A PLATFORM FOR RADIOSONDE TEMPERATURE SENSORS COMPATIBILITY TESTS USING STRATOSPHERIC BALLOON FLIGHTS AND FIRST FLIGHT RESULTS

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ABSTRACT

It's described STAS (System for Testing Aerological Sensors) – a lightweight platform for investigation of compatibility of radiosonde temperature sensors from various Russian radiosonde manufacturers in free atmosphere. STAS is deployed as an autonomous piggy-back payload to high-altitude stratospheric balloons during various international research programs. It allows simultaneous registration of 8 (in basic configuration) or 16 (in extended configuration) thermistors during ascent, drift and descent of a balloon. As well, basic configuration includes a pair of Vaisala RS80 and RS92 radiosonde sensor units while in extended configuration it may takes two pairs of them. STAS can carry out thermistors of the same type but with different well-defined coating thus utilizing accurate radiation-free temperature measurement methodology like ATM radiosonde.

To avoid thermal influence of a central unit the temperature sensors are mounted on the ends of two or four crossed light-weighted 1.2 m arms in position similar to that in a radiosonde.

The thermistors and Vaisala sensor units are connected to the central unit with wires fastened to the pipes. The central unit comprises microprocessor based data acquisition system and flash memory storage.

As at daylight conditions orientation of a sensor plays a role, central unit is equipped with 8 photodiodes, evenly spaced by 45°, that allows unambiguous determination of sensors' orientation relative to the Sun and investigation magnitude of such influence. To facilitate such an investigation several pairs of sensors of the same type are placed orthogonally.

Presented and discussed are initial results obtained during experiments with stratospheric balloons of 2009-2010 undertaken by CNES, France, in Swedish Space Corporation ESRANGE Space Center in Kiruna, Sweden.

Introduction

There were several reasons to develop the technique for radiosonde temperature sensors (RTS) comparisons. Currently, the Russian upper-air network utilizes radiosondes from several manufacturers. Although all major types use the same MMT-1 rod thermistor as a sensitive element, at least a calibration may differ as well as slight variations in the design of sensor mounting and anti-radiation coating may affect thermal equilibrium.

Anti-radiation enamel is known to differ from that used earlier in the former USSR. Existing technical specifications stipulates factory check of the coefficient of reflection of anti-radiation coating, but its reliability is also in doubt.

Radiation correction, used on the Russian upper-air network, was obtained in the 70-s by obsolete "day-night" method and have bias and insufficient reproducibility because doesn't take into account infrared radiation.

It's not possible to reproduce under laboratory conditions the full range of factors determining the radiation error in the flight conditions.

To obtain reliable conclusions about relative performance of the RTS in actual flight conditions reasonable statistics is required.

A favorable factor promoted the fulfillment of this work was the cooperation between CAO and CNES, which provides to CAO a possibility to perform in-flight RTS tests during CNES stratospheric balloon flights to altitudes as high as 36 km. To carry out such experiments it was designed STAS system.

Design of STAS addressed several issues like:

- RTS resistance measurement accuracy;
- Similar to routine radiosonde flight RTS mounting;
- Ensuring the equal conditions to all RTS under investigation;
- Using of reference-quality temperature sensors (sensors of Vaisala radiosondes);
- Knowing sensors orientation relative to the Sun;
- Last but not least – recoverability as well as reliability and safety requirements to equipment used in stratospheric balloons flights.

System for Testing of Aerological Sensors (STAS)

Structurally STAS consists of :

- Mounting rack;
- Four or eight 1.2 m arms with platforms for mounting of external sensors on their ends and respective wiring;
- Thermally insulated enclosure with electronic control unit and the optional power supply unit;
- Double strap type (to avoid twisting and spinning) system.

The very first STAS prototype, tested in 2009, was able to carry out up to 8 RTS on 4 arms, an extended version is capable to carry out up to 16 RTS on 8 arms.

Thermally insulated enclosure has a form of a hollow cylinder is made of Styrofoam with 1 cm thick wall. It has holes that serve as windows for the 8 optical photodiodes.

