THE RELEVANCE OF THE WMO INTERNATIONAL RADIOSONDE COMPARISON RESULTS TO THE GLOBAL OPERATIONAL RADIOSONDE NETWORK

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Summary: The quality of radiosonde observations determined by the WMO International Radiosonde Comparison is compared against that of operational radiosonde observations by the same radiosonde types.

It is demonstrated that for temperature and standard level geopotential height observations the WMO Comparison results provide a reliable basis from which to derive the relative performance of other radiosonde types which did not participate in the original intercomparison.

The methods by which this should be attempted are discussed.

1. INTRODUCTION

Improvement of the compatibility of temperature measurements by different operational radiosonde types (to better than ± 0.2 °C) is required in order to :-

- optimise the use of temperature and geopotential height observations in meteorological analysis, especially that used by numerical forecast models.
- optimise the use of radiosonde observations in the retrieval and verification of temperature observations from satellite radiance measurements, especially in the radiometer calibration required by physical temperature retrieval schemes.
- improve the monitoring of long term climatological changes in the temperature of the upper atmosphere. Small changes (≃ 1°C) are significant and have been introduced by changes in the radiosonde type used at certain stations in recent years (e.g. when the UK RS3 radiosonde was introduced into the United Kingdom network in 1979 , a design fault in the temperature sensor caused temperature observations

to be low by about 1.5°C in the stratosphere ,until the fault was rectified in the middle of 1981.)

In the past, a variety of techniques have been applied to monitoring the quality and compatibility of radiosonde measurements. These have included estimation of the reproducibility and selfconsistency of measurements from time series of geopotential height measurements at individual radiosonde stations ,and the compilation of statistics of measurement bias relative to numerical analysis fields e.g. see Spackman (1978), and the series of reports by the CIMO Rapporteur on Radiosonde Compatibility which include Moores (1982) and Nash (1984), and the review of long term trends in performance by Forrester (1985). Day-night differences between temperature measurements were also quantified in additional studies by McInturff, et. al. (1979). More recently ,the use of statistics of observational bias relative to short term numerical forecast fields at ECMWF has been advocated in Hollingsworth, et al (1986) and summaries of such statistics have been made available to other users in publications such as Böttger, et al (1987) .

It has not been possible to evaluate the limitations of these techniques very thoroughly because of the lack of insitu comparison data on the relative performance of different radiosonde types, particularly those which have been operated in widely separated regions of the global network. The WMO International Radiosonde Comparison was designed to remedy this deficiency by the provision of a reliable comparison data set. This was generated from simultaneous observations by different radiosonde types on a single flight rig. The radiosonde types tested were typical of those in widespread use in all areas of the global radiosonde network ,apart from the area of central and eastern Asia in which the networks of China, Japan and U.S.S.R. are situated.

The purpose of this paper is to examine the relationship between the WMO Comparison data and the results from some of the other compatibility evaluation techniques indicated above.

2. THE WMO INTERNATIONAL RADIOSONDE COMPARISON

The WMO International Radiosonde Comparison (Phase I in the U.K. and Phase II in the U.S.A.) has provided the most comprehensive set of direct intercomparison measurements on the relative performance of modern operational radiosonde types (Nash and Schmidlin ,1987).

Particular features of each phase of the test were :-

- The equipment was generally operated by national representatives so that observational practices employed could be related to standard national methods of observation.
- Five radiosonde types were flown together on most comparison flights with output from each sensor (pressure .temperature and relative humidity) sampled simultaneously at 1 minute intervals to provide direct comparison data .Hence,the performance of the pressure and temperature sensors could be evaluated independently to provide insight into the origin of differences between the standard operational radiosonde products.
- Flight schedules were designed to provide a limited number of specified flight conditions with a large number of comparison flights associated with each condition ,e.g.in each phase at least 20 comparison flights were obtained in darkness with most flights rising to levels above the 10 hPa level.The earlier SONDEX radiosonde intercomparison ,Richner and Phillips (1982),provided valuable qualitative information to the various participants ,but the data sets were much too small to be of value in the adjustment of operational observations.

The operational radiosonde types which participated in the WMO comparison were, in Phase I , Vaisala RS80 (Finland) ,VIZ 1392 (U.S.A.) and UK RS3 (U.K.) and ,in Phase II, Graw M60 (radiosondes supplied by U.K., with the permission of the F.R.G.), Indian Met.Dept MK.III (India),Philips RS4 (Australia),Vaisala RS80 (Finland) and VIZ 1392 (U.S.A.).The Beukers Microsonde which also participated in Phase I is in operational use at a limited number of stations in Thailand and Korea,but not in the U.S.A..

