EFFECTS OF DEVIATIONS FROM RECOMMENDED PROCEDURES ON RADIOSONDE DATA AND THE MANUFACTURER'S POSSIBILITIES TO CORRECT SUCH DEVIATIONS

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Summary

The quality of upper-air measurements can be significantly improved by applying radiative correction on temperature readings to remove the contribution of solar heating and night-time IR cooling. In addition to the type and make of the radiosonde, factors affecting such correction include solar elevation, radiosonde altitude at the instant of reading and balloon ascent rate. However, the lack of the latter in the TEMP message makes accurate radiative correction of radiosonde data impossible except by a special procedure at the observation station. In addition, critical procedures susceptible to human error are involved when preparing the radiosonde for launch and reducing received data.

The quality of work done by the operator depends on many factors. It does not necessarily correlate directly with his formal qualifications but a strong socio-cultural factor can be identified. The quality of manual data reduction work achieved in high work ethics cultures such as in the far East may not be easily reproduced elsewhere. In the opinion of the authors obstacles preventing the improvement of the quality of human work are too many, notably so in many developing countries. Even more difficult it is for equipment manufacturers to affect this, beyond providing clear and accurate instructions. It is therefore best to eliminate the possibility of human error. Data reduction and correction can be automated to provide results of sufficient accuracy and consistency. Modern equipment can be built more reliable than manually operated instruments, improving data availability and facilitating maintenance. Cooperation between users, MWO, and equipment manufacturers is recommended.

1
Introduction

Assuming that an upper-air sounding station is provided with a well maintained and calibrated set of equipment the quality of work done depends on established operating procedures and how they are followed. The procedures are the responsibility of the technical management although an important part is played also by the equipment maker in providing thorough and accurate instructions for use of the instruments.

Procedures actually applied at sounding stations are often inadequate. Sometimes, due to gross incompetence of the management, no established procedures are followed. Sometimes procedures, themselves well established, use only part of the techniques available to improve measurement quality. How well the procedures are followed depends on the management as well as on the operators. Little can be done by the equipment manufacturer in this respect. Where proper management is lacking the situation may easily deteriorate into one in which even important steps are ignored. Training may be insufficient, working morale and attitudes variable. In certain cultures indifferent attitudes result in poor general performance.

Modern automated equipment is decisively less sensitive to operator performance. Tasks requiring the highest degree of skill and conscientious work are carried out by machine in a uniform manner. The following deals with the effects of deviations from some important procedures, giving probable causes and suggesting remedies.

2
Operating Errors

The following deals with a few procedures the omission or improper execution of which directly affect the quality of radiosonde measurements. Balloon filling and radiosonde ground handling, which may also have an impact, are not discussed. Much of the following does not apply when using equipment in which these procedures are automated.

2.1
Baseline errors

The height difference between two pressure levels P_1 and P_2 is given by the equation

$$H_2 - H_1 = \frac{R}{g} T_{mv} \left(\ln P_1 - \ln P_2 \right) \qquad (1)$$

where

H_1 = height of pressure level P_1
H_2 = height of pressure level P_2
P_1 > P_2
R = 287.05 Jkg^{-1}
g = acceleration of Earth's gravity
T_{mv} = mean virtual temperature between pressure levels P_1 and P_2

The height error of a pressure level is derived from equation (1):

$$\Delta H = \frac{R}{g} \int_{P_2}^{P_1} \Delta T \frac{dP}{P} - \frac{R}{g} \int_{P_2}^{P_1} \frac{\partial T}{\partial P} \Delta P \frac{dP}{P} \qquad (2)$$

where

ΔT = thermometer error (T measured - T actual)
ΔP = barometer error (P measured - P actual)

The magnitude of the cumulative height error due to 1°K error in the ground check (baseline check) temperature reading is shown in Table 1 (standard atmosphere) {1}.

Table 1

Pressure/hPa	Height error/m
10	134
20	114
30	102
50	87
100	67
300	35
500	20
980	0

In a similar way the impact of a 1 hPa error on height in the ground check pressure reading is demonstrated in Table 2.

