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COMPLEX QUALITY CONTROL OF RAWINSONDE HEIGHTS AND TEMPERATURES (CQCHT) AT THE NATIONAL METEOROLOGICAL CENTER

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1. INTRODUCTION

As is well known, some meteorological data received at prognostic centers can be distorted by so-called rough errors. Such errors may originate in the course of measurement, processing, or communicating the data. Although comparatively rare, rough errors may lead, particularly in data-poor regions to substantial errors in analyzed meteorological fields and, therefore, in predicted ones. That is why some special procedures are performed at every prognostic center both manually and automatically trying to get rid of rough errors. These procedures are usually referred to as the quality control (QC) of operational meteorological information.

The necessity of an automatic QC performed by a computer was recognized at the beginning of the numerical weather prediction era (Gilchrist and Cressman, 1954), and the first such methods were proposed and applied soon after that (Bergthorsson and Döös, 1955, Bedient and Cressman, 1957, Staff Members, Joint Numerical Weather Prediction Unit, 1957). There was, however, little progress in improvement of QC methods during several following decades, just because the most important task was to improve existing prediction models and data assimilation systems, and also because the QC design was considered by many specialists as a purely technical task having nothing to do with science.

As a result, the QC systems in operational use for many years at major prognostic centers were due to tradition rather than to logical reasons, and the NMC was not an exception. Until several years ago, the QC system at NMC consisted of four sequentially performed procedures:

(1) Subjective QC, mostly of rawinsonde data over North America, by the Senior Duty Meteorologist (SDM) or another specialist at the Meteorological Operations Division (MOD). It resulted in deletion of some data determined to be wrong, or even in the subjective correction of some of them.

(2) QC of rawinsonde data by a computer program called HYDROCHK, which found violations of the hydrostatic equation, as well as unrealistically large vertical gradients of wind (the wind shear). All data rejected and many of those modified by the HYDROCHK were not used in the course of the data assimilation.

(3) The so-called gross check was applied to differences between each reported value and its forecast first guess, defined as a numerically predicted value from initial data 6 hours (or 12 hours) before. We shall call these differences increments (in contrast to "full values"). If the absolute value of an increment was very large then the reported value was purged.

(4) The buddy check compared each increment with those at two closest points. If the increment under check differed substantially from the other two while they were close to each other, then the reported value was purged.

The situation with the QC at NMC has become much better during the last few years due mainly to substantial amount of work performed at the NMC Development Division (DD) under the general supervision by Dr. E. Kalnay. The gross check and buddy check have been replaced by the Complex of Optimum Interpolation Checks designed by J. Woollen (1991). The functions of HYDROCHK were taken by the Comprehensive Hydrostatic Quality Control (CHQC) which is capable of confident, entirely automatic, corrections of many errors detected by it (Collins and Gandin, 1990).

The CHQC also provided MOD with outputs containing information on those detected errors which the CHQC was unable to correct. This marked the beginning of an interactive QC performed jointly by a computer program and by a human specialist. Unfortunately, the lack of appropriate software at the MOD hampered this interaction under operational conditions. Nevertheless, many MOD specialists expressed their interest in this new kind of their activity, and the CHQC outputs provided, at least, a good training tool in it.

A Complex QC of significant level temperature, using data already quality-controlled by the CHQC, was designed soon after that (Collins, 1990), and its algorithm was included into the CHQC one.

The CHQC was in operational use at NMC for about three years. It proved to be very productive not only in its operational mode. Quasi-operational monitoring of the CHQC outputs, which was performed on a regular basis by DD specialists, as well as their analysis of automatically produced CHQC Monthly Summaries, allowed us to discover many problems with operational data arriving at NMC and to resolve some of these problems (Gandin and Collins, 1990, Morone, Gandin and Collins, 1992). The

CHQC algorithm is well documented, and the code is now used at many other centers, both in this country and abroad.

It was understood from the very beginning that the CHQC design and implementation was just the first stage in developing a much more advanced Complex Quality Control (CQC) of rawinsonde data on height and temperature, containing other, statistical, checks in a complex with the hydrostatic one. The CQCHT (Complex Quality Control of rawinsonde data on Height and Temperature) design at the NMC DD was begun in January 1991. After several months of thorough testing and improvements, the CQCHT has finally replaced, in November 1991, the CQHC as an operational data quality control at the NMC.

The CQCHT Decision Making Algorithm (DMA) is a complicated code containing very many logical operations. Although written in a highly modular format, the CQCHT code consists of as many as about 13,800 FORTRAN 77 lines (as compared with about 3,000 lines of the CHQC). This is quite natural: while each CHQC decision was based on an analysis of three (or less) hydrostatic residuals (Collins and Gandin, 1990), the CQCHT DMA analyses a combination of up to 15 residuals of several checks in order to make each decision.

As will be explained in some detail below and illustrated by many examples, the CQCHT is substantially more productive than the CHQC was. The CQCHT DMA not only automatically corrects a majority of those errors which were only suspected by the CHQC, it also detects errors that could not be detected by the CHQC and automatically corrects many of them and, also automatically, excludes non-correctable wrong data from the set used in the data assimilation systems. As a result of the CQCHT implementation, several kinds of human activity in the QC have become unnecessary because the computer performs this work automatically. This means that the MOD specialists have now more time and opportunities to perform less technical, more meaningful work, than before the CQCHT was implemented.

An essential part of this work is, or at least should be, the interaction of MOD specialists with the automatic quality control performed by the CQCHT. The CQCHT DMA provides the MOD specialists with a special output, just as the CHQC did before. Superficially, these actions by CHQC and CQCHT look analogous, but the essence is quite different. An overwhelming majority of cases, which would be sent to MOD by the CHQC DMA, are now treated by the CQCHT DMA entirely automatically (as are many other cases not even detectable by the CHQC). The cases transferred to MOD by the CQCHT DMA include the most complicated ones, those for which the help by a human specialist is highly desirable. In order to be able to provide such help, the specialist has to know quite perfectly, among other things, what the CQCHT is and how it works.

How can this understanding be achieved? Studying the CQCHT technical documentation, i.e., the code itself and comments to it, would practically lead nowhere, the code is too complicated. On the other hand, the desirable actions of a specialist can not be formulated by simple rules, like "if you see this and this, do that and that": everything that might be described this way has been already programmed and is automatically performed by the CQCHT DMA.

The only solution to the problem is to provide the MOD specialists with appropriate training, performed by the CQCHT developers. This should include some lecturing as well as practical assistance in the operational work with the CQCHT outputs. In order to make the training more effective, it is highly desirable to provide participants with a kind of guide book allowing them not only to find information about various details of the CQCHT and its outputs, but also to understand better, so to say, the spirit of the Complex Quality Control and the role of human specialists when interacting with it.

This is one main aim of this Office Note. It may be also used by specialists involved in design and application of the automatic quality control, particularly by those who want to design and implement their own QC algorithms analogous to the CQCHT. Several specialists at various centers already expressed their desire to do so. We hope that this Office Note can facilitate their work. Naturally, the Office Note provides the major documentation of the CQCHT for everyone who needs information about its methodology and operation.

The text is organized in the following way. The overall structure and functioning of the CQCHT algorithm is described in Section 2. Section 3 presents all individual checks used in the CQCHT, and their reaction to errors of various kinds is described in Section 4. Section 5 contains existence and magnitude conditions for hydrostatically suspected errors, as well as equations for hydrostatically proposed corrections. The most complicated part of the CQCHT, its DMA, is described in some detail in Section 6, and more details about the DMA can be found in Appendix B. Description of the CQCHT operational output, as well as of its modified form used in this Office Note and of the Events File, is given in Section 7. Numerous examples, illustrating various aspects of the CQCHT DMA functioning and of the interaction with specialists, are presented in Section 8. The final Section 9 contains some general conclusions.

2. General Description of the CQCHT Algorithm

2.1. Statistical checks.

The CQCHT algorithm, like that of any CQC, consists of two major parts: the checks and the Decision Making Algorithm (DMA). Every result of each check is described in its quantitative form by so-called residual, reflecting the degree of inconsistency found by this particular check. Residuals of all checks are then analyzed by the DMA in order to detect and, if possible, to correct erroneous data. Table 2.1 contains the list of CQCHT checks. Only the first two of them, the hydrostatic check and the baseline check, were in the CHQC algorithm (and the baseline check results were not used by the CHQC DMA), all other checks are present only in the CQCHT.

Formally, the incremental check does not differ from what was called the gross check: it just considers the difference between reported value and its forecast first guess (the increment) and suspects the reported datum if the absolute value of the increment is large. However, the main aim of incremental checks in the CQCHT is quite different from that of gross checks: the incremental check is used in order to confirm (or deny) a correction proposed by the hydrostatic or the baseline check, or to chose among several corrections implied by that check. The incremental check is much more sensitive under these circumstances than if applied solely, i.e., as a gross check. Moreover, the presence of other checks makes the incremental check results more informative even when there are no hydrostatic or baseline check suspicions.

At the same time, large increments may also be caused by errors in the forecast first guess. That is why two other checks, horizontal and vertical ones, are included in the CQCHT. Both are optimum interpolation checks applied to increments. The interpolation into the station under check from four (or fewer) surrounding stations is performed by the horizontal check, and the difference between the increment at the station under check and its interpolated value is the horizontal check residual. If the residual is large, then the reported value is suspected. As to the vertical check, it is analogous to the horizontal one, except that vertical interpolation from two surrounding levels (or from one if the level under check is the lowest or the highest among those reported) is used instead of the horizontal interpolation. Both horizontal and vertical check residuals are also used, additionally to increments, in order to examine the hydrostatic and baseline check suspicions.

Table 2.1 CQCHT checks

Name	Applied to	Residual
Hydrostatic	Each layer between neighboring "complete" mandatory surfaces i.e., surfaces with neither height (z) nor temperature (T) missing	Difference between the layer thickness computed from heights of its boundaries and that hydrostatically computed from their temperatures. Also applied in terms of temperature
Baseline	Layer between the station level (z_s) and lowest reported mandatory surfaces	Difference between z_s in station dictionary and z_s hydrostatically computed from surface pressure p_s and heights z_1 and z_2 of lowest reported surfaces. Also applied in terms of p_s, z_1, and z_2
Incremental	Reduced mean sea level pressure, temperature and height of all mandatory surfaces, if (and where) the forecast first guess is not missing	Difference between the reported value (or reduced mean sea level pressure) and its first guess (called the increment)
Horizontal	Reduced mean sea level pressure, temperature and height of all mandatory surfaces, if (and where) the forecast first guess is not missing	Difference between the increment at the station and its value interpolated from four (or fewer) surrounding stations situated in different quadrants
Vertical	Temperature and height of all mandatory surfaces, if (and where) the forecast first guess is not missing	Difference between the increment at the level and its value interpolated from two surrounding levels (or, for the first and the last level, extrapolated from the neighboring level)

We shall refer to incremental, horizontal and vertical checks as statistical checks, in contrast with hydrostatic and baseline checks which are functional, or "quasi-functional".

2.2. Hydrostatically suspected errors.

It was decided from the very beginning to design the CQCHT as a generalization of the CHQC, rather than as a completely new algorithm. The main reason for doing so was that the hydrostatic check is much more sensitive than statistical checks are and it can identify most correctable errors by itself. It is also important that the first guess information, which is necessary for statistical checks, is not universally available. The

NMC prediction models still have insufficient vertical resolution at high elevations, and therefore no first guess data exist for heights exceeding that of the 50 HPa surface. Moreover, it happens sometimes that the first guess is available only up to the 100 HPa surface, or even not available at all. Under such conditions, the CQCHT just reduces itself to CHQC. It is certainly inconvenient to deal with such a "mixed" situation, but that is much better than not to perform any QC where and when there is no first guess information.

As described in detail elsewhere (Collins, Gandin, 1990), the CHQC DMA uses hydrostatic residuals for neighboring layers in order to detect erroneous data and to investigate the cause of each detected error. To deal not only with isolated communication-related errors, but also with such errors at two neighboring mandatory levels, the CHQC DMA analyses hydrostatic residuals for three neighboring layers, i.e., for four levels.

Like the CHQC, the CQCHT uses a "template" of four mandatory levels, moving it upwards, level by level, for each report. It also uses the same set of hydrostatically suspected error types (Table 2.2) and the same algorithms to detect them. The subsequent actions of the CQCHT DMA are, however, quite different. The CHQC DMA automatically corrected all confidently correctable communication-related errors, i.e., Type 1,2,7,8,9 and 10 errors, leaving all other data unchanged and providing the MOD with information about other suspected errors. As to the CQCHT DMA, it first examines for each such correction (like for those of other types), what will happen to statistical check residuals after the correction, and makes the corrections only if these residuals will become sufficiently small. This is almost always the case with single confidently correctable errors, i.e., Type 1 and 2 ones. There are, however, some rare exceptions, when the DMA decides to make no correction, either rehabilitating the hydrostatically suspected datum, or leaving it suspected. The same is true for hydrostatically suspected errors of Types 7-10, i.e. errors at two adjacent levels. In those cases, however, an intermediate decision is also possible: to correct one of two suspected values, not changing another one.

When analyzing increments and horizontal check residuals for heights, the DMA takes into account that comparatively large values of them may result from rather small observational errors (or first guess errors) in the temperature, if these errors persist vertically. The DMA considers therefore not the residuals of height incremental and

Table 2.2. Types of hydrostatically suspected errors.

Type	Suspicion
1	Communication, in Z_k $(2 \le k \le N\text{-}1)$
2	Communication, in T_k $(2 \le k \le N\text{-}1)$
3	Communication, in T_k and Z_k $(2 \le k \le N\text{-}1)$
4	Communication, in T_1 and/or Z_1, or computation of Z_2-Z_1
5	Communication, in T_N and/or Z_N
6	Computation of $Z_{k+1} - Z_k$ $(2 \le k \le N\text{-}2)$
7	Communication, in Z_k and Z_{k+1} $(2 \le k \le N\text{-}2)$
8	Communication, in T_k and T_{k+1} $(2 \le k \le N\text{-}2)$
9	Communication, in Z_k and T_{k+1} $(2 \le k \le N\text{-}2)$ (denoted Type 19 for Z and 29 for T)
10	Communication, in T_k and Z_{k+1} $(2 \le k \le N\text{-}2)$ (denoted Type 20 for T and 10 for Z)
11	Like Type 1, but small
12	Hydrostatically proposed correction would lead to substantial super-adiabatic lapse rate
13	Data hole including 100 HPa surface
14	Data hole not including 100 HPa surface
22	Like Type 2, but small
99	Hydrostatically proposed corrections of Type 8, 9, or 10 would lead to substantial super-adiabatic lapse rate

horizontal check themselves, but their deviations from the average of their values at two surrounding mandatory levels. As a result, a height correction is often accepted by the DMA when it makes the increment large but consistent with the background formed by those at adjacent levels.

