SUMMARY OF WMO RADIOSONDE INTERCOMPARISONS

Seppo Huovila
President of CIMO/WMO
Finnish Meteorological Institute
Helsinki, Finland

Summary: The paper reviews international radiosonde intercomparisons coordinated by the World Meteorological Organization. Results of the latest comparison, organized in two phases in 1984 - 1985, are summarized in more detail.

1. INTRODUCTION

The history of WMO radiosonde intercomparisons derives from 1950 when an international comparison of six different radiosonde types was organized in Payerne, Switzerland. The results of this comparison were rather confusing because large differences between various radiosondes were found but the participants were unable to agree upon suitable reference values or instruments. In 1953 the first session of the Commission for Instruments and Methods of Observation of WMO (WMO/CIMO), therefore, requested the president of CIMO to make ar - rangements for a second international comparison of radiosondes.

The second comparison was also held in Payerne in 1956. Fourteen different radiosonde types were compared. It turned out that significant systematic differences still existed between different types. In particular, in the case of several radiosonde types, large radiation errors were found and investigations to determine radiation corrections were requested to be started as a matter of urgency. As one can see from Table 1, the daytime range of systematic temperature differences in 1956 was more than 4°C and the daytime range of systematic geopotential differences about 200 metres at the 100 hPa level. All participants also became convinced that routine radiosondes should be compared with internationally accepted reference radiosondes.

The development of reference radiosondes proceeded slowly, but in 1967 the CIMO working group on radiosonde and radiowind measurements noted the existence of five reference thermo -

Table 1 Mean differences in temperature and geopotential, calculated as deviations of radiosondes 1 - 14 from an arbitrary reference (FRG radiosonde) of the WMO radiosonde comparison in Payerne in 1956. (Abridged Final Report of CIMO-II, WMO - No. 64).

Mean differences in temperature (2 - x) and standard deviations affecting those mean differences (in tenths of degrees Celsius)

Mb	850		700		500		300		200		100	
	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night
2 - 1	-03 (08)	00 (07)	+01 (05)	+05 (04)	+07 (08)	+11 (04)	+16 (09)	+18 (12)	+22 (14)	+17 (09)	+11 (21)	+13 (03)
2 - 3	00 (04)	+02 (04)	-01 (05)	-01 (07)	-05 (08)	-01 (11)	-10 (13)	-07 (09)	-10 (11)	-10 (08)	-16 (14)	-10 (04)
2 - 4	+02 (04)	00 (02)	+03 (08)	-01 (06)	+04 (05)	+10 (09)	+01 (07)	+04 (02)	-02 (06)	+02 (11)	00 (07)	00 (04)
2 - 5	00 (05)	+02 (05)	-05 (08)	+07 (03)	-12 (15)	+07 (08)	-18 (10)	+01 (15)	-11 (13)	+02 (14)	-04 (08)	00 (05)
2 - 6	-03 (06)	00 (09)	-05 (11)	-02 (05)	-11 (11)	-06 (10)	-14 (10)	-05 (18)	-12 (14)	-05 (25)	-24 (14)	-04 (08)
2 - 7	-04 (06)	-02 (04)	-05 (11)	-02 (06)	-06 (05)	00 (10)	-08 (07)	-07 (06)	-04 (07)	-04 (10)	-02 (12)	-05 (03)
2 - 8	+02 (04)	-01 (03)	-01 (04)	-04 (08)	-05 (11)	-04 (10)	-14 (10)	-15 (21)	-13 (08)	-12 (06)	-17 (07)	-17 (12)
2 - 9	-01 (05)	+01 (02)	-01 (03)	+01 (04)	-02 (05)	+07 (04)	+09 (07)	+03 (06)	+08 (07)	00 (07)	+12 (09)	-03 (03)
2 - 11	+09 (08)	+06 (06)	+11 (07)	+10 (06)	+07 (08)	+07 (07)	+04 (09)	+07 (14)	+01 (14)	+05 (19)	+02 (11)	+02 (18)
2 - 12	00 (07)	-01 (04)	+01 (04)	-03 (05)	+02 (13)	-02 (06)	-01 (13)	-05 (10)	-05 (15)	+03 (08)	+05 (24)	+03 (08)
2 - 13	-02 (06)	-03 (04)	-02 (07)	-04 (07)	-08 (13)	-04 (12)	-15 (15)	-11 (10)	-18 (12)	-11 (10)	-22 (14)	-06 (06)
2 - 14	-11 (12)	-11 (x)	-15 (06)	-10 (x)	-21 (08)	-09 (x)	-40 (14)	-19 (x)	-34 (14)	-08 (x)	-31 (16)	-01 (x)

