COMPREHENSIVE QUALITY CONTROL

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1. INTRODUCTION

A new approach to the quality control of the operational meteorological information has been proposed in the USSR comparatively long ago. As applied to the rawinsonde data on temperature and height of mandatory isobaric surfaces, it has been implemented into routine practice at the Hydrometeorological Center in Moscow about a decade ago. The approach, known as the Complex, or Comprehensive, Quality Control (CQC), has been described in detail in a recent paper (Gandin 1988, hereafter referred to as G). The description is based on investigations performed in the USSR.

Thanks to the initiative by Drs. W. Bonner, R. McPherson and E. Kalnay, work directed towards a complete revision of the existing QC system is being planned at the NMC. The main part of this work will begin in 1989, but some first investigations in this direction have already begun by Dr. W. Collins and the author. Some results of these investigations will be considered in this paper. Its main aim, however, is to describe, and, so to say, to defend the principles of the QC, as well as to consider the desirability and possibility of its implementation at various prognostic centres, particularly at the ECMWF.

It is necessary to mention in this respect that, although the possibilities of the CQC application to various kinds of meteorological information were investigated, this approach has been so far implemented only to one kind of information, namely, to rawinsonde data on height and temperature of mandatory isobaric surfaces. It is also true that, due, primarily, to the presence of the hydrostatic redundancy in these data, the CQC approach should be most successfully applied to them. This does not mean, however, that the approach cannot be applied to other kinds of data. Both logical considerations and numerical estimates show that the CQC approach can be applied to any kind of meteorological data, provided that there exist at least two more or less independent quality-control checks applicable to them.

2. EXISTING QC SYSTEMS

The quality-control systems now in use at different prognostic centres differ from each other in some important details. For example, the ECMWF system includes a multivariate three-dimensional interpolation check, while much less sensitive means, the so-called buddy check, is being used instead at the NMC. The degree of human intervention into the quality-control process also varies substantially from one centre to another. At the same time, the QC systems at all centres (except, maybe, the Hydrometeorological Centre in Moscow) have very much in common.

First, all the systems are sequential or, using another word, hierarchial. That means that they consist of several checking methods applied in succession, and decisions - to retain or to reject suspected data - are taken immediately after the application of each method. There exists some kind of interaction between sequentially applied methods. This is the so-called flagging: a special digit, a "flag", may be assigned to a suspected datum in order to make it more suspected for subsequent checking methods. The flags are, however, semi-qualitative, rather than quantitative, and they provide an interaction only in one direction, from previous to subsequent check, not vice-versa.

Second, only two alternatives, either to reject the suspected datum or to retain it, are usually considered. Only in rare cases connected mainly with the hydrostatic check or with a human intervention, a possibility to correct the erroneous datum is also under consideration. Experience shows that there exist many possibilities to correct erroneous data. It is, however, difficult to realize these possibilities as long as the hierarchial QC is being used.

Third, almost no attempts are being undertaken to distinguish, in the course of the QC (not after it), between various origins of suspected errors. As a result, it is often assumed, more or less implicitly, that all rough errors in data reports received at a prognostic centre are introduced in the course of observations. These errors are therefore referred to as observation, or measurement, errors. The reality is very far from that.

It is convenient to divide all rough errors, according to their origin, into three categories: observational, computational, and, so to say, "communicational" (Fig. 1). There is a great deal of evidence that the most part of rough errors belongs to the third category. In other words, the majority of rough errors are mostly those introduced not when the measurements are being done but when the data are put into, following along, and are taken from, the communication lines.

Needless to say, the knowledge of the rough-error origin, if achievable, is very useful. It helps not only to detect and locate the erroneous datum more confidently, but also to compute the rough error and, thus, to correct the erroneous datum.

3. THE CQC APPROACH

The main principle of the CQC approach is very simple: no decision is to be made until all available checking procedures have been applied to all the data under consideration. This means that each CQC algorithm consists of two parts: the application of all included checks (called the CQC components), and the decision making algorithm.

Two points are to be stressed concerning the CQC components. First, all the components have to be, so to say, of the same hierarchial level. It would be meaningless, for example, to include a so-called gross check, based on a comparison between observed and a background-field (e.g. climatological or predicted) values, if an interpolation check is also included, consisting in statistical interpolation of the deviations from background field and comparison between interpolated and reported values. The latter component will suspect all the data suspected by the former one, as well as many others in addition. This means that the gross check would simply be obsolete.

The second point is that the more powerful a CQC is, the higher the number of its components. To illustrate this point, let me consider a quite different problem, connected with long-term storage of data, e.g. of climatological archives. The longer the storage time is, the higher the probability for some stored data to become distorted, and the problem is how to protect the archive against such distortions. A usual means is to compute the so-called formal sums, i.e. the results of a formal summation of each m numbers (Fig. 2a) and to store these sums together with the data. If the datum becomes distorted then the equation for the corresponding sum does not

