QUALITY OF TEMP DATA

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ABSTRACT

This paper discusses the quality of TEMP data from the point of view of studies performed by the WMO and several national and international institutes including the ECMWF. Methods for assessing the quality and removing solar radiation biases from the geopotential data are outlined.

1. INTRODUCTION

Large NWP Centres such as the European Centre for Medium Range Weather Forecasts (ECMWF) receive, process and use many thousands of observational reports, including the TEMP messages, on a daily basis in order to fulfill their basic mission of providing guidance for hemispheric or global forecasts. The TEMP data of upper-air Pressure, Temperature, Humidity (PTU) and wind are obtained from the worldwide radiosonde station network operated independently in different countries. The World Meteorological Organization (WMO) has laboured zealously over the years to compare and improve the accuracy of the PTU sensors on radiosondes (Hawson, 1970; Hooper and Vockeroth, 1975; Finger, McInturff and Spackman, 1978; Moores, 1982; and Nash, 1984). Less attention has been paid to upper-air winds (Hooper and Vockeroth, 1975; Passi, 1978; and Lange, 1984).

A determination of the quality of any TEMP data set is indeed a very difficult task. A major part of the problem is the lack of an international standard by which the behaviour of all radiosonde systems could be judged.

Practical experiences gained during many international radiosonde experiments, such as the Boulder Low-Level Intercomparison Experiment (BLIE) in 1979 (Kaimal et al., 1981) and the current WMO/CIMO International Radiosonde Comparison in 1984/85 (Nash et al., 1984), show clearly that the simultaneous flights of different radiosondes may reveal types of failures in the systems that cannot be detected by laboratory simulation. Unfortunately, relatively few radiosonde systems have been submitted to such intercomparisons. Recent investigations into the errors in TEMP data indicate that these are usually larger or at least about the same order of magnitude than those of the ECMWF data assimilation system (Hollingsworth and Lönnberg, 1984). Thus, the Data Assimilation Data Base System (DADBS) of the ECMWF may provide a common basis for the development of such a standard.

Figure 1 gives an overall view of how well the observed wind and geopotential height for a typical synoptic time of observation in the northern hemisphere match the corresponding data produced by the ECMWF data assimilation system. The number of observations available for each pressure level are given in the column between the two sets of the profiles. The departures from the first guess (FG) fields are usually largest and from the analysis (AN) fields smallest. Initialization (IN) brings the analysis closer to the first guess field, thus making the respective departures larger again. We shall be mainly looking at the FG departures because a first guess field is more independent of observational errors than the analysis or the initialized analysis. The first guess field carries some of the radiosonde biases from 6 or 12 hours before. However, they are usually quite different from the present ones, and sometimes even have the opposite sign. The accuracy of the