Key

(a) X = 1 Belgian sonde
2 German Graw H50 sonde (Federal Republic of Germany)
3 German sonde (German Democratic Republic)
4 United States sonde (AN/AMT 4 B)
5 Finnish sonde
6 French sonde
7 Japanese sonde
8 Indian sonde (chronometric)
9 British sonde (Kew Mark II B)
10 Netherlands sonde
11 Swiss sonde
12 USSR sonde
13 Indian sonde (fan type)
14 Polish sonde

N O T E : It has not been possible to give figures for sonde No. 10 because the heights have not been calculated for that sonde.

Table 1 Cont.

Mean differences in height (2 - x) and standard deviations affecting those mean differences (in geopotential metres)

Mb	850		700		500		300		200		100	
	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night	Jour/ Day	Nuit/ Night
2 - 1	-4 (3)	-1 (2)	-5 (7)	-2 (3)	-1 (9)	+6 (10)	-2 (25)	-10 (15)	+4 (31)	-9 (12)	+26 (52)	-10 (22)
2 - 3	-3 (3)	-3 (4)	-3 (5)	-3 (6)	-8 (10)	-2 (11)	-23 (19)	-9 (14)	-47 (28)	-56 (62)	-95 (34)	-67 (60)
2 - 4	-1 (3)	-4 (4)	-2 (5)	-5 (5)	0 (9)	-2 (5)	-3 (15)	+2 (7)	-8 (22)	+2 (8)	-16 (23)	-1 (11)
2 - 5	-4 (4)	-4 (2)	-7 (8)	-3 (1)	-19 (9)	-6 (2)	-46 (21)	-27 (5)	-67 (24)	-47 (11)	-91 (61)	-63 (4)
2 - 6	-5 (18)	-1 (4)	-3 (11)	+2 (10)	-15 (13)	-8 (11)	-47 (24)	-35 (26)	-73 (33)	-52 (43)	-153 (124)	-38 (53)
2 - 7	-3 (5)	-3 (1)	-10 (9)	-8 (5)	-21 (11)	-11 (9)	-44 (16)	-28 (22)	-59 (23)	-40 (33)	-95 (42)	-43 (35)
2 - 8	0 (3)	-2 (4)	-2 (5)	-4 (5)	-4 (5)	-8 (11)	-26 (13)	-39 (29)	-53 (13)	-16 (45)	-94 (19)	-55 (69)
2 - 9	-2 (2)	-3 (3)	-2 (4)	-3 (2)	+4 (5)	-1 (4)	+8 (9)	0 (8)	+7 (15)	-4 (9)	-7 (54)	-6 (13)
2 - 11	-3 (11)	-1 (4)	0 (16)	+8 (8)	-8 (21)	+17 (19)	+21 (32)	+18 (31)	+12 (27)	+21 (55)	-8 (54)	+49 (89)
2 - 12	+5 (6)	-3 (5)	+1 (14)	-1 (8)	+6 (15)	+12 (14)	+12 (15)	-6 (27)	+13 (31)	-8 (51)	+15 (30)	-10 (35)
2 - 13	0 (3)	-1 (3)	-4 (4)	+1 (4)	-14 (9)	-4 (14)	-44 (33)	-32 (11)	-76 (62)	-58 (41)	-149 (77)	-97 (25)
2 - 14	-5 (3)	x (x)	-8 (5)	x (x)	-17 (17)	x (x)	-44 (52)	x (x)	-104 (62)	x (x)	-176 (68)	x (x)

metric sonde systems, and recommended a series of comparisons between them to be organized. Following this recommendation, three bilateral comparisons between four reference thermometric sondes were held: between Finland and the Federal Republic of Germany in 1968 in Stuttgart, Germany, between Japan and U.S.S.R. in 1968 in Tateno, Japan and between Finland and U.S.S.R. in 1969 in Leningrad, U.S.S.R.. It turned out that the systematic temperature differences between all these sondes, integrated from 600 to 5 hPa, were very small indeed or of an order of not more than 0.1°C. One should note that this value refers to simultaneous readings during twin soundings. In 1969 CIMO-V therefore observed with satisfaction that any of these types may be used as a (temperature) reference.