3. THE INFLUENCE OF ERRORS IN PRESSURE AND TEMPERATURE MEASUREMENTS ON STANDARD PRESSURE LEVEL GEOPOTENTIAL HEIGHT ERRORS

The error, ϵ_ϕ, in a radiosonde observation of the geopotential height of a standard pressure level p_1 can be written as :-

$$\epsilon_\phi = -1000.R/9.8065\{\int_{\ln p_o*}^{\ln p_1} [\epsilon_T(p*)+\epsilon_p.\delta T_v/\delta p+\epsilon_U.\delta T_v/\delta U+\epsilon_{fit}+\epsilon_{rep}].d(\ln p*)$$

$$+\int_{\ln p_o}^{\ln p_o*} T_v.d(\ln p*)\} \qquad (1)$$

where $p*$ is the true atmospheric pressure,

T_v is the virtual temperature attributed to the value of $p*$ in the processed radiosonde data

R is the gas constant for dry air, (0.28705 joule.$g^{-1}.K^{-1}$),

p_o is the pressure attributed to the nominal height above sea level of the station, whilst p_o* is the true value of this pressure (an error of 1 hPa in p_o introduces an error of about 10m into the geopotential heights through the last term in equation (1));

and where the errors in the virtual temperature are as follows:-

(i) $\epsilon_T(p*)$, the error in virtual temperature introduced by the radiosonde temperature sensor measurement. This error could be due, amongst other reasons, to sensor calibration error, error resulting from the relatively slow thermal response of the sensor, heating of the sensor by solar radiation, cooling of the sensor at infrared wavelengths if the sensor has a high emissivity in the infrared, or errors introduced by the poor thermal isolation of the sensor from its mount onto the radisonde body. All current radiosonde types require correction for solar heating of the temperature sensor. For this reason, evaluation of performance in daylight conditions must be considered separately from performance in darkness. Note that a mean layer temperature error of 1°C from the surface to 100 hPa produces a geopotential height error of about 65m in a measurement of 100 hPa geopotential height in midlatitudes.

(ii) $\epsilon_P.\delta T_v/\delta p$, the virtual temperature error introduced by incorrect assignation of the pressure at a given time into flight, due to error in the radiosonde pressure measurement, ϵ_P. The temperature error introduced by a 1 hPa pressure sensor error throughout a flight for three typical atmospheric profiles is illustrated in Fig. 1, together with estimates of the resultant errors in some of the standard pressure level geopotential height measurements. The WMO comparison identified a systematic positive bias in the Philips RS4 pressure sensor of between 2 and 3 hPa. This error was rectified in operational measurements in the middle of 1985. Reference to Fig. 1 indicates that at this time significant temperature changes in mean layer temperature (as large as 1°C in the tropics) resulted at the stations where this radiosonde was in use.

(iii) $\epsilon_U.\delta T_v/\delta U$, the virtual temperature error introduced by the error ϵ_U in the relative humidity sensor. In the United Kingdom a mean error of 10 per cent in the relative humidity measurement at levels between the surface and 700 hPa , would produce an error in the geopotential height of pressure levels above 700 hPa of about 2m . The errors would be somewhat larger in tropical regions.

(iv) ϵ_{fit}, the temperature error at pressure p* introduced in the ground processing and message generation. In modern automated systems, this error is generally negligible. However, in the many countries where messages are generated manually by the operator , the fitting limits of ± 1° C in the troposphere and ± 2°C in the stratosphere allowed by the current WMO coding procedures, even if obeyed by the operator leave considerable scope for significant mean layer temperature errors. These are often larger than $\epsilon_T(p*)$ and will vary from operator to operator. There is little purpose in attempting very accurate station adjustment procedures when using the TEMP messages from a station with such practices, even though the radiosonde type in question produces measurements of very high reproducibility when used with automated ground equipment.

(v) ϵ_{rep}, the representativeness error in the radiosonde measurement. This error is introduced by small scale temperature and relative humidity perturbations in the atmosphere encountered during the radiosonde ascent. These limit the radiosonde sample to an imperfect representation of the mean state of the atmosphere relevant to the large scale motion fields. The representativeness error in a radiosonde temperature measurement at a given pressure level is larger than 0.5°C at all levels from the surface to 100 hPa . However, these errors tend to canacel out during the integration in the vertical necessary to generate the 100 hPa geopotential height , so that the representativeness error relevant to current synoptic scale models in this geopotential height is about 12m , equivalent to about 0.2°C in mean layer temperature error, (Kitchen, 1987).

For this reason, operational radiosonde performance should be evaluated in terms of measurements of mean layer temperature or difference in geopotential height between widely separated standard pressure levels in the atmosphere to ensure that representativeness errors are relatively small compared to the other terms in equation (1). Note also that with modern automated systems the standard level geopotential height observations are computed from fine structure radiosonde observations which are not subject to the significant fitting errors which are present in mean layer temperatures computed from the significant level data reported in parts B and D of the coded TEMP messages. Hence geopotential height observations are used in preference to mean layer temperatures wherever possible in the remaining sections.

4. THE REPRODUCIBILITY OF MEASUREMENTS OF STANDARD PRESSURE LEVEL GEOPOTENTIAL HEIGHT

Table 1(a) summarises the estimates of the reproducibility (1 standard deviation) with which the geopotential heights of standard pressure levels were measured in the WMO comparison. These are compared with estimates from time series of operational observations at individual stations in summertime conditions between 1983 and 1985 produced by the CIMO Rapporteur on radiosonde compatibility.

