IL NUOVO CIMENTO Vol. 27 C, N. 5 Settembre-Ottobre 2004
DOI 10.1393/ncc/i2005-10016-6

Radiosounding: Possible change in aerological data due to instrument change

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(ricevuto il 20 Gennaio 2005)

Summary. — A radiosounding system allows to measure the profile of some meteorological quantities (temperature, humidity, pressure) from the ground up to a certain altitude. Such systems are continuously used by meteorological services in order to perform periodical measurements during the day, at pre-determined times. The evolution of instrumentation technology leads to a fast obsolescence of equipment through time, so that, inevitably, new instrumentation replaces the old one. The new VAISALA Radiosound RS92 has been recently introduced to substitute previous model RS90. The RS90 is currently used by many national and international institutes, including the Italian Air Force Meteorological Service (Servizio Meteorologico dell'Aeronautica Militare). In order to assess the way in which the substitution of RS90s with the new RS92s would affect measures performed by the altitude observation network with regard also to the historical series, several comparative measurements have been conducted by the "Reparto Sperimentazioni di Meteorologia Aeronautica" at Vigna di Valle (Rome). During this testing series, Company VAISALA has given a remarkable level of cooperation by a continuous presence of technicians. The entire test has been performed according to WMO (World Meteorological Organization) protocols.

PACS 93.85.+q – Instrumentation and techniques for geophysical research.
PACS 92.60.Ry – Climatology.
PACS 92.70.Cp – Atmosphere.

1. – Introduction

Radiosondes have for several dacades been the primary means of obtaining atmospheric vertical profile data from the surface to the lower stratosphere. They are routinely used as input to the operational meteorological analyses that are used in numerical weather prediction and meteorological diagnostics. The network of stations RBSNs (Regional Basic Synoptic Networks stations), which provide the service for the meteorological

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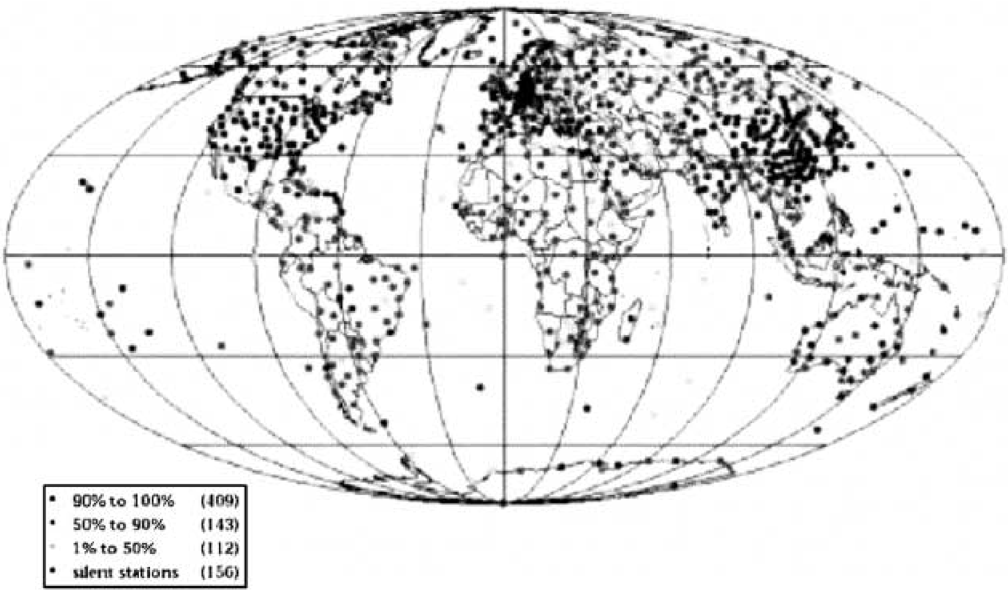

Fig. 1. – Availability of temp reports from RBSNs during the monitoring period October 1st to 15th, 2002 (the percentage of received reports is based on Part A of message Temp for 0000 and 12 UTC) [2].

Fig. 2. – Map of temp reports from GUAN. Availability of temp reports from GUAN is continuously monitored by ECMWF `http://www.ecmwf.int`.