Two RTS are installed on the end of each arm, thermisor frames are placed into standard plastic mounting supports, used in respective radiosondes. For the investigation of influence of sensors orientation relative to the Sun pairs of sensors of the same type might be placed onto orthogonal arms. Basic configuration includes a pair of Vaisala RS80 and RS92 radiosonde sensor units, placed onto orthogonal arms, while in extended configuration STAS takes two pairs of them with each sensors of the same type placed orthogonally. The scheme of RTS arrangement in one of the flight is shown on the Fig 1.

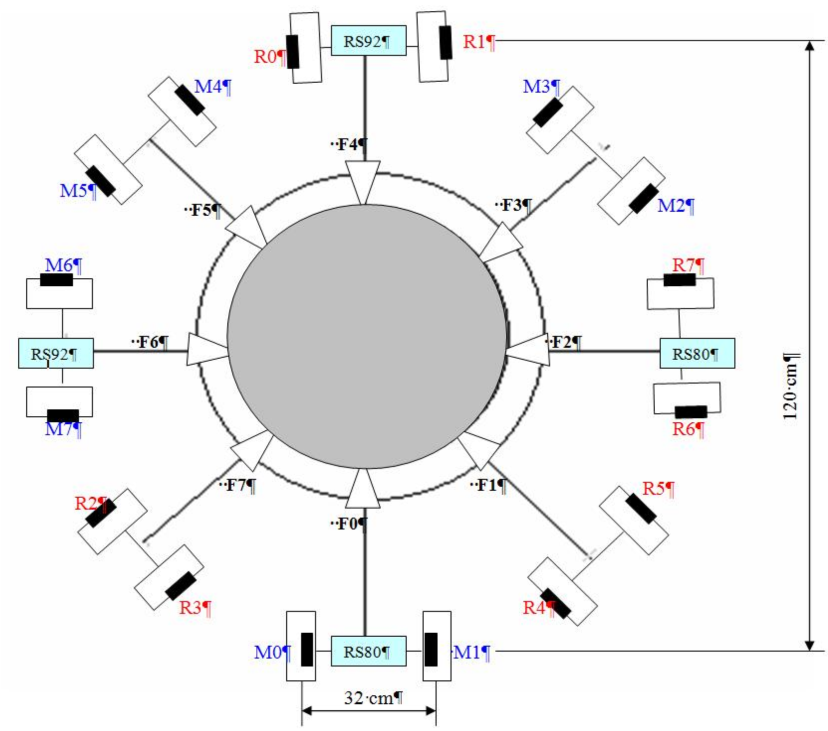


Fig.1. The scheme of RTS arrangement in the STAS (extended configuration):
F0-F7 - optical photodiodes. M0-M7 –"Meteo" RTS.
R0-R7 - "Radiy" RTS

Electronic control unit consists of one (basic configuration) or two (extended configuration) microcontrollers, reference voltage source and flash memory. It measures and stores in the memory resistance of the thermistors, frequencies of telemetry channels of RS80 and RS92 sensor units, output voltages of the photodiodes and some internal parameters.

At 2 s sampling rate the memory capacity is sufficient for continuous operation within 18 days. Normal power supply unit consisting of four lithium cells (3.6 V), provides continuous operation of STAS within 5 days.

Laboratory tests were conducted to check reliability and performance of a system:

- Test in a climate chamber under temperatures from +30 to -80 °;
- Test of the accuracy of measuring thermistor resistance;
- Test of measuring RS80 and RS92 sensor unit frequencies.