The measurements of the Vaisala RS80 and the UK RS3 have been compared on two other occasions, in 1983 and 1987, utilising operational flights at Crawley radiosonde station, but with experimental technique similar to that of the WMO comparison. The standard deviation associated with the differences between the geopotential height observations in these tests are presented in Table 1b, together with samples from the WMO comparison.

Pressure (hPa)	Graw M60	Indian Mk III	Philips RS4	Vaisala RS80	UK RS3	VIZ 1392
500	6	11	4	4	4	4
200	14	21	9	7	6	7
100	21	27	13	9	8	9
*100	16,21	60	19	13	11	16
50	25	32	18	11	10	11
*50	18,29	≥100	22	16	12	21
30	30	40	24	13	12	16
20	40	45	27	16	15	16
*20	30,53	--	--	25	16	30
10	55	60	45	25	25	25

* Estimates from individual station time series. The first value quoted for the Graw M60 was taken from the F.R.G. stations and the second value from Gibraltar. (At 100 hPa, 13m error in geopotential height corresponds to approximately 0.2 °C in mean layer temperature from the surface to 100hPa.)

Table 1(a) Estimates of the reproducibility (1 standard deviation) of radiosonde measurements of standard pressure level geopotential heights taken from the WMO comparison, units (m).

Pressure (hPa)	Crawley 1983	WMO Comparison 1984	Crawley 1987
300	7	6	5
100	13	11	9
50	17	15	11
30	21	17	14
20	33	21	18
10	--	33	28

Number of flights : Crawley 1983, 0000 GMT ≃ 20, 1200 GMT ≃ 20;
Crawley 1987, 0000 GMT ≃ 20. 1200 GMT ≃ 20, 1800GMT ≃ 20.

Table 1(b) Direct measurements of the standard deviation of the differences between the standard pressure level geopotential height differences of the Vaisala RS80 and the UK RS3 radiosondes, units (m).

The design of the RS80 pressure sensor mount was modified in 1984 to improve the performance of the pressure sensor assembly. In addition, the external mounting of the temperature and relative humidity sensors was also modified prior to the WMO comparison to allow the clear plastic cap protecting the relative humidity sensor , which overheated in sunshine, to be replaced by an aluminised cap. The modifications have proved effective, particularly in the case of the pressure sensor. The scatter between the measurements in the two later tests was less than in 1983 , but all support the high quality of measurements of these two radiosonde types. In the latter two tests the measurement reproducibility of the two radiosonde types can be assumed to be equivalent so that the values in Table 1(b) should be divided by 1.4 to produce an estimate of individual instrument performance.

As noted earlier the standard deviation of the difference between standard level geopotential height measurements and the ECMWF first guess forecast field has also been used to estimate measurement reproducibility. Standard deviations sampled from June, July and August 1986 are presented in Table 1(c).

Pressure	Graw M60	Indian	Vaisala RS80		UK RS3	VIZ
(hPa)	F.R.G.	Mk.III	Ireland	Finland		U.S.A/Alaska
300	16,15	55	17	13	16	
100	22,22(17)	107	16(12)	14(10)	16(11)	18
30	29,32	131	22	22	22	27
20	33,39	140	29	30	25	32
10	42,62	--	--	--	36	43

The values for the Graw M60 are cited separately for 0000 and 1200 GMT respectively. The values in parentheses are estimates of reproducibility from the analysis of the station time series during the same period.

Table 1(c) Examples of the standard deviation of the difference between radiosonde geopotential height measurement and the ECMWF first guess field in June, July and August 1986, units (m).

If the uncertainty in the forecast first guess fields in summertime conditions at 100 hPa is $\sigma_{F.G.}$, an estimate of measurement reproducibility, $\sigma_{R/S}$, can be derived from the observation -first guess (OBS-F.G.) biases using :-

$$\sigma_{R/S}^2 = (\text{s.d. of OBS} - \text{F.G.})^2 - \sigma_{F.G.}^2 \qquad (2)$$

Comparison of the results in Table 1(a) with those in Table 1(c) for the higher performance radiosondes indicates that a value of $\sigma_{F.G.}$ of

12± 2m at 100 hPa was appropriate for summertime conditions in 1986 in western Europe and north America. The results at levels above 100 hPa in Table 1(c) indicate that measurements by the UK RS3 and the Vaisala RS80 were of very similar quality. Thus the differences in the results at 300 hPa are taken to indicate a significant variation in the reproducibility of the ECMWF first guess field between the British Isles and Finland rather than any difference in measurement quality.

Reference back to Table 1(a) indicates that the operational measurements of the VIZ and Philips radiosondes appear to be of slightly lower quality than those obtained in the WMO comparison, see Table 1(a). The geopotential height computations in the WMO comparison were computed from data sampled once per minute which was a higher rate than that generally used in operational observations with these radiosonde types. Hence, ε_{FIT} errors in the WMO comparison were reduced relative to usual station practice. However all the values cited in Tables 1(a) and (c) indicate performance superior to that indicated by the twinflight testing of Hoehne (1980).