Due to the involvement of statistical check residuals, the CQCHT reaction to comparatively small hydrostatically suspected errors (Types 11 and 22) does not differ from that to large errors of the same kind (resp., Types 1 and 2). The only difference is that the DMA much more often decides not to change a datum in spite of the hydrostatically suspected Type 11 or 22 error, than happens with Type 1 or 2 error suspicions. The only reason to preserve Types 11 and 22, not merging them with Types

1 and 2, is the fact that the first guess may be missing. Particularly, the DMA never reacts to Type 11 and 22 suspicions at 30 and 20 Hpa.

Nor does the CQCHT DMA react to hydrostatic suspicions of Types 12 and 99, i.e., to hydrostatically proposed corrections which would result in an unrealistic lapse rate and are not made therefore by the CHQC. Statistical checks provide much better information for the DMA decisions, than that resulting in Types 12 and 99. These types are, however, preserved just in order to protect against wrong corrections when the first guess is missing. Preservation of these types (unlike that of Types 11 and 22) may, at least in principle, lead to inability of the CQCHT DMA to find proper correction of some data correctable by the aid of statistical checks and, therefore, to rejection of such data.

Except for Types 12 and 99, the CQCHT DMA automatically analyses each hydrostatic suspicion and makes corresponding corrections (if any). To do so, the DMA considers what would happen with statistical residuals after the correction(s): if they would become reasonably small, then the correction is performed, otherwise another option for correcting the error(s), if such an option exists, is investigated, and so on.

As considered above, there exist only two trivial options for Type 1 and 2 errors: either to correct the suspected datum or to leave it as it was. The same is true for a Type 6 error suspicion, i.e., a probable error in a layer thickness computation. If the incremental and horizontal residuals for several heights above this layer would become small after these heights are corrected, then the corrections are made, otherwise all heights remain unchanged.

There are as many as four options for a Type 3 hydrostatic suspicion, i.e., that of communication errors in both temperature and height of the same level: to correct both, to correct only temperature, to correct only height, to correct nothing. To chose among these options, the DMA uses the same approach, it analyses resulting statistical residuals. Just like Type 7-10 suspicions, it happens comparatively often that only one of two hydrostatically suspected parameters should be corrected. It is convenient to use a "mathematically-absurd" notation for such events, connecting suspicion and correction types by the equality sign. For example, Type "3=2" denotes that, despite a Type 3 hydrostatic suspicion, only the temperature was found wrong and corrected by the DMA.

The situation with Type 5 hydrostatic suspicion, that of a communication error at the highest level (among those reported), may seem quite analogous to that with Type

3: the DMA also has four options, "5=1", "5=2", "5=3" and "5=0". There is, however, an important difference (reflected by the absence of a "mathematically correct" option, like "3=3"). A Type 5 suspicion is based on only one large hydrostatic residual, that for the highest layer, and therefore the corrections of types "5=1" and "5=2" proposed by the hydrostatic check are, so to say, of equal footing, none of them is preferable a-priori. The DMA first examines these two options. If none of them is acceptable, it attempts the option "5=3", trying to corrects both temperature and height of the highest level. When doing so, the DMA makes more essential use of statistical checks, than just to confirm or deny corrections: the statistical residuals allow a proper partitioning of the hydrostatic residual, that is, to specify its parts caused by errors in temperature and in height. If none of the options "5=1", "5=2" and "5=3" is justified by sufficiently small resulting statistical residuals, then the option "5=0", making no correction, is chosen by the DMA.

The situation with Type 4 hydrostatic suspicion, that of an error at the lowest level, is even slightly more complicated, because five options, "4=1", "4=2", "4=3", "4=6" and "4=0", are considered by the DMA. The first three of them are analogous to those for Type 5 suspicion, and so are the DMA actions. As to the "4=6" version, assuming a computational error in the thickness of the lowest layer, the DMA uses it as a last resort, when none of three first options achieves its aim. The DMA actions in that case do not differ from its treatment of a Type 6 hydrostatically suspected error.

The treatment by the DMA of two remaining hydrostatic diagnoses, those of so-called data holes (Types 13 and 14), contains much in common with that of Type 4 and 5 suspicions. A data hole is a sequence of two missing levels (that is, levels with no data on temperature and/or height) in a row. If a hole includes the 100 HPa surface, thus dividing Parts A and C of the rawinsonde report, it is assigned Type 13, otherwise it has a Type 14 diagnosis.

Since the layer between the hole boundaries is thick, its hydrostatic residual may be distorted by the influence of the temperature profile curvature. The value of this residual cannot therefore be trusted. This means that the parts of such a report before the hole and after it should be treated as if they were two separate reports.

That is exactly what the DMA does. It considers the hole's lower boundary as an upper boundary of a report, making and treating the hydrostatic suspicion at this level just like it does for a Type 5 suspicion. Analogously, the DMA actions with a hydrostatic suspicion at the upper boundary of a hole are like those with a Type 4 suspicion.

In most cases, however, the DMA concludes that there were no errors at the hole's boundaries and decides to retain these data in spite of the large hydrostatic residual within the hole.

2.3. Errors detected with the aid of the baseline and surface pressure checks.

The baseline check is essentially a hydrostatic check applied not to a layer between two mandatory isobaric surfaces but to the layer between the earth's surface (or sea level) and the lowest reported mandatory surface. In order not to be perturbed by local effects, the baseline check does not use the observed surface air temperature, extrapolating instead its value, estimated from heights of two lowest mandatory surfaces, to the station level, using the standard lapse rate of 6.5 K/km. In the CQCHT, the baseline check is accompanied by the incremental and horizontal checks of the surface air pressure. To obtain the increments, both observed pressure and the first guess are first reduced to the mean sea level, so that these two checks are actually checks of the mean sea level pressure.

Extrapolation involved in the baseline and surface pressure checks diminishes their accuracy, particularly for elevated stations. Nevertheless, these checks proved to be sufficient, in corroboration with each other, as well as with other checks, to diagnose and correct several types of errors. These types are listed in Table 2.3.

Table 2.3. Types of errors detected with the aid of baseline and surface pressure checks

Type	Cause	Correction
100	Communication, in p_s	p_s
101	Communication, in z_1 (T_1 missing)	z_1
102	Not specified	none
106	Observation, in p_s	p_s and all heights
116	Computation, z_1	all heights

Type 100 error is a communication-related error in the surface pressure. The DMA recognizes it by the fact that the surface pressure increment, its horizontal residual and the baseline residual expressed in terms of surface pressure are all large and close to each other. Such an error does not influence anything except the surface pressure, and the DMA corrects this pressure.

An error of Type 106 is also in surface pressure, but it is a measurement error, and it acts in quite a different way. It also leads to large increment and horizontal residual of the surface pressure, but the baseline residual is small and, most importantly, this error results in errors in all mandatory level heights. These errors are close to $K_p p'$, where p' is the pressure measurement error and

$$K_p = \frac{RT}{gp}$$

(Practically, K_p is equal to 8 m/HPa for stations close to the sea level and increases with the station elevation.) To diagnose a Type 106 error and to estimate its value, the DMA uses statistical residuals of both surface pressure and mandatory level heights. It then corrects the surface pressure and all reported mandatory level heights.

A Type 116 error also distorts all heights, but its origin is quite different: a computational error in the thickness of the layer between the station level and the lowest reported mandatory surface. Such error, unlike those of Types 100 and 106, does not result in large statistical residuals of the surface pressure. It leads to a large baseline check residual (in terms of station elevation) and to large statistical residuals of all heights. To diagnose a Type 116 error the DMA compares increments and horizontal residuals for several lowest mandatory levels between themselves and with the baseline check residuals. If they are sufficiently close to each other, then the error is diagnosed and all heights are corrected. These corrections are analogous to those of Type 106 error, except that nothing is done with the surface pressure.

It often happens, in accordance with existing rules, that the temperature of the lowest reported surface (or even of several surfaces) is missing. The hydrostatic check does not react therefore to a communication error in the height of such surface, but the baseline check does, as do the statistical checks of this height. This is a Type 101 error, it is diagnosed and corrected when the statistical residuals for such height are large and close to the baseline residual expressed in terms of this height.

One should mention that the DMA behavior with errors diagnosed with the baseline check's aid is different from that with hydrostatic suspicions (and close to the CHQC DMA actions): the DMA not only diagnoses errors of Types 100, 101, 106 and 116, it immediately corrects each such error. There actually is no other possibility, because several checks, not only the baseline one, are used to identify each of these types.

That is why an additional category, Type 102 error, is used, that for unidentified baseline and surface pressure check suspicions. For these suspicions, it is not clear not only whether any error exists, it also remains unknown which data, if any, are in error.

The DMA also uses the baseline check results (if they are available) when analyzing hydrostatically suspected communication errors at the lowest mandatory level (Type 4). In such cases, however, the baseline check is used as an auxiliary way to confirm (or deny) the height correction (Type "4=1") or the partition between the temperature and height corrections, proposed by other checks (Type "4=3").

2.4. Observational errors. Scans and decision types.

A substantial advantage of the CQCHT over the CHQC is its ability to detect errors of observational origin. As long as the heights of mandatory surfaces are not obtained from independent measurements but computed hydrostatically from temperature profiles, the hydrostatic check does not react to these errors, and this absence of reaction proves to be a powerful means to identify observational errors. It is also important that, due to the hydrostatic computations, even small errors in temperature measurements may result in large errors in heights of elevated mandatory surfaces, if the temperature errors, as most often happens, persist along the vertical. For example, a temperature error as small as 2K, but persisting vertically, leads to an error in the 50 HPa height which exceeds 300 m.

If there were no hydrostatic or baseline suspicions for a report, then the DMA simply considers, on its second scan through the report, absolute values of all statistical check residuals for every reported datum. If several of these residuals exceed some limits, then the datum is suspected for its distortion by observation error(s). For those reports, which underwent correction(s) on the first scan (or even on the second scan as well), corrected values are analyzed instead of reported ones.

There are actually two sets of limits used by the DMA in making its decisions. If only the lower among them is exceeded, then the DMA requests a specialist's decision whether to reject or to retain the datum (DMA Decision 3, see Table 2.4). If the statistical residuals are very large, so that the higher limits are exceeded, then the DMA assigns a flag for the datum to be rejected from the set used by the assimilation system

(Decision 4), but still provides the MOD with all information about this. These actions, common for all quality control methods, will be referred to as "rejection" or "deletion".

Table 2.4. DMA decisions

Decision No.	Description
1	Automatically corrected
2	Suspected, retained as it was (rehabilitated)
3	Suspected, likely bad, not corrected
4	Definitely bad, not corrected
5	Undetermined baseline error (used only for Type 102 suspicions)

It is thus the CQCHT Scan 2, that deals mainly with observational errors in height and temperature of mandatory surfaces, while communication and computation errors are dealt with by the Scan 1. It happens sometimes that the DMA decides, on the first scan, not only to decline a hydrostatically proposed correction of a datum, but even to suspect an observation error in it. On the other hand, the second scan is sometimes used to correct some errors still remaining in a report after the first scan. Such cases are, however, rare exceptions. As a rule, the Scan 1 is for correction and the Scan 2 is for rejection.

3.0 COMPLEX QUALITY CONTROL CHECKS

3.1 HYDROSTATIC CHECK

The single most important check is the hydrostatic check. The first version of the CQC program (CHQC) used only the hydrostatic check and yet was able to make roughly half as many corrections as the full program. It will become clear which corrections may be made solely with this check.

The hydrostatic residual is defined as the difference between the thickness of a layer computed from the mandatory level heights and computed from the mandatory level virtual temperatures. It is

$$s_{l1,l2} = z_{l2} - z_{l1} - A_{l1,l2} - B_{l1,l2}\left(T_{l1} + T_{l2}\right)$$

where T is the virtual temperature in Celsius and z the geopotential height. The residual, $s_{l1,l2}$, is calculated between every successive pair of mandatory levels, *l1* and *l2*, with non-missing height and temperature. The coefficients, *A* and *B*, are summed over any layers that may have missing data. For a single layer, i.e. no missing data,

$$A_{i,i+1} = \left(\frac{R}{T_0 g}\right)\ln\left(\frac{p_i}{p_{i+1}}\right), \qquad (i = l1, i+1 = l2)$$

and

$$B_{i,i+1} = \left(\frac{R}{2g}\right)\ln\left(\frac{p_i}{p_{i+1}}\right)$$

where T_o = 273.15K, R is the gas constant for dry air and g is the acceleration of gravity. For layers with intervening missing data

$$A_{l1,l2} = \sum_{i=l1}^{l2-1} A_{i,i+1}$$

and

$$B_{l1,l2} = \sum_{i=l1}^{l2-1} B_{i,i+1}.$$

The hydrostatic residual may alternatively be expressed in terms of temperature. This is useful when considering corrections to temperature. In this form, it is written as

$$X_{l1,l2} \equiv \frac{s_{l1,l2}}{B_{l1,l2}} = \left(\frac{z_{l2} - z_{l1} - A_{l1,l2}}{B_{l1,l2}} \right) - T_{l1} - T_{l2}$$

3.2 INCREMENTAL CHECK

The incremental check forms the difference between the observation and a 6 hour forecast interpolated to the observation location. The increments are formed at the rawinsonde mandatory levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50 HPa. The 925 HPa level is not presently considered, nor are levels above 50 HPa.

Since the CQC code is presently run on the HDS 9000 computers, only spectral model pressure coefficients at reduced truncation are available. From these, a 2.5 by 2.5 degree, latitude/longitude grid of heights and temperatures is formed. These values are interpolated bi-linearly to the observation locations. The increments are then

$$i_l = o_l - g_l$$

where i_l is the increment, o_l is the observed value, and g_l is the "guess" value interpolated to the observation location.

One potential problem is the influence on the increment of guess errors. Usually, temperature guess errors are small, but their influence on heights can be considerable, nevertheless. The following discussion shows a method of reducing this influence.

The increment can be referenced to the truth, writing it as

$$i_i = (o_i - t_i) - (g_i - t_i)$$

where t_i represents the "true" value (its exact definition is not important for our purpose). In the absence of error, the first term is small, but the second term will reflect forecast errors. It is the influence of this second term that can confuse decisions regarding the quality of mandatory level height. However, if the value of i_i is differenced from the average of its neighbors vertically, the following is obtained.

$$
\begin{aligned}
d_i &\equiv i_i - \tfrac{1}{2}(i_{i-1} + i_{i+1}) \\
&= (o_i - t_i) - \tfrac{1}{2}\left[(o_{i-1} - t_{i-1}) + (o_{i+1} - t_{i+1})\right] \\
&\quad -(g_i - t_i) + \tfrac{1}{2}\left[(g_{i-1} - t_{i-1}) + (g_{i+1} - t_{i+1})\right]
\end{aligned}
$$

Again, in the absence of error, the (o-t) terms will be small. And the (g-t) terms will also be small, since the vertical change (or curvature) of the forecast error is normally small. Therefore, whenever d_i can be calculated, it is used in making decisions of the quality of heights, rather than i_i. It will be referred to as the increment deviation.