CIMO-V also asked the newly-established working group on radiosonde instruments and measurements to study radiosondes using pressure and humidity sensors suitable for reference purposes. This request was never realized. Neither were temperature reference sondes ever widely compared with standard operational radiosondes. In particular, development of reference humidity sensors turned out to be an extremely difficult task, while the relatively high price of temperature reference sondes prevented their worldwide use.

Although some small-scale radiosonde comparisons were made e.g. in connection with the GATE and FGGE experiments of WMO, the Organization's interest in radiosondes was rather low during the following decade. On the other hand, very intensive research and development was initiated by several countries in the 1970's in order to modernize and improve standard radiosondes. Significant coordination of this work took place within the COST 72 project by a group of European countries. The rapid evolution of electronics offered an opportunity to introduce superior radio-sonde components, digital technology and partial or total automation of data treatment and compilation of messages. The ninth WMO Congress in 1983, therefore, recommended organi-zation of an international WMO radiosonde intercomparison and noted the offers by the U.S.A. and the U.K. to host such a comparison.

2. WMO INTERNATIONAL RADIOSONDE COMPARISON 1984 - 1985

2.1 Organization

The WMO International Radiosonde Intercomparison 1984 - 1985 was carried out in two phases. Phase I took place at the Meteorological Office Experimental Site, Beaufort Park, near Bracknell, U.K. from 18 June until 27 July 1984, and Phase II at the NASA Wallops Island facility, Virginia, U.S.A. from 4 February till 15 March 1985.

The radiosonde systems flown in Phase I and Phase II are given in Table 2. Two radiosonde types, those of Finland and the United States, participated in both phases in order to establish a link between Phases I and II.

The contents and rules of the comparison were carefully planned by an International Organizing Committee composed of experts of participating countries and representatives of the WMO Secretary. The Committee held a preparatory meeting in Geneva in November 1983 and a field meeting during each Phase.

2.2 Summary of results

The comparison produced the largest amount of material ever collected from a radiosonde comparison. Data were received from about 200 soundings each of which was a simultaneous in situ test of five different radiosonde types.

The typical bursting altitude of balloons was about 32 kilometres and statistically significant performance records could thus be obtained up to the 10 hPa pressure level. Detailed descriptions of participating systems, data analysis, results and conclusions are to be found in the reports of Phase I (Hooper, 1986) and Phase II (Schmidlin, to be published in 1988) and in the Final Report (Nash and Schmidlin, 1987) of the comparison.

One can see from Figures 1 and 2 that the range in the simultaneous temperature comparison of participating operational radiosondes in daylight was about 1°C at the 100 hPa level and about 4°C at the 10 hPa level, while the corresponding figures for geopotential were about 40 metres at 100 hPa and 100 metres at 10 hPa. Although the comparison methods in 1956 and in 1984 - 1985 somewhat differ from each other, one might conclude from Table1 and from Figures 1 and 2 that the uncertainty in observations made using operational radiosondes is today at the 10 hPa level, in degrees and metres, roughly of the same order as it used to be at the 100 hPa level thirty years ago. The main reasons for this achievement are probably improved sensors, receivers and data evaluation and, in particular, removal of or correction for the radiation errors which were inadequately known in 1956.

Estimates of the reproducibility of standard level temperature and geopotential height measure - ments are given in Tables 3 and 4. In Table 4 values estimated from monitoring the performanceof national networks are also given for comparison. The reproducibility obtained from the in situ comparisons is in general slightly better than the corresponding figures obtained from the

Table 2 Radiosonde systems flown in WMO International Radiosonde Comparison 1984 - 1985 (Nash and Schmidlin, 1987).