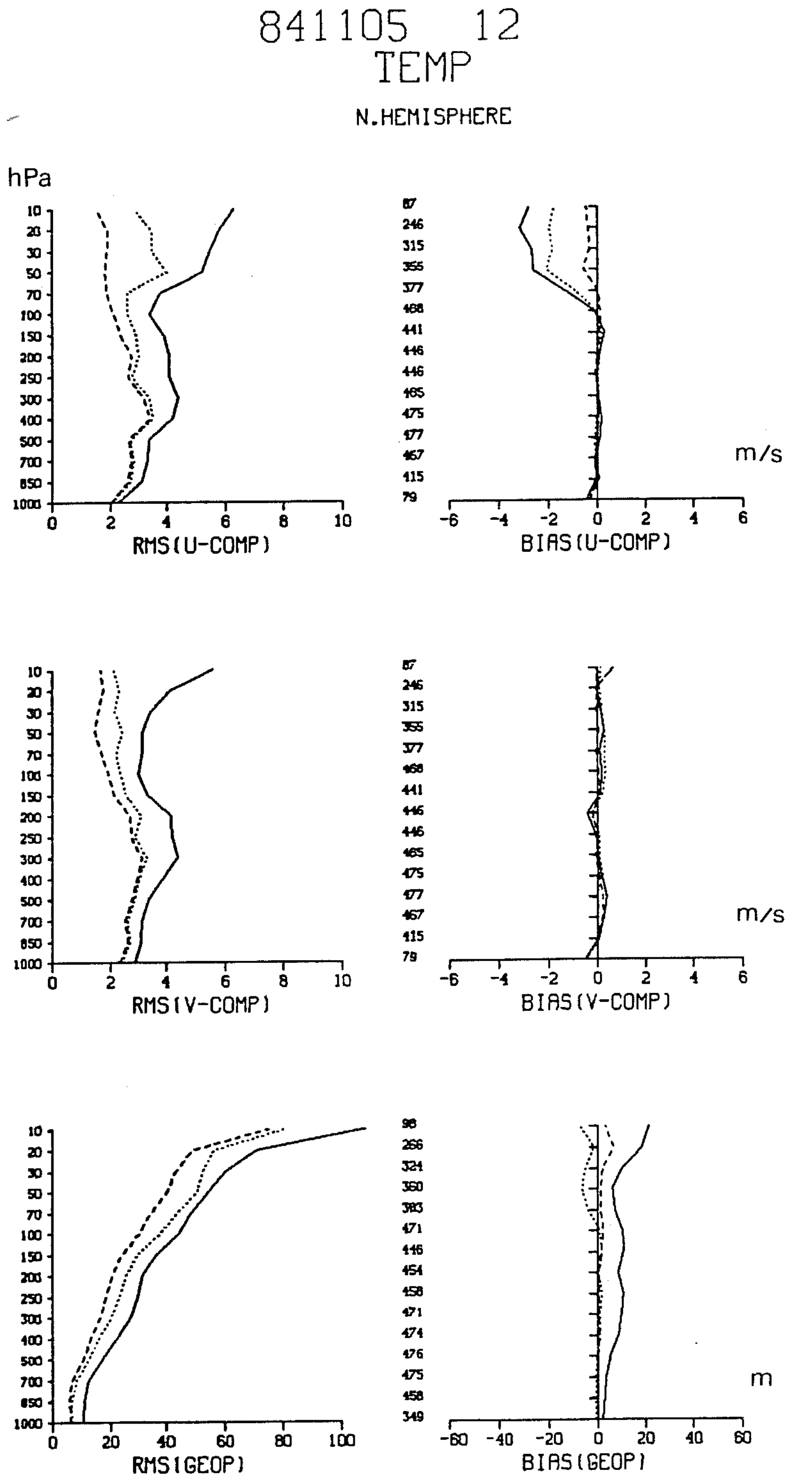

Figure 1 - Departures of the TEMP observations from the first guess (FG, solid line), analysis (AN, dashed line) and initialized (IN, dotted line) fields at the different pressure levels of the ECMWF data assimilation system for the Northern Hemisphere at 12Z on the 5 November 1984. The left and right hand side graphs indicate the Root-Mean-Square (RMS) and mean (BIAS) values, respectively.

first guess field is by definition that of the ECMWF forecast model at 6 hours.

The systematic (BIAS) component in Figure 1 is negligible because the systematic errors in different radiosonde systems tend to cancel each other in the hemispheric averaging, although the data assimilation system also exhibits certain biases (Hollingsworth and Arpe, 1982).

The RMS profiles of the FG departures provide us with some rough estimates of the magnitude of the TEMP data errors at each pressure level. The RMS values are strikingly large. All manufactures of upper-air equipment claim significantly better accuracies than suggested by these poor fits. It has turned out that the quality of TEMP data from different upper-air stations has unexpectedly large variations. There exist both very good and bad upper-air stations.

2. METHODS FOR ASSESSING THE DATA QUALITY

A quality index of the following type is being investigated:

$$Q(RMSE) = \frac{RMSE^2 - b^2}{a^2 - b^2} \; 100\ \%$$

where parameters a and b have been obtained from WMO Technical Note No. 112: "Performance Requirements of Aerological Instruments" by Hawson (1970) and RMSE stands for the Root-Mean-Square Error of a set of observations. The reference values a and b are functions of latitude, season and pressure level as well as of the meteorological use the observations are intended for.

Quality number Q equals 100% when the RMSE value reaches a limit (a) which specifies the accuracy requirement. On the other hand, if the RMSE exceeds a certain limit (b) beyond which the observations are considered to be misleading, then a negative Q value will be obtained.

The RMSE values are derived from the FG departures i.e. on the basis of how well the observational data from a station fits the first guess field values during a month or season. Before a Q value is computed the contribution which results from the estimated local errors in the first guess fields is to be removed from the RMS of the FG departures. These Q values can be averaged in the vertical. Each pressure level may have its own relative weight.