Fig. 3. – Map of only Air Force Italian radiosounding stations.

model initialization, is described in fig. 1. Such a system is used for real-time local atmospheric monitoring, performed by tracing thermodynamic diagrams, too. The instrument packages carried aloft by ballons are generally equipped with temperature, humidity and pressure sensors, whose measurements are radio-trasmitted to a ground receiving station. Wind data are also obtained by tracking the position of the instruments during ascent. An excellent overview of radiosonde instruments, including discussion of measurement error characteristics, is provided by the World Meteorological Organization [1].

Radiosonde observations have recently been used to assess trends of atmospheric conditions above surface, even though they were not designed for this purpose. The statistical analysis of long historical radiosounding series can be applied to the investigation of climatological changes through time (see fig. 2). To recognize the limits of such statistical analyses it is necessary to know, along with the numerical values stored in the databases, the features of the measurement instruments by which the data acquisition has been performed.

A sub-set of the network is used with the additional purpose of analyzing the change in temperature on a global level, by studying the historical temperature-profile series, so that the analysis is not limited to the mere data coming from surface stations.

As far as Italy is concerned, the Servizio Meteorologico dell'Aeronautica Militare operates a network of 6 stations from which 4 launches are performed, once every 6 hours. Among these stations, one is also included in the GUAN network (GCOS Upper-Air Network, GCOS is Global Climate Observing System) and, furthermore, the Vigna di Valle station (which does not belong to the group) can be added in case of experimental or operational needs (see fig. 3).

Fig. 4. – Aerial picture of ReSMA. The Experimental Site includes six equipped areas under both automatic and manual control everyday.

2. – Purpose and site of testing

There have been many and widespread changes of radiosonde sensor durino the history of the global radiosonde network. The instrumentation used by the Servizio Meteorologico in performing radiosounding has been produced by VAISALA. This company has recently ceased the production of radiosound RS90 (present on market since 1997), with the new RS92. The difference between the two types is mostly related to the transmission system, which was analog on the RS90 and is now digital on the RS92. Even though the sensors stay the same on both models, there are some changes in the calibration-at-launch system and in the humidity measurement system. With regard to the latter, there are now two separate sensors; in order to prevent freezing during ascent, in this phase the sensors are used alternatively: one performs measures, while the other is heated to defrost. Instrument details and specifications are presented in [3].

In order to assess differences in temperature, humidity and pressure measures which result from the described modifications, testing has been conducted with the sole purpose of comparing the two devices and provide the prospective user with a reference for trend analysis. The goal was to determine whether systemic errors could be found in the modified system; therefore, no attention was given to the correspondence between measures performed by each sound and the real data.

The performed test was an evaluation of the measure reproducibility according to the ISO and WMO standards.

The location for the test was the “Reparto Sperimentazioni di Meteorologia Aeronautica”, Servizio Meteorologico dell’Aeronautica Militare, a historical site for Italian meteorology, inaugurated in 1907 (see fig. 4).

3. – Materials and methods

In agreement with VAISALA and in accord to the WMO intercalibration instructions [4], two receivers have been provided at the site. The receivers had similar features. An experimental protocol was developed, discussed and agreed upon. The compliance of testing operations with such protocol was ensured by the continuous presence of both Italian Air Force and VAISALA technicians.

The launches were scheduled as shown in table I.

Testing was not conducted by grouping several launches per day, as it would be

Table I.

Launch time	13.00 (Local time)	18.00 (local time)
Friday 7th	RS92-SGP and RS90-AG-CE	
Mon 10th	RS92-SGP and RS90-AG-CE	
Tue 11th	RS92-SGP and RS90-AG-CE	
Wed 12th	RS92-SGP and RS90-AG-CE	
Fri 14th	RS92-SGP and RS90-AG-CE	
Mon 17th	RS92-SGP and RS90-AG-CE	
Wed 19th	RS92-SGP and RS90-AG-CE	RS92-SGP and RS90-AG-CE
Thu 20th		RS92-SGP and RS90-AG-CE

desirable from an economic point of view; rather, several days were chosen so that all launches could be made at corresponding times. This allowed to compare the sounds performance in different weather but under similar solar radiation conditions.

Each launch was done with both sounds suspended under the same balloon, at a fixed distance between one another (see fig. 5). Data were sampled once every 2 seconds as in normal operation.

Significant figures used in describing results as well as in error calculation are consistent with measure precision not according to resolution, which is display-device dependent, but according to sensor errors [1]; some specifications related to temperature are given in table II.

A similar management was done for the other quantity.