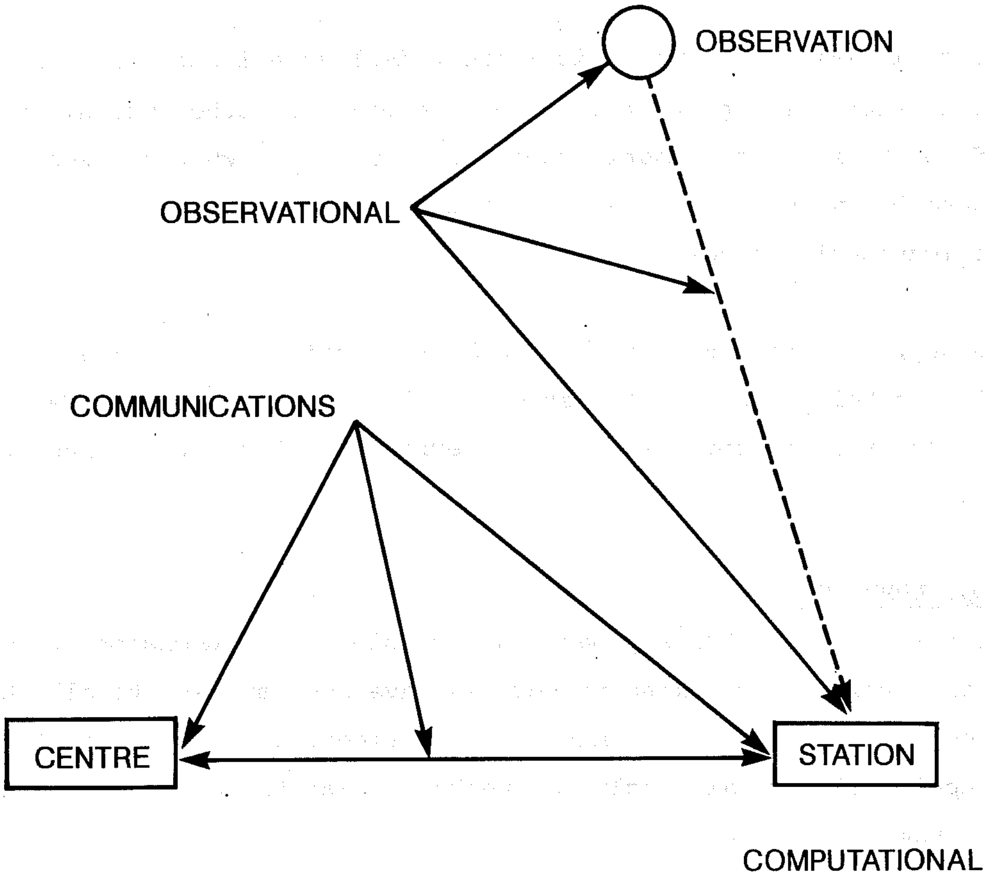

Fig. 1 Error origins

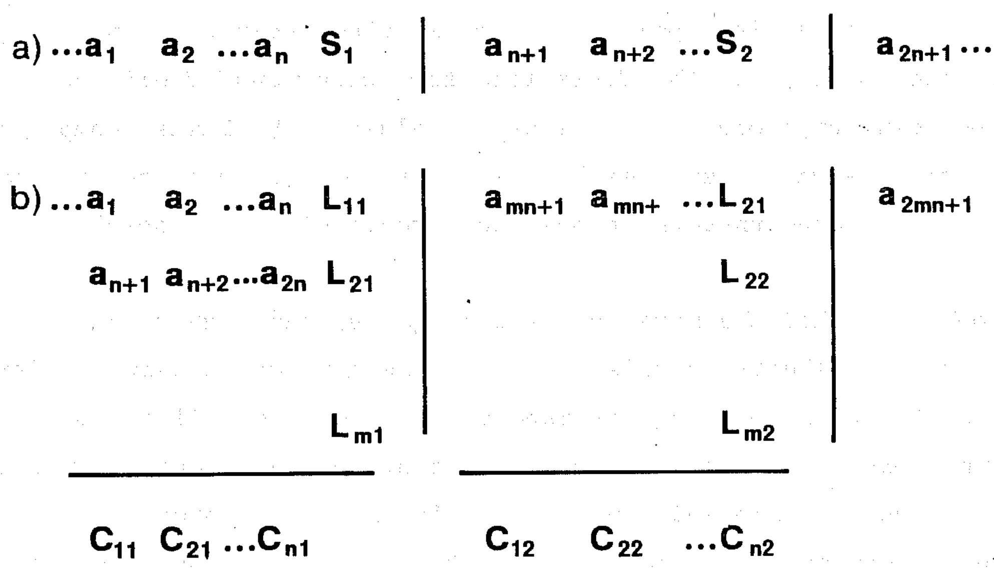

Fig. 2 Archive protection:
a) One-dimensional summation
b) Two-dimensional summation

hold. It is thus possible, by periodic inspections of the archive, to detect all violations of these equations. It is, however, impossible to decide, which of the data has become wrong. It may even happen that all of them remained correct, while the formal sum itself was distorted.

The situation improves dramatically if a two-dimensional formal summation is applied, that is if the data are ordered in rectangular matrices and the formal sums are computed both along rows and along columns of each matrix (Fig. 2b). An error, d, in an element a_{ij} of the matrix will lead to residuals, i.e. differences between two parts of equation, in both sums L_i and C_j, both residuals being equal to d. It is therefore highly probable that, if two such residuals are detected, the corresponding element is distorted by the error d. It may be mentioned that this approach, in substantially more advanced version, has been developed for the protection of climatological archives (Afinogenov, 1983).

The situation with the quality control is analogous. Based on a single check, it is often difficult even to locate the rough error, and it would be rather risky to change the suspected datum. If, however, several checks were applied, then the possibility first to locate the error and then to estimate its value substantially increases. In many cases, it becomes possible even to discover the cause of the error.

As applied to statistical interpolation checks, it follows that, instead of a multivariate check, it is better to use a complex containing univariate and crossvariate interpolation. A complex including horizontal and vertical checks is preferable to a three-dimensional check. Moreover, it may be worthwhile, in some cases, to split further the horizontal check into latitudinal and meridional ones (Fig. 3). This is particularly so for a parameter known only on one level.