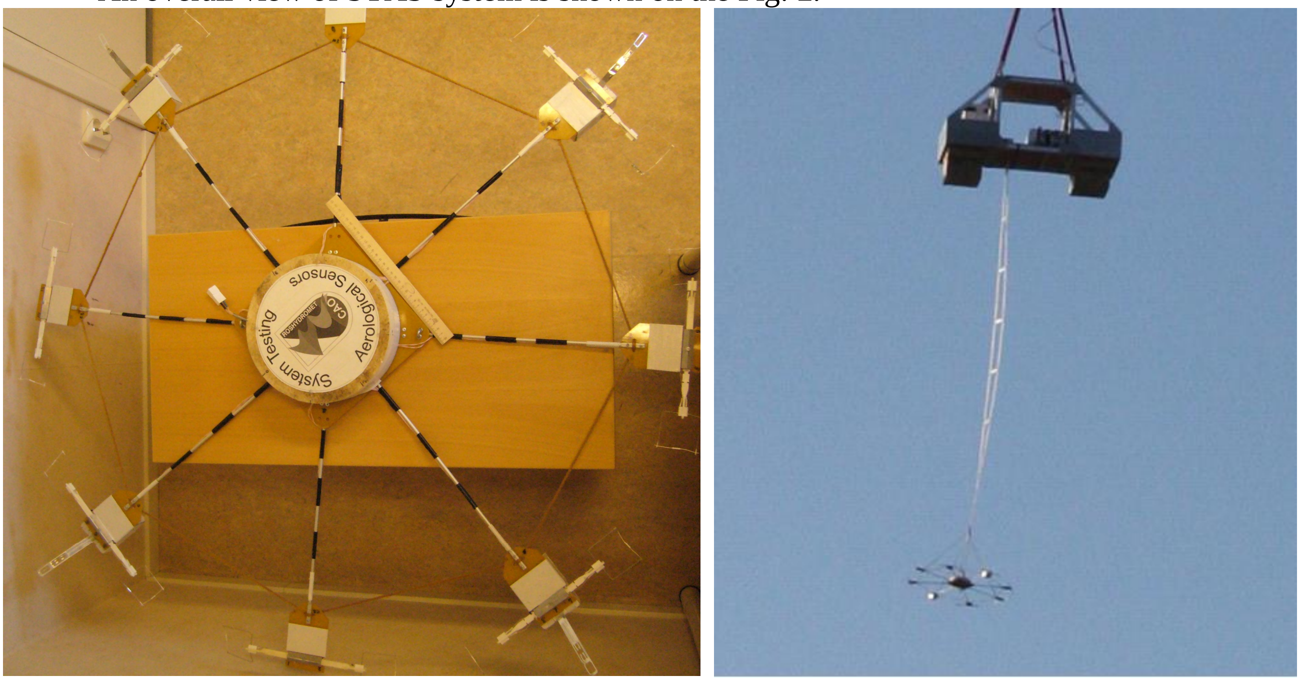
The tests showed that accuracy of measuring thermistor resistance and Vaisala sensor unit frequency in terms of temperature is within 0.1 K under temperatures ranging from -80 to +30°C.

Other STAS specifications are (for extended version):

- Dimensions (without suspension elements) – 120x120x15 (cm);
- Sun orientation resolution – 22.5°;
- length of suspension (determines distance between sensors and carrying gondola and other elements of aerostat) -5 m;
- total mass with power supply for long-drifting flights– less of 5 kg;
- mass without power supply unit – less of 3 kg.

There were fabricates 4 samples of STAS system.

An overall view of STAS system is shown on the Fig. 2.



a) b)

Fig. 2. An overall view of STAS on the ground (a) and in the flight (b).

STAS flight experiments (the very first results)

Six STAS systems flights were undertaken in September 2009 and April-May 2010 in experiments with stratospheric balloons of 2009-2010 performed by CNES, France, in Swedish Space Corporation ESRANGE Space Center in Kiruna, Sweden. Flights summary is shown in Table 1. In four flights S1_09, S2_09, S1_10 and S2_10 maximum height (Hmax) stratospheric balloons reached more than 30 km. In two last flights S3_10 and S4_10 Hmax did not exceed 22 kilometers. In the flight S1_10 almost all ascent (up to a height of 29980 meters) took place in the darkness. Ascents in the rest of the flights took place at Sun elevations from 2.5 to 30.6°.

Table 1.

STAS flights summary

Flight ID	Date	Time of flight (UTC)			Hmax [m]	Sun elevation on ascent [O]	Remarks
		Ascent	Drift	Descent			
S1_09	09.09.2009	3:55-5:31	5:31-5:45	5:45-6:23	31420	2.5-18.6	Basic version
S2_09	12.09.2009	6:42-8:27	8:27-8:29	8:29-9:08	30330	15.6-22.7	
S1_10	11-12.04.2010	23:41-2:07	2:07-2:21	2:21-4:56	30490	-	Sunshine detected by phodiodes at 1:57:15 UTC
S2_10	21.04.2010	5:39-7:48	7:48-8:06	8:06-12:41	30480	17.0-27.7	
S3_10	4.05.2010	6:40-7:32	7:32-8:20	8:20-8:49	21730	26.4-30.6	
S4_10	13.05.2010	4:55-6:11	6:11-6:15	6:15-8:30	22210	19.1-26.1	

One of the goals of these experiments was to investigate the production stability, i.e. consistency between readings of RTS of the same manufacturers. RTS from 3 manufacturers took part in the experiments: "Meteo", "Radiy" and "Vektor" companies. Code figures of respective radiosondes in WMO Code Table 3685 are 27/88, 58/88 and 68/69 (for AVK/MARL of VEKTOR ground system). Because RTS of "Vektor" took part only in the experiments of 2009 (their radiosondes now are almost not in use) and have less statistics. Results below are presented for "Meteo" and "Radiy" only.