3.3 VERTICAL CHECK

The vertical check provides the vertical residual: the difference between the observed increment of either height or temperature on mandatory surfaces and the vertically interpolated value, excluding the value at the observation level in the interpolation. Only the two adjacent pressure levels are used in the interpolation. The general form of the residual is

$$
s_l^v = o_l - w_{l-1} i_{l-1} - w_{l+1} i_{l+1}
$$

where s^v_l is the vertical residual, o_l is the observed increment, w_{l-1} and w_{l+1} are Optimal Interpolation (OI) weights and i_{l-1} and i_{l+1} are observed increments at the adjacent levels. The index, l, is for the vertical level.

The weights are determined using OI theory. They are given by

$$
w_{l+1} = \left((1+\gamma) r_{l,l+1} - r_{l,l-1} r_{l-1,l+1}\right) / \left((1+\gamma)^2 - r_{l-1,l+1}{}^2\right)
$$

and

$$
w_{l-1} = \left((1+\gamma) r_{l,l-1} - r_{l,l-1} r_{l-1,l+1}\right) / \left((1+\gamma)^2 - r_{l-1,l+1}{}^2\right)
$$

where w's are the weights, $r_{l1,l2}$ is the correlation of the increments between levels $l1$ and $l2$, and $\gamma = 0.5$ is the assumed ratio of the observation to 6-hour forecast error variance. For the lower and upper levels, the extrapolation uses only the adjacent level. The equations are simplified to

$$s^v{}_+ = o_+ - w_- i_-$$

with

$$w_+ = r_{+-} / (1 + \gamma)$$

where + refers to quantities at the boundary and - refers to quantities at the level adjacent to the boundary.

The correlation model is similar to that used in NMC's regional system:

$$r_{l1,l2} = \frac{1}{1 + c_a \left| \ln\left(\frac{p_{l1}}{p_{l2}}\right) \right|^{1.2}}$$

where $r_{l1,l2}$ is the vertical correlation between increments of variable v at levels $l1$ and $l2$. The value of c_a is 1.1 for height and 8.0 for temperature.

3.4 HORIZONTAL CHECK

The horizontal check requires several steps. Each step will be described in some detail. They are listed as:

1. Placing the data within 5-degree latitude/longitude cells.
2. Collection of data to be used in the check, surrounding each observation point.
3. Computation of the terms of the weight equation matrix.
4. Solution of the equation.
5. Computation of the horizontal residual.

3.4.1 Placing the Data Within 5-degree Cells

As the data are read in, a list is made of the station latitudes and longitudes. These are placed in an ordered array, increasing with (east) longitude and separated into

5-degree latitude bands. The diagram below schematically shows the result. The ordered index of stations increases within each row, beginning in the south, and progressing northward (upward). An array is set up with the indices of the observations within each box, to be used in the next step.

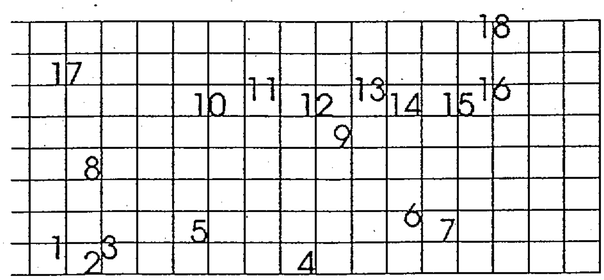

Fig. 3.1 Ordering of Stations by Latitude/Longitude

The diagram is only schematic as there are actually 72x36 boxes and around 700 observations.

3.4.2 Collection of the Data

The purpose of the collection is to make available an array of observations from which some will be selected to compute the horizontal residuals. The list is first narrowed down by selecting data from only those 5x5-degree boxes that are within about 20 degrees of latitude of the observation to be checked. The data within these boxes is known from the previous step. From this list, the final selection of four observations will be made. The number is limited to four in order to reduce the possible influence of erroneous observations at surrounding stations.

The distance and angle between the observation to be checked and each data in the nearby boxes is determined, and the observations are ordered by distance. As the increment most highly correlated with the data point is the closest, the closest observation, if it exists, is selected for each compass quadrant.

3.4.3 Formation of the Terms of the Weight Equation Matrix

The equation for the residuals may be written

$$s_l^h = o_l - \sum_{i=1}^{4} w_i i_i$$

where s^h_l is the horizontal residual, o_l is the observed increment value, w_i are the weights, and i_i are the increments. The weights are given by

$$XW = R$$

or

$$\begin{vmatrix} 1+\varepsilon & r_{12} & r_{13} & r_{14} \\ r_{21} & 1+\varepsilon & r_{23} & r_{24} \\ r_{31} & r_{32} & 1+\varepsilon & r_{34} \\ r_{41} & r_{42} & r_{43} & 1+\varepsilon \end{vmatrix} \begin{vmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{vmatrix} = \begin{vmatrix} r_{01} \\ r_{02} \\ r_{03} \\ r_{04} \end{vmatrix}$$

where the unknown weights are w, ε is the ratio of 6-hour observation error variance to forecast error variance, and r_{ij} is the correlation between the increments at points i and j. The observation point is denoted by the subscript 0. The correlations are modeled with a squared exponential form that depends only upon distance:

$$r_{ij} = \exp\left(-k d_{ij}^{\,2}\right)$$

The constant, k, has the value $3.5 \times 10^{-6} m^{-2}$.

3.4.4 Solution of the Equation

The set of linear equations for the weights is solved by the Crout reduction method (see e.g. Hildebrand, 1974, p. 545). The method may be described by the following equations:

$$x'_{ij} = x_{ij} - \sum_{k=1}^{j-1} x'_{ik} x'_{kj} \qquad (i \geq j)$$

$$x'_{ij} = \frac{1}{x'_{ii}} \left[x_{ij} - \sum_{k=1}^{i-1} x'_{ik} x'_{kj} \right] \qquad (i < j)$$

$$r'_i = \frac{1}{x'_{ii}} \left[r_i - \sum_{k=1}^{i-1} x'_{ik} r'_k \right]$$

$$w_i = r'_i - \sum_{k=i+1}^{n} x'_{ik} w_k$$

The equations are used sequentially. The first two equations determine the intermediate quantity x'_{ij}, the third determines r'_{ij}, which is used finally in the last equation to give the weights w_i.

3.4.5 Calculation of the Horizontal Residual

The calculation of the horizontal residual consists in evaluating the equation given above. It is repeated here:

$$s_l^h = o_l - \sum_{i=1}^{4} w_i i_i$$

The forecast error can influence the horizontal residuals, just as for the increments. Therefore, the difference of the horizontal residuals from the neighbors in the vertical can be helpful in reducing this influence, just as for increments. This difference is called the horizontal residual deviation, and is defined by

$$d_h \equiv s_l^h - \frac{1}{2}\left(s_{l-1}^h + s_{l+1}^h\right).$$

3.5 BASELINE CHECK

The baseline residual is the difference between the station elevation (given by NMC's dictionary) and the value consistent with the two lowest reported mandatory level heights. In calculating the consistent value, a constant, standard, lapse rate, b, is assumed (6.5 degrees/km). The baseline residual is computed by the following series of equations.

$$b = -.0065 \text{ deg/m}$$
$$\bar{z} = (z_1 + z_2)/2$$
$$\bar{\alpha} = \left(\frac{p_1}{p_2}\right)^{-\frac{Rb}{g}}$$
$$\bar{T} = -\frac{b}{2}(z_2 - z_1)\left(\frac{1+\bar{\alpha}}{1-\bar{\alpha}}\right)$$
$$\alpha = \left(\frac{p_s}{p_1}\right)^{-\frac{Rb}{g}}$$
$$z_s^c = z_1 + \left(\frac{\alpha - 1}{b}\right)\left[\bar{T} + b(z_1 - \bar{z})\right]$$
$$s^b = z_s^d - z_s^c$$

where $\bar{z}$ is the mean layer height, $\bar{T}$ is the mean layer temperature, z_s^d is the NMC dictionary value of the station elevation, and z_s^c is the calculated station elevation. The baseline residual is s^b.

In addition, the baseline algorithm calculates the following: 1) p_s^c, the correction to the surface pressure value that would lead to zero baseline residual, 2) p_m, the reduced mean-sea-level pressure, and 3) z_1^c and z_2^c, the corrections to the lowest and second reported level heights which individually would lead to zero baseline residual. They are calculated from the following equations.

$$p_s^c = p_1\left(\frac{1 + b(z_s^d - z_1)}{\bar{T} + b(z_1 - \bar{z})}\right)^{\frac{g}{Rb}}$$

$$p_m = p_s\left(\frac{1 + bz_s^d}{\bar{T} - b\bar{z}}\right)^{\frac{g}{Rb}}$$

$$z_1^c = \frac{(\bar{\alpha}-1)z_s^d - (\alpha-1)z_2}{\bar{\alpha}-\alpha}$$

$$z_2^c = z_1 + \left(\frac{\bar{\alpha}-1}{\alpha-1}\right)\left(z_s^d - z_1\right)$$

3.6 REDUCED MEAN-SEA-LEVEL CHECKS

In order to be able to check the reported surface pressure value, it is necessary to refer it to a common height. This is accomplished by first reducing the reported surface pressure to mean-sea-level. The reduction of the reported value is done along with other baseline computations; the equations were given above. In addition, the "guess" value of the mean-sea-level pressure (mslp) is obtained by the identical method, using the 6-hour forecast 1000 and 850 HPa heights. From these, the increment may be obtained.

$$i^m = o^m - g^m$$

where i^m is the increment of mslp, o^m is the value reduced from the observed lowest level heights, and g^m is the value reduced from the 6-hour forecast values of the lowest level heights.

A horizontal optimal interpolation check of the mslp is also performed, thus comparing the pressures at nearby stations. The collection of data and interpolation are made in the same way as for mandatory level values of height and temperature. Even the horizontal correlation function used is the same. The reader is referred to subsection 3.4 for the details. The resulting residual of the horizontal interpolation of mslp is denoted s^m. In terms of the interpolation weights w^m and the increments, i^m at the four surrounding points, it is:

$$s^m = o^m - \sum_{i=1}^{4} w^m i^m$$

4.0 REACTION OF CHECKS TO VARIOUS ERRORS

The previous section outlined the checks used by the CQCHT: hydrostatic, incremental, horizontal statistical, vertical statistical, baseline, p_{msl}-increment, and p_{msl}-horizontal statistical. This section will consider the effect upon the checks of each elementary error and some more complicated errors that may occur. This is not the real problem of the CQCHT, which is the reverse: given a pattern of increments and residuals, to find the error(s). But the illustrations that follow will make it clear that each error cause has its characteristic pattern of increments and residuals, thus making the reverse also approximately true, at least for more simple cases. The examples of actual CQCHT operation, given in Section 8 will show how well this goal may be achieved in practice.

All elementary errors may be divided into three broad classes: communication errors, computation errors, and observation errors. A communication error is a "human" error--error of transcription of data, typing of data, etc. A computation error may be due to an addition error, wrong procedure, etc. It is made during the workup of a sounding and affects all height values above the level of the error. A communication error, on the other hand, only affects a single value, either height or temperature. The final class, observation errors, includes not only errors made by the observing instrument itself, but those happening at any stage preceding the computation of mandatory level heights at a station. This type of error is unique in that it shows no reaction from the hydrostatic check.

The following sub-sections will show the reaction of the various checks to these specific error types: communication, computation and observation.

4.1 Reaction of Checks to Communication Errors

There are several types of errors that can occur during communication of the data. They usually show as a bad digit, interchange of digits, wrong sign (for temperature) or a code rule violation. The specific types are listed in Table 4.1.

Each error type is characterized by the various checks' reaction to the errors, either positive or negative. The following tables will show these reactions.

Table 4.1 Communication Errors

Type	Description
1	Single height, interior level
2	Single temperature, interior level
3	Height and temperature at same level, interior level
	Errors at Bottom Level
"4=1"	Height at bottom level
"4=2"	Temperature at bottom level
"4=3"	Height and temperature at bottom level
	Errors at Top Level
"5=1"	Height at top level
"5=2"	Temperature at top level
"5=3"	Height and temperature at top level
	Errors Diagnosed by Baseline Check
100	Surface pressure
101	Height at bottom level when temperature is missing at this level
	Errors at Adjacent Levels
7	Height at two adjacent interior levels
8	Temperature at two adjacent interior levels
9	Height at lower and temperature at upper of two adjacent interior levels
10	Temperature at lower and height at upper of two adjacent interior levels

4.1.1 Type 1 Error--Communication Error in Single Height

Table 4.2 shows the reactions of the checks due to a height communication error at an interior level, e.g. not bottom or top level. The columns in the table are labeled lev for level, inc z for the increment of z, inc T for the increment of T, hyres for the hydrostatic residual, vert z for the vertical residual of z, vert T for the vertical residual of T, hor z for the horizontal residual of z, hor T for the horizontal residual of T, baseline resid for the baseline residual, hor p_{msl} for the horizontal residual of the reduced mean-sea-level pressure, and inc p_{msl} for the increment of reduced mean-sea-level pressure. Four levels of data will ordinarily be shown in these tables, since four levels are treated as a unit by the Decision Making Algorithm.

The hydrostatic residuals show equal and opposite values, equal in absolute value to the height error, d. The vertical and horizontal checks also react with values at the level (for vertical check) and position (for horizontal check) equal to the error. The vertical check shows some reaction, indicated by +, at adjacent levels, and the horizontal

Table 4.2 Type 1 Error--Communication Error in Single Height

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	k-2	0	0		0	0	000	000	0	0	0
error in				0							
height at	k-1	0	0		+	0	000	000			
intermediate				d							
level k	k	d	0		d	0	+d+	000			
communication				-d							
	k+1	0	0		+	0	000	000			

check shows some reaction, indicated by +d+, at horizontally adjacent observation points (stations) The baseline and p_{msl} checks do not react to this error, the absence of reaction being indicated by 0.

4.1.2 Type 2 Error-Communication Error in Single Temperature

The reaction of various checks to a single temperature error is similar to their reaction to a single height error. However, the hydrostatic residuals have the same sign. And the temperature, rather than height increment and residuals are non-zero. Table 4.3 shows the reactions. Again, it should be emphasized that a lack of reaction of one of the checks is as important to diagnosing an error as the positive reaction to an error. It is the magnitude of the residuals that allows the value of the error to be determined.