The sensitivity of each CQC component, taken alone, is, of course, lower than that of a more sophisticated check. For example, RMS residuals of horizontal and vertical checks are higher than those for the three-dimensional one. This increase is comparatively small. Even, however, if this loss of sensitivity were substantial, the gain due to the use of the checks in their complex would

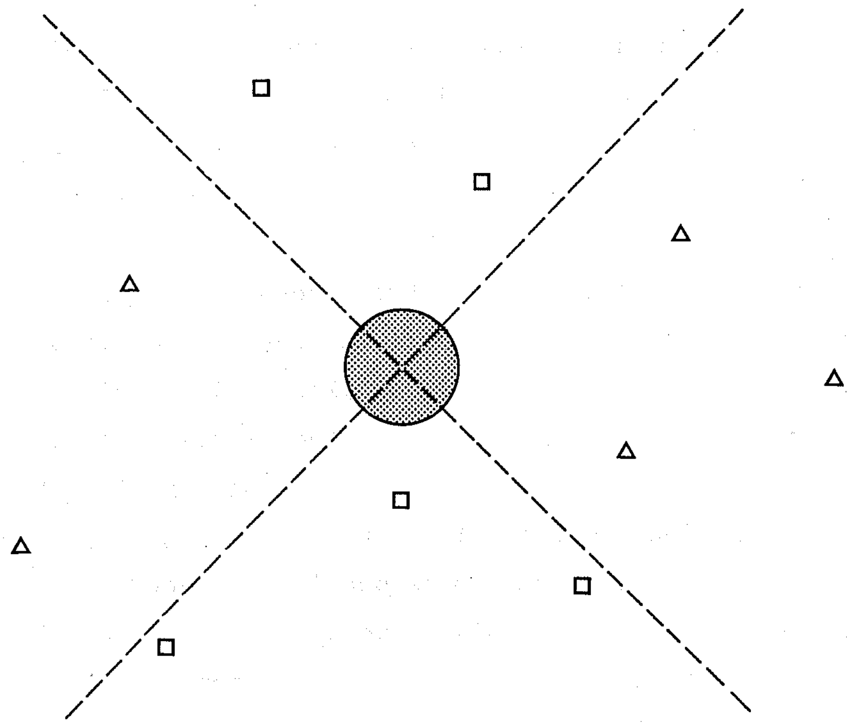

Fig. 3 Latitudinal and meridional checks

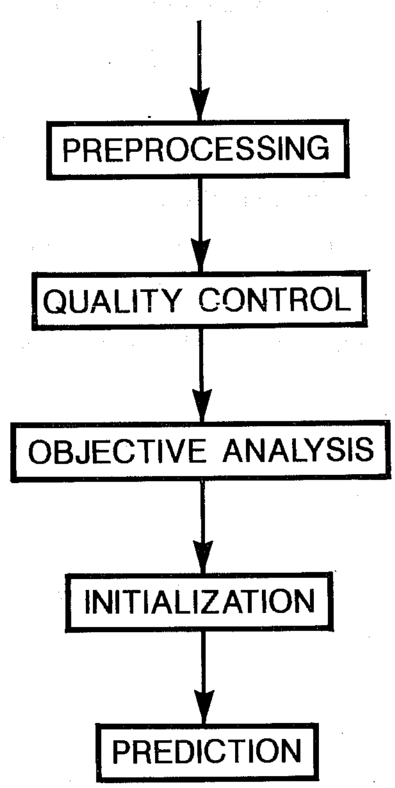

Fig. 4 Data assimilation system

more than overweigh this loss. Another consequence of the main principle of the CQC is that the QC procedures are to be performed within a separate, quality-control, stage of the Data Assimilation System (Fig. 4).

4. INTERPOLATION CHECKS

The residual of an interpolation check is just the difference between the reported value $f_{o,rep}$ of the parameter f at the point in question, r_o, and the value interpolated from data at adjacent points, r_k (k = 1, 2, ..., n). Deviations from some background field, rather than the values of parameter itself, are used in the interpolation which is performed by the equation

$$f_{o,int} = \sum_{k=1}^{n} p_k g_{k,rep} \qquad (1)$$

where p_k are the interpolation weights determined by the usual optimum interpolation formalism.

If data on the same parameter, f, are used for the interpolation, i.e. if g = f, then it is a univariate check, otherwise it is a crossvariate one. If all points r_k are at the same level or isobaric (or sigma) surface as the point r_o is, then it is a horizontal check. If, instead, all points are at the same vertical, this is a vertical check. For the latter case, it may be shown that only two influencing points, one above r_o and one below it, have to be taken; other points are "screened" from r_o by already taken points, r_1 and r_2, and do not practically influence the result.

The root mean square difference between observed and interpolated values, E_c (the so-called RMS comparison error) is computed as a by-product when computing the weights p_k, its square exceeding that of more commonly used RMS interpolation error, E_{int} (which characterizes the difference between interpolated and true values), by the mean square random observation error:

$$E_c^2 = E_{int}^2 + E_{obs}^2, \qquad (2)$$

The admissible residual is equal to DE_c, where D is an empirical factor usually taken equal to 4. If a residual exceeds the admissible one by the absolute value, that is, if

$$|f_o - f_{o,int}| > DE_c, \tag{3}$$

then the reported datum, f_o, is brought into the category of suspected data, to be analyzed by the decision making algorithm.

5. HYDROSTATIC CHECK

The hydrostatic check is based on the so-called barometric equation which is the result of the integration of the hydrostatic equation along the vertical. If the integration is performed for a layer between two isobaric surfaces, p_k and p_{k+1}, and these surfaces are close enough to each other, then one can assume the temperature T in the layer between $p=p_k$ and $p=p_{k+1}$, to be a linear function of lnp. Under this assumption, the barometric equation can be written in the form

$$Z_{k+1} - A_k = A_k^{k+1} + B_k^{k+1} (T_k + T_{k+1}), \tag{4}$$

where the height, Z, is in meters, T is in °C.

$$\begin{aligned} A_k^{k+1} &= (R\ T_{oo}/g)\ \ln (p_k/p_{k+1}), \\ B_k^{k+1} &= (R/(2\ g))\ \ln (p_k/p_{k+1}), \end{aligned} \tag{5}$$

R is the gas constant for the air, g is the gravity acceleration, and T_{oo} is the Kelvin temperature of 0°C.