Table 2

Pressure/hPa	Height error/m
10	11.0
20	1.5
30	-1.7
50	-4.2
100	-4.5
300	-3.2
500	-1.4
980	0

2.2
Errors due to Lack of Proper Correction of Temperature Readings for Solar Heating/IR Cooling

Table 3 gives an illustration of the solar heating effect on temperature readings in a sounding made in Helsinki on 2 July 1987 at 08.17 UTC. The radiosonde was Vaisala type RS 80.

Table 3

Pressure/hPa	Radiation correction/°K[1]	Height difference/m (corrected - uncorrected)
20	-1.9	-98
30	-1.6	-77
50	-1.3	-55
70	-1.1	-48
100	-0.8	-32

The solar heating effect, besides being specific to instrument type and depending on solar elevation and radiosonde altitude is also affected by the balloon ascent rate. The latter again determines the ventilation fac-

[1] As determined by Vaisala for Radiosonde Type RS 80.

tor to be used to modify the correction which assumes some nominal rate of ascent. This is not insignificant as a temperature sensor exhibiting a nominal 2°K IR cooling at a certain altitude at night might actually be anything from 1.8 to 4.5°K off when the rate of ascent can vary in the range 200 to 600 m/min, depending on balloon type, free lift and gas used. This results in tens of metres in cumulative height towards the end of the sounding.

As the TEMP message cannot convey information on the rate of ascent it is not possible to correct accurately for radiative heating/cooling except at the station before encoding the message. This is carried out either by the operator using manual data reduction or by software when automatic sounding equipment is used. Vaisala recommended procedures for manual data evaluation provide for radiative correction with the ventilation factor included. Corresponding improvements are incorporated in the software of the Vaisala CORA family of ground equipment (MicroCORA, DigiCORA, MARWIN). The corrections are determined on the basis of extensive research and are subject to strict quality control for a uniform product quality.

2.3 Heated Wake of Balloon

Solar heating of the balloon results in a wake of heated air trailing it on ascent. A sufficiently long suspension string between the balloon and the radiosonde allows the wake to disperse before being met by the radiosonde. If this precaution is not taken temperature readings may be significantly affected.

In windy conditions use of a suspension string of sufficient length is difficult. To avoid this problem and the possibility that operators, through ignorance or negligence, use a short string, the Vaisala RS 80 radiosonde is provided with a reel-out device with 30 metres of string.

2.4 Errors in Manual Data Reduction

In addition to the inherent accuracy limitations of analog recorders, another source of error is the process of reading from them. Even the use a system providing digitally recorded values does not completely remove the human factor when transferring readings by manual means. Additional errors are introduced when plotting readings on thermodynamic graph paper (aerogram sheet) for graphical height computation. With well designed automatic equipment reading and computation errors are insignificant. An example of the performance of manual observers versus automated system appears in Table 4. It is based on a study conducted by the Finnish Meteorological Institute {2}. In the study, data obtained by a group of well qualified operators reading and computing data from a set of radiosondes was compared against data automatically produced by the Vaisala MicroCORA equipment.

Table 4. Temperature (ΔT) and geopotential (Δh) differences MicroCORA minus operators A - F at 500 hPa, 100 hPa and 50 hPa levels, calculated from 30 soundings which were reconstructed from significant PTU data selected automatically by MicroCORA and manually by operators.

M = mean, SD = standard deviation, $\bar{M}$ = mean of operators A - F, Cy = difference between original and reconstructed MicroCORA data.