Table 4.3 Type 2 Error--Communication Error in Single Temperature

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	k-2	0	0		0	0	000	000	0	0	0
error in				0							
height at	k-1	0	0		0	+	000	000			
intermediate				$-B_{k-1,k}d$							
level k	k	0	d		0	d	000	+d+			
communication				$-B_{k,k+1}d$							
	k+1	0	0		0	+	000	000			

4.1.3 Type 3 Error--Communication Errors in Both Height and Temperature at the Same Level

This type of error illustrates that the effect of errors on the residuals is additive. If the increments and residuals are exactly zero in the absence of this type of error, as is assumed for these examples, then it is easy to diagnose a Type 3 error. If, on the other hand, the temperature profile is not linear between mandatory levels or if moisture is important, then these relatively small influences can affect the hydrostatic residuals enough so that the existence of a Type 3 error cannot be determined definitely without the use of the other checks. The following table shows the reaction of all the checks. They are merely the sum of the reactions of a Type 1 error, accompanied by a Type 2 error.

Table 4.4 Type 3 Errors--Communication Errors to Both Height and Temperature at the Same Level

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	k-1	0	0		+	+	000	000	0	0	0
errors in				$d_z-B_{k-1,k}d_T$							
height and	k	d_z	d_T		d_z	d_T	$+d_z+$	$+d_T+$			
temperature				$-d_z-B_{k,k+1}d_T$							
at z_k	k+1	0	0		+	+	000	000			
communication				0							
	k+2	0	0		0	0	000	000			

4.2 Errors at the Bottom Level (Type 4)

4.2.1 Type "4=1" Error--Communication Error in Height at the Bottom Level

Errors at the top and bottom levels will show reaction to only one hydrostatic residual. Therefore, other residuals, and the increments are essential for error type determination and correction. For an error in height at the bottom, there will be a reaction by the baseline residual, since it measures the agreement between the station elevation and the two lowest reported mandatory level heights. The reactions of various checks are shown in Table 4.5.

Table 4.5 Type "4=1" Error--Communication Error in Lowest Level Height

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline in z_1	hor p_{msl}	inc p_{msl}
	1	d	0		d	0	+d+	000	d	0	0
error in z_1				-d							
communication	2	0	0		+	0	000	000			
				0							
	3	0	0		0	0	000	000			
				0							
	4	0	0		0	0	000	000			

4.2.2 Type "4=2" Error--Communication Error in Temperature at Bottom Level

A communication error in temperature at the bottom level leads to a hydrostatic residual of the lowest layer, along with increment of temperature, vertical check residual, and horizontal residual with values equal to the error. The baseline residual does not responds to the error. Other residuals and the height increment show no response. Table 4.6 shows this pattern.

Table 4.6 Type "4=2" Error--Communication Error in Lowest Level Temperature

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	1	0	d		0	d	000	+d+	+	0	0
error in T_1				$-B_{1,2}d$							
communication	2	0	0		0	+	000	000			
				0							
	3	0	0		0	0	000	000			
				0							
	4	0	0		0	0	000	000			

4.2.3 Type "4=3" Error--Communication Error in Lowest Level Height and Temperature

All the increments and residuals show the combined effect of the two errors at the lowest level. And their effect on the increments and residuals is linear. The pattern is shown in Table 4.7.

Table 4.7 Type "4=3" Error--Communication Error in Lowest Level Height and Temperature

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline in z	hor p_{msl}	inc p_{msl}
errors in z_1 and T_1 communication	1	d_z	d_T		d_z	d_T	$+d_z+$	$+d_T+$	d_z	0	0
				$d_z-B_{1,2}d_T$							
	2	0	0		+	+	000	000			
				0							
	3	0	0		0	0	000	000			
				0							
	...	0	0		0	0	000	000			

4.3 Errors at the Top Level

4.3.1 Type "5=1" Error-Communication Error in Height of the Top Level

An error in the height of the top level leads to a hydrostatic residual for the top layer, height increment, vertical residual, and horizontal residual equal to the error. All other residuals are zero except the adjoining level for the vertical check and the neighboring points for the horizontal check. The pattern of values is shown in Table 4.8.

Table 4.8 Type "5=1" Error--Communication Error in Height of Top Level

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
error in z_n communication	n-3	0	0		0	0	000	000	0	0	0
				0							
	n-2	0	0		0	0	000	000			
				0							
	n-1	0	0		+	0	000	000			
				d							
	n	d	0		d	0	+d+	000			

4.3.2 Type "5=2" Error--Communication Error in Temperature of Top Level

The increment and residual pattern for an error in temperature of the top level is similar to that for height, except the temperature checks respond instead of the height checks. Table 4.9 shows the pattern.

Table 4.9 Type "5=2" Error--Communication Error in Temperature of Top Level

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor P_{msl}	inc P_{msl}
	...	0	0		0	0	000	000	0	0	0
error in T_n				0							
communication	n-2	0	0		0	0	000	000			
				0							
	n-1	0	0		0	+	000	000			
				$-B_{n-1,n}d$							
	n	0	d		0	d	000	+d+			

4.3.3 Type "5=3" Error--Communication Error in Both Height and Temperature of the Top Level

An error in both height and temperature at the top level, leads to a single large, in general, hydrostatic residual for the top layer. Its value shows contributions from both the height and the temperature errors. There is even possible a complete compensation from each error in the hydrostatic residual. The increments, horizontal residuals, and vertical residuals will show the individual influence of the errors. Table 4.10 shows the pattern of increments and residuals.

Table 4.10 Type "5=3" Error--Communication Error in Height and Temperature of Top Level

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor P_{msl}	inc P_{msl}
	...	0	0		0	0	000	000	0	0	0
error in z_n				0							
and T_n	n-2	0	0		0	0	000	000			
communication				0							
	n-1	0	0		+	+	000	000			
				$d_z-B_{n-1,n}d_T$							
	n	d_z	d_T		$-d_z$	d_T	+d+	+d+			

4.4 Errors Detectable with the Aid of the Baseline Check

4.4.1 Type 100 Error--Communication Error in Surface Pressure

A communication error in surface pressure has no effect on the mandatory level temperatures or heights. However, the baseline residual in terms of p_s, the horizontal residual of p_{msl} and the increment of p_{msl} will have the same value, equal to the error. Table 4.11 shows this pattern of increment and residuals.

Table 4.11 Type 100 Error--Surface Pressure Communication Error

Error Description	lev	inc z	inc T	hyres •	vert z	vert T	hor z	hor T	baseline in p_s	hor p_{msl}	inc p_{msl}
	1	0	0		0	0	000	000	p	p	p
error in				0							
surface	2	0	0		0	0	000	000			
pressure				0							
communication	3	0	0		0	0	000	000			
				0							
	...	0	0		0	0	000	000			

An error in NMC's dictionary value of a station elevation leads to a persistent error of Type 100. The baseline residual in z_s gives the error in the dictionary value; several values have been corrected as a result of their identification by CQCHT (and earlier by CHQC).

4.4.2 Type 101 Error--Communication Error in Lowest Height (with lowest level temperature missing)

Not infrequently, the lowest level temperature is missing and the lowest level height has a communication error. The increment, vertical residual and horizontal residual of height will reflect the error. This is confirmed by the baseline residual in terms of z_1. All other increments and residuals are small. This is shown in Table 4.12.

Table 4.12 Type 101 Error--Communication Error in Lowest Height (with lowest level temperature missing)

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline in z_1	hor p_{msl}	inc p_{msl}
error in z_1 communication with T_1 missing	1	d	-		d	-	+d+	0-0	d	0	0
				-							
	2	0	0		+	0	000	000			
				0							
	3	0	0		0	0	000	000			
				0							
	...	0	0		0	0	000	000			

4.5 Errors at Adjacent Levels

4.5.1 Type 7 Error--Communication Error of Height at Adjacent Interior Levels

The effect of communication errors of heights at adjacent levels is just the sum of the effects of the individual errors. This is seen clearly in Table 4.13 in the increments, horizontal residuals, and hydrostatic residuals. The vertical residuals at levels k and k+1 are influenced by both the errors, and those at the adjacent levels, k-1 and k+2, are each influenced by a single height error. This illustrates why the vertical residual values cannot be used to determine the error magnitude when more than one error is present in the same variable for adjacent levels.

Table 4.13 Type 7 Error--Communication Error of Height at Adjacent Interior Levels

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
errors to heights at levels k, k+1	k-1	0	0		+	0	000	000	0	0	0
				d_k							
	k	d_k	0		+	0	$+d_k+$	000			
				$d_{k+1}-d_k$							
	k+1	d_{k+1}	0		+	0	$+d_{k+1}+$	000			
				$-d_{k+1}$							
	k+2	0	0		+	0	000	000			

4.5.2 Error Type 8--Communication Errors at Temperature at Two Adjacent Interior Levels

For errors at adjacent levels, as indeed for all errors, the influence of the errors upon the increments and residuals is the sum of the influences of the individual errors. The pattern of influences for two adjacent temperature errors is shown in Table 4.14.

Table 4.14 Error Type 8--Communication Errors to Temperature at Two Adjacent Interior Levels

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	k-1	0	0		0	+	000	000	0	0	0
errors to				$-B^{k}_{k-1}d_k$							
temperature at	k	0	d_k		0	+	000	$+d_k+$			
levels k, k+1				$-B^{k+1}_{k}(d_k+d_{k+1})$							
	k+1	0	d_{k+1}		0	+	000	$+d_{k+1}+$			
				$-B^{k+2}_{k+1}d_{k+1}$							
	k+2	0	0		0	+	000	000			

4.5.3 Error Type 9--Communication Error in Height at Lower and Temperature at Upper of Two Adjacent Interior Levels

The increments, horizontal residuals, and vertical residuals react to the errors as if there were a single error in each variable. The values are equal the error in the corresponding variable, and the hydrostatic residual has a value equal to the sum of the individual effects of the errors. The increment and residual pattern follows in Table 4.15.

Table 4.15 Error Type 9--Communication Error in Height at Lower and Temperature at Upper of Two Adjacent Interior Levels

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
	k-1	0	0		+	0	000	000	0	0	0
error in z_k				d_z							
and T_{k+1}	k	d_z	0		d_z	+	$+d_z+$	000			
communication				$-d_z-B^{k+1}_{k}d_T$							
	k+1	0	d_T		+	d_T	000	$+d_T+$			
				$-B^{k+2}_{k+1}d_T$							
	k+2	0	0		0	+	000	000			

4.5.4 Error Type 10--Communication Error in Temperature at Lower and Height at Upper of Two Adjacent Interior Levels

The same comments apply as for Type 9 errors. See Table 4.16.

Table 4.16 Error Type 10--Communication Error in Temperature at Lower and Height at Upper of Two Adjacent Interior Levels

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor Pmsl	inc Pmsl
	k-1	0	0		0	+	000	000	0	0	0
error in T_k				$-B_{k-1}^{k} d_T$							
and z_{k+1}	k	0	d_T		+	d_T	000	$+d_T+$			
communication				$d_z-B_{k}^{k+1} d_T$							
	k+1	d_z	0		d_z	+	$+d_z+$	000			
				$-d_z$							
	k+2	0	0		+	0	000	000			

4.6 Reaction of Checks to Computation Errors

A computation error is an error introduced into a height or heights as a result of improper accumulation of thickness(es), computed from the observed temperatures (and moisture). As such, this error type shows itself in the hydrostatic residual, as well as in the increments and horizontal residuals of height. In its simplest form, a single, intermediate level thickness is incorrect, and all the heights above also show the error. A simple computation error is illustrated below. Following are more complicated situations.

4.6.1 Type 6 Error--Single Computation Error at an Intermediate Level

The Type 6 error shows itself by the isolated large hydrostatic residual, d, at a level, k. It results in all mandatory level heights at levels greater than k in error by the same amount, d. The horizontal residuals show a similar pattern. And the vertical residuals are close to d/2 in absolute value, and only two are large, at levels k-1 and k. All other increments and residuals are small. The CHQC was only able to detect the likelihood of this error. The addition of the other checks allows its confirmation and correction. The pattern is shown in Table 4.17.

Table 4.17 Type 6 Error--Single Computation Error

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
thickness computation error	k-1	0	0		≅-d/2	0	000	000	0	0	0
				d							
	k	d	0		≅d/2	0	+d+	000			
				0							
	k+1	d	0		0	0	+d+	000			
				0							
	...	d	0		0	0	+d+	000			

4.6.2 Type 116 Error--Computation Error of the Lowest Mandatory Level Height

An error in the computation of the lowest mandatory level height leads to errors in all heights, resulting in large height increments and horizontal residuals at all levels, and with values equal to the error. This baseline residual in terms of z_1 also shows the same value. All other increments and residuals are small. In particular, the hydrostatic residuals is small. Table 4.18 shows this pattern.

Table 4.18 Type 116 Error--Error in the Lowest Mandatory Level Height

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline in z_1	hor p_{msl}	inc p_{msl}
error in computing z_1	1	d	0		0	0	+d+	000	d	0	0
				0							
	2	d	0		0	0	+d+	000			
				0							
	3	d	0		0	0	+d+	000			
				0							
	...	d	0		0	0	+d+	000			

4.7 Reaction of Checks to Observation Errors

By an observation error is meant an error introduced into the observation of temperature before it is processed to produce thicknesses and heights or an error introduced into the observation of surface pressure before it is used in any way in working up a profile. Such an error can be an instrument error, a communication error from rawinsonde to ground, or another error which makes the mandatory level temperature or surface pressure used in computations inappropriate. This error can, therefore, not produce an effect on the hydrostatic residual, and this is one main means for its detection.

4.7.1 Temperature Observation Errors

Observation errors of temperature may occur in isolation, but that is rather uncommon. Most usually, the error is a true instrument, calibration, or processing error which begins at one level and continues with similar or growing magnitude above. The effect upon heights is a growing error in the vertical, above the level of the first error. Table 4.19 illustrates the increments and residuals for an isolated observation error and Table 4.20 illustrates them for the more usual continuing errors.