Strictly speaking, R is to be for moist air, or, which is the same, T is to be replaced by the virtual temperature, T_v. For quality control purposes, however, it seems better to neglect the difference between T_v and T, first because it is small, particularly aloft, compared with the rough error influence, and second, because otherwise rough errors in humidity might influence the hydrostatic check results.

The hydrostatic check residuals, i.e. the differences between two sides of the barometric equation.

$$S_k^{k+1} = Z_{k+1} - Z_k - A_k^{k+1} - B_k^{k+1} (T_k + T_{k+1}) \quad (6)$$

are, in the absence of rough errors, caused mainly by non-linearities in the temperature profiles. The admissible residuals, S_k^{k+1}, may be derived statistically, like those presented in Table 1 taken from G. The hydrostatic check is widely applied nowadays, it is used in every operative quality-control system. It is a very powerful means, particularly if applied in a complex with interpolation checks. This makes the quality control of Z and T much more sensitive than that of other data.

6. DECISION MAKING ALGORITHM

Almost every prognostic centre makes one or another interpolation check, NMC is rather an exception in this respect. Every centre applies some kind of hydrostatic check. The only new part of the CQC is thus the decision making algorithm.

A scheme of its operation is presented in the upper part of Figure 5. First of all, it divides all reports in two categories: correct and suspected ones. If, at least, one of the CQC components has found at least one large residual when checking this report, the report is brought into the category of suspected reports. Every other report remains in the category of correct ones. There are, of course, much more correct reports than suspected ones.

The DMA then tries to realize what happened with each suspected report, testing several hypotheses about a possible error in it, based on the configuration and values of large residuals. As a rule, it is easy to do, particularly when there exists a communication error or a computational one. In such cases, the error is located and estimated, and its correction is attempted: the CQC for the station in question, as well as for those influenced by it in the course of horizontal checks, is repeated using the corrected value. If all existed large residuals disappear and no new ones are produced because of the correction, then it is accepted, and the corrected report is brought into the category of correct ones. Otherwise, the DMA tries to find another explanation.

Table 1 A, B and S for a 10-level scheme

i		1	2	3	4	5	6	7	8	9
p_i	mb	1000	850	700	500	400	300	250	200	150
p_{i+1}	mb	850	700	500	400	300	250	200	150	100
A_i^{i+1}	m	1300	1552	2690	1784	2301	1458	1784	2301	3242
B_i^{i+1}	m/°C	2.38	2.84	4.93	3.27	4.21	2.67	3.27	4.21	5.94
S_i^{i+1}	m	40	30	40	30	40	30	30	50	60

In some cases, the DMA finds that the data are definitely wrong but they cannot be corrected. This is particularly so for observational errors. The DMA excludes such data, and once again, the CQC is repeatedly applied to data that were influenced by them.

There are some rare cases when the DMA concludes that the suspicion by one of the CQC components was wrong. This is the case when the residual exceeds the admissible value only slightly and no other CQC component confirms the suspicion. Such reports are rehabilitated by the DMA and brought back into the category of correct ones.

The main source of rehabilitation is, however, different. It often happens that an error at one station leads to a large horizontal-check residual for another station influenced by it. As soon as the erroneous datum is corrected or rejected, there remain no large residuals for this other station. Its report is then brought back to the category of correct reports.

The majority of all suspected reports can be successfully treated by the DMA this way. They are thus either rejected by the DMA, or accepted after correction or rehabilitation. A small portion of suspected reports, however, remains suspected because the DMA is unable to come to any decision. This is particularly so when there are two or more rough errors in one report.

The simplest way is just to reject all data which have remained suspected. There exist, however, two other ways. One of them may be called the second iteration of the CQC (see Figure 5). Only the data remaining suspected are subjected to the CQC during this iteration, and only correct data are used as influencing ones. Some additional data can be successfully treated, that is, rejected, or corrected, or rehabilitated, by this iteration, and some still remain suspected. Another way is a human intervention which may be applied instead of the second iteration or after it.

Unlike the CQC components, the DMA contains many logical operations, and its code may be rather complicated, particularly for the most effective CQC algorithms. It is necessary to stress, however, that the computer time taken by a DMA is practically negligible as compared with that necessary for some components, and particularly with computer time needed for objective analysis and numerical prediction.