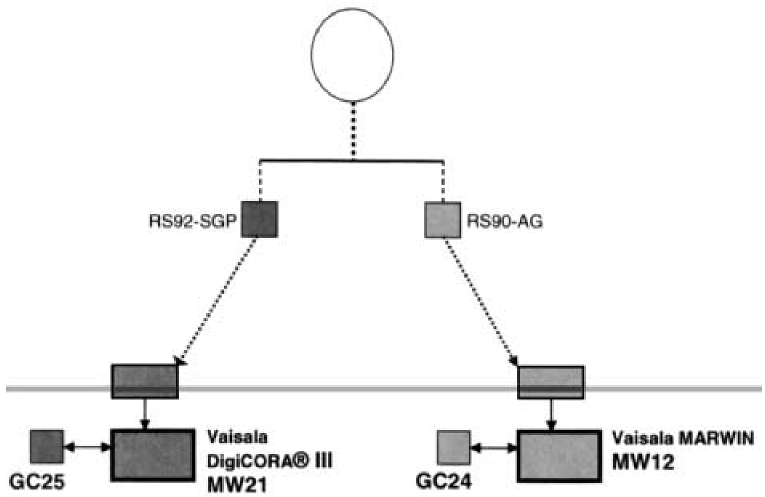

Fig. 5. – Scheme of the experimental facility.

TABLE II. – *Meteorological sensors.*

Temperature	Vaisala F-THERMOCAP capacitive wire
Measurement range	+60 °C to −90 °C
Response time (63.2%, 6 m/s flow)	
1000 hPa	< 0.4 s
100 hPa	< 1 s
10 hPa	< 2.5 s
Resolution	0.1 °C
Accuracy	
Total uncertainty in sounding (*)	0.5 °C
Repeatability in calibration (**)	0.15 °C
Reproducibility in sounding (***)	
1080–100 hPa	0.2 °C
100–20 hPa	0.3 °C
20–3 hPa	0.5 °C

(*) 2-sigma ($k = 2$) confidence level (95.5%). Cumulative uncertainty including:

- Repeatability.
- Long-term stability.
- Effects due to measuring conditions.
- Dynamic effect (such as response time).
- Effects due to measurement electronics.

(**) Standard deviation of differences between two successive repeated calibrations, $k = 2$ confidence level.
(***) Standard deviation of differences, in twin sounding.

4. – Results and discussion

Data was analyzed using the new RSK32 software which is the official WMO comparison software. During the analysis, according to what was done in similar WMO activities, data has been broken down by 1000 m layers and each layer has been analyzed as a group of independent measures, under the hypothesis that within each one of them variations of sensor performance were negligible.

Performance variations become sensible, and no longer negligible, when comparing different layers. The new transmission system gives a remarkable improvement in the quantity of sampled and received data. Average received information levels from the sondes are shown in table III.

Both the radiosondes started to measure from a specific demarcation value of pressure and the timing error resulted to be negligible. Data quantity when both measures are present, see fig. 6, and comparable indicate a more-than-sufficient amount of cases.

TABLE III. – *PTU data availability.*

	Pressure	Temperature	Humidity
RS92-SGP	98.6%	97.5%	99.3%
RS90-AG-CE	86.7%	92%	92.6%