For express assessment of reproducibility there were calculated differences between the maximum and minimum values of the simultaneously measured RTS temperatures Tmax – Tmin, which were averaged over 1 km layers (dTav). Hereinbelow, only ascent parts of flights were taken into consideration. The main factors affecting the variation in temperature, provided the temperature in the sampling volume is homogeneous, are accuracy and stability of thermistors calibration and various orientations relative to the Sun.

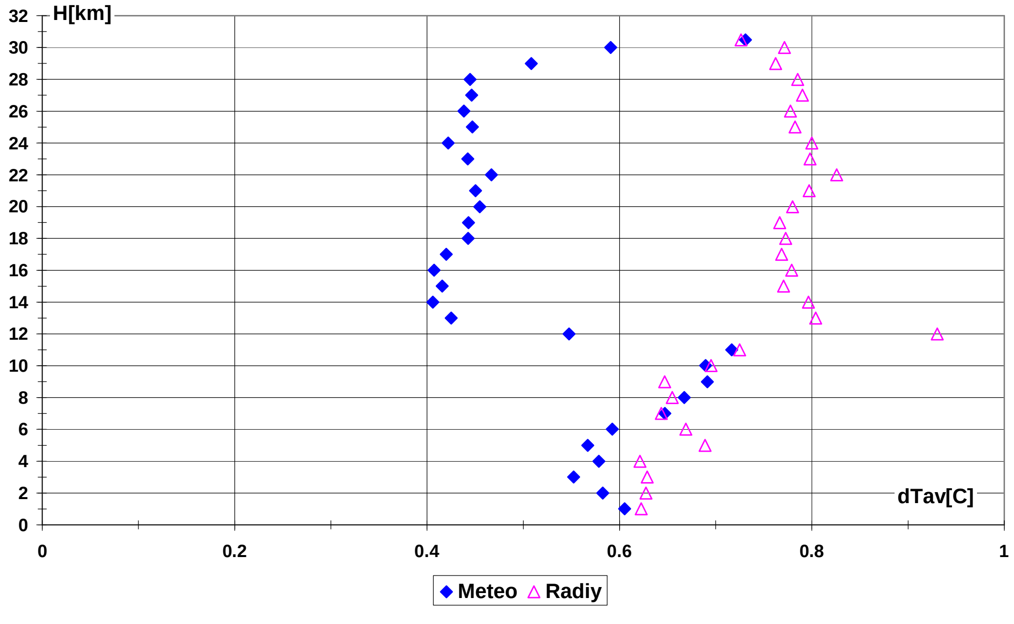


Fig. 3. Temperature variations between RTS of the same type in the night-time flight.

Fig. 3 shows the estimates of dTav for RTS of two manufacturers – "Meteo" (8 pcs) and "Radiy" (7 pcs[1]) observed during an ascent part of the flight S1_10, which up to an altitude of 30 km took place in the absence of solar radiation. There are two apparent sections in the dTav

[1] One "Radiy" RTS was excluded from the analysis due to evident calibration error (significant systematic overestimation of temperature).

variations, namely: below and above the tropopause, happened at 12600 m. Below the tropopause differences in dTav for both manufacturers do not exceed 0.1 °C, while above the tropopause dTav for "Meteo" RTS is equal to 0.4 – 0.5 °C and dTav for "Radiy" RTS is equal to 0.8 °C.

Results of the evaluation of the five day-time flights are presented on Fig. 4. It shows the maxima of dTav estimates over all those flights for "Meteo" and "Radiy" RTS. In daytime to an altitude of 20 km dTav for "Meteo" and "Radiy" RTS did not exceed 0.9 and 1.2 °C respectively. Above 20 km it is observed an increase both in magnitudes and variations of dTav.