The operational measurements of the Graw M60 at Gibraltar were of similar quality to those obtained in the WMO comparison , but not as good as those obtained operationally in the F.R.G.. The results in Table 1(c) illustrate one of the advantages of the use of the ECMWF first guess field in that it is possible to identify that the reproducibility of the daytime geopotential height observations at 10 hpa was inferior to that of the nighttime observations , a result which would have been expected from the better reproducibility of Graw temperature measurements at night observed in the WMO comparison at levels above 100 hPa , see Nash and Schmidlin (1987).

The quality of the Indian measurements in the WMO comparison was vastly superior to that of Indian operational measurements. The operational measurements are degraded primarily by deficiencies in the ground equipment and methods of observation at operational stations in India , many of which were identified in the WMO comparison , rather than by the poor quality of the radiosonde and its sensors. Note that in the operational estimate in Table 1(a), 10 per cent of the observations have been discarded. This level of quality control has not been exercised before generation of the statistics in Table 1(c) and consequently the measurements appear even poorer than in Table 1(a).

In summary ,the WMO comparison data provide a reliable estimate of the reproducibility of geopotential height measurements obtainable by radiosondes operated with fully automated ground equipment. Deficiencies in methods of observation lead to operational data of poorer quality than those obtained in the WMO comparison for radiosonde types where data reduction is not automated. A mechanism by which deficiencies in ground equipment or methods of observations can be rectified should be a priority for any monitoring scheme ,since it appears that it is these aspects rather than the quality of airborne equipment which are devaluing the observations at many stations.

Evaluation of measurement reproducibility from the time series of geopotential height observations at a station does not need a knowledge of forecast field errors . In midlatitudes this technique can produce reliable estimates at levels above 100 hPa when there is a near continuous series of observations at the station . This is generally not the situation at pressure levels above 20 hPa. Thus for stations and pressure levels where missing data are common, evaluation against forecast fields is clearly necessary ,even if quantitative interpretation is more complex.

5. SYSTEMATIC BIAS BETWEEN OBSERVATIONS OF STANDARD PRESSURE LEVEL GEOPOTENTIAL HEIGHT AT NIGHT

Table 2(a) presents the systematic bias measured between standard level geopotential height measurements of the Vaisala RS80 and the UK RS3 at 100,30 and 10 hPa from the three intercomparison tests which were mentioned in the previous section. Systematic biases between simultaneous temperature and pressure sensor measurements have also been included in order to aid interpretation. The systematic biases between the geopotential height measurements in the two later tests agree very closely but are quite different from those in the first test. This difference originates from the correction applied by the Vaisala ground equipment to the temperature measurements in the 1983 test (1982 correction scheme.). This scheme was modified by Vaisala prior to participation in the WMO comparison in 1984 e.g. the temperature correction at 100 hPa was reduced from 0.8°C to zero , at 30 hPa from 0.8°C to 0.3°C and at 10 hPa from 1.0°C to 0.7°C. The correction scheme used in the WMO comparison was subsequently revised again (although nighttime corrections values were not altered any further) and issued officially as the 1986 scheme, see Nash and Schmidlin (1987). Vaisala CORA or MicroCora ground systems may have any one of these three correction schemes at present , although action is being taken by the manufacturer, in the long term, to convert all to the 1986 scheme. [Stations in Europe and North Africa at which the day-night difference in the 100 hPa geopotential height measurement is about -30m are probably still using the 1982 correction scheme.]

Systematic bias [Vaisala RS80 - UK RS3]

Test	Geopotential height (m)			Pressure (hPa)			Temperature (°C)		
	100	30	10 hPa	100	30	10 hPa	100	30	10 hPa
Crawley'83	54	98	--	1.3	1.2	--	1.0	1.0	--
WMO I '84	27	43	57	-0.2	-0.0	-0.2	0.4	0.6	1.4
Crawley'87	22	40	64	-0.3	-0.3	-0.3	0.4	0.6	1.1
Standard error	2	4	9	0.2	0.2	0.2	<0.1	<0.1	0.1

Table 2(a) Direct comparison between Vaisala RS80 and UK RS3 measurements at 0000 GMT.

Geopotential height difference (Vaisala RS80 -UK RS3) (m)

Station	100 hPa			30 hPa		
	1	2	3	1	2	3
Valentia[03953]	46(16)	49(19)	44(14)	--	87(32)	78(23)
De Bilt [06260]	43(13)	54(24)	43(13)	--	92(37)	85(30)
St-Hubert[06476]	53(23)	60(30)	54(24)	--	104(49)	98(48)
Thorshavn[06011]	27(12)	35(20)	32(17)	--	56(41)	48(33)

1 using mean bias relative to analysed field after Moores (1982).
2 using mean bias relative to ECMWF first guess field.
3 using mean bias relative to ECMWF analysis.

Table 2(b) Systematic bias between operational Vaisala RS80 and UK RS3 measurements at 0000GMT derived from nearest neighbour comparisons against analysed or first guess fields. ( ) indicate values which have been adjusted to correspond to the Vaisala WMO/1986 temperature correction scheme.