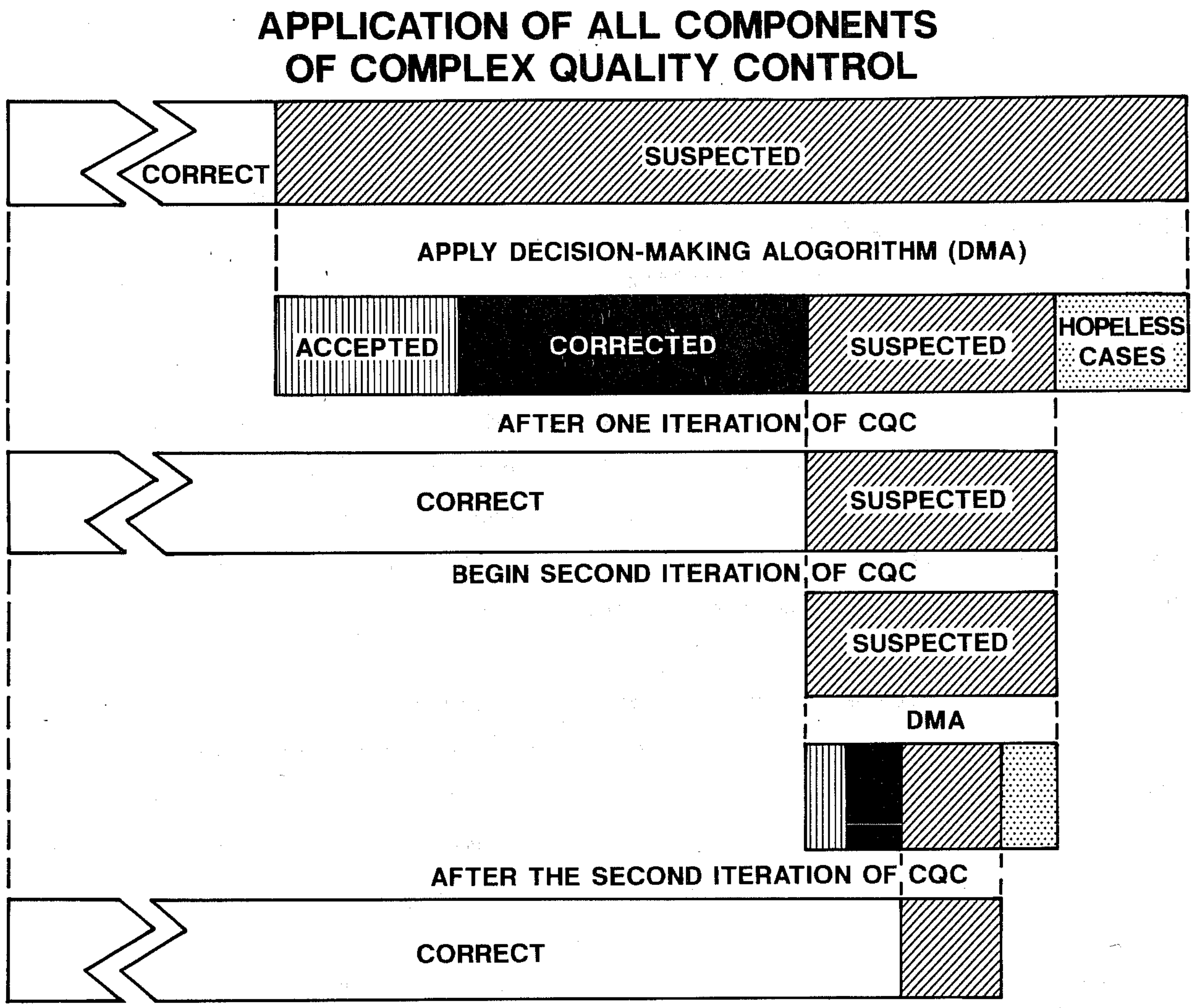

Fig. 5 Data flow in the course of a CQC

7. CQC OF RAWINSONDE DATA ON HEIGHT AND TEMPERATURE OF MANDATORY ISOBARIC SURFACES

Reaction of this CQC components on various rough errors is presented in Table 2. The CQC is assumed to contain five components: the hydrostatic check (HSC) and horizontal and vertical interpolation checks of both height Z and temperature T. These two checks are denoted by corresponding arrows. k refers to the level number, counted upwards, so that k=1 is the lowermost level among those reported, and k=n is the uppermost level. For each horizontal check, the middle column is for the station under check, two other columns being for adjacent, influenced, stations.

The rough error value is, in each case, denoted d. The presence of a component reaction is shown either by plus sign or by an expression for the component residual in terms of d. Minus sign means the absence of reaction.

It is to be mentioned, first of all, that the HSC does not react at all to observational errors. This is true as long as the hydrostatic equation is used when processing rawinsonde data at a station. The absence of the HSC reaction, while other CWC components, particularly the horizontal checks, show large residuals, is an important indication that an observational error may be present.

There exist two other, comparatively rare kinds of rough errors also not producing any HSC residuals, namely, a computational error in Z_1, and an error in the station-position. As may be seen from Table 2, it is easy to distinguish them from observational errors, as well as from each other.

Most common are the communication errors. If such an error occurs at an intermediate, i.e. not the uppermost or lowermost level, it results in two HSC residuals for layers divided by this level. If the error is in height, then the two residuals are of opposite signs and of the same value. If the error is in temperature, then the residuals are of the same sign and proportional to coefficients B.

It is natural, therefore, to assume that, if only two HSC residuals, S^{k}_{k-i} and S^{k+1}_{k}, are large then there is a communication-related error either in Z_k, or

Table 2 Error Types and CQC Reaction (continued)

	Level	HSC	$Z^{\uparrow}_{\downarrow}$	$T^{\uparrow}_{\downarrow}$	$\overset{Z}{\leftarrow\rightarrow}$	$\overset{T}{\leftarrow\rightarrow}$
A computational error, d						
(7)						
	k-1		+	-	---	---
		d				
	k		+	-	+d+	---
in Z^{k}_{k-1}		-				
	k+1		+	-	+d+	---
		-				
	...		+	-	+d+	---
(8)						
	1		+	-	+d+	---
		-				
in Z_1	2		+	-	+d+	---
		-				
	...		+	-	+d+	---
(9)						
Measurement error(s) at level k (and upwards)						
	k-1		+	+	---	---
		-				
	k		+	+	+++	+++
		-				
	...		+	+	+++	+++
(10)						
An error in the station position						
	1		-	-	+++	+++
		-				
	2		-	-	+++	+++
		-				
	...		-	-	+++	+++