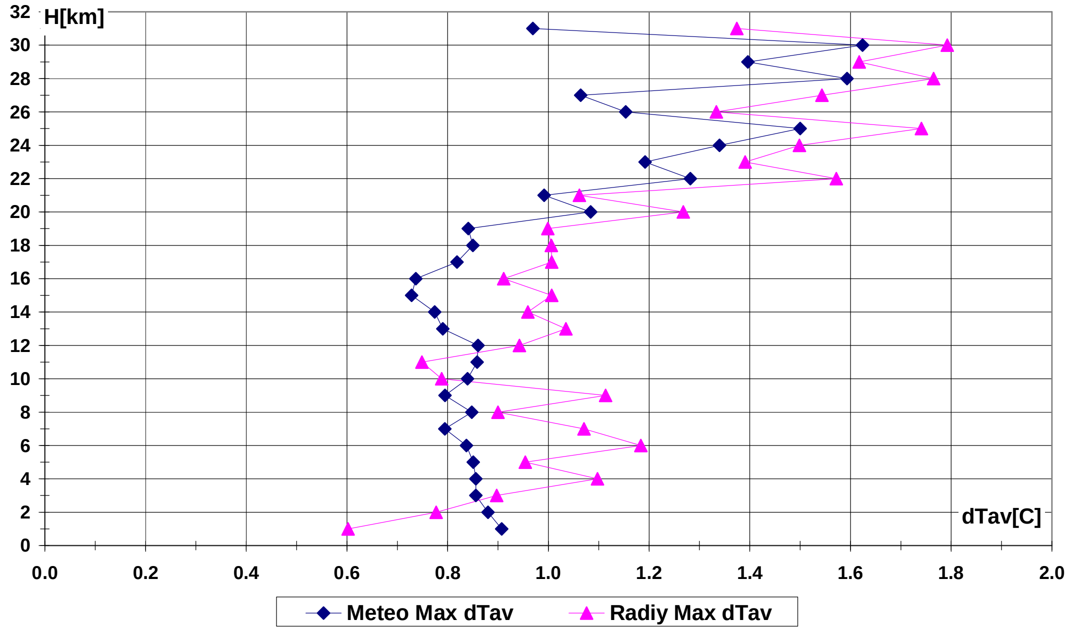


Fig. 4. Maximal temperature variations between RTS of the same type in the day-time flights.

Analysis of experimental results confirmed that RTS temperature strongly depends on an orientation of a thermistor relative to the Sun, that is, from what part of thermistor surface is currently exposed to the Sun (let us remind that investigated RTS have a cylindrical form with 2.2 mm diameter and 12 mm length).

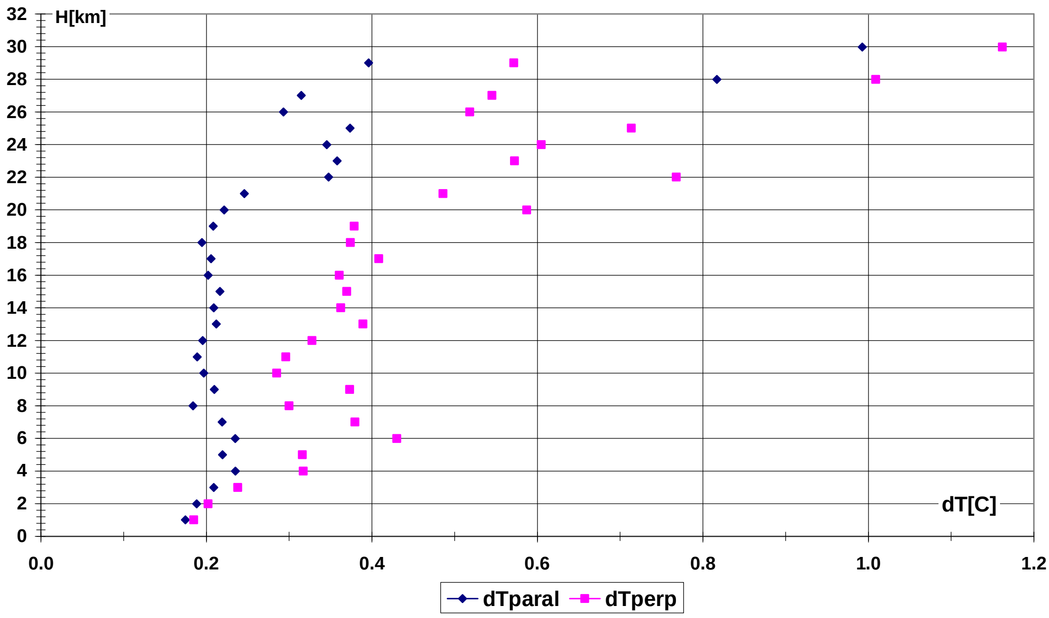


Fig.5. Average temperature differences between the RTS pairs with a different orientation relative to each other. Flight S2_10, (day-time flight).