Table 4.19 Isolated Observation Error

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
isolated error observation	k-1	0	0		+	+	000	000	0	0	0
				0							
	k	+	d		+	d	+++	+d+			
				0							
	k+1	+	0		+	+	+++	000			
				0							
	k+2	+	0		0	0	+++	000			

Table 4.20 Observation Errors Beginning at One Level and Continuing Above

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
observation errors beginning at level k	k-1	0	0		+	+	000	000	0	0	0
				0							
	k	+	d_k		+	+	+++	$+d_k+$			
				0							
	k+1	+	d_{k+1}		+	+	+++	$+d_{k+1}+$			
				0							
	k+2	+	d_{k+2}		+	+	+++	$+d_{k+2}+$			
				0							
	...	+	d...		+	+	+++	+d...+			

4.7.2 Type 106 Error--Observation Error in Surface Pressure

An observation error in surface pressure causes not only the increment of p_{msl} and horizontal residual of p_{msl} to be large, but all mandatory level heights are in error by a value (in meters) of about 8 times the pressure error (in HPa). This is confirmed by the horizontal check. At the same time, there is no reaction by the hydrostatic check or by the baseline check, since the mandatory level heights and temperatures are all hydrostatically consistent. Table 4.21 shows the pattern of increments and residuals.

Table 4.21 Type 106 Error--Observation Error in Surface Pressure

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
error in surface pressure observation	1	8p	0		0	0	+8p+	000	0	p	p
				0							
	2	8p	0		0	0	+8p+	000			
				0							
	3	8p	0		0	0	+8p+	000			
				0							
	4	8p	0		0	0	+8p+	000			

4.8 Error in Station Location

One possible type of error that does not fall into the classes already discussed is an error in station horizontal location. This should be rare. It appears that it could only happen if one station used another station's identification, if a ship reports an incorrect location, or if NMC's dictionary had a bad horizontal location. In this case, assuming no errors in the report itself, the report would be hydrostatically consistent, but likely not fit the guess. A bad fit of increments and residuals is assumed in Table 4.22. (Compare with subsection 4.7.1, the table Observation Errors Beginning at One Level and Continuing Above.)

Table 4.22 Error in Station Location

Error Description	lev	inc z	inc T	hyres	vert z	vert T	hor z	hor T	baseline	hor p_{msl}	inc p_{msl}
error in station location	k-1	+	+		0	0	+++	+++	0	+	+
				0							
	k	+	+		0	0	+++	+++			
				0							
	k+1	+	+		0	0	+++	+++			
				0							
	...	+	+		0	0	+++	+++			

There are no special provision in the CQCHT for this error, and so it is treated as a profile with observation errors. Those that differ significantly from the first guess are marked as bad.

5.0 Existence and Magnitude Conditions

The previous section showed the response of various checks to specific known errors. The problem facing CQCHT is actually the opposite: given various check increments and residuals, what are the likely errors, if any. Office Note 363 (Collins and Gandin, 1989) gave the detailed derivation of criteria for the various errors for which a confident correction could be made exclusively with the hydrostatic check. The criteria are of two kinds: existence conditions and magnitude conditions. The existence conditions are used to identify the kind of error that may exist, while the magnitude condition is used to determine that a correction will be of sufficient size.

The CQCHT continues to use the same method for determining hydrostatically detected error types as used by CHQC. This is possible, and appropriate, since almost all correctable errors may be found, using only the hydrostatic residuals--the exceptions are baseline errors that can be diagnosed only with the use of additional checks. At the same time, the treatment of hydrostatically suspected errors by the CQCHT DMA is essentially different from their treatment by the CHQC DMA. As soon as the CHQC DMA discovered a confidently correctable error (or a pair of such errors at neighboring levels), it immediately performed the correction(s). Therefore, coming to the next level, even within the same template of four levels, the CHQC DMA used already corrected value at the previous level. This is not the case with the CQCHT DMA: it first applies all statistical checks to hydrostatically suspected values at both internal levels of the template. It may happen therefore with the CQCHT, that it suspects an error at some level just because it uses an already suspected but not yet corrected value at the previous level.

5.1 Limiting Hydrostatic Residuals for Suspicion of Error

It is necessary first to determine whether an error is present. Statistics were collected for the magnitude of the hydrostatic residuals **when no error is present.** It is assumed, and examination of the statistics approximately confirms, that the hydrostatic residuals are normally distributed. It is also assumed that the hydrostatic residuals that result from height and temperature errors will not be normally distributed, but rather be more randomly distributed. Under these conditions, an error is extremely likely, to either height or temperature, or both, when the absolute value of the hydrostatic residual exceeds a value that is α standard deviations of the value with no error, where

α is about 2 or larger. The CHQC and CQCHT are both very conservative, using $\alpha = 7.0$. Table 5.1 shows the limiting value of the hydrostatic residuals for an error to be suspected.

Table 5.1 Limiting Value of Hydrostatic Residual for Hydrostatic Suspicions

Pressure (HPa)	limiting value (m)
1000-850	40
850-700	35
700-500	50
500-400	35
400-300	40
300-250	35
250-200	40
200-150	50
150-100	85
100-70	70
70-50	70
50-30	80
30-20	70
20-10	100

5.2 Existence Conditions for Hydrostatic Errors

When it has been determined that an error is likely, then it is possible to determine the origin of the error (its type). The existence and magnitude conditions were given in Office Note 363 and are repeated in Table 5.2 for convenience. These criteria only cover types 1, 2, 7, 8, 9 and 10 since these are the only types for which CHQC could make confident corrections. A more thorough discussion of determination of the hydrostatic error algorithm may be found in Appendix A.

Table 5.2 Existence Conditions

Error Type	Existence Condition
1 - single height error at level k+1	$\left\|s_{k,k+1} + s_{k+1,k+2}\right\| < 2\,\bar{t}_{all}\left(B_{k,k+1}{}^2 + B_{k+1,k+2}{}^2\right)^{1/2}$
2 - single temperature error at level k+1	$\left\|X_{k,k+1} - X_{k+1,k+2}\right\| < 2\,\bar{t}_{all}$
7 - two height errors at levels k, k+1	$\left\|s_{k-1,k} + s_{k,k+1} + s_{k+1,k+2}\right\| < \left(B_{k-1,k}{}^2 + B_{k,k+1}{}^2 + B_{k+1,k+2}{}^2\right)^{1/2}$
8 - two temperature errors at levels k, k+1	$\left\|X_{k-1,k} - X_{k,k+1} + X_{k+1,k+2}\right\| < 2\sqrt{3}\,\bar{t}_{all}$
9 - lower height, upper temperature errors at levels k, k+1	$\left\|s_{k-1,k} + s_{k,k+1} - \frac{B_{k,k+1}}{B_{k+1,k+2}} s_{k+1,k+2}\right\| < 2\left(B_{k-1,k}{}^2 + 2B_{k,k+1}{}^2\right)\bar{t}_{all}$
10 - lower temperature, upper height errors at levels k, k+1	$\left\|s_{k,k+1} + s_{k+1,k+2} - \frac{B_{k,k+1}}{B_{k-1,k}} s_{k-1,k}\right\| < 2\left(B_{k+1,k+2}{}^2 + 2B_{k,k+1}{}^2\right)\bar{t}_{all}$

5.3 Magnitude Conditions for Hydrostatic Errors

The magnitude conditions have been unified in terms of an allowable temperature error, $\bar{t}_{all}$. Office Note 363 derives the relationships, shown in Table. In this table, δz is the height error and δT is the temperature error. The value of the z*'s depend only on $\bar{t}_{all}$ and the pressures of the mandatory levels. Experiments have shown that $\bar{t}_{all}$ may be taken as a constant with pressure, with a value of 3.5K, giving the values of T* and z* shown in Table 5.4.

Table 5.3 Magnitude Conditions (Relationships)

Error Type	Magnitude Condition
1 - single height error at level k+1	$\left\|\delta z_{k+1}\right\| > 2\,\bar{t}_{all}\left(B_{k,k+1}{}^2 + B_{k+1,k+2}{}^2\right)^{1/2} \equiv z^*_{k+1}$
2 - single temperature error at level k+1	$\left\|\delta T_{k+1}\right\| > 2\,\bar{t}_{all} \equiv T^*_{k+1}$
7 - two height errors at levels k, k+1	$\left\|s_{k-1,k}\right\| > z^*_{k-1}$ and $\left\|s_{k+1,k+2}\right\| > z^*_{k+1}$
8 - two temperature errors at levels k, k+1	$\left\|X_{k-1,k}\right\| > T^*_{k-1}$ and $\left\|X_{k+1,k+2}\right\| > T^*_{k+1}$
9 - lower height, upper temperature errors at levels k, k+1	$\left\|s_{k-1,k}\right\| > z^*_{k-1}$ and $\left\|X_{k+1,k+2}\right\| > T^*_{k+1}$
10 - lower temperature, upper height errors at levels k, k+1	$\left\|X_{k-1,k}\right\| > T^*_{k-1}$ and $\left\|s_{k+1,k+2}\right\| > z^*_{k+1}$

Table 5.4 Magnitude Conditions (Values)

Pressure (HPa)	T^*_k (deg K)	z^*_k (meter)
1000	7	35
850	7	26
700	7	40
500	7	41
400	7	37
300	7	35
250	7	30
200	7	37
150	7	51
100	7	55
70	7	60
50	7	63
30	7	67
20	7	82
10	7	99

5.4 Limiting Hydrostatic Residuals for Suspicion of Errors of Other Types

There are other criteria determining whether error suspicions are given at the bottom (Type 4), at the top (Type 5), at a single level (Type 3), or in thickness (Type 6). These criteria were also discussed in Office Note 363. Table 5.5 shows the admissible residual values for layers used in these type determinations, where in general an admissible residual is the largest residual that leads to no error suspicion. More specific use of these values will be given in the Section 6 on the DMA.

Table 5.5 Admissible Residuals Used for Types 3, 4, 5 and 6

Pressure Range (HPa)	admissible residual (meter)
1000-850	40
850-700	35
700-500	50
500-400	35
400-300	40
300-250	35
250-200	40
200-150	50
150-100	85
100-70	70
70-50	70
50-30	80
30-20	70
20-10	100

5.5 Proposed Hydrostatic Corrections

Once a hydrostatic error type is determined, then a correction is also proposed for each type. These proposed corrections are rounded, appropriately to the level. Then a correction near the proposed value is sought that would result in the original error being a simple one: sign error (for temperature), single digit error or exchange of digits error. The following table shows the proposed corrections before these modifications.

Table 5.6 Proposed Correction for Each Error Type

Error Type	Proposed Correction
1 - single height correction at level k+1	$ZCOR_{k+1} = \left\{\frac{s_{k+1,k+2}}{B_{k+1,k+2}{}^2} - \frac{s_{k,k+1}}{B_{k,k+1}{}^2}\right\} \div \left\{\frac{1}{B_{k,k+1}{}^2} + \frac{1}{B_{k+1,k+2}{}^2}\right\}$
2 - single temperature correction at level, k+1	$TCOR_{k+1} = 0.5\left(X_{k,k+1} + X_{k+1,k+2}\right)$
3 - correction to both height and temperature at the same level, k+1	$ZCOR_{k+1} = \frac{B_{k,k+1}s_{k+1,k+2} - B_{k+1,k+2}s_{k,k+1}}{B_{k,k+1} + B_{k+1,k+2}}$ $TCOR_{k+1} = \frac{s_{k,k+1} + s_{k+1,k+2}}{B_{k,k+1} + B_{k+1,k+2}}$
4 - correction at the lowest level,1	$ZCOR_1 = s_1$ $TCOR_1 = X_1$
5 - correction at the top level, N	$ZCOR_N = -s_N$ $TCOR_N = X_N$
6 - thickness correction	$ZCOR_l = -s_{k,k+1}, \quad l = k+1 \text{ to } NLEV$
7 - two height corrections at levels k, k+1	$ZCOR_{k+1} = \left\{-\frac{X_{k-1,k}}{B_{k-1,k}}\frac{1}{B_{k,k+1}^2} - \frac{X_{k,k+1}}{B_{k,k+1}}\frac{1}{B_{k-1,k}^2} + \frac{X_{k+1,k+2}}{B_{k+1,k+2}}\left(\frac{1}{B_{k-1,k}^2} + \frac{1}{B_{k,k+1}^2}\right)\right\} \div \left\{\left(\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k+1,k+2}^2}\right)\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k,k+1}^2 B_{k+1,k+2}^2}\right\}$ $ZCOR_k = \left\{-\frac{X_{k-1,k}}{B_{k-1,k}}\left(\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k+1,k+2}^2}\right) + \frac{X_{k,k+1}}{B_{k,k+1}}\frac{1}{B_{k+1,k+2}^2} + \frac{X_{k+1,k+2}}{B_{k+1,k+2}}\frac{1}{B_{k,k+1}^2}\right\} \div \left\{\left(\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k+1,k+2}^2}\right)\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k,k+1}^2 B_{k+1,k+2}^2}\right\}$

Table 5.6, cont.

Error Type	Proposed Correction
8 - two temperature corrections at levels k, k+1	$TCOR_k = \left(2X_{k-1,k} + X_{k,k+1} - X_{k+1,k+2}\right)/3$ $TCOR_{k+1} = \left(2X_{k+1,k+2} + X_{k,k+1} - X_{k-1,k}\right)/3$
9 - lower height, upper temperature corrections at levels k, k+1	$ZCOR_k = \left\{\frac{X_{k,k+1}}{B_{k,k+1}} - 2\frac{X_{k-1,k}}{B_{k-1,k}} - \frac{X_{k+1,k+2}}{B_{k,k+1}}\right\} \div \left\{\frac{2}{B_{k-1,k}^2} + \frac{1}{B_{k,k+1}^2}\right\}$ $TCOR_{k+1} = \left\{\frac{X_{k,k+1}}{B_{k-1,k}{}^2} + \frac{X_{k-1,k}}{B_{k-1,k}B_{k,k+1}} + X_{k+1,k+2}\left(\frac{1}{B_{k-1,k}^2} + \frac{1}{B_{k,k+1}^2}\right)\right\} \div \left\{\frac{2}{B_{k,k-1}^2} + \frac{1}{B_{k,k+1}^2}\right\}$
10 - lower temperature, upper height corrections at levels k, k+1	$TCOR_k = \left\{X_{k-1,k}\left(\frac{1}{B_{k,k+1}^2} + \frac{1}{B_{k+1,k+2}^2}\right) + \frac{X_{k,k+1}}{B_{k+1,k+2}{}^2} + \frac{X_{k+1,k+2}}{B_{k,k+1}B_{k+1,k+2}}\right\} \div \left\{\frac{1}{B_{k,k+1}^2} + \frac{2}{B_{k+1,k+2}^2}\right\}$ $ZCOR_{k+1} = \left\{\frac{X_{k-1,k}}{B_{k,k+1}} + 2\frac{X_{k+1,k+2}}{B_{k+1,k+2}} - \frac{X_{k,k+1}}{B_{k,k+1}}\right\} \div \left\{\frac{1}{B_{k,k+1}^2} + \frac{2}{B_{k+1,k+2}^2}\right\}$

6.0 The Decision Making Algorithm

The two major components of the CQCHT are the individual checks and the Decision Making Algorithm (DMA). Of the two, the DMA is the most complex. It must coordinate the hydrostatic error type determination with the result of other checks, including the baseline checks. And it must also make tentative corrections and check them for acceptability. Further, it must set data quality marks for corrected and non-correctable errors, including observational errors. This section will outline the procedures followed, leaving further detailed criteria for decisions and use of limits for each error type correction to Appendix B.