Index value Q will be improved by an amount:

$$Q'(BIAS) = \frac{-\ BIAS^2}{a^2 - b^2}\ 100\ \%$$

if the bias could be entirely removed from the observations. This results from the obvious identity: $Q(STD)=Q(RMSE)+Q'(BIAS)$.

A similar treatment to that illustrated in Figure 1 has been given to the FG, AN and IN departures in graphs such as in Figure 2, but now the results are available for each single radiosonde station and the averaging was made over one month. In addition, standard deviation (STD) profiles were plotted instead of the RMS profiles. A typical plot for a good station is given in Figure 2.

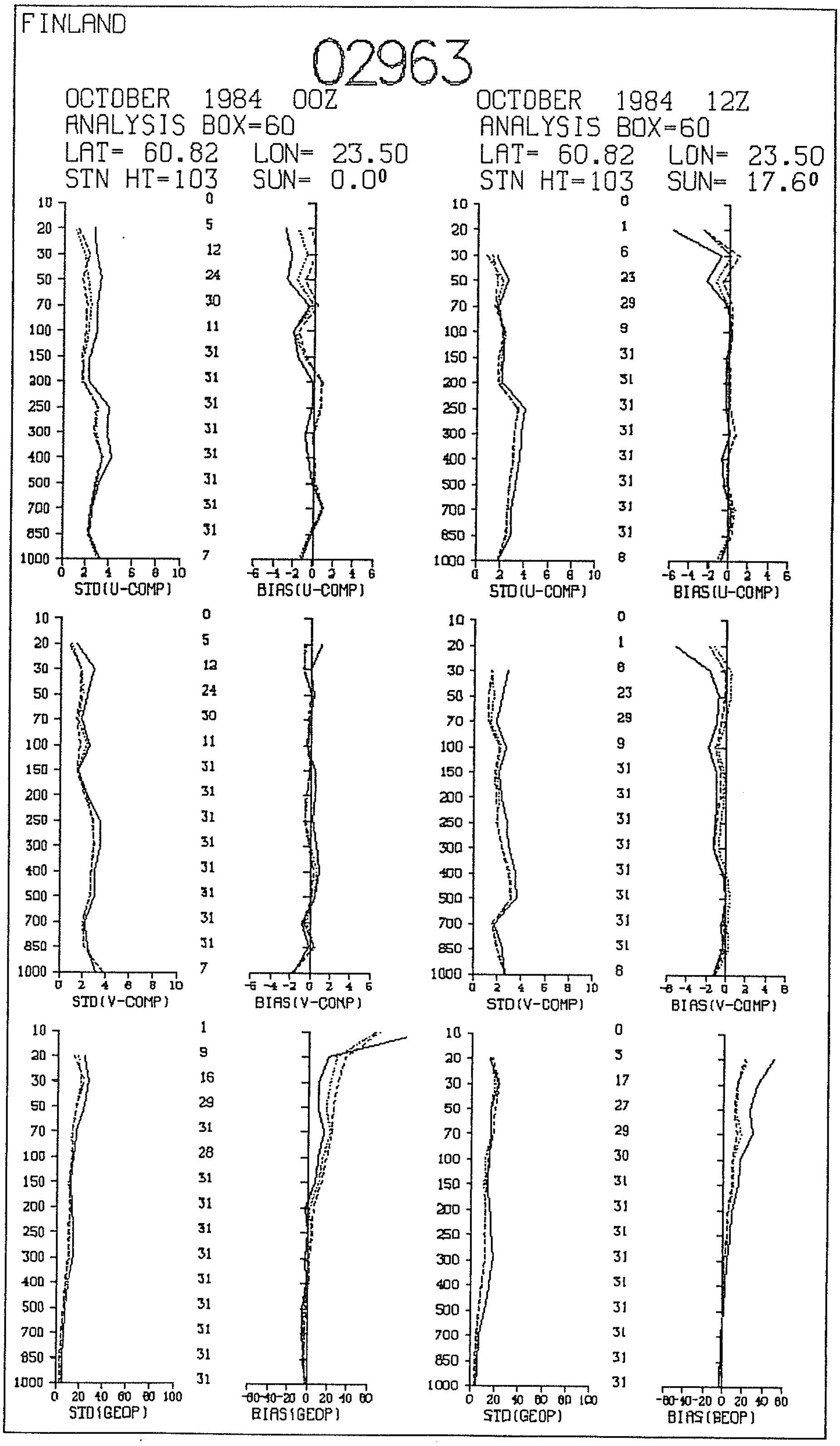

Figure 2 - The profiles of the standard deviations (STD) and systematic errors (BIAS) at station Jokioinen 02963, Finland, as derived from the FG (solid line), AN (dashed line) and IN (dotted line) departures. The international Omega Navigation System (ONS) is being used for windfinding. The geopotential heights are based on the Vaisala RS80 radiosonde system (Micro- CORA). The units are hPa, m/s and m as in Figure 1.

The STD and BIAS profiles show a decomposition into random- and systematic-type errors of the TEMP data. Such plots have been produced on a monthly basis at the ECMWF for all radiosonde stations of the World Weather Watch (WWW) in connection with the investigations into the TEMP data quality. It appears that upper-air stations using different radiosondes and ground equipment usually have quite different error patterns. Use of poor equipment leads inevitably into large systematic and random errors. However, high quality equipment does not yet guarantee that the resulting observations are free of systematic errors.

It is sometimes difficult to distinguish whether erroneous behaviour of an upper-air observing system is due to a poor instrumental precision or a shifted calibration. Especially in windfinding the two types of errors are to a large extent intermingled (Lange, 1984). The systematic and random-type errors will be discussed in the following two sections.

3. RANDOM-TYPE ERRORS

3.1 Wind

Errors in the measurement of the mean wind in a shallow layer arise partly from errors in the observed plan positions of the balloon and partly from errors in the observed geopotential height attributed to the measured wind. The relationship between wind errors and the errors in the actual measurements such as azimuth, elevation, slant-range or Navaid signal phase varies according to the method of windfinding. Passi (1978) and Lange (1984) have discussed the problem quite generally.