In Table 2(b) the differences between operational geopotential height measurements of a Vaisala RS80 station and those at two neighbouring UK RS3 stations have been evaluated using comparison against an analysis or first guess forecast field at the station location , where :-

$$\Delta\phi_{(Vaisala - UK)} = \Delta\phi_{(Vaisala-REFA)}) - \Delta\phi_{(UK-REFB)} \qquad (3)$$

and where REFA is the reference field at the Vaisala station and REFB the reference field at the UK station. These data were taken from sample periods between June 1986 and June 1987 when Valentia and St- Hubert were still using the 1982 correction scheme ,The performance at De Bilt appears similar to these stations so use of 1982 corrections will be assumed. Thorshaven used a modified version of the 1982 scheme which results in 100 and 30 hPa geopotential height measurements which are low by about 15 m relative to the stations using the 1982 scheme. The stations using the 1982 scheme are, in turn, biased high relative to stations using the WMO/1986 scheme by about 30m at 100 hPa , about 55m at 30 hPa and about 67m at 10 hPa. Once the systemtic biases in Table 2(b) have been adjusted to be compatible with the Vaisala WMO /1986 correction scheme, it can be seen that the use of the first guess field as a reference has provided estimates of systematic bias which are on average almost identical to those measured in the WMO comparison.

Table 3(a) contains a summary from the WMO comparison of the performance of the Vaisala RS80 relative to the VIZ 1392 and Graw M60 radiosondes. The discrepancies in the systematic bias between Vaisala and VIZ geopotential height measurements in the two phases originated primarily from a difference in relative temperature sensor performance between the surface and 100 hPa which is typified in the temperature comparison data at 100 hPa. Phase I and Phase II values should be averaged together for the purpose of this evaluation. At 10 hPa there was clearly a significant difference in the systematic bias of the VIZ temperature sensors relative to Vaisala between each phase of the WMO comparison. This was much bigger than the difference between the two VIZ sensors in each phase and also the difference between tests in the (Vaisala - UK) comparison in Table 2(a). The VIZ thermistor indicates colder temperatures at this level than the Vaisala mainly as a result of infrared cooling errors. These will vary to some extent with according to the infrared background and ambient temperature. Hence ,the difference in systematic bias between the two phases was probably the result of changes in this infrared error.

Results from the application of the nearest neighbour technique at Prince George, B.C. [Vaisala RS80 radiosondes flown with 1986 corrections] ,with neighbouring VIZ stations and between Graw stations in the F.R.G. and neighbouring Vaisala stations are summarised in Table 3(b).The biases obtained using the ECMWF first guess field or the analysis field were generally within 10 m of those measured in the WMO comparison ,see Table 3(a).

Systematic bias [Vaisala RS80 - X]

Radiosonde X [WMO Phase]	Geopotential height (m) 100	 30	 10hPa	Pressure (hPa) 100	 30	 10hPa	Temperature (°C) 100	 30	 10 hPa
VIZ [I]	11	30	72	-0.6	-0.4	-0.1	0.3	1.1	3.1
Beukers [I]							0.5	1.3	3.5
VIZ [II]	27	47	86	-0.3	-0.2	0.2	0.6	1.1	2.6
Philips[II]							0.7	1.2	2.4
Stand.Error	2	5	10	0.2	0.2	0.2	<0.1	<0.1	0.1
Graw [II]	14	31	85	-0.2	1.0	2.0	0.1	0.9	3.2
Stand.Error	5	9	22	0.5	0.5	0.6	<0.1	0.1	0.3

Table 3(a) The relative performance of the Vaisala RS80,VIZ and Graw M60 radiosondes from the WMO comparison.

Geopotential height difference [Vaisala RS80 - X] (m)

X	100 hPa 1	 2	 3	30 hPa 1	 2	 3	10 hPa 2	 3
VIZ	-9	13	12	--	45	36	--	--
F.R.G.[N]	35(5)	34(4)	37(7)	--	76(21)	81(31)	156(89)	160(93)
F.R.G.[S]	22(-8)	41(11)	39(9)	--	79(24)	69(14)	184(117)	160(93)

1,2 and 3 as in Table 2(b).
VIZ between Vaisala ,71896(Prince George) and neigbouring VIZ stations to the north and west in Canada and Alaska at 1200 GMT during December 1986-February 1987.
F.R.G.[N] between Vaisala (06260,06476) and northern Graw stations
F.R.G.[S] between Vaisala (16044,16080) northern Italy and southern Graw stations.All F.R.G. comparisons at 0000 GMT,data samples between June 1986 and June 1987.

Table 3(b) Systematic bias between operational Vaisala RS80 and VIZ or Graw measurements in darkness derived from nearest neighbour comparisons against analysed or first guess fields. ( ) indicate values which have been adjusted to correspond to the Vaisala WMO/1986 temperature correction scheme.

In summary, the systematic biases observed between nighttime measurements in the WMO comparison are clearly supported by monitoring of operational observations.Correction of daytime observations at a station to nighttime values will not in itself ensure compatibility between the temperature and geopotential height measurements of all radiosonde types , adjustment of the nighttime measurements according to radiosonde type is also required. The impact of different methods of observation on operational observations by a given radiosonde type have also to be quantified and compensated.