Radiosonde Systems Flown in Phase I

	Radiosonde Type	Data Processing Method	Operational Status
Finland	Vaisala RS80-15N	Fully automatic (MicroCora system)	*versions in operational use worldwide
FRG	Graw G78C	Fully automatic	Development system
UK	UK RS3	Fully automatic	UK operational system
USA	VIZ 1392	Data extracted manually, processed automatically	Widespread operational use
Beukers Lab., Inc.	Microsonde 1524	Fully automatic	**Development system

*The version of the Vaisala RS80-15N flown in Phase I was not commercially available outside of Finland until mid-1985. This differed from the version available previously in that the mounting of the relative humidity sensor on the outrigger (including the protective cap) was modified. This could be expected to change the performance of the relative humidity sensor in all conditions and to a lesser extent the temperature sensor in sunlit conditions.

**The Beukers Microsonde was in very limited operational use in Region III. The ground system in use during the comparison was under development and will not correspond directly to systems in operational use.

Radiosonde Systems Flown in Phase II

	Radiosonde Type	Data Processing Method	Operational Status
Australia	Philips RS4-MK3	Manual data selection with automatic processing	In use in Australia and other countries of RA II
Finland	Vaisala RS80-15N	Fully automatic (MicroCora)	Versions used global wide
India	India Meteo. Dept. MKIII	Same as Australia*	Indian region
USA	VIZ 1392	Same as Australia	In use in USA and other global wide sites
Graw	M60	Morse-coded signal reduced manually	FRG and UK overseas station at Gibraltar

*Processing at Wallops Island used a mini-computer whereas within India processing is done manually.

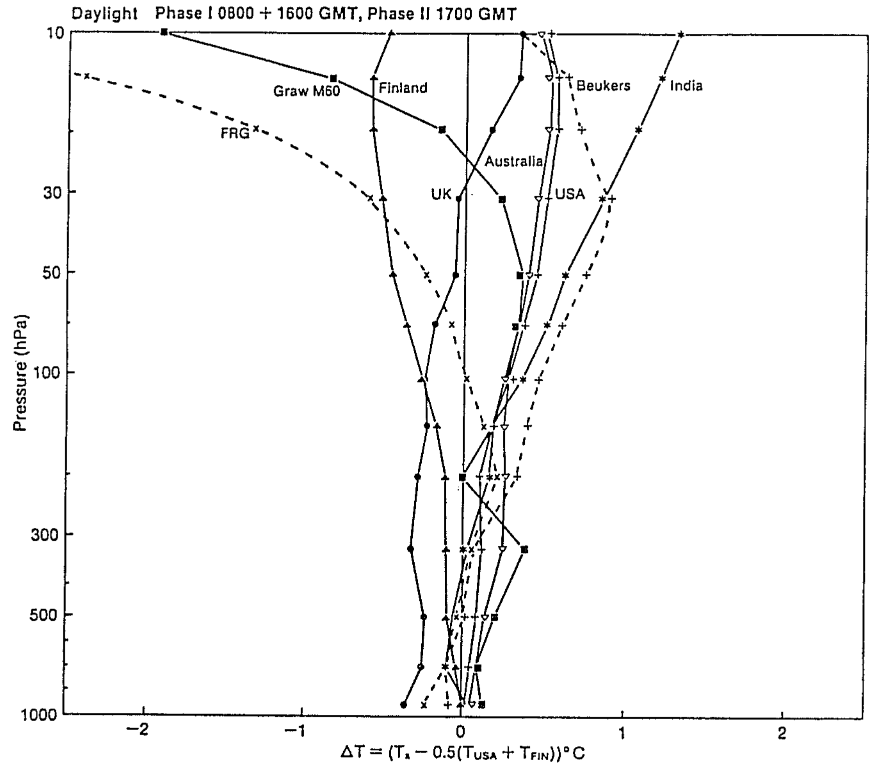

Fig. 1 Combination of simultaneous temperature comparison data from Phases I and II for daylight conditions (Nash and Schmidlin, 1987).

