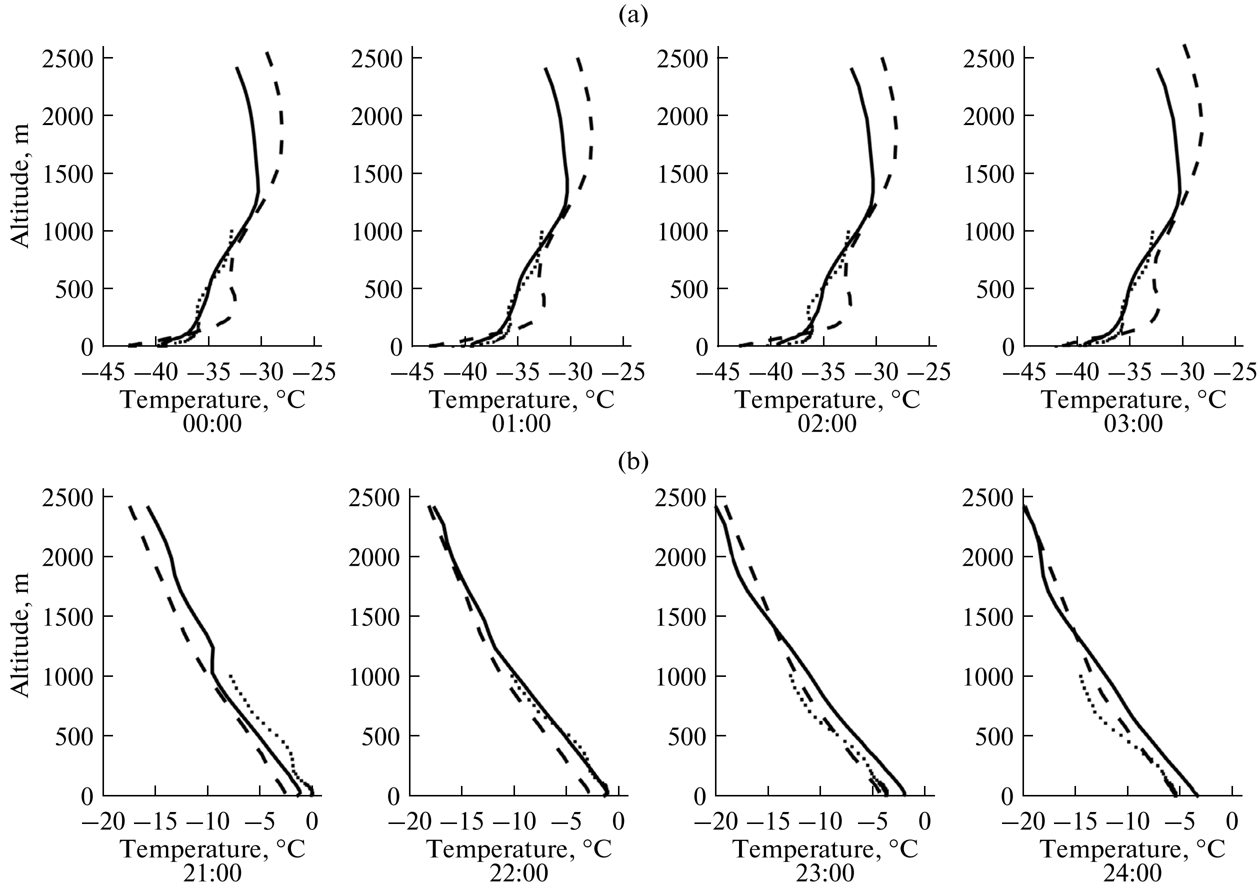

Fig. 4. Vertical temperature profile over Bogashevo airport during (a) severe cooling and (b) thaw. Dots indicate measurements, solid line indicates calculations according to the model [8], and dashed line indicates calculations according to the model [9].

humidity near the ground along with temperature change from negative to positive values, which were observed on that day favored more severe icing. As follows from Figs. 1b and 2b, this period was from approximately 07:00 to 19:00 LT. The AMIS-RF data indicate that icing of runway took place from 07:00 to 18:00 LT.