The CIMO Guide to Meteorological Instruments and Methods of Observation (WMO, 1983) gives a straightforward approach to estimating operational windfinding accuracies of a well-calibrated and properly operated tracking system:

- For conventional systems the errors tend to be an approximate function of the ratio of the mean atmospheric flow to the rate of ascent of the balloon. It is emphasized that the accuracies vary very much depending essentially on the geometry of the balloon and the tracking sensors. The estimates of the standard vector errors e.g. for the 5 km and 30 km vertical distances vary within the unexpectedly wide ranges of 0.5-21 m/s and 1.5-196 m/s, respectively. It is stressed that these are the extremes which are only valid for 1-minute averaging intervals. It is a normal practice to increase these averaging intervals up to 2 minutes or more for improved accuracy in case of very low elevation angles which may frequently occur in the high latitudes during winter flow conditions.

- Table 1 has been given by Beukers (1978) to indicate how the two Navaid systems - Omega and Loran C - usually intercompare within their coverage areas.

Table 1 - Standard vector error of Navaid winds

Navaid system	Wind accuracy, m/s (90% of observations)		Averaging time, minutes
Loran C	< 0.5	(ground wave)	1
	1 - 2	(sky wave)	1
Omega	1 - 2	(daylight path)	2
	1 - 4	(night path)	2

This information from the WMO Commission for Instruments and Methods of Observation (CIMO) is intended for approximate estimation of the accuracy of each single data element. For better results the track of the balloon must be derived and the equipment type known more precisely. The effects of increased averaging intervals would also call for further studies.

During FGGE and the subsequent 5 years a lot of practical experience has been gained about Navaid windfinding (Lange, 1985). Some new Omega-based systems have been augmented with Very Low Frequency (VLF) transmissions used normally for communication and time dissemination purposes. This may result in slightly better nocturnal accuracies. In any case, the Omega-based systems usually employ averaging over 3- or 4-minute intervals which represents a layer thicknesses of about 1 km. The windfinding error may be less than 2 m/s even for stratospheric winds during strong flow conditions. This is also suggested by the high quality of the u and v components in Figure 2 which were measured by an Omega-based windfinding system.