6. IMPLEMENTATION OF A RADIOSONDE COMPATIBILITY ADJUSTMENT SCHEME

On the basis of the preceding evidence ,the following are suggested as the principal elements of a radiosonde compatibility adjustment scheme:-

- the relative performance of several different radiosonde types within a region should be established by direct intercomparison with radiosonde types of known performance relative to the WMO intercomparison reference. For the moment ,this reference has to be taken,see Nash and Schmidlin(1987), as the average of the VIZ and Vaisala (WMO/1986 scheme) measurements in the dark. A direct comparison of Japanese measurements (the measurements of which are of much better reproducibility than the radiosondes of China and the U.S.S.R.) with VIZ and Vaisala would be of the greatest immediate benefit following the WMO comparison. The relative performance of the most widely used radiosonde types should be further checked with an ongoing series of intercomparison tests at appropriate intervals.
- if the relative performance of sufficient radiosonde types within a region has been established, the variation of sytematic bias errors in model reference fields throughout the region should be estimated. For example ,the variation in systematic bias error of the nighttime ECMWF First Guess field in western Europe for June,July and August 1986 has been estimated in Fig.2. This plot shows that the first guess bias errors relative to the WMO reference were not constant over the whole of the region considered,particularly over the British Isles. Comparison with similar plots in winter 1986 and summer 1987 indicated that the systematic errors in the first guess field also vary from with time.
- daytime reference fields should be referenced to nighttime measurements through the day- night differences established in the direct comparison tests and from measured day-night differences in operational observations ,given that these are interpreted in terms of a reliable model of the diurnal tide at the stations,e.g. see the tidal plots derived by Nash in Hooper (1986) and the WMO comparison measurements in Fig.3. The recommended temperature adjustments for temperature in Nash and Schmidlin (1987) were derived in this fashion.

- the biases relative to the reference fields at individual stations should then be examined to determine atypical station performance within a national network .Atypical stations should be flagged (e.g.see Fig.2)and notified to the operators so that the origin of the anomaly can be identified and rectified.

- the performance of radiosonde types which have not participated in direct intercomparisons should be estimated using nearest neighbour techniques with a suitable field as a reference .Table 4 contains estimates of the systematic bias of the radiosondes of Austria,France and the U.S.S.R.(selected stations near the border with Finland) relative to the WMO comparison reference derived using the ECMWF first guess fields in June and July 1986.

Pressure (hPa)	Austria 0000	Austria 1200 GMT	France 0000	France 1200 GMT	U.S.S.R. 0000	U.S.S.R. 1200 GMT
300	-10	12	0	5	11	13
100	-40	12	-5	25	25	30
50	-55	30	-10	35	30	40
30	-70	50	-10	45	30	40
20	-75	65	-20	65	30	35
10	-100	90	-45	55	0	0

U.S.S.R.(stations 22802,26038,26063,26258,26702).

Table 4 Systematic biases of geopotential height (m) measurements related to the nighttime WMO reference ,through nearest neighbour comparisons using the ECMWF first guess fields as a reference to Graw,Vaisala and UK RS3 measurements in June and July 1986.

- in regions where the systematic errors in the reference field canoot be related to the WMO comparison reference through known radiosonde performance ,attempts should be made to use satellite radiance observations to validate the reference fields.Some progress has been made towards this goal in the Meteorological Office by comparison of radiances synthesised from radiosonde observations with collocated radiance observations by the MSU radiometer on NOAA-9.Initial results of intercomparisons of radiosonde measurements with channel 23 radiances in autumn and winter nighttime observations in 1985 amd 1986 indicate a difference in Vaisala(Scandinavia) - VIZ (U.S.A./Alaska) of 0.5 ± 0.1°C .The channel 23 radiance originates from emission through a layer ,approximate halfwidth in the vertical ≃ 10 km ,which is centred close to 300 hPa so that this difference appears compatible with the direct comparison data in Table 3(a).Lange (1987) has also proposed a method by which satellite radiance observations may be incorporated in radiosonde monitoring.

7. STRUCTURE OF A RADIOSONDE MONITORING CENTRE

The considerations in the preceding sections lead to the following comments on the possible structure of a radiosonde monitoring centre. This structure should take into account the following considerations :-

- recommended adjustment schemes should be applicable to the requirements of all users and not just numerical modellers.
- any radiosonde measurement adjustment scheme should result from a complex investigation of monitoring and comparison data as indicated above .At present suitable adjustments cannot be provided solely by reference to numerical model fields without recourse to other performance data.
- Apart from variation with solar elevation ,the performance of a given radiosonde type does not usually vary very rapidly from month to month if the equipment is utilised correctly.Thus,adjustment procedures whilst reviewed regularly on a monthly basis should not be updated frequently unless there is unequivocable evidence over several months that the performance at a given station has changed.
- liaison with national operators to rectify atypical performance, and deficiencies in methods of observation is essential.Similarly the implementation of effective record keeping and quality control at the source of the observations by the establishment of station monitoring procedures should be encouraged.Liaison is also essential to ensure rapid identification of changes in equipment or methods of observation .
- liaison with the manufacturers is necessary to identify changes in equipment design and methods of observation which are likely to change the quality of the measurements.Monitoring information should be disseminated to manufacturers so that they can identify and rectify problems associated with the use of their equipment.