	ΔT °C			Δh m		
	M	SD	Range	M	SD	Range
500 hPa						
A	0.02	0.37	1.0...-0.6	-1.3	4.9	14...-10
B	0.03	0.25	0.6...-0.6	-1.5	3.4	5... -8
C	0.05	0.40	1.0...-0.6	-1.7	4.3	6...-11
D	0.02	0.45	1.0...-0.7	-2.1	4.2	6...-11
E	0.07	0.23	0.7...-0.3	-1.1	3.8	5...-10
F	0.08	0.24	0.7...-0.3	-1.6	3.8	5...-11
$\bar{M}$	0.05	0.28		-1.5	3.7	
Cy	0.09	0.18	0.5...-0.3	-0.8	3.6	7... -6
100 hPa						
A	0.15	0.55	1.0...-1.7	4.0	9.0	28...-14
B	0.06	0.59	1.9...-0.7	5.1	7.5	21... -8
C	-0.03	0.64	1.1...-1.7	3.2	9.8	21...-14
D	-0.04	0.62	1.0...-1.7	2.4	9.8	16...-30
E	0.03	0.57	1.1...-1.7	5.6	8.4	22...-10
F	0.16	0.53	1.1...-0.7	4.6	7.8	23...-14
$\bar{M}$	0.06	0.48		4.2	7.4	
Cy	0.03	0.67	1.4...-1.3	-1.0	9.4	15...-17
50 hPa						
A	-0.04	0.47	0.9...-1.3	5.1	11.7	33...-21
B	0.17	0.37	1.2...-1.3	7.3	13.1	55...-12
C	0.09	0.86	1.5...-2.8	2.4	12.6	22...-22
D	0.26	0.96	2.9...-2.8	2.7	10.4	23...-17
E	0.12	0.75	1.5...-2.8	5.9	10.6	28...-15
F	0.06	0.78	1.2...-3.0	5.3	12.8	29...-34
$\bar{M}$	0.12	0.57		4.8	9.8	
Cy	-0.10	0.67	1.7...-1.9	-0.3	12.4	22...-28

3
Causes of Operational Errors

It is obvious from the above that the main concern is the manually operated stations. Apart from the quality of equipment and maintenance, the reliability of measurement data is affected by a multitude of interrelated factors such as

- established procedures
- supervision and discipline
- general educational level of employees
- on-job training of employees
- work ethics and attitudes

With automatic equipment, presuming that observations are made at all, data should be reliable on all accounts. Admittedly the possibility still exists of making gross mistakes as mixing data calibration tapes of radiosondes or damaging the sonde by rough handling. Such misuse would, however, mostly result in deviations of an order sufficient for the rejection of corresponding data in numerical analysis.

In manual data evaluation high marks in all five points listed above are essential for a good end result. Unfortunately the record in all is generally unsatisfactory in developing countries. There are notable exceptions, though, especially in far East countries with high work ethics. It is, however, all too common to see procedural details skipped, readings taken without care, station reference instruments misused or balloons carelessly handled and even intentionally damaged for early burst. Sometimes soundings are prematurely cut to meet only minimum height requirements, with too few significant points. In extreme cases TEMP messages are fabricated. To be sure, these are not unknown in industrialised countries either.

The baseline check (ground check) is especially sensitive to deviations from established procedures. Reference instrument readings are not taken with care or too little time is allowed for the temperature sensor to attain the checking ambient temperature. Or then the interval between taking the reference and the radiosonde readings which are supposed to represent the same situation is too long.

Applying radiation corrections to temperature readings may be tedious, a long suspension string may be difficult to handle. It is only human to cut corners if sufficient supervision or ingrained ethic and interest in high quality work do not prevent it. Control and motivation are issues of management. It takes proper education, training, experience, and talent to deal with people to make a good manager. Such resources are often scarce in developing countries. Moreover, cultural inhibitions may prevent managers from involving themselves in real hands-on work needed to develop well functioning systems and procedures. Cultural values may also induce able individuals to seek other positions for status where technical/operational work is not viewed as prestigious.

It is possible that no sound basis for operators to follow may ever be established. WMO recommendations and guidelines may not be fully understood and implemented. Instruction manuals may be ignored and no clear criteria may be set against which to assess performance.

It is difficult to bring scientific evidence to verify the above claims. Still, they cannot be ignored, as shown by experience in the field.

4 Scope for Improvement

The title implies that answers are now given as to what equipment manufacturers can do. It must be emphasised, though, that the best result is the outcome of coordinated effort by several parties involved: the user, WMO, and the manufacturer must share in. Suggestions for action are given in the following.

The first priority is to remove the human factor as far as possible by applying automatic equipment capable of using all data improvement techniques which cannot be applied centrally. It is not possible to achieve such a general improvement in the operational standards of stations as to make manual operation an alternative to automation. The high quality of manual data reduction in a country such as the People's Republic of China should not lead to a belief that this is easy to reproduce elsewhere. To remove all weak links also the radiosonde should be made simple to prepare for lauch and rugged to tolerate moderately rough handling.