in T_k (or in both). Criteria slightly different from those in G were applied to decide which of them is erroneously. Namely, if

$$|S_{k-1}^{k} + S_{k}^{k+1}| < (B_{k-1}^{k} + B_{k}^{k+1})\ (dT)_k, \qquad (7)$$

where $(dT)_k$ is the acceptable hydrostatic discrepancy in T_k, then an error in Z_k is assumed, and the correct value may be found from equation

$$(Z_k)_{corr} = Z_k + 0.5\ (S_{k}^{k+1} - S_{k-1}^{k}). \qquad (8)$$

If

$$|B_{k-1}^{k}\ S_{k}^{k+1} - B_{k}^{k+1}\ S_{k-1}^{k}| < (B_{k-1}^{k} + B_{k}^{k+1})\ (dZ)_k, \qquad (9)$$

where $(dZ)_k$ is the acceptable hydrostatic discrepancy in Z_k, then an error T_k is assumed, and the correct value may be found from equation

$$(T_k)_{corr} = T_k + 0.5\ (S_{k-1}^{k}/B_{k-1}^{k} + S_{k}^{k+1}/B_{k}^{k+1}) \qquad (10)$$

It seems sufficient to use constant values for $(dT)_k$ and $(dZ)_k$, namely,

$$(dT)_k = 5°C;\ (dZ)_k = 10m$$

If none of the conditions (7) and (9) takes place, then a hypothesis may be tested that both Z_k and T_k are wrong. They may be then replaced by those found from the equations for S_{k-1}^{k} and S_{k}^{k+1}, that is, by results of the hydrostatic interpolation. Before doing so, it is necessary, however, to prove that the hypothesis is correct. This may be achieved by analyzing the residuals of interpolation checks.

If only one HSC residual is in a report is large, then the probable explanation is that the thickness, $Z_{k+1} - Z_k$, has been computed incorrectly (see Table 2). In that case, all the heights Z_{k+1}, Z_{k+2} ... have to be corrected. To do so based only on the HSC residual would be risky. The interpolation checks, particularly the horizontal check of height, are very important in order to confirm or to reject this hypothesis.

Even more important is the role of interpolation checks when the only large HSC residual is for the uppermost layer or for the lowermost one. Two different decisions exist in the former case: to correct either the height Z_n, or the temperature T_n, and even three decisions may be for the latter case, because the thickness $Z_z - Z_1$ could be computed with an error and one has to change all heights, beginning with Z_z, in order to correct such error. The only way to choose among several decisions is to analyze the results of interpolation checks as well.

The situation is more complicated when not one but several rough errors have caused large residuals in the same report. Unfortunately, such situations occur much more often than it would follow from a formal application of the probability theory. Some examples of this kind will be presented in Section 10. In principle, the DMA is able to take care of any combination of rough errors. It is, however, hardly possible, or desirable, to foresee every such combination beforehand. The best way is to provide detailed outputs for every complicated case and to use them as a feed-back in gradual improvement of the decision making algorithm.

8. SOME STATISTICS

As one could foresee (e.g. Gustavsson, 1981), the percentage of rough errors in meteorological information is permanently decreasing. This may be seen from Table 3 representing percentage of rough-error containing reports among those received at various Centres. The last line of Table 3 shows, however, that the percentage still remains large enough. It is necessary to stress in this respect that the figures in Table 3 reflect the rough error frequency only in data on height and temperature of mandatory surfaces, and the Collins' estimates are based exclusively on the HSC application.

Recent estimates confirm the conclusion that the main part of rough errors is of the communicational origin. These errors are caused by manual intervention into the communication process, still taking place in many countries. This may be clearly demonstrated by the geographical distribution of rough errors like that presented in Table 4. There exist many errors in reports coming from USSR, China, and, particularly, India. At the same time, there are very few rough errors over the USA and over those West European countries where all procedures connected with the observation, processing, and communication are completely computerized.

Table 3 Percentage of rawinsonde reports containing rough errors

Studies 1971-1974	> 20
Operational, NMC 1978	> 15
FGGE IIB, WDC (1979-80)	≈ 10
NMC, Collins 1988	≈ 7

Table 4 Distribution of rough errors among the WMO blocks

	0	1	2	3	4	5	6	7	8	9
0	-	2	3	0	1	-	0	3	4	0
10	2	0	1	1	-	15	7	13	-	-
20	0	2	3	5	9	9	7	9	9	12
30	9	13	3	2	3	6	7	13	25	-
40	5	19	48	37	21	0	4	19	17	-
50	4	14	13	7	14	6	21	15	6	12
60	15	5	4	5	0	0	0	3	3	-
70	1	7	3	0	0	-	11	-	4	-
80	2	1	5	5	1	2	0	3	0	3
90	-	19	-	4	24	-	13	7	0	-

The complete restructuring of existing communication systems in large regions is necessary in order to make it possible to avoid any human intervention into the communication process. It would be unrealistic therefore to expect a substantial improvement of the present situation earlier than in several decades.. Even then, however, there will still exist rough errors in meteorological information, although the properties of them may become different.

9. RECENT INVESTIGATIONS AT THE NMC

An improved hydrostatic check algorithm has been recently developed by William Collins, and designed to become a part of the CQC of rawinsonde data on height and temperature. Collins has applied his code to several cases, each case containing all rawinsonde reports for a particular time received operationally at NMC. The application included some subjective examination of vertical profiles. No attempts to consider horizontal distributions were undertaken. The procedure applied may be thus characterized as a complex consisting of the hydrostatic check and the manual imitation of vertical checks.

The following main conclusions have been drawn from these experiments:

(1) There still exist many violations of the hydrostatic constrains in operationally received data. The main cause of them continues to be the data distortion due to manual operations connected with the communication process.