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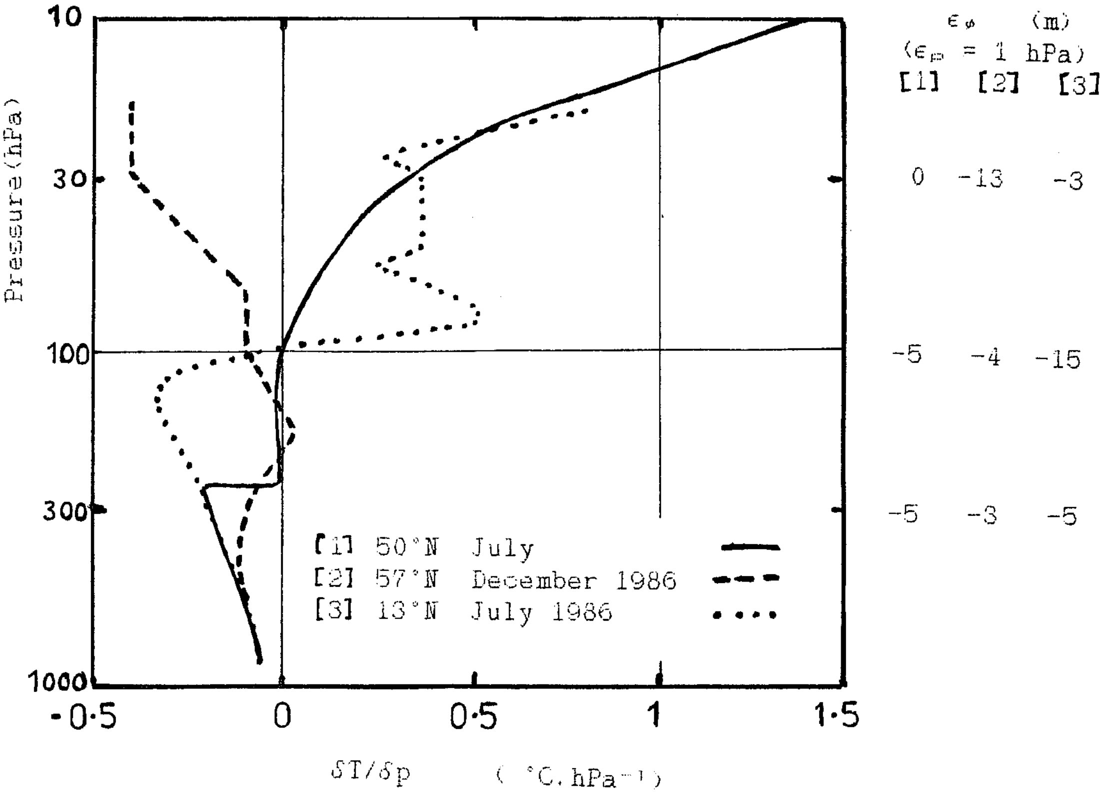

Fig.1 Error in temperature at given pressure levels resulting from a constant 1 hPa positive bias in the pressure sensor.

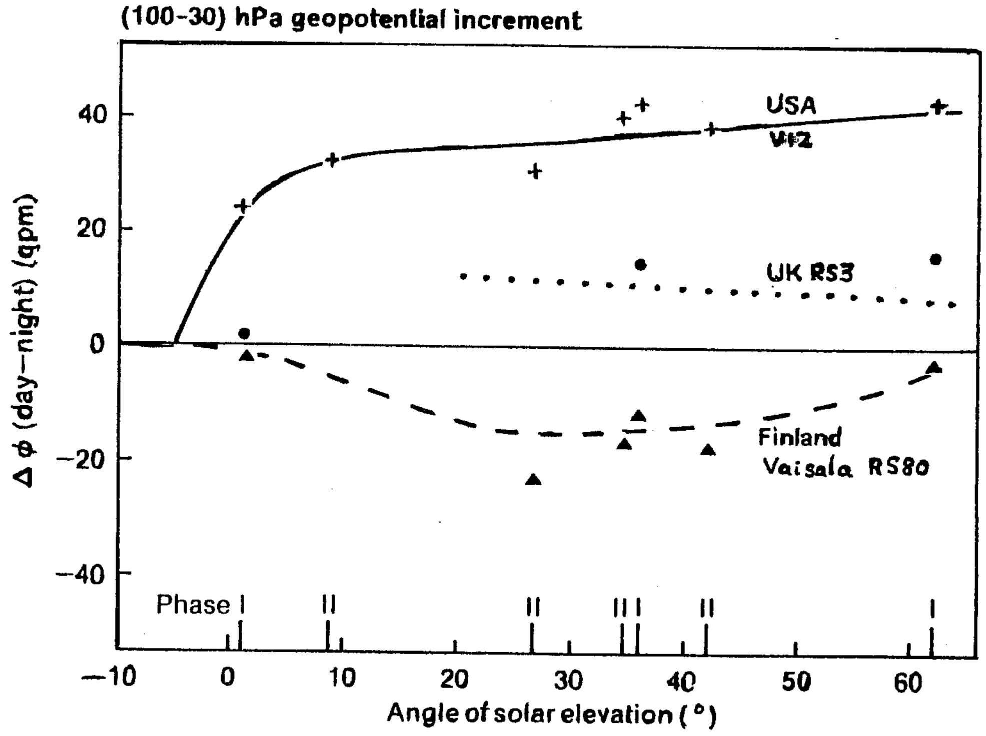

Fig.3 Day-night difference in standard pressure level geopotential height measurements ,after Nash and Sshmidlin (1987).