Figure 5 shows averaged over 1-km layers temperature difference between all the pairs of perpendicular (dTperp) and parallel (dTparal) RTS of the same type for the flight S2_10. The scheme of the sensors placement in this flight is shown in Figure 1. For pairs of RTS with parallel axes, temperature differences were weakly dependent from a height (dTparal less than 0.2°C) up to 27 km. For pairs of RTS with perpendicular axes, both dTperp magnitude and its variability growed along with height. Above 22 km dTperp exceeds 0.5°C.

Fig. 6 illustrates the influence of RTS position relative to the Sun on its temperature. For the flight S2_10 it shows instant temperature difference between a pair of two orthogonal RTS R0 and R1 ($dT=T_{R0}-T_{R1}$) versus time with indication the periods with maximum solar insolation for each sensor. Time intervals with maximum RTS R0 and R1 insolation are mareked with red and green respectively. The figure clearly demonstrates that variation of orientation relative to the Sun resulted in 1 – 2 °C variations of temperature difference between pair of two orthogonal RTS.

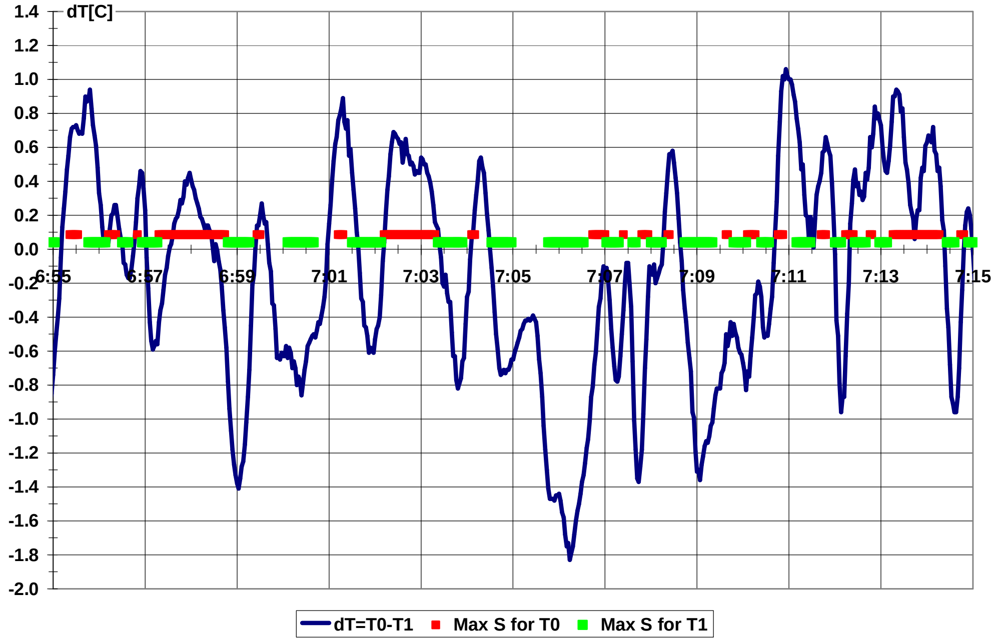


Fig.6. The effect of the orientation of two orthogonal RTS relative to Sun onto temperature difference between them. Flight S2_10 (day-time flight).

The gondola rotation around its vertical axis also influenced temperature difference between orthogonal RTS. During the ascent in all flights gondola rotation varied from 20 to 120 seconds per revolution. Sometimes a direction of rotation of the gondola changed to an opposite one. Variation of gondola rotation speed resulted in a change in dTperp to as large as 0.5 – 1.0 C.