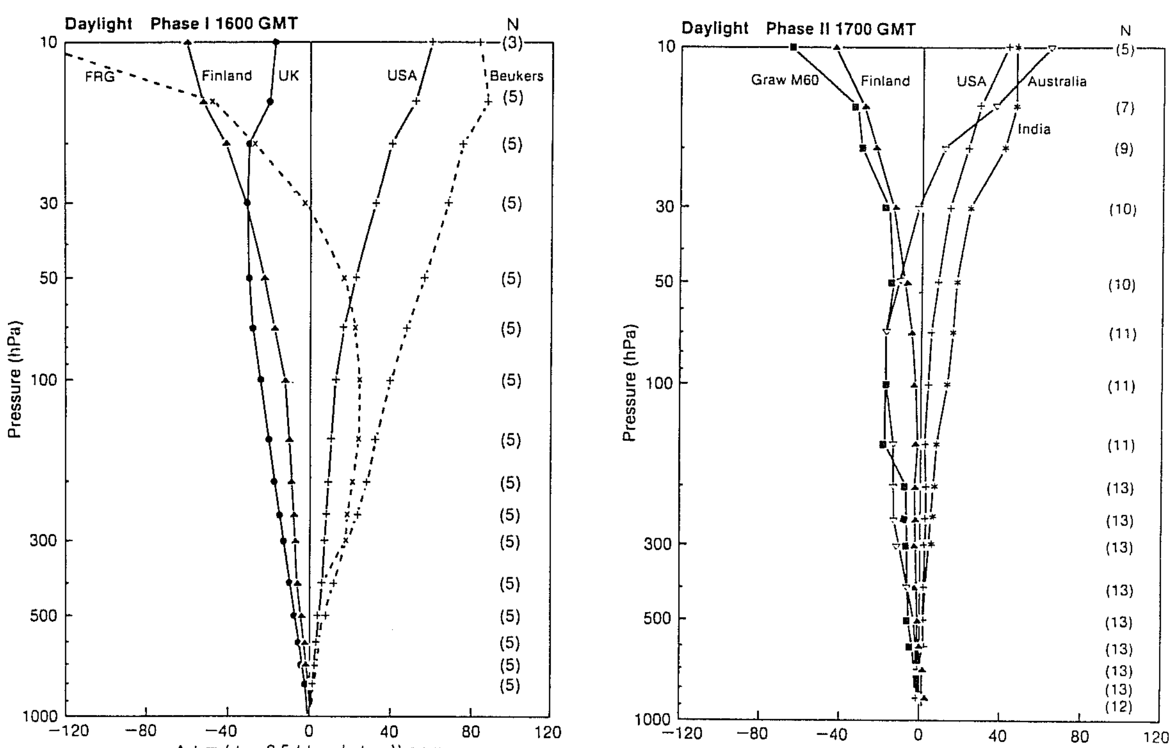

Fig. 2 Examples of standard pressure level geopotential comparison data from Phase I (left) and Phase II (right) for daylight conditions (Nash and Schmidlin, 1987).

Table 3 Estimates of the reproducibility of standard level temperature measurements in °C. The estimates are for one standard deviation (Nash and Schmidlin, 1987).

Pressure Level (hPa)	Link Radiosonde FIN I,II	Link Radiosonde USA I,II	AUS	FRG	IND	UK	BEUK	GRAW
1000	0.3	0.8,0.4	0.5	0.3	0.7	0.3	0.4	0.5
900	0.2	0.4,0.2	0.4	0.2	0.7	0.2	0.3	0.4
850	0.2	0.3,0.2	0.4	0.2	0.7	0.2	0.3	0.4
700	0.2	0.3,0.2	0.4	0.3	0.7	0.2	0.3	0.4
600	0.2	0.3,0.2	0.3	0.3	0.7	0.2	0.3	0.3
500	0.2	0.3,0.2	0.3	0.3	0.7	0.2	0.4	0.4
400	0.2	0.3,0.2	0.3	0.4	0.7	0.2	0.4	0.4
300	0.2	0.3,0.2	0.4	0.4	0.7	0.2	0.5	0.5
250	0.2	0.3,0.2	0.6	0.4	0.7	0.2	0.6	0.5
200	0.2	0.3,0.2	0.8	0.4	0.7	0.2	0.7	0.6(0.5)
150	0.2	0.3,0.2	0.8	0.5	0.6	0.2	0.8	0.8(0.5)
100	0.2	0.3,0.2	0.8	0.5	0.6	0.2	0.9	1.0(0.5)
70	0.2	0.3,0.2	1.2	0.5	0.7	0.2	1.0	1.3(0.7)
50	0.3	0.6,0.3	1.2	0.5	0.8	0.3	1.2	1.5(1.2)
30	0.4	0.8,0.4	1.4	1.0	1.0	0.4	1.4	2.0)1.2)
20	0.5	1.0,0.5	1.6	1.5	1.5	0.5	1.6	2.0(1.2)
15	0.6	1.2,0.7	2.2	2.0	2.0	0.6	1.8	2.5(1.5)
10	1.0	1.5,1.2	3.0	2.5	2.5	1.0	2.0	4.0(1.5)