A windfinding experiment with several radars, theodolites, Omega, laser etc. was performed in Finland in 1972, see Figure 3 below:

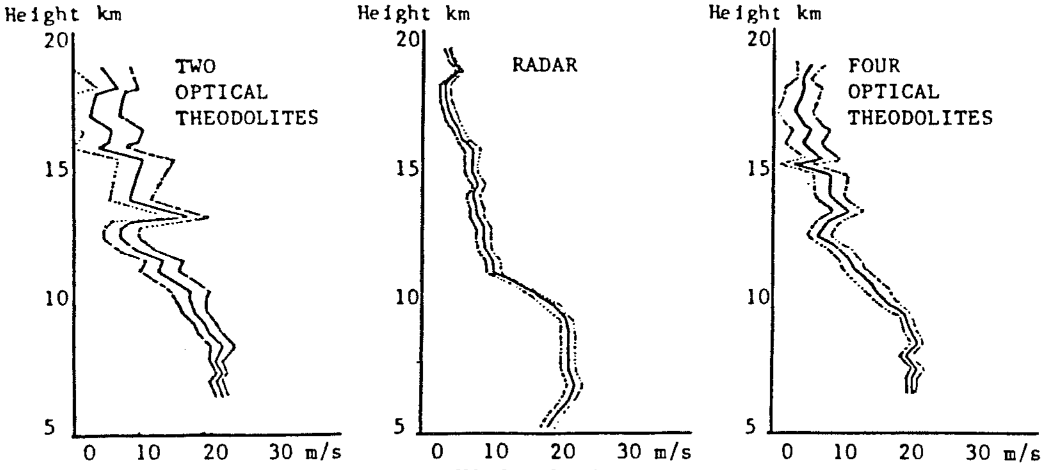

Figure 3 - Comparison of windfinding accuracies from three different configurations of tracking devices (Lange, 1984), see text.

The three graphs are to illustrate how important it is that tracking sensors have a good geometry. They are all from the same sounding. The optical theodolites were several kilometers apart. Above the 10 km vertical distance the balloon was so far away that the Geometric Dilution of Precision (GDOP) became the main reason for the poor accuracy in the optically derived profiles. A single radar maintained a constant accuracy because of its slant-range capability. The accuracies are indicated by plus/minus 1-standard deviation confidence bands.

Differences in observational error patterns of the WWW radiosonde stations are reflected in the plotted departure profiles of the type shown in Figure 2. For example radar- or Navaid-based upper-air stations tend to exhibit wind departures that are almost constant up to the 10 hPa level, whereas the situation is not so good for stations using radio-theodolites. Some countries augment their radio-theodolite systems with transponders for improved accuracy during strong flow conditions (Sanders and Barr, 1978). The WMO is currently developing a system that will allow such information to be gathered and passed to the users of the data. Hopefully, the upper-air stations will promptly report changes to station equipment and procedures as they occur. A catalogue of such information will also be prepared and regularly updated. A similar system has already been established for the exhange of radiosonde information (WMO, 1981).

It must be stressed that the recent studies based on the data from the ECMWF data assimilation system have indicated that there are serious windfinding problems with many upper-air stations. Some detected problems have already been sorted out. The tracking devices had not been well-calibrated or were not properly operated. A typical error at some Navaid-based stations was an erroneous inclusion of a long-path contaminated Omega signal in the wind computations (Lange, 1982). At some ocean island stations there were mechanical problems with tracking aerials.

3.2 Pressure, Temperature and Humidity (PTU)

Arpe (1985) has given an account of the PTU measurement errors in radiosonde data from different systems. The WMO maintains a catalogue on the radiosonde systems in use at the WWW upper-air stations (WMO, 1981). Further sources of minor errors are related to a poor selection of significant points, truncation errors in the TEMP message encoding and transmission errors on the Global Telecommunication System (GTS). The measurement errors have an accumulating effect on the geopotential heights that are based on hydrostatic computations. Both the random and bias components are usually affected, as also seen in Figure 2.

4. SYSTEMATIC ERRORS IN THE GEOPOTENTIAL HEIGHTS

4.1 Radiosonde Biases

All of the different (about 15) types of radiosonde systems used operationally around the world exhibit varying degrees of PTU measurement biases at higher atmospheric levels, primarily in response to solar radiation. Although the temperature errors are most noticeable at stratospheric levels and tend to increase rapidly with increasing height, many radiosonde systems have even exhibited significant errors of this type at upper tropospheric levels.