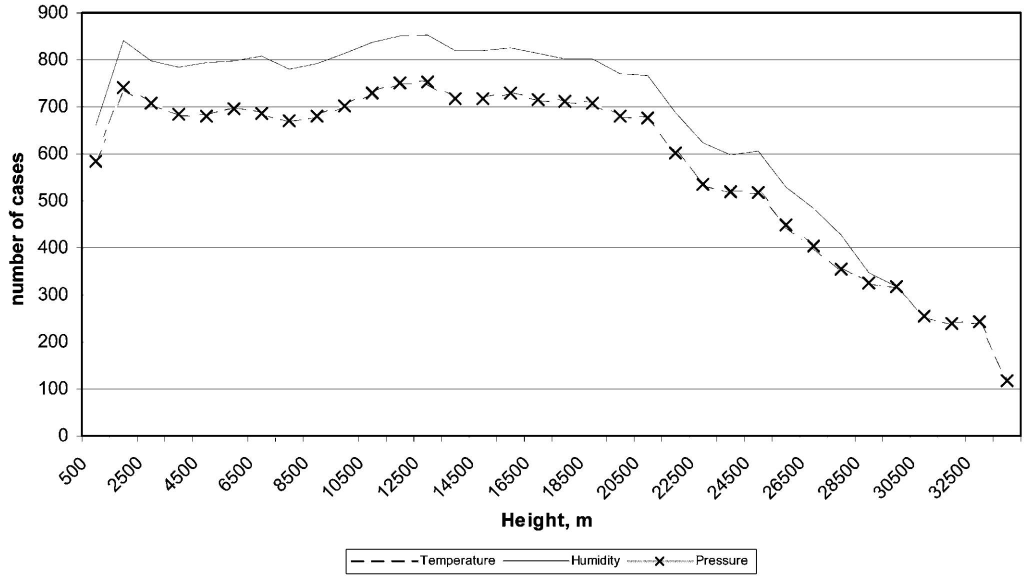

Fig. 6. – Data availability by "layer", pressure and temperature's line are overlap.

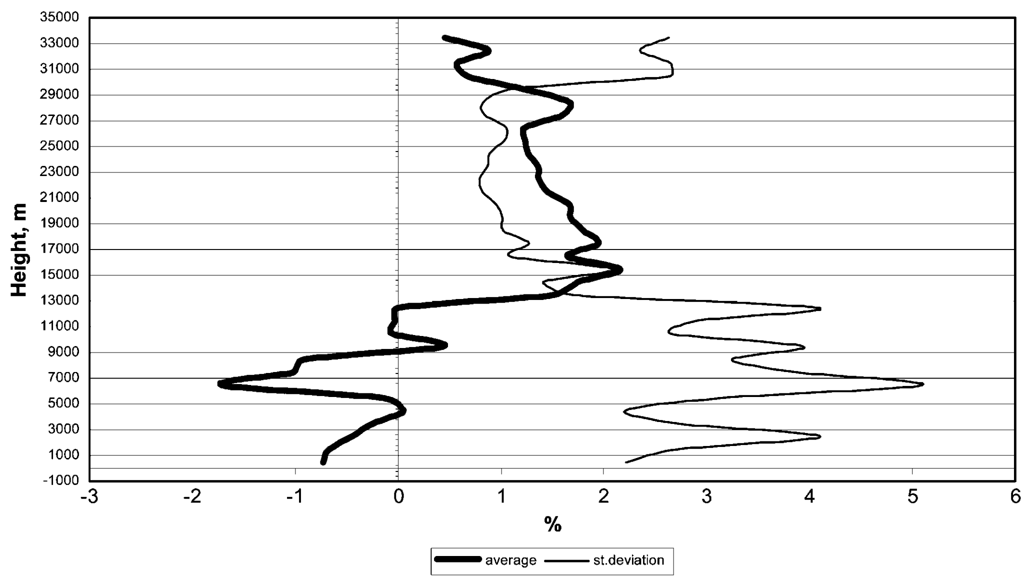

Fig. 7. – Humidity, average direct differences calculated with RS92-SGP as a reference. Also "standard deviation" line is presented.

TABLE IV. – *PTU average direct differences calculated with RS92-SGP as reference and standard deviation.*