(2) These distortions often result in errors where only one digit, not the last one, is wrong, or two digits are transposed, or the temperature sign is wrong. Special measures are included in the Collins' code to recognize such errors.

(3) About one third of the overall number of detected errors may be confidently corrected by the Collins' check alone. It has been decided to implement these corrections into operational data processing, by applying the Collins' code at an early stage, before any other, objective or subjective, quality-control procedure is used. This is, of course, an urgent, temporary, measure to be replaced further by the implementation of the CQC.

(4) Almost all correctable data are being rejected by the present NMC quality control system, which was implemented many years ago and contains both automatically performed procedures and human intervention. In about 50% of all cases, the system rejects something else in addition. There are some rare cases, when the existing system retains erroneous values, when it rejects correct values instead of erroneous ones, and even when it introduces false corrections to correct data. There exists thus a strong need to develop and implement a better QC system, capable of correcting correctable data.

10. SOME EXAMPLES

The following examples illustrate the performance of the Collins' check when coming across different kinds of errors. Almost all examples are given for one observation time, 12Z June 11, just to illustrate the conclusion that a variety of rough errors exists at almost every observation time.

In each case, Collins' check has been applied at least twice: first to data received at NMC and/or to those written on the so-called history tape (this is presented under the heading "HSC"), and then, to data accepted for NMC analyses and stored on the 36-day archive disk. Corrections, i.e. changes in values, computed by the HSC, are denoted by Z_c and T_c, while the corrected values are shown under headings "corrected", if they could be found by the Collins' check alone, and "correct" otherwise. F is a digit (flag) denoting the error type.

The first 4 examples illustrate the cases when an error can be confidently corrected by the HSC alone: an error in one digit, not in the last valuable one, in height (F=1) and in temperature (F=2), an error in the temperature sign, and a transposition of digits. Not every error belonging to type 1 or 2 is so evident, as it can be seen in example 5. It would be risky to introduce the correction as small as 50 m in this case, until other checks, particularly the horizontal check of Z, are performed.

The desirability of other checks is even higher when there exists only one, intermediate, layer with a large residual (F=6), as it may be seen from example 6. Only in rare cases, when this residual is extremely large, like it

88/7/11/12 Station 85201: La Paz, Bolivia

	HSC			Corrected				36-day archive			
P	Z	T	S	Z	S	Z_c	F	Z	T	S	F
150	14170	-67.5						14170	-67.5		
			-10.3								
100	16570	-72.5						99999	9999.9	13.6	
			81.8		-18.2						
70	18770	-67.9		18670		-100	1	18770	-67.9		
			-112.6		-12.6					-112.6	
50	20700	-63.9						20700	-63.9		6

Example 1

88/7/11/12 Station 24959: Yakutsk, USSR

	HSC					Corrected	
P	Z	T	S	F	T_c	T	S
700	3008	3.4				-3.4	
			14.8				14.8
500	5670	-12.5				-12.5	
			38.9				5.9
400	7340	-34.7		2	10.0	-24.7	
			35.2				-7.4
300	9360	-40.5				-40.5	
			5.3				5.3
200	10580	-50.9				-50.9	

Example 2

88/6/29/00 Station 43371: Trivandrum, India

	HSC					Corrected	
P	Z	T	S	F	T_c	T	S
850	1467	17.2					
			62.6				10.8
700	3106	-9.1		2	20.0	9.1	
			89.0				-0.7
500	5820	-4.5			10.0		
			2.2				
400	7550	-13.1					

Example 3

88/7/11/12 Station 44373: Dalanzadgad, Mongolia

	HSC					Corrected	
P	Z	T	S	F	Z_c	Z	S
500	5830	-7.1				5830	
			10.3				10.3
400	7540	-19.1				7540	
			-573.5				-33.5
300	9060	-30.3		1	540	9600	
			528.3				-11.7
250	10850	-43.5				18050	
			-2.2				-2.2
200	12320	-52.3				12320	

Example 4

88/7/11/12 Station 72220: Apalachicola, US

	HSC					Corrected	
P	Z	T	S	F	Z_c	Z	S
250	10990	-41.9				10990	
			-3.6				-3.6
200	12460	-53.5				12460	
			63.9				13.9
150	14320	-66.5		1	-50	14270	
			-35.3				14.7
100	16720	-69.7				16720	
			-13.1				-13.1
70	18870	-62.5				18870	

Example 5

88/7/11/12 Station 46747: Tungkong, Taiwan

	HSC						Corrected	
P	Z	T	S	F	Z	T	S	Z_c
500	5870	-4.3			5870	-4.3		
			7.4				7.4	
400	7600	-14.9			7600	-14.9		
			107.9				7.9	
300	9820	-30.1		6	9720	-30.1		-100
			-8.6				-8.6	
250	11180	-41.1			11080	-41.1		-100

Example 6

88/7/11/12 Station 33041: Gomel, USSR

	HSC: SWING1					HSC: History Tape		36-day archive		
P	Z	T	S	F	Z	Z	S	Z	T	S
			1.5							
700	2875	-1.9						2875		
			1003.5							1016.0
500	6740	-18.5		6	5740	5767		99999		
			6.1				1.1			
400	8110	-30.9			7110	7092		99999		
			0.3				1000.3			
300	10070	-47.9			9070	10062		99999		
			-7.8				0.2			
250	11240	-57.3			10240	11240		11233		
			5.7				5.7			5.0
200	12680	-50.1			11680	12680		12672		
			2.2				5.2			8.7
150	14560	-50.5			13560	14563		99999	9999.9	
			4.0				1.0			
100	17200	-51.9			16200	17200		17191		
			-7.7				-7.7			-8.2
70	19510	-50.7			18510	19510		19500		
			2.7				-8.3			
50	21710	-49.7			20710	21699		99999	9999.9	