As is explained in subsection 6.1, a template of values, which moves upward during the error determination and correction, is used by the DMA. At each position in the vertical for the template, all error determination and correction is performed for the appropriate error types for the interior levels k and k+1. Each station profile is considered in turn and the complete process is performed two times (scans). The DMA considers consecutively the various possible error types. For each error determination or suspicion, it writes information about the datum to an interim "events file". This information includes old and new values, increments, residuals, etc. Information from this file is later extracted by CQCHT to make the actual changes to the input data file (ADPUPA).

6.1 Filling Template with Values

Just as the CHQC (and the part of CQCHT that determines the hydrostatic type) used a template of four adjacent levels, containing both heights and temperatures, that shifts upward during the type determinations, so does the DMA use such a template. This allows all error determination and correction to be done on a small set of information. It also means that all determinations are fairly local, using only information from at most four levels in the vertical, i.e. three layers of hydrostatic residuals. From the results of use of CQCHT, this seems to be adequate. Figure 6.1 illustrates values in such a template. The values of the variables, and their increments and horizontal and vertical residuals are at the same locations. The hydrostatic residuals, s, are layer values. As before, k-1, k, k+1, and k+2 refer to consecutive mandatory levels in the vertical at which both heights and temperatures are available. And the residuals $s_{k-1,k}$, $s_{k,k+1}$ and $s_{k+1,k+2}$ are computed for the corresponding layers.

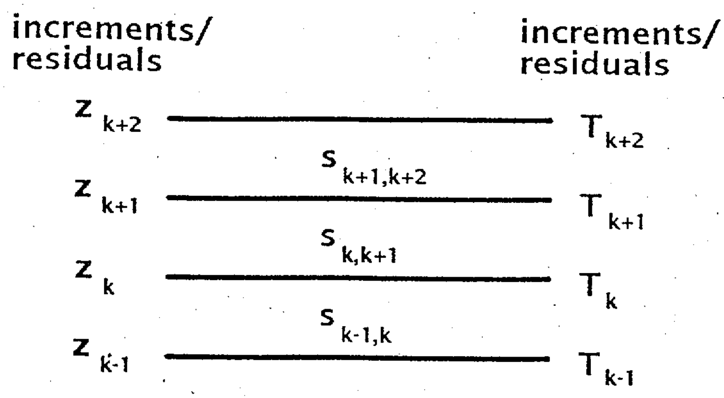

Figure 6.1 DMA Template

Before filling the template with values, it is necessary for the DMA to determine which four levels of data are to be inserted into the template. They include the level in question, the level below and the next two levels above for which both height and temperature are available. Once these levels are determined, the following quantities are filled into the template:

1. observed increments for height and temperature
2. horizontal residuals for height and temperature
3. vertical residuals for height and temperature
4. hydrostatic residuals, values of B
5. surface pressure
6. observed heights and temperatures
7. proposed corrections for heights, temperatures, and surface pressure
8. hydrostatic error types
9. baseline residual

As explained in sections 3.2 and 3.4, the increment deviation and horizontal residual deviation are often of more value for error determination and correction than the values themselves. The DMA computes the height increment deviation, DOZ_k, and the horizontal residual deviation of height, DHZ_k, for level k.

6.2 Baseline Error Determination

Four different baseline corrections may be made. The information is taken from all the relevant increments and residuals, including the quantities described in section 3.5. The correctable errors are: Type 100--surface pressure communication error, Type 101--communication error in the lowest level height with temperature missing, Type 106--surface pressure measurement error, and Type 116--computation error in the height of the lowest mandatory level. Type 102 is used for undetermined baseline errors: these errors are given to MOD for manual examination and possible correction. The details of determination of baseline error types may be found in Appendix A.

6.2.1 Type 100 error--Communication error in surface pressure

A communication error in surface pressure is determined from the baseline check residual, surface pressure increment, and surface pressure horizontal residuals all being large and close to each other. Actually, there are two possible causes for this diagnosis: a communication error in surface pressure or error in surface elevation in NMC's station dictionary. If the error persists from one observation time to another, and with the same or nearly the same value, then the surface elevation is wrong. Otherwise, the error is a surface pressure communication error. The correction is given by p_s^c (see section).

6.2.2 Type 101 error--Communication error in the height of the lowest mandatory level

This error is diagnosed only if the lowest mandatory level temperature is missing. For, if it were present, a Type 4 error could be diagnosed and any necessary correction(s) made. A Type 101 error is diagnosed when the height increment of this lowest level and its horizontal residual are large and close to each other and to the height error estimated from the baseline check. The correction, z_1^c, is given in section 3.5.

6.2.3 Type 106 error--Surface pressure measurement error

A surface pressure measurement error is diagnosed when there are large increments and horizontal residuals of surface pressure accompanied by persistent (with elevation) large errors in height of mandatory levels equal to about 8 times, and of the same sign as, the surface pressure increments. The baseline residual is small. The surface pressure correction, p_s^c, is the average of the surface pressure increment and residual. All mandatory heights are corrected by z^t, given by the following equation.

$$z_k^t = \frac{R}{g}(T_k + T_0)\ln\left(\frac{p_s + p_s^c}{p_s}\right)$$

where p_s is the uncorrected surface pressure.

6.2.4 Type 116 error--computation error in the height of the lowest mandatory level

A computation error in the height of the lowest mandatory level is diagnosed from a large baseline error accompanied by persistent (with elevation) errors in heights. These height errors are close to the baseline residual. The surface pressure increments and horizontal residuals are small. A correction is made to all mandatory level heights equal to the baseline residual.

6.2.5 Type 102 error--Undetermined baseline error

It sometimes happens that there is a large baseline residual, but other increments or residuals do not agree with any of the correctable error types. In this case, a Type 102 is assigned. Specifically, it is assigned under the following conditions:

1. The baseline residual is large, no hydrostatic type is diagnosed, and the surface elevation is less than 1000 m, or
2. Either the increment or horizontal residual of surface pressure is large or both are, no hydrostatic type is diagnosed, and the surface elevation is less than 850 m.

6.3 Hydrostatically Detected Errors

For all the hydrostatically determined error types, it is necessary to check the proposed correction against the other check results. The procedure discussed in section 6.3.1 for a Type 1 diagnosis is similar to that followed for other error types.

6.3.1 Type 1 or 11 Error--Communication error in a single height

The routine that assigns a hydrostatic type (called CORECT) also provides a suggested correction. A single height correction is assigned by CORECT only to an intermediate level. However, a single height correction may be made by CQCHT also for the lowest level, uppermost level, or at hole boundaries (see sections 6.3.7, 6.3.8 and

6.3.9). For a lower hole boundary or the top level, the suggested correction is replaced with $-s_{k-1,k}$, while for an upper hole boundary or the lowest level, the suggested correction is replaced with $s_{k,k+1}$. The suggested correction is then modified to be "simple". And the magnitude condition is checked. Then the smallness of the increments and residuals, **after** the correction would made, are checked. If the correction would lead to small enough values of the increment and residuals, the corrected value is passed on for inclusion in the events file.

If the correction is not good enough, then the **value of the height (not the proposed correction!)** is either marked as definitely bad, marked as doubtful, or marked as likely all right, and no correction is performed. The corresponding decision numbers are shown in Table 2.4 . They apply to all error types. The exact conditions for these markings, and other details of the Type 1 error correction may be found in Appendix B.

6.3.2 Type 2 or 22 error--Communication error in mandatory level temperature

As for a Type 2 error, the proposed correction will depend on where the error is suspected. For an intermediate level, the value was given in the Table 5.6. For the top level or the level just below a hole, the proposed correction is $X_{k-1,k}$. For the bottom level or the level just above a hole, the proposed correction is $X_{k,k+1}$. A sign error is tested to see if it is close enough to the proposed correction and would lead to acceptable lapse rates. If so, such a correction is passed on for further testing. Otherwise, the proposed correction is modified to be "simple" when possible. The magnitude of the increment and residuals after the correction is checked against the original values. The criterion for acceptance is given in Appendix B. The decision is either to correct the datum or to mark it with good, questionable or bad quality.

6.3.3 Type 7 error--Communication error in two consecutive mandatory level heights

The routine which assigns hydrostatic types, CORECT, can assign Type 7 at any levels, excluding the top and bottom. The proposed corrections are used directly by the DMA. It uses a general routine, called TSTCOR (for TeST CORrection) to test the corrections. The details of the routine may be found in Appendix C. In outline, it recomputes quantities as they would be if the correction were applied: increment, hydrostatic residuals, horizontal residual, vertical residual, and vertical difference of increment and horizontal residuals for height. It then assigns an integer, ranging from 0 to 2, to the result from each check. These are used in the decisions regarding the proposed corrections. If there are enough checks available, and they agree that the correction is good, then it is accepted. If both height corrections cannot be accepted, then one or the other may be accepted. Otherwise, the appropriate quality mark is assigned. Details of the criteria may be found in Appendix B.

6.3.4 Type 8, 9, and 10 errors--Communication errors in two consecutive mandatory level temperatures, consecutive height and temperature, or consecutive temperature and height

The correction to these types follows the correction for Type 7. Each calls TSTCOR for the appropriate variable(s) and makes its decisions based upon the results.

6.3.5 Type 3 error--Communication errors in height and temperature of the same level

First, the suggested corrections are specified. If the level is the lowest or second lowest level, and adjacent levels do not have errors, then the suggested corrections are taken from CORECT (see section 5.5). Otherwise, the suggested corrections are formed from the average of the available increments and residuals at the error level. The corrections are made "simple" if possible. Then TSTCOR is called and decisions are made. If a) the height correction fits well enough and the height correction is large enough, and b) the temperature correction fits well enough and the temperature correction is large enough, and c) the resulting hydrostatic residuals are small enough, then both height and temperature correction are accepted. Otherwise, if either correction alone is good enough, it is accepted. (These may be called Type "3=1" if the height correction alone is accepted or Type "3=2" if the temperature correction is accepted.) And if neither correction is acceptable, then the original data are assumed to have been all right (decision 2). Details of the criteria may be found in Appendix B.

6.3.6 Type 6 error--Computation error to the thickness, resulting in several height errors of the same magnitude

The provisional correction for a Type 6 error is the negative of the hydrostatic residual (see section 5.5), but it is modified to be "simple". This correction is acceptable if it makes the next two values in the vertical of height increments and horizontal residuals small. In principle it would be good to check the values at all levels above, but the template available only contains the next two values, and tests show this to be sufficient. The proposed correction is further tested by TSTCOR at the first level. If the height increment, horizontal residual, vertical residual, and hydrostatic residual at this first level are small enough, the proposed correction is accepted. Otherwise, a decision 2 is assigned. See Appendix B for details of the conditions for acceptance of the correction.

6.3.7 Type 4 error--Communication error at the lowest reported mandatory level

An error, diagnosed as Type 4 by CORECT, may have one of several communication-related causes: the lowest height or temperature or both may be bad. And it may have a computation-related cause: the thickness may have been computed incorrectly. These four possibilities are sequentially tested, first an error in both height and temperature (Type "4=3"), then a height error (Type "4=1"), then a temperature error (Type "4=2"), and finally a thickness error (Type "4=6").

Testing for Type "4=3": The trial correction is formed as an average of the available increments and residuals for height and temperature. For height, the vertical differences of the increment and horizontal residual are used in preference to the values themselves, if available. The averages are formed from the increment (or vertical difference of the increment), the horizontal residual, and the vertical residual. This average is modified, minimally, so that the hydrostatic residual, after correction, becomes zero. The values of the trial correction, after modification to give zero hydrostatic residual are given by:

$$ZCOR_k^c = ZCOR_k + 0.5\, s_{k,k+1}^c$$

$$TCOR_k^c = TCOR_k + 0.5 \left(\frac{s_{k,k+1}^c}{B_{k,k+1}} \right)$$

where $ZCOR_k$ and $TCOR_k$ are the trial corrections formed from the averages of the increments and residuals and $s^c_{k,k+1}$ is the new hydrostatic residual, using the trial solutions $ZCOR_k$ and $TCOR_k$. (As stated above, the final hydrostatic residual, using $ZCOR^c_k$ and $TCOR^c_k$ is zero.)

The Type "4=3" correction is further modified to be simple. If the magnitude of both the height and temperature trial corrections is large enough, this correction pair is tested by TSTCOR for acceptability of the resulting increments and residuals.

If a Type "4=3" correction is not acceptable, then a Type "4=1" correction is attempted, using $ZCOR^c_k$, as the proposed correction. It uses the same method as for a Type 1 correction (see subsection 6.3.1).

Next, if neither a Type "4=3" or Type "4=1" correction is acceptable, a Type "4=2" correction is attempted, using $TCOR^c_k$ as the proposed correction, and following the same methodology as for a Type 2 correction (see subsection 6.3.2).

And finally, if no other correction is acceptable, a Type "4=6" correction is attempted, using the negative of the hydrostatic residual as the proposed correction. See section 6.3.6 for a description of the method.

6.3.8 Type 5 error--Communication error at the highest reported mandatory level

A communication error at the highest reported mandatory level may be a communication error in height or temperature or both. A thickness computation error cannot be distinguished from a communication error in height and so need not be considered separately. The method is nearly identical to that for Type 4 errors. See section 6.3.6 for a discussion.

6.3.9 Communication errors at hole boundaries

At the lower boundary of a hole (Type 13 or 14), a Type 5 correction is attempted, and at the upper boundary of a hole, a Type 4 correction is attempted. See sections 6.3.7 and 6.3.8 for details.

6.4 Observational Errors

Observational errors, Type 0, are detected by the absence of hydrostatic errors in the presence of large height or temperature increments, horizontal residuals, and vertical residuals. These errors do not reflect a hydrostatic error since the erroneous temperatures were used to compute the (also erroneous) heights.

All increments and residuals are normalized for use in decisions with values of 0, 1, or 2, where values of 2 reflect large values. The criteria for observational errors use these normalized values, called indicators See Appendix C for their definition. The normalized values are referred to as IINC for increment, IHOI for horizontal residual, and IVOI for vertical residual These criteria are open to modification based upon the wishes of MOD, since these errors are presented to them for further examination. The criteria for a height or temperature observational error at a level other than the bottom are:

1) at least 2 values of (IINC, IHOI, IVOI) non-zero at both k and k-1 or k+1, or
2) IINC + IHOI + IVOI ≥ 4 at level k.