Height (m)	Diff. Temp. (°C)	St.m Temp. (°C)	Diff. Hum. (%)	St.d. Hum. (%)	Diff.Press. (hPa)	St.d. Press. (hPa)
500	*−0.4*	0.4	*−1*	2	*−0.2*	0.7
1500	*−0.4*	0.4	*−1*	3	*−0.1*	0.8
2500	*−0.3*	0.4	*0*	4	*0.0*	0.7
3500	*−0.3*	0.4	*0*	3	*0.0*	0.7
4500	*−0.3*	0.3	*0*	2	*0.0*	0.6
5500	*−0.1*	0.4	*0*	3	*0.0*	0.5
6500	*−0.2*	0.3	*−2*	5	*0.0*	0.5
7500	*−0.2*	0.3	*−1*	4	*0.0*	0.5
8500	*−0.2*	0.2	*−1*	3	*0.1*	0.5
9500	*−0.2*	0.2	*0*	4	*0.1*	0.4
10500	*−0.2*	0.2	*0*	3	*0.0*	0.4
11500	*−0.2*	0.2	*0*	3	*0.0*	0.3
12500	*−0.2*	0.2	*0*	4	*0.0*	0.2
13500	*−0.2*	0.2	*2*	2	*0.0*	0.2
14500	*−0.2*	0.2	*2*	1	*0.0*	0.2
15500	*−0.2*	0.2	*2*	2	*0.0*	0.2
16500	*−0.3*	0.4	*2*	1	*0.0*	0.2
17500	*−0.3*	0.3	*2*	1	*0.0*	0.2
18500	*−0.2*	0.4	*2*	1	*0.0*	0.2
19500	*−0.3*	0.3	*2*	1	*0.0*	0.1
20500	*−0.3*	0.4	*2*	1	*0.0*	0.2
21500	*−0.2*	0.4	*1*	1	*0.0*	0.2
22500	*−0.2*	0.3	*1*	1	*0.0*	0.1
23500	*−0.1*	0.4	*1*	1	*0.0*	0.2
24500	*−0.3*	0.6	*1*	1	*0.0*	0.2
25500	*−0.2*	0.4	*1*	1	*0.0*	0.2
26500	*−0.1*	0.4	*1*	1	*0.0*	0.2
27500	*−0.1*	0.5	*2*	1	*0.0*	0.2
28500	*0.0*	0.4	*2*	1	*−0.1*	0.2
29500	*0.0*	0.4	*1*	1	*−0.1*	0.2
30500	*−0.3*	0.4	*1*	3	*−0.1*	0.2
31500	*−0.1*	0.7	*1*	3	*−0.1*	0.2
32500	*0.0*	0.5	*1*	2	*−0.1*	0.2
33500	*−0.2*	0.6	*0*	3	*−0.1*	0.2
average	−0.2	0.4	1	2	0.0	0.3
Average until 10500	−0.3	0.3	0	3	0.0	0.6

In each layer, any value given by the difference of the measurements by the two devices is a result of an experiment, *i.e.* a random variable. The sampling space is continuous, the number of tests is high; we make the reasonable hypothesis that the random error depends on many independent factors, all of them having the same order and each one of them producing a very small error, of any sign. Then only under these conditions, according to the central limit theorem, the error distribution function is coincident with Gauss' [5].

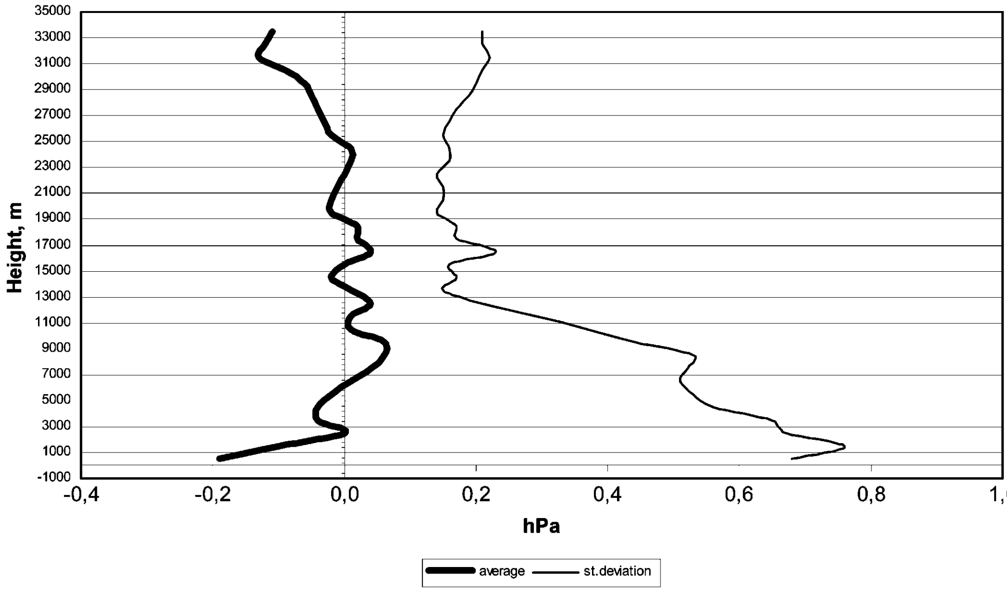

Fig. 8. – Pressure, average direct differences calculated with RS92-SGP as a reference. Also "standard deviation" line is presented.

We expect a Gaussian distribution of the average of PTU (Pressure, Temperature and hUmidity) variable differences; particularly, we expect a Gaussian distribution around zero and random errors. Indeed, such a situation would ensure the continuity of the historical series.