A straightforward method for deriving temperature and geopotential height corrections that a NWP center can apply to compensate for systematic radiation errors is through an evaluation of day-night geopotential height differences in reported values from a radiosonde station (McInturff, 1979; and Uddstrom, 1984). The differences have been found to be functions of radiosonde type, pressure and solar elevation angle at the time of a daylight observation (Finger et al., 1978; and Finger, 1981).

Similar experiences were gained from the plotted departure profiles of the type shown in Figure 2. The monthly averages of daylight solar elevation angles are indicated on the top of the two sets of profiles for each radiosonde station. The bias profiles of the geopotential heights tend to tilt to the left during the day and to the right at night for almost all radiosonde stations. This is mainly due to the fact that the solar radiation corrections made at the stations are usually too modest or even nonexistent (WMO, 1981). The pressure readings may also be in error although temperature errors are usually the main reason for this type of geopotential biases.

4.2 Joint Bias and Tide Model

A general model has recently been developed for the correction of the geopotential biases in the WWW radiosonde data. The proposed formulation uses both the biases of the observation minus first guess (FG) and the day-night differences to generate a set of corrections for each station. They are applied to homogeneous groups of stations identified on the basis of radiosondes used, types of the ground equipment at a station and the operational experiences obtained through the data monitoring activities of the ECMWF and the WMO.

In addition, the tropospheric and stratospheric thermal diurnal tides and the semi-diurnal pressure tide play a role in the estimation of the true geopotential heights of the pressure levels (Lindzen, 1966; and Chapman et al., 1970). Their exact amplitudes are still unknown and must be estimated as well.

The regression equation system for the simultaneous solution of all these unknown quantities appeared to be sufficently overdetermined. The standard Gauss-Markov theory on best linear unbiased estimates has been employed, see e.g. Rao (1972). However, the cross-product matrix to be inverted is so huge that no existing computer can handle it as such. Fortunately, the matrix is sparse and has a certain structure that can be handled with existing computer software (Lange, 1982).

5. CONCLUSIONS

There is an urgent need for an operational system to make routine assessments of the quality and usability of the TEMP and PILOT data from the WWW upper-air stations around the world. A data assimilation data base such as that of the ECMWF may provide a common basis for the quality assessments. The usability of the reports from an upper-air station depends also on the data volume that has been received. A "usefulness index" of the following type has been proposed:

$$U = Q * N$$

where Q is the quality index varying from 0 to 100%, the upper reference value being the observation error of an "ideal" station using the ECMWF analysis as reference; and

N is the number of pieces of information divided by the number of data that ideally should have been received for full soundings up to, say, 10hPa at all scheduled times (WMO, 1980b).

The index U, complemented by indices Q and N, should make it possible to identify promptly all problem stations (Söderman, personal comm.). In fact, this is becoming increasingly important because the ever increasing level of automation is rapidly leading to the use of observing systems with minimum manual supervision. However, the term "test" should be preferred to the term index because such quantities Q and U will not be capable of measuring the quality and usefulness of the data from a station in any absolute sense as long as there still exists some major uncertainties in the separation between data-assimilation and observational errors. In other words, if the quality test Q of a station is worse than those of other stations it indicates only that the data-assimilation system (used as the common reference) is providing us with more definite evidence of the fact that the station does not fully comply with its given performance requirements i.e. the others are not necessarily any better. More sophisticated statistical procedures should also be developed for diagnostic purposes in order to give early alarms e.g. on a shifting instrumental calibration.

There are serious systematic errors in the TEMP data which depend to a large extent on the radiosonde systems used. The end user may improve the data compatibility by using the sophisticated correction methods outlined in the text or in the referenced publications to remove such biases. An effort need to be made for a precise identification of the tidal waves.

The WMO/CIMO efforts in conducting international radiosonde experiments and cataloguing the WWW radiosonde and windfinding systems are of vital importance for the development of improved quality control procedures for the TEMP and PILOT data.

The observing systems should make use of redundant sensors so that built-in quality control procedures could be implemented. Such a system should also report its estimated observational accuracy on a continous basis. Provision for this should be made in the transmission codes. Experiences on such a type of quantitative quality control indices has already been gained in FGGE (WMO, 1980).

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