7. CQCHT files

7.1. General description of CQCHT outputs.

A distinctive property of the CQCHT algorithm is that it automatically creates numerous output files reflecting, with various degree of detail, each DMA action and used for various purposes. The most detailed among these outputs, which we call the Action Motivation File, contains, for each DMA action, all information that is necessary in order to understand, why this particular action has been undertaken. This kind of output was extensively used at the stage of CQCHT design and testing. The availability of Action Motivation Files proved to be very important for every improvement of the DMA made at this stage. We still use them occasionally when considering possibilities of some further DMA improvements. At the same time, the format of these files is not easy to understand, and they were never used, or intended for a use, outside the group of scientists at the NMC Development Division (DD) involved in the QC design.

On the other side of the detailness spectrum, there are the CQCHT Events Files presenting the CQCHT DMA actions in most condensed form. Each DMA action occupies one record in the Events File containing all information necessary to understand what the DMA did, but not always sufficient for understanding why it did so. The main aim of this file is to be able to attach a record of all data quality decisions to each NMC data set. These files are also used in creation of the CQCHT Monthly Summaries. We at DD also use a modified, more easy-to-read, display of the Events File in the course of our quasi-operational CQCHT performance monitoring. It allows us to spend much less time doing the monitoring than would be possible otherwise.

The most widely used CQCHT output files are intermediate, in their detailness, between the two files described above. They are presented in so-called Operational Output format, which is the easiest for understanding. This format is used in both the CQCHT Monitoring File and the CQCHT-MOD Interaction File. It is described in detail in Subsection 7.2 and illustrated by an example, presented in Fig. 7.1.

7.2. Operational Output

Like any other CQCHT output file, the operational output contains information only about reports suspected by the CQCHT algorithm. The majority of reports do not cause any CQCHT suspicions, and the output files just contain no information about them (except, maybe, for numbers of such reports). Unlike some other files, however, those in the Operational Output format present information about all values in each suspected report, not only about suspected one(s).

The first two lines of the operational output contain general information: the station WMO index, denoted ID, (or, if it is a ship, its coded name) the observation time (year, month, date, hour), the CQCHT Scan number (1 or 2), a special INDEX assigned for the horizontal check purposes, the station (or ship) latitude, longitude, and elevation. As mentioned above, the CQCHT is performed by two successive scans: after the first scan is completed, the second one begins. The difference between the two is mainly that, as a rule, no rejection is proposed by the DMA at the first scan. The main purpose of the second scan is thus to propose rejection of some data if this is desirable, or even to reject some data automatically. It sometimes happens, however, that the second scan performs some additional corrections not made by the first scan. Such complicated cases occur seldom, and the main aim of the first scan is therefore to correct suspected values (if they should be corrected or, otherwise, to retain them), while the main aim of the second scan is to reject or to propose to reject (or, again, to retain).

The next 6 lines of an output contain data and results of the CQC baseline check: the mean sea level pressure P-MSL, its value implied from the first guess data GES P-MSL, the difference OINPC between these two (the sea-level pressure increment), the horizontal check residual HINPC, i.e., the difference between the increment and its horizontally interpolated value for the mean sea-level pressure, the baseline residual, which is the difference between the station elevation and its value from the baseline check. All listed data are on the first line of this group (the third line of the output), its remaining lines containing some more detailed information about the baseline check. The column VALUE contains reported surface-air pressure PS, the station elevation ZS, and the heights Z1 and Z2 of lowest reported mandatory surfaces (the pressures at these levels are indicated in the column PRESSURE). The column NEW-VALUE contains modified values of listed values, each modification making, by itself, the baseline residual equal to zero. Finally, each CORRECTION is the difference between NEW-VALUE and VALUE.

The next part of the output may be called Quick Recognition Data. It allows the user to quickly recognize the kind of problem(s) with the report. It should be looked at first of all because this makes the analysis of the main body of the output much easier. The general idea of quick recognition is as follows.

For each increment and for each residual, except the hydrostatic ones, there exist two thresholds, a small and a large one (the latter being twice as large as the former). These thresholds have been estimated at an early stage of the CQCHT design from a specially collected statistics of the increments and residuals (when there are no rough errors). If the absolute value of an increment or residual is less than its small threshold, then the corresponding check is given the index 0 implying that there exist no reason for suspicion. If the absolute value is between its small and large thresholds, then the index is 1, "there exist something suspicious", is assigned. Finally, if the absolute value of the increment or residual exceeds the large threshold, then the index is put equal to 2, indicating that something is more or less definitely wrong.

These "semi-qualitative" indicators IINC, IVOI and IHOI for incremental, vertical and horizontal checks of height and temperature of each reported surface are at the left hand side of the quick recognition data. (See also Appendix C for use of these indicators.) The continuation of the first (1000 HPa) line to the right contains such indicators for the baseline check (IBAS) and for incremental and horizontal checks of the surface pressure (IIPL and IHPL). Considering all these indicators together with the suspected hydrostatic error type in the column IHSC (see Tables 2.2 and 2.3), it is usually easy to realize which numbers in the main body of the output deserve to be looked at.

So, everything in the quick recognition part in Fig. 7.1 indicates a rough error in the 300 HPa height. Indicators for increments, vertical check, and horizontal check residuals for this height are 2. Those for vertical check of 400 and 250 HPa heights are 1 (because the erroneous Z_{300} value has influenced the vertical check residuals for neighboring heights), and there is a hydrostatically suspected Type 1 error at 300 HPa. All other indices are zero. If we want to analyze this case in more detail, we have just to consider numerical values of listed increments and residuals paying no attention to other numbers in the main body of the output.

As illustrated by Fig. 7.1, the main body contains, for each reported level, observed (better to say, received and decoded) height and temperature, their increments, the hydrostatic check residuals (HYRES) both in terms of height and of temperature, the vertical check residuals for height and for temperature, and those of horizontal check accompanied by estimated root mean square relative difference between observed value and that interpolated from neighboring stations, called the comparison error (COMP), and finally the height and temperature values according to the forecast first guess (denoted GUESS).

```
ID: 61223    DATE/TIME: 92090712  SCAN: 1
INDEX:  140  LAT:   16.73  LON:  357.00  ELEVATION:  263.00
P-MSL:  1012.4  GES P-MSL:  1011.2  OINCPS:     1.2  HINCPS:      0.7  BASELINE RESID:    4.1
           VALUE    NEW-VALUE  CORRECTION  PRESSURE
   PS      983.0       982.5        -0.5
   ZS      263.0       258.9        -4.1
   Z1      106.0       110.6         4.6    1000.0
   Z2     1535.0      1573.7        38.7     850.0
         IINC  IVOI  IHOI
  PRES   Z  T  Z  T  Z  T  IHSC  IBAS  IIPL  IHPL
  1000   0  -  0  -  0  -     0     0     0     0
   850   0  0  0  0  0  0     0
   700   0  0  0  0  0  0     0
   500   0  0  0  0  0  0     0
   400   0  0  1  0  0  0     0
   300   2  0  2  0  2  0     1
   250   0  0  1  0  0  0     0
   200   0  0  0  0  0  0     0
   150   0  0  0  0  0  0     0
   100   0  0  0  0  0  0     0
    70   0  0  0  0  0  0     0
     OBSERVATION   INCREMENT    HYRES HYRES   VERTICAL   -----HORIZONTAL------   --GUESS--
PRESS HEIGHT  TEMP HEIGHT  TEMP HEIGHT  TEMP HEIGHT  TEMP HEIGHT  TEMP ZCMP TCMP HEIGHT  TEMP
 1000   106.9999.9      6.9999.9 99999.9999.9     7.9999.9     3.9999.9 1.2*****   100.  37.4
  850  1535.  20.8    -1.  -2.1 99999.9999.9    -8.  -2.6    -2.  -2.1 1.2  1.2  1536.  22.9
  700  3190.  11.4    11.   1.5   11.   3.9     5.   1.9     8.   1.5 1.2  1.2  3179.   9.9
  500  5900.  -5.3    20.   1.5  -10.  -2.1    11.   1.7    17.   1.7 1.2  1.2  5880.  -6.8
  400  7610. -17.5    14.  -1.7    0.   0.1   -69.  -1.8    11.  -1.5 1.2  1.2  7596. -15.8
  300  9910. -31.9   212.  -1.2  208.  49.4   200.  -1.0   209.  -1.3 1.2  1.2  9698. -30.7
  250 10980. -40.9    17.   0.5 -193. -72.5   -78.   0.6    15.   0.5 1.2  1.2 10963. -41.4
  200 12460. -52.5    23.   0.8    1.   0.3     5.   0.9    21.   0.8 1.2  1.2 12437. -53.3
  150 14260. -66.5    32.  -0.9    1.   0.2     2.  -0.7    30.  -0.4 1.2  1.2 14228. -65.6
  100 16670. -74.1    61.  -2.1    3.   0.4    46.  -2.2    63.  -1.3 1.2  1.2 16609. -72.0
   70 18750. -67.7    12.   1.4  -32.  -6.0   -19.   1.8    18.   1.0 1.2  1.2 18738. -69.1
DMA RESULTS
PRESSURE  VARIABLE  NEW VALUE  CORRECTION DECISION  IHSC  SCAN
   300        Z       9710.0     -200.0      1        1     1
```

Fig. 7.1 Example of operational output

Note that each hydrostatic check residual is, of course, not for the level where it is displayed but for the layer ending at this level. For example, residuals of -10 m and -2.1 K in Fig. 7.1 are for the layer between 700 and 500 HPa. It should also be noted that, as long as the operational model does not produce numerical predictions above 50 HPa, the first guess at 30, 20 and 10 HPa is always missing, and so are all increments and residuals of statistical checks. The CQCHT is applied to levels 30, 20 and 10 HPa as well, but for them, it reduces itself to a purely hydrostatic quality control. We still hope that the vertical resolution of the NMC operational model will be improved soon and this will allow us to get rid of this inconsistency and of complications caused by it.

The last part of the CQCHT operational output, called DMA RESULTS, expresses actions which either were undertaken by the CQCHT Decision Making Algorithm or proposed to be made. As already mentioned (see Table 2.4), there are five kinds of these actions denoted as DECISIONs. Decision 1 is an automatically made correction, decision 4 is an automatic rejection (or, to be more exact, a flagging for rejection from initial data set for the NMC Data Assimilation Systems). Decision 2 is to retain the datum as it was, decision 3 indicates questionable quality and is a call for the MOD to decide whether the datum should be rejected or retained. Decision 5, used only (and always) for Type 102 baseline suspicions, also applies to the MOD for the decision, but in those cases it is necessary to decide, first of all, which data (if any) are wrong.

Every DMA action occupies one line. Each line contains the PRESSURE of the level in question, the variable name (Z, or T, or PS), its NEW VALUE and CORRECTION, and three indices expressing the DECISION type, the hydrostatically suspected error type IHSC and the SCAN number. For convenience, the DMA RESULTS for the second scan contain also DMA actions at the first scan (if there were any).

The format used in this Office Note to illustrate the CQCHT performance is an abridged and modified version of the operational output. While the quick recognition part and the last part, expressing the DMA actions, remain of the same format as in operational outputs, the main part is slightly different, and so is the baseline part. Hydrostatic residuals are placed between lines for corresponding levels. Baseline check residuals in terms of p_s, z_s, z_1 and z_2 are presented instead of corresponding corrections, differing from them by sign. Finally, only those lines of the main part and baseline part are retained, which contain information about suspected errors, as implied by the quick recognition part.

In order to compare this abridged format with the "full" format of the operational output, one may consider Example 1 in the next section (pp. 801-802) corresponding to the same case which is presented in Fig. 7.1

7.3 Contents of Events File

The Events File contains the information necessary to identify all decisions regarding the data and to give sufficient information to understand the reasons for decisions. Fig. 7.2 shows the Events File record for the correction of Fig. 1. The contents differ, depending upon whether the problem is related to the baseline checks (hydrostatic error types ≥ 100) or not, as shown in Table 7.1. All Events File records begin with the date and time, the station identifier and its geographical location. The variable, level, scan, and decision are combined in a single word. The last two (units and tens) digits are used for the decision. The decisions are listed in Table 2.4. Counting from the right, the next two digits are used for the scan, then next two for the level

Table 7.1 Events File Contents

Word	Item		Comments	Data Type	Format
1	date/time		YYMMDDHH	I*4	I8
2,3	station ID			C*4	2A4
4	longitude		x100	I*4	I6
5	latitude		x100	I*4	I6
6	variable, level, scan, decision		combined	I*4	I10
7	error no.		IHSC, IINC, IHOI, IVOI, IBAS, IIPL, IHPL	I*4	I10
	Types < 100	**Types > 100**			
8	old height	station elevation		I*4	I6
9	old temperature	old value	x10	I*4	I6
10	new height or temperature	new value	z or (T ,ps)x10	I*4	I6
11	old increment	old baseline residual		I*4	I6
12	old $HYRES_{12}$	new baseline resid.		I*4	I6
13	old $HYRES_{23}$	P-MSL (HPa)		I*4	I6
14	new $HYRES_{12}$	P-MSL increment		I*4	I6
15	new $HYRES_{23}$	P-MSL residual		I*4	I6
16	old HRES	z_1 increment		I*4	I6
17	old VRES	z_2 increment		I*4	I6
	reserved for temporal check				
18	temporal error no.				
19	old temporal residual				
20	new temporal residual				
21	station internal index		only in code	I*4	NA

(1=1000 HPa, 2=850 HPa, etc.), and the next two for the variable. The code numbers for the variables are listed in Table 7.2.

Fig 7.2 Example of record from Events File corresponding to correction in Fig. 7.1.

92090712	61223	35700	1672	1060101	1222000	9910	-318	9710	211	207	-193	7	6	209	200

Table 7.2.Events File Variable

1 - z
2 - T
4 - ps
5 - ps and all z's

The next word in the Events File (word 7) is also a combined word, combining the indicators for the horizontal surface pressure residual (1 digit, counting from right), surface pressure increment (1 digit), baseline (1 digit), vertical check residual (1 digit), horizontal check residual (1 digit), increment (1 digit), and hydrostatic check error type (3 digits).

Beginning with word 8, the record contents change depending upon the error type. First, the contents for errors not involving baseline problems (hydrostatic error type < 100) will be described. Words 8 and 9 contain the original values of the mandatory level height and temperature, while word 11 contains the original value of the increment. Word 10 contains the new value (height or temperature). Words 12 and 13 contain the original values of the hydrostatic residuals for the layers, bounded by the error level, and words 14 and 15 contain the values of the hydrostatic residuals after the correction (if any). Word 16 contains the value of the original horizontal residual, and word 17 contains the original value of the vertical residual.