The provided data are presented in figs. 7, 8, 9 and table IV by showing the average difference and the standard deviation. It should be remembered that up to 10 km we are still in the troposphere, *i.e.* the region which is involved in meteorological phenomena.

By analyzing temperature, it can be noted that, in addition to the random error, there is a not-null difference. In all layers there is a systemic error which causes the RS92 to indicate higher temperature values than the RS90.

The difference average as calculated in different layers results to be between 0.0 °C and 0.4 °C, showing higher values in the troposphere. The sigma assessment, *i.e.* the assessment of temperature measurement "reproducibility" varies between 0.2 °C and 0.7 °C.

The described systemic error is not detected in humidity and temperature measures.

The reported data have been analyzed and discussed with VAISALA which, in its report about the testing, stated that the detected systemic error in temperature measure "is a well-known phenomenon in RS90 (Luers article) and corrected in RS92". According to such a statement, it would result that RS92 provides an improved measurement. Since no certified baroclimatic chamber was available, this circumstance could not be verified.

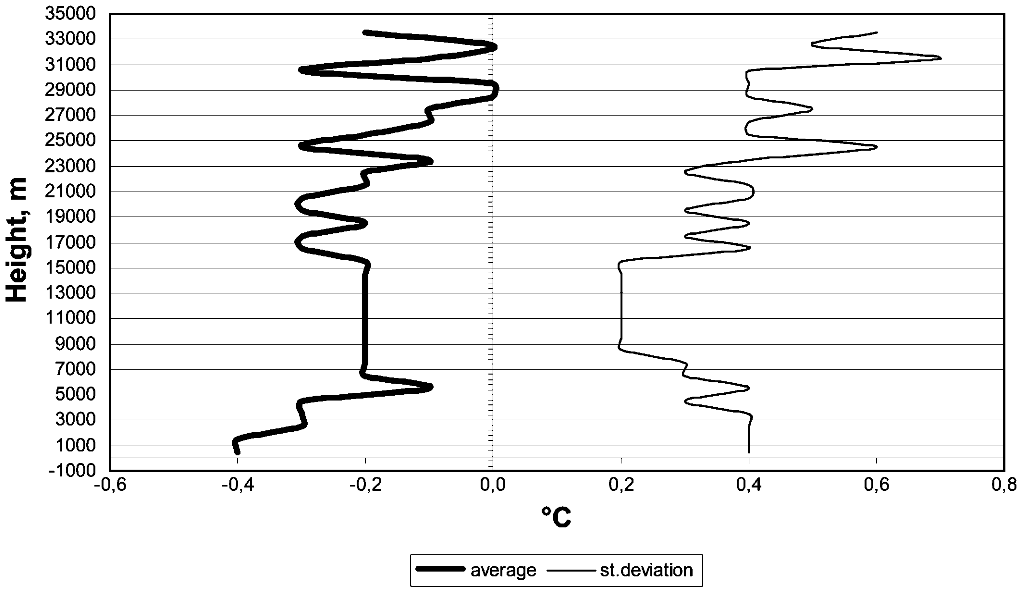

Fig. 9. – Temperature, average direct differences calculated with RS92-SGP as a reference. Also "standard deviation" line is presented.

5. – Conclusions and remarks

The described test has demonstrated the excellent performance of instruments and confirmed the improvements of the new radiosonde.

The impact of the future instrumentation change from RS90 to RS92, considering the measurement accuracy required by current working standards will be negligible whenever atmospheric sounding is used for local monitoring or for model initial analysis. In the climatological field, however, since the statistical analysis is performed taking into account tenth or even hundreth Celsius degrees precisions (for example Hurrel *et al.* found that global trends for 1979-1998 were $(0.04 \pm 0.07)\,^{\circ}$C/decade for radiosondes [7]), consequences could be relevant should the presented results be confirmed and not properly taken into account during the analysis. In fact, as the new equipment will replace the old one, a gradual and progressive atmospheric heating indication will result from records.

For climatological studies which are supposed to properly take into account, beyond mathematics, physics as well, it is necessary to store not only meteorological data, but also meta-data about the detection systems features. Such features, along with proper operation of measurement equipment, should be under control of specific "quality management systems".

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We acknowledge the cooperation in welcoming and supporting our experimentation shown by "Ufficio Generale per la Meteorologia", company VAISALA and EUROELETTRONICA Icas. The radiosonde comparison software was originally written by Mr Sergei.

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