100 hPa GEOPOTENTIAL HEIGHT (m), JUNE - AUGUST 1986

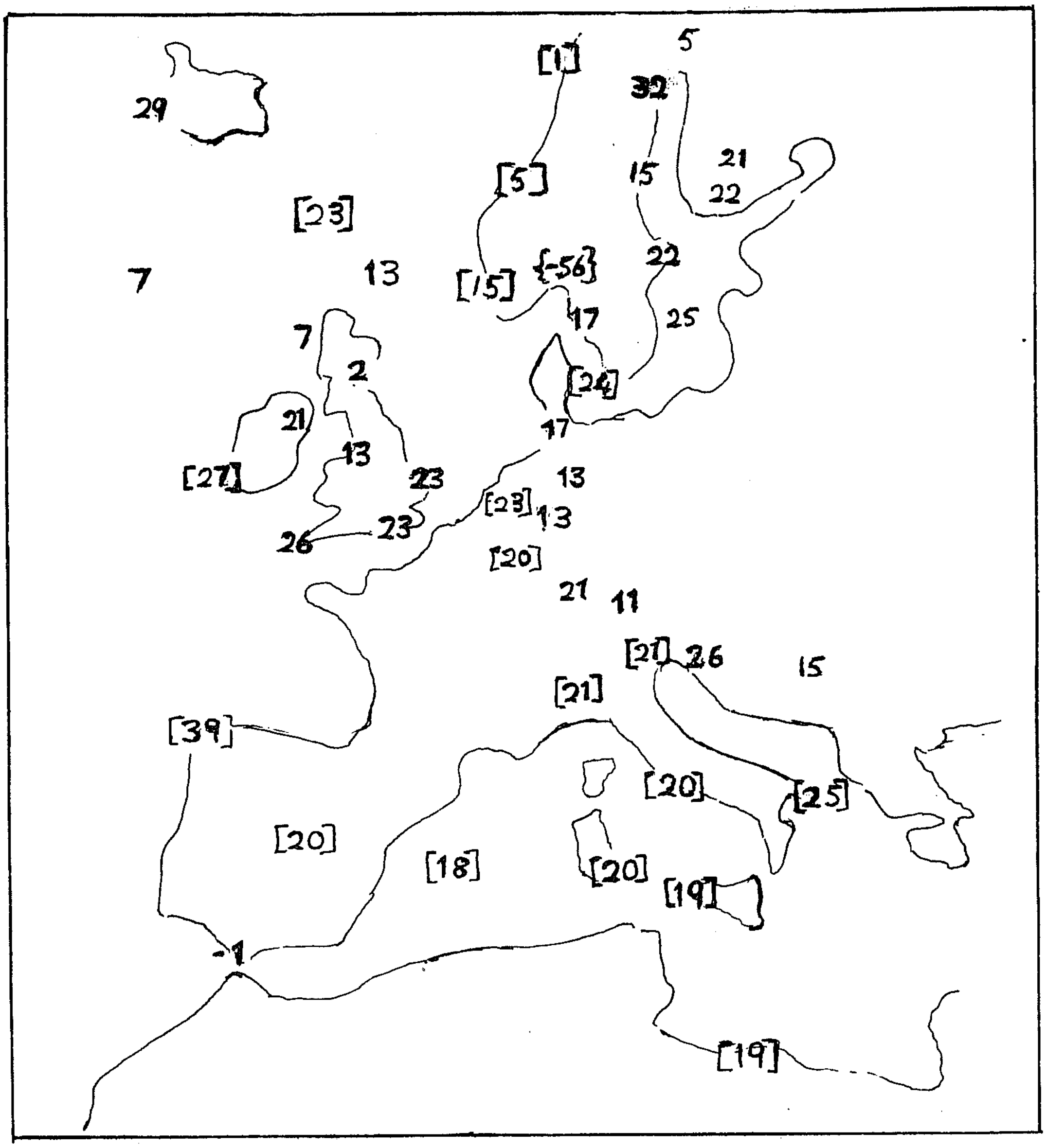

Fig.2 Estimated systematic bias between ECMWF First Guess field and the WMO Reference at 0000 GMT, assuming:-
Vaisala RS80 (WMO/1986) - WMO Ref. = 9m; VIZ -WMO Ref. = -9m ;
UK RS3 - WMO Ref. = -16m; Graw M60 - WMO Ref. = -2m.
[ ] denotes a Vaisala station which was not using 1986 corrections, and has been adjusted accordingly for this analysis.
{ } denotes an atypical station performance , which has subsequently been rectified with the help of the manufacturers.