Estimates for the USA and Finland reproducibility differ from Phase I to II as indicated. Bracketed estimates for Graw are for nighttime flights only.

Table 4 Estimates of the reproducibility of standard level geopotential height measurements in metres. The estimates are for one standard deviation (Nash and Schmidlin, 1987).

Pressure (hPa)	AUS II	FIN I,II	FRG I	IND II	UK I	USA I,II	BEUKERS I	GRAW II
1000	1	2,1	2	1	2	2,1	2	1
900	1	2,1	2	1	2	2,1	2	1
850	1	3,1	3	2	3	3,1	3	2
700	2	3,2	3	6	3	3,2	3	4
600	3	4,3	4	9	4	4,3	4	5
500	4	4,4	4	11	4	4,4	4	6
400	4	5,4	5	14	5	5,4	5	8
300	6	5,5	5	19	5	5,5	5	10
250	8	6,6	6	20	6	6,6	6	12
200	9	6,7	6	21	6	6,7	7	14
150	10	7,8	7	24	7	7,8	8	17
100	13	8,10	8	27	8	8,10	9	21
*100	*19	*13	--	*60	*11	*16(±2)	--	*16,21
70	17	8,11	9	30	9	9,11	10	23
50	18	10,12	10	32	10	10,12	15	25
*50	*22	*16	--	*≥100	*12	*21(±3)	--	*18,29
30	24	12,14	15	40	12	12,14	20	30
20	27	15,16	20	45	15	15,16	25	40
*20	--	*25	--	--	*16	*30(±5)	--	*30,53
15	32	20,20	25	50	20	20,20	30	45
10	45	25,25	30	60	25	25,25	35	55

*Values estimated from monitoring time series of measurements from individual stations within the respective national networks between 1983 and 1985. The values quoted are estimates of the average performance for the national network. The estimates are dependent on the method of quality control applied prior to the analysis of the observations. The estimate of the reproducibility of the higher performance radiosondes may vary by about ±2 m according to the quality control in use, with about 1 to 2 percent of the observations being rejected. In the case of India about 10 percent of the observations have been rejected by the quality control applied prior to the analysis.

The data in brackets following the reproducibility estimates for the operational USA network are the standard deviations taken from the distribution of the individual station estimates of the network.

Two estimates of operational reproducibility are quoted for the Graw M60, the first being the value found within the FRG, and the second being the value found at Gibraltar.

monitoring. The Indian radiosonde, however, turned out to be considerably better in the instrument comparison than one might expect in the light of the monitoring results.

2.3 Conclusions and recommendations

The Final Report of the comparison also contains certain conclusions, of which the following may call for particular attention:

- The comparison demonstrated that fully-automated radiosonde systems were able to reproduce geopotential measurements better than non-automated systems, mainly due to a decrease in observer mistakes

- The observed temperature differences between radiosonde measurements were as large at night as in daytime conditions

- Significant inconsistencies were still found between the nighttime and daytime measurements, as well as significant bias errors in the pressure measurements of some radiosonde types.

In addition, the Final Report makes recommendations to manufacturers, operators and users. The manufacturers are e.g. encouraged to increase automation in order to minimize errors caused by manual treatment of chart records and manual computation of geopotential heights. On the other hand, automated systems should be provided with highly standardized instrumental correction procedures in order to avoid systematic errors.

Finally, a suggestion is made in the Final Report to hold, as soon as possible, an intercomparison of those widely-used radiosondes which did not participate in Phases I and II, i.e. the radiosondes of China, Japan and the U.S.S.R.

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