Manufacturers cannot intervene directly to improve the situation at the stations. Field engineers visiting sites can, and are encouraged by Vaisala to give suggestions for improvement to local managements. A prerequisite for this is that field engineers be trained in all operational steps including TEMP message encoding. This has always been the case with Vaisala field engineers. Naturally great diplomacy is in order when a manufacturer's representative is to make suggestions affecting the internal workings of a customer's organization.

Another area where manufacturers can do much is to ensure that all instruction manuals and other means of instruction are clear, complete and unambiguous. This makes it possible for the local management to establish the correct procedures. Where no factory or on-site training is arranged instruction manuals are the only source of information for the user. Training by manufacturer should, however, be the aim whenever possible. Funds, e.g. through WMO programs should be made available to finance training courses for customers in countries in need and unable to do it on their own. Manufacturers should be well prepared to arrange such training courses.

As to the relative merits of on-site and factory training, Vaisala's experiences are mixed. Training at the factory gives access to all facilities and teaching aids which, in the case of Vaisala, include a sounding station provided with ground equipment of several versions and generations. Such training courses can be very efficient. However, a culture shock and low trainee motivation can often offset these advantages. At the site, trainees are under supervision and their number, expenses considered, can be larger. Facilities and arrangements may leave something to be desired, but successful training can still be given at the site to operate the equipment. However, training for equipment maintenance and repair, requiring more support and specialised instructors, is still best arranged at the factory.

Maintenance aspects in general are not in the scope of this discussion but are touched briefly here. Many developing countries have limited or nonexistent resources to maintain their equipment. Periodic WMO sponsored check-up visits of manufacturers' field engineers to such countries would be very cost effective. Customs formalities are complicated and time consuming in most developing countries, which usually prevents field engineers from carrying spare parts. Ways should be found to establish sufficient stocks of spares on a local basis. As far as manual equipment is concerned, both data availability and measurement quality are affected by poor maintenance. An analog recorder may be in need of calibration, yet data looks good.

With automatic equipment, the question is more one of data availability. If coming through at all, data is likely to be sound. This again speaks for automatic equipment. In addition it is possible to build automatic equipment much more reliable. Purpose built equipment, with embedded software, no analog recorders, printers or disk drives, and with closed cooling system to avoid desert dust and sea side salt spray, can do the basic job of providing TEMP messages direct to the telecommunication channel. General purpose, office environment hardware is not equal to the demands of such conditions and does not offer the same performance in the long run.

With regard to specific causes of data degradation as discussed in Section 2, a lot can be done by manufacturers by product development. The correction schemes necessary must be developed and incorporated in products and/or recommended procedures. Their validity must be verified and product consistency guaranteed to make corrections meaningful. Even better if some sources of data degradation can be eliminated. For example a long suspension string/reel-out device can be made an integral part of the radiosonde and the need for a baseline check eliminated. This development can be speeded up by users specifying automatic equipment provided with such features, and WMO can provide technical guidance.

As a final note, after improvements along the suggested lines, radiosonde performance will ultimately depend on the consistent quality of the radiosonde itself. The radiosonde is a physical measuring instrument in the first place. Sensors, not electronics, are critical. It is doubtful whether radiosondes can be successfully made as a sideline, or in small irregular batches, by the general electronics manufacturer. Specialisation is necessary as are the economies of scale. Small scale production cannot support sound procedures and facilities for proper quality assurance.

5 References

1. J. RIEKER: Influences of Temperature and Pressure Errors on the Determination of the Geopotential between two Constant Pressure Levels and the Height of a Spatial Body in the Atmosphere, translated by H.H. de Carle, Zurich, Switzerland. *Met. Zentralan., Arbeitsber.* No. 65, 1976.

2. SEPPO HUOVILA and ASKO TUOMINEN: Comparisons between Automated and Manual Radiosonde and Upper Wind Observations in Finland, *Finnish Meteorological Institute*, 1986.