Example 7

88/7/11/12   Station 56294: Chengtu, China

	HSC						Corrected	
P	Z	T	S	F	Z_c	T_c	T	S
850	1478	5.0		4	60	21.0	25.0	
			59.7					2.8
700	3144	13.6					13.6	
			7.1					7.1
500	5890	-4.1					-4.1	

Example 8

88/7/11/12   Station 60630: In Salah, Algeria

	HSC						Corrected	
P	Z	T	S	F	Z_c	T_c	Z	S
150	14280	-67.1					14280	
			-15.1					-15.1
100	16680	-72.5					16680	
			-696.2					3.8
70	18080	-72.5		5	700	-133.3	18780	

Example 9

88/7/11/12 Station 59647: Wsi-Chou-Tao, Taiwan

	HSC						Corrected	
P	Z	T	S	F	Z_c	T_c	T	S
850	1456	22.2					22.2	
			11.9					11.9
700	3122	13.2					13.2	
			239.8					15.6
500	5870	-50.5		5	-240	48.7	-5.0	

Example 10

88/7/11/12 Station 44231: Muren, Mongolia

	HSC			Correct		36-day archive		
P	Z	T	S	T	S	Z	T	S
850	1456	-23.1		+23.1		1652	-23.1	
			194.6		20.6			-0.8
700	3117	-7.5		+7.5		3117	-7.7	
			67.5					66.5
500	5780	-12.1			-6.4	5777	-12.3	
			1.7					1.3
400	7450	-23.7				7445	-24.0	

Example 11

88/8/11/12 Station 93986: Chatham Island

	HSC			Correct	
P	Z	T	S	Z	S
250	10090	-54.3			
			18.9		
200	11540	-54.1			
			-394.2		5.8
150	13000	-52.1		13400	
			-4993.0		6.1
100	10610	-55.7		16010	
			5408.1		8.1
70	18270	-59.5			
			7.2		
50	20370	-62.1			

Example 12

88/7/11/12 Station 47158: Kwangju, Korea

	HSC			Correct		36-day archive		
P	Z	T	S	T	S	T	S	F
500	5890	-4.3						
			-1.9		-1.9			
400	7610	-15.1				-15.1		
			-42.5		-0.5			
300	9730	-38.1		-27.9		9999.9	-64.6	
			-2.5		-2.5			
250	11010	-27.9		-38.1		-27.9		
			-32.4		1.0			
200	12510	-49.5				9999.9	-91.6	
			-1.6		-1.0			
150	14350	-59.7				-59.6		6

Example 13

is in the case 7, one can be confident by the HSC results alone that there was a computational error. For the cases when a large residual has been found only in the lowest layer (F=4), or in the uppermost one (F=5), the Collins' check gives both alternative corrections: in height, Z_c, and in temperature, T_c. To choose among them, additional checks are necessary, or at least, a human inspection as successfully applied in examples 8-10.

The last three examples may seem exotic, because there are large errors at two consecutive levels in each of those examples. A case was even met when the two temperatures had been transposed (example 13); it is a mystery, how that could happen. Unfortunately, such complicated cases occur not so seldom as one could expect. Special measures are being undertaken therefore by W. Collins in order to make the decision making algorithm capable of detecting not only two errors at the same level (F=3) but any combination of two errors at two consecutive levels as well.

Considering some results of the Collins' check application to 36-day archive data, one can see that the present NMC quality-control system sometimes does not reject definitely wrong data (it practically never corrects such data) and even erroneously changes correct data instead of wrong ones (example 11).

11. IMPLEMENTATION

As mentioned in G, the CQC of rawinsonde data on height and temperature of mandatory isobaric surfaces was implemented at Hydrometeorological Center in Moscow about a decade ago (Antsipovich, 1980). It also was successfully applied to FGGE data (Aldukhov, 1982). Many specialists agree that it is highly desirable to implement this approach elsewhere, particularly at NMC and at ECMWF, and work in this direction has already begun at NMC. This is not an easy task for the NMC, due primarily to the multi-forecast structure of its operations, and, as pointed out by Ronald McPherson (personal communication), the implementation of the CQC approach at the ECMWF would be substantially easier.

Two objections against the CQC approach have been, however, formulated. First, there is some degree of subjectivity in specifying the admissible residuals, and a more objective approach would be preferable. This is, of course, true. It is necessary to take into account that the application of some predefined criteria is the consequence of the very nature of the QC, and such criteria are intrinsic in any QC approach, however objective it looks. As to the CQC, experience shows that its decisions do not depend too much on these criteria, because the DMA analyses results obtained by application of all CQC components. If, for example, one of the components has been made excessively sensitive, so that it suspects some correct data, these suspicions are not supported by other CQC components, and the DMA rehabilitates the data.

The second objection is based on the fact that the CQC has been so far applied only to a small, though essential, part of all operative information, while every piece of information, particularly the data of new, non-traditional, observing systems, have to be subjected to QC.

There exists a simple way to implement a CQC of any kind of data as soon as it has been developed and tested. The new CQC is just to be performed not instead of the existing QC system, but before it begins to operate. This will not only lead to increased quantity and higher quality of data checked by the new CQC, but also improve the possibilities of the existing system to perform the QC of other data.

It is, of course, very important to develop the CQC approach application to as many kinds of data as possible. We have, however, to take into account, that new observation methods and devices are being developed in addition to, or instead of, those in use now, and that the properties of any observing system have to be accounted for in the CQC of its data. It is highly probable, therefore, that, at any time, some types of data will remain for which a CQC is still to be developed and which have, meanwhile, to be subjected to a simpler, less sensitive, quality control.

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