In addition to precipitations and high humidity, the presence of clouds influences the icing of aircrafts. Measurements of temperature profile at the airport in the first half-day on January 26 showed that negative temperatures in the atmosphere had changed to positive ones; and the AMIS-RF data reported the presence of clouds, which had led to the icing of aircrafts at an altitude of 400–500 m. Rain Showers and strengthening of wind and wind gusts as strong as 20 m/s indicate that air masses changed (front passed) between 18:00 and 24:00 LT. The MTP-5PE-based vertical temperature profile clearly indicated that cold front had passed at the end of the day starting from 22:00 LT.

3. NUMERICAL FORECASTING RESULTS

The prognostic calculations were performed for these dates using two high-resolution mesoscale meteorological models, i.e., a model developed at TSU and the Weather Research & Forecasting (WRF) model [6–9]. The characteristics of the atmospheric boundary layer were calculated using the results of real-time numerical foresting obtained based on the PLAV global model of the Hydrometeorological Center of Russia.

Figure 4 shows the vertical temperature profiles in the lower part of the atmospheric boundary layer; the profiles were measured using MTP-5PE temperature profiler and computed using the TSU Cyberia cluster and the high-resolution models in the region of Bogashevo airport during the night of December 13, 2012 and on January 26, 2013. The comparison shows that the calculations and the measurements very well agree quantitatively and qualitatively. The maximum discrepancy does not exceed 3°C. For the case of strong cooling (Fig. 4a), both the models and observations detect the presence of isothermal fragment in the temperature distribution at an altitude of 50–300 m above the Earth's surface. During the thaw (Fig. 4b), the temperature varies almost linearly with altitude, as can be seen from the calculations and the measurements.

CONCLUSIONS

We described the measurement–calculation complex for monitoring and forecasting the meteorological situation at airports. The complex is based on a MTP-5PE meteorological temperature profiler, WXT520 Vaisala Weather Transmitter, a terminal for operating and managing the measuring instruments, as well as two meteorological models, a server, a network data storage, and the TSU SKIF Cyberia cluster.

The atmospheric temperature profile and the surface wind speed and direction, pressure, humidity, and temperature were monitored and forecasted for December 2012, when there was anomalously cold weather and for January 2013, when there was a thaw with positive temperatures at Bogashevo airport. It was found that the weather throughout the day on December 13, 2012 was exceptionally stable with anomalously low air temperature, which led to intense and thick inversion and the presence of isothermal regimes. This situation favored a strong pollution of the atmosphere, there were haze and fog with visibility range much lower than the acceptable minimum level for the Tomsk airport, and an intense and thick inversion could lead to a change in the flight conditions and complicate take-off and landing of aircraft.

In the period of thaw on January 26, 2013, there was an elevated inversion with the gradually subsiding lower boundary, which had broken up in the second half of the day. In the evening, the temperature decreased starting from higher atmospheric levels, colder air gradually subsided, the temperature decreased to −6°C toward the end of the day, and the temperature decreased to −14°C at high altitudes of the measurements. The transition of the temperature from negative to positive values in different atmospheric layers and passage of cold front in combination with precipitation, high humidity, and clouds on that day had led to dangerous events such as icing of runway and wind strengthening, which also was reported by airport services.

Thus, the numerical calculations showed that the vertical temperature profiles in the lower part of the atmospheric boundary layer, measured using MTP-5PE temperature profiler and calculated on the TSU Cyberia cluster with the use of the above-indicated high-resolution models, well agree quantitatively and qualitatively.

The measurement–calculation complex presented here makes it possible to monitor and forecast the meteorological situation at airports under extreme weather conditions.

ACKNOWLEDGMENTS

This work was supported by the Siberian Branch, Russian Academy of Sciences (project VIII.77.1.2 of the basic research program), by the "Program of Strategic Development of Altai State University", and by the Federal Target Program "Scientific and Teaching Stuff of Innovative Russia" for 2009–2013 (agreement no. 14.B37.21.0667).

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Translated by O. Bazhenov