There were undertaken also an evaluation of biases between "Meteo" and "Radiy" RTS and temperature sensor of Vaisala RS92 sensor unit. Prior to the evaluation RTS temperature was corrected according to standard radiation correction scheme routinely used on the Russian upper-air network. We calculated averaged over 1 km layers differences between temperatures measured by RTS and RS92 sensors ($\Delta T = T_{RTS} - T_{RS92}$) with a vertical resolution of 1 km.

Fig. 7 shows ΔT as a function of height for flight S1_10 in nighttime. The same figure shows the variation of relative humidity (right ordinate). Bias as large as 0.3 – 0.4°C is evident between "Meteo" and "Radiy" RTS.

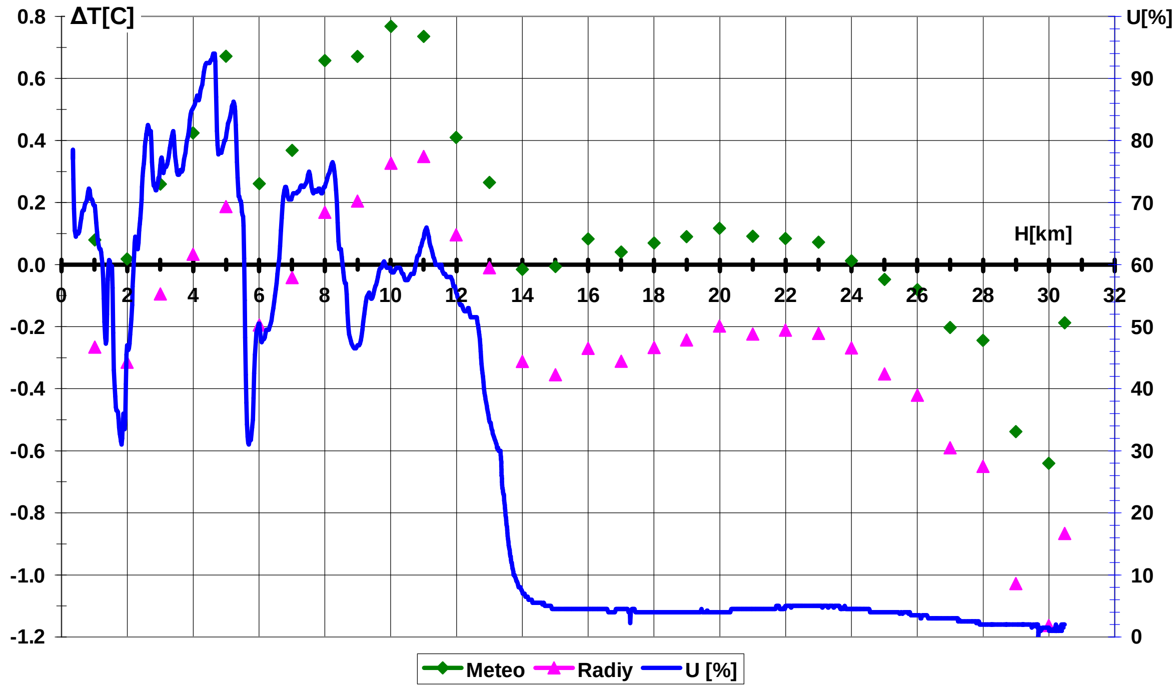


Fig.7. ΔT of "Meteo" and “Radiy" RTS and relative humidity versus height. Flight S2_10, (day-time flight).

It seems "Meteo" RTS overestimated the temperature because as on exit from clouds at altitudes near 2 and 6 km RTS temperature expected to be lower than one of RS92 due to evaporation of the water film covering them (Nash at al., 2006). Surface observations indicated presence of lower and middle levels clouds (from 3 to 7 oktas) when relative humidity varied within 30 to 95%RH below height of 12 km. For "Meteo" RTS ΔT was positive up to 24 km, although at relative humidity below 30%RH, ΔT expected to be negative. Above 24 km because of cooling ΔT began to decrease. Growth of ΔT after 30 km happened due to the appearance of the sun and RTS heating.

For day-time flights, where Sun elevation was within 8 – 30 °, it was calculated the averaged over 1 km layers temperature difference ΔT (ΔTaver). For height range within 0 – 22 km 5 flights data were taken into calculation, while for height range within 22 – 30 km it was used data from 3 flights. Fig. 8 shows ΔTaver for "Meteo" and "Radiy" RTS versus height.

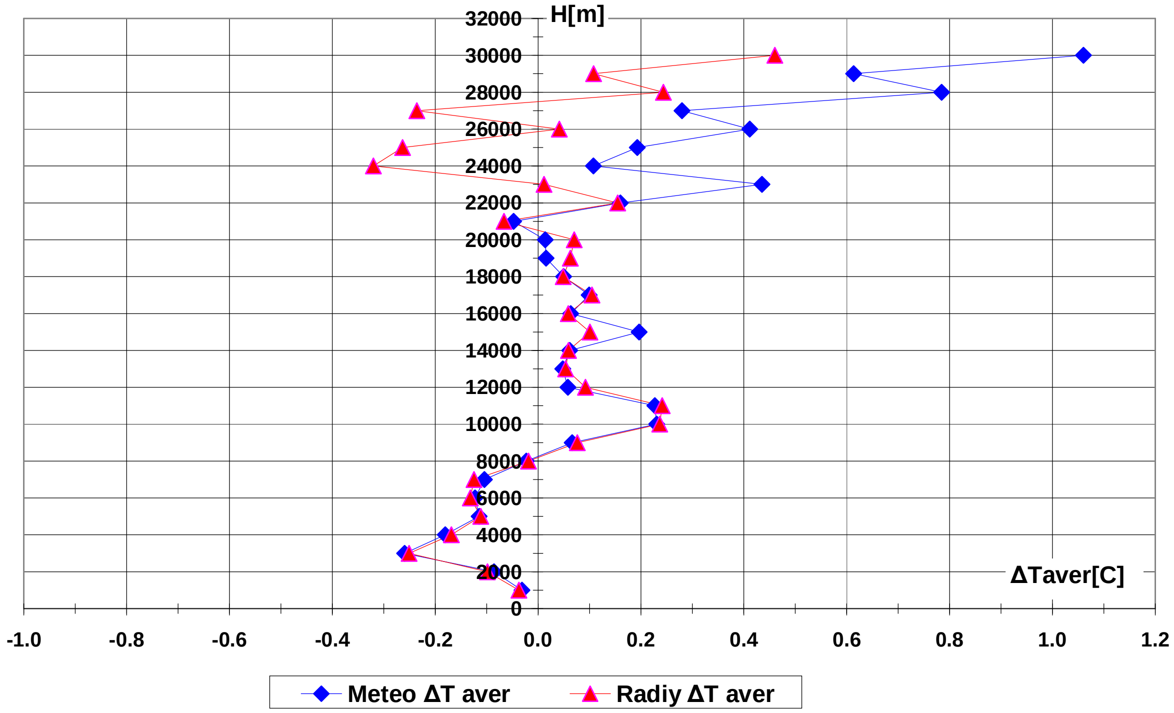


Fig. 8. ΔTaver of "Meteo" and "Radiy" RTS versus height for day-time flights.

Below height of 22 km ΔTaver for "Meteo" and "Radiy" RTS had virtually no difference and lies in the range from -0.3 to +0.3 °C.

Below height of 8 km in average RTS were cooler of RS92 and within height range of 9 – 30 km were warmer. The difference between ΔTaver for "Meteo" and "Radiy" RTS increased above 22 km.

Conclusions

1. Conducted laboratory and flight tests proved the developed STAS system to be a suitable platform for intercomparison of atmospheric temperature measurements by thermistors with resistance ranging from 1 to 2000 kOhm and Vaisala RS80 and RS92 sensor units.

2. Intercomparison of 76 RTS from two manufacturers (38 pcs "Meteo" and 38 pcs "Radiy") showed absence of significant systematic bias between them. The differences between ΔT for "Meteo" and "Radiy" RTS vary randomly with height and do not exceed 0.4 °C. The averaged over 1 km temperature scatter between RTS of one manufacturer can reach 1.8 °C.

3. In comparison with Vaisala RS92 routine radiation correction scheme, currently used on the Russian upper-air network, does not fully compensate the radiation night-time overcooling and day-time overheating.

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References

Nash J., Smout R., Oakley T., Pathack B., Kurnosenko S., 2006: WMO Intercomparison of Radiosonde Systems. Vacoas, Maurutius, 2-25 February 2005. Report No.83 WMO/TD-No. 1303, 115p.