For baseline errors (hydrostatic error types > 100), word 8 contains the station elevation. Words 9 and 10 contain the original and new values of the variable identified in word 6. The old and new values of the baseline residual are in words 11 and 12. The reduced value of the mean sea level pressure is contained in word 13, while its increment is contained in word 14, and its residual is contained in word 15. The increments of the lowest two mandatory level heights are in words 16 and 17.

Words 18 through 20 are reserved for use by the temporal check, when it is included, as it is for use in the CDAS/Reanalysis project. Word 21 gives the sequential index described in Subsection 3.4.1 which identifies the station only within the CQCHT code.

Note that Table 7.1, in addition to summarizing the contents of the Events File, also shows any scaling, the data type, and the data format. The Events File is written with formatted write statements. It is normally added onto each 12 hours by a running of CQCHT at final time and a modified easy-to-read form of this addition to the file is available with each run for monitoring purposes. Each month, a summary job is run after which the Events File is emptied.

8.0 EXAMPLES

8.1 Errors correctable by the hydrostatic check alone.

The Comprehensive Hydrostatic Quality Control (CQHC) Decision Making Algorithm automatically corrects isolated communication-related errors in either height or temperature (Type 1 and 2 errors). Isolated errors of communicational origin happen most often and the availability of additional checks does not result, as a rule, in any difference between the CQCHT and CHQC corrections. However, subjective inspection of CQCHT outputs in such cases does not leave any doubt that errors of this kind actually existed and that they have been properly corrected by the CQCHT DMA.

8.1.1 Type 1 error

So, in Example 1, the Type 1 error is confirmed by the height increment, as well as by the horizontal and vertical check residuals for the same height: all of them are close to each other and to the error estimated from hydrostatic check residuals (in terms of height). The absence of large increments or residuals for temperature is "negative evidence" also confirming the correctness of the DMA action, as is the absence of large height increments at neighboring levels. Finally, the fact that a simple correction of a single digit has been found by the DMA also contributes to our confidence in this decision. (Compare with Table 4.2.)

Example 1
Type 1 correction

ID: 61223 LAT: 16.73 LON: 357.00 TIME: 92/09/07/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	-	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	1	0	0	0	0			
300	2	0	2	0	2	0	1			
250	0	0	1	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
400	7610	-17.5	14	-1.7			**-69**	-1.8	11	-1.5
					208	49.4				
300	9910	-31.9	**212**	-1.2			**200**	-1.0	**209**	-1.3
					-193	-72.5				
250	10980	-40.9	17	0.5			**-78**	0.6	15	0.5

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	Z	9710	-200	1	1	1

8.1.2 Type 2 error

The situation is quite analogous in Example 2, where a Type 2 error correction has been made. This correction was also simple: that of one digit and sign.

Example 2
Type 2 correction

ID: 15120 LAT: 46.78 LON: 23.57 TIME: 92/04/01/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	1	0	0	0			
700	0	2	0	2	0	2	2			
500	0	0	0	1	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
850	1375	4.2	-1	1.7			1	**-9.0**	-10	2.5
					-94	**-33.1**				
700	2922	27.0	6	**34.2**			6	**33.7**	6	**36.6**
					-172	**-35.0**				
500	5460	-22.9	1	-0.2			-3	**-6.6**	28	3.0

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
700	T	-7.0	-34.0	1	2	1

One may see that situations of this kind can be easily recognized by looking at the quick recognition part of the output. A "cross-like" pattern of indices 1 and/or 2 in Example 2 for temperature statistical checks, accompanying the Type 2 hydrostatic suspicion is, practically, a proof of the temperature communication error's existence (this pattern occurs because such errors also influence vertical check residuals for adjacent levels which are of opposite sign and smaller in absolute value). (Compare with Table 4.3.)

8.1.3 Type 1 correction with a "small" increment

A similar pattern exists in the quick recognition part of Example 1. However, this is not always the case for height communication errors, particularly for small ones, as may be illustrated by Example 3. In this example, the height increment in question is not large, but very small. What matters, however, is that the difference between it and the "background" formed by neighboring increments is large and close to the hydrostatically estimated error of -100 m. As mentioned above (see subsections 3.2, 3.4 and 6.1), the DMA analyses not the height increments themselves, but their deviations from the background formed by increments at two adjacent levels, in other words, from their arithmetic mean. The same is done with the height horizontal check residuals. The reason for this is connected with the fact that the mandatory level heights are computed from temperatures, and therefore a small measurement (or first guess) error in temperature results in a vertically persistent height error. This effect has nothing to do with the influence of communication related errors on the height increments and horizontal residuals and should be therefore excluded from consideration by the DMA while searching for height communication errors. This complication sometimes makes the quick subjective recognition of small height communication errors slightly more difficult.

Example 3
Type 1 correction with a "small" increment

ID: 35394 LAT: 49.80 LON: 73.13 TIME: 92/04/30/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	-	0	0	0	0
850	0	0	1	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	1	0	0	0	0			
400	0	0	0	0	0	0	0			
300	1	0	1	0	0	0	0			
250	0	0	1	0	0	0	1			
200	1	0	1	0	0	0	0			
150	1	0	0	0	0	0	0			

100	0	0	0	0	0	0	0				

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
300	8950	-46.3	91	3.3			**64**	1.8	47	3.1
					-104	-38.9				
250	10050	-48.9	**8**	3.3			**-69**	2.5	**-32**	4.2
					101	31.0				
200	11610	-50.7	110	-0.5			**63**	-1.6	74	0.8

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
250	Z	10150	100	1	1	1

8.1.4 Type 7-10 corrections

Along with isolated errors, the CHQC also corrected pairs of communication-related errors at two neighboring levels (Types 7-10), due to a special provision in its Decision Making Algorithm. The CQCHT DMA contains the same provision, and its actions are illustrated by Examples 4 and 5. Once again, all corrected errors are simple ones: transposition of digits in each of two heights in Example 4, and one-digit error in height plus temperature sign error in Example 5. All other CQCHT checks confirmed the hydrostatically proposed corrections in both cases. As to the quick recognition parts, the "double-cross" patterns on them allow one to suspect the errors of such kind even before looking at the main parts of the outputs. (Compare with Tables 4.13-4.16.)

Example 4
Type 7 corrections

ID: 17030 LAT: 41.28 LON: 36.33 TIME: 92/04/12/12

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	2	0	0	0	0	0	1	1
850	2	0	2	0	2	0	7			
700	2	0	2	0	2	0	7			
500	0	0	2	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ Z	T	Increment Z	T	Hydrost inZ	inT	Vertical Z	T	Horizont Z	T
1000	54	9.6	53	-7.8			**183**	-6.3	49	-6.1
					-251	-105.3				
850	1139	5.6	**-219**	-4.2			**-375**	-1.3	**-221**	-2.6
					599	210.9				
700	3295	-4.1	**361**	-2.4			**455**	-0.8	**361**	-1.7
					-340	-69.1				
500	5510	-23.3	4	-2.1			**-110**	-1.1	-6	-2.6

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
850	Z	1391	252	1	7	1
700	Z	2953	-342	1	7	1

Example 5
Type 9 corrections

ID: 43295 LAT: 12.97 LON: 77.58 TIME: 92/04/01/00

PRES	IINC Z	T	IVOI Z	T	IHOI Z	T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	1	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	1	0	0			
250	0	0	1	0	1	0	0			
200	1	0	2	2	1	0	19			
150	0	2	1	2	0	2	29			
100	0	0	0	2	1	0	0			

P	Observ Z	T	Increment Z	T	Hydrost inZ	inT	Vertical Z	T	Horizont Z	T
250	10960	-40.7	35	-1.5			**77**	-1.0	114	2.6
					-198	-60.6				
200	12240	-53.1	**-169**	-0.9			-196	-27.3	**-136**	2.6
					-353	**-83.8**				
150	14240	65.6	37	**133.1**			**80**	**133.7**	77	**136.8**
					-789	**-132.9**				
100	16600	-81.3	80	-2.4			62	-26.3	126	4.0

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
200	Z	12440	200	1	19	1
150	T	-65.6	-131.2	1	29	1

8.1.5 Type 2 suspicion found wrong by DMA: no correction needed.

The examples above just illustrate the high sensitivity of the hydrostatic check and the good performance of the CHQC DMA. This does not mean, however, that all confident hydrostatic corrections are automatically accepted by the CQCHT DMA. Even for isolated errors of Types 1 and 2, it sometimes happens, though very rarely, that a hydrostatic suspicion is not supported by other checks, particularly when the suspected error is not very large. A situation of this kind is presented in Example 6, where no correction was made by the CQCHT DMA despite the hydrostatically suspected error in the 850 HPa temperature. All other checks did not confirm this suspicion. What probably happened in this case was that two small errors of the same sign in 1000-850 and 850-700 thicknesses were either made in the course of computations or caused by the curvature of the temperature profile. The resulting hydrostatic residuals in terms of temperature were comparatively large (because the B coefficients are small for these layers) and had the same sign, and that led to the wrong Type 2 error suspicion.

Example 6
Type 2 suspicion found wrong by DMA: no correction needed.

ID: 97180 LAT: -5.07 LON: 119.55 TIME: 92/04/08/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	2			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	100	25.2	10	-5.0			-3	-4.6	10	-4.3
					25	10.3				
850	1530	19.4	22	-1.1			5	0.4	22	-0.8
					16	5.5				
700	3182	10.2	34	0.0			10	0.3	35	0.2

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
850	T	19.3	0.0	2	2	1

8.1.6 Type "9=1+0" correction

For Type 1 or 2 error suspicions, one of only two possible decisions can be made, either to correct the suspected datum or to rehabilitate it. An "intermediate" decision may be right when errors at two adjacent levels are suspected (Types 7-10): to correct only one of the two suspected data while retaining the other datum as it was. This was the case in Example 7. The hydrostatic check suspected both the 150 HPa height and the 100 HPa temperature in this case, but, according to all other checks, only the height was wrong and should be corrected, and that is what the DMA did.

Example 7
Type "9=1+0" correction

ID: 87155 LAT: -27.45 LON: 300.95 TIME: 92/05/27/12

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	-	0	-	0	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	2	0	0	0	0			
150	2	0	2	0	2	0	19			
100	0	0	2	0	0	0	29			
70	0	0	0	0	0	0	0			
50	0	1	0	1	0	1	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
200	12150	-53.1	27	1.0			196	0.7	34	0.7
					-561	-133.2				
150	13400	-63.1	-509	-0.7			-529	-0.8	-504	-0.7
					544	91.6				
100	16420	-65.9	31	-0.4			207	-0.7	37	0.3
					-50	-9.6				

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
150	Z	13970	570	1	19	1
100	T	-65.9	0.0	2	29	1

Generally, our experience with the CHQC showed that it is practically impossible, when dealing only with the hydrostatic check, to set a good working threshold as to whether two data at neighboring levels or only one of them should be corrected. The availability of additional checks makes such decision much easier. So, it was the hydrostatic residual of -50 m for the 100-70 HPa layer in Example 7 that led to Type 9 error suspicion, rather than Type 1: although much smaller than two other residuals, this one was not small enough to reject the Type 9 error alternative. However, the 100 HPa temperature increment and its horizontal and vertical check residuals are very small, and that has led to the CQCHT DMA decision to correct only the 150 HPa height.

Cases like those in Examples 6 and 7, when the DMA decision differs from that implied by the hydrostatic check, are also included into the MOD file in order to give a specialist the opportunity to make the final decision.

8.2. Errors not large enough for correction by the hydrostatic check alone.

It would be risky to correct comparatively small suspected communication-related errors based only on the hydrostatic check results, and the CHQC DMA just included such cases into the MOD file along with many other cases for which a specialist was needed to make the decision. As opposite to this, the CQCHT DMA makes its decision for any suspicion of this kind, Type 11 (for height) or 22 (for temperature): it either performs the correction, as it did in Examples 8 and 9, or leaves the suspected datum unchanged and includes such case into the MOD file. In these situations, as in many others, the DMA behaves in a "conservative" way, preferring to make no corrections to making questionable ones. Therefore a specialist sometimes decides, after examining the file, to make corrections in spite of the DMA's decision not to do so. More often, however, such negative decisions by the DMA are undoubtedly correct, as in Example 10.

Example 8
Type "11=1" correction

ID: 94035 LAT: -9.43 LON: 147.22 TIME: 92/04/01/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	1	0	1	0	1	0			
500	0	0	0	1	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	1	0	0	0	11			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
400	7600	-15.3	1	-0.1			**-21**	0.3	-1	-0.1
					53	12.5				
300	9760	-30.5	**52**	-0.4			**51**	0.8	**48**	-0.5
					-38	-14.3				
250	10980	-44.3	2	-4.1			**-15**	-3.5	-2	-4.0

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	Z	9720	-40	1	11	1

Example 9
Type "22=2" correction

ID: 74732 LAT: 32.85 LON: 253.90 TIME: 92/04/01/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	-	0	-	0	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	1	0	1	0	1	22			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
850	1487	13.4	-38	-2.0			17	**1.0**	-3	1.7
					29	**10.0**				
700	3096	-3.5	-13	**-9.6**			-8	**-9.0**	-9	**-7.9**
					47	**9.4**				
500	5750	-13.3	-10	-0.1			0	**1.3**	-5	0.6

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
700	T	3.5	7.0	1	22	1

Example 10 illustrates a typical situation when comparatively large hydrostatic residuals are caused by the curvature of the temperature profile near the tropopause and have nothing to do with any errors. The sign of such "curvature-created" hydrostatic residuals is opposite to the sign of the temperature profile curvature. For the usual, positive, curvature of the temperature profile near the tropopause, the residual (as it is defined above) should be negative. That is exactly what happened with the layers 150-100 and 100-70 HPa in Example 10.

Example 10
Type 22 suspicion found wrong by DMA; no correction needed

ID: 91610 LAT: 1.35 LON: 172.92 TIME: 92/05/28/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	22			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
150	14290	-66.3	16	0.7			-10	0.6	13	0.8
					-40	-6.7				
100	16660	-73.9	58	2.2			45	1.9	51	2.5
					-44	-8.5				
70	18700	-73.1	21	0.9			-27	-0.8	20	0.9

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
100	T	-73.9	0.0	2	22	1

8.3. Communication-related errors in height and temperature of the same level.

Another kind of error that could be, in principle, univaluedly corrected by the hydrostatic check alone, but was not corrected by the CHQC DMA, occurs when there are communication errors in both height and temperature at the same mandatory surface (Type 3 errors). Considering hydrostatic equations for two layers, below and above the surface in question, as a system of two equations with two unknowns, which are the height and the temperature at this surface, one could solve this system and thus compute the correct values. However, such a solution may be too sensitive to small variations in heights and temperatures of adjacent mandatory levels. Particularly, it can happen that only one parameter, either temperature or height, not both of them, should be corrected, and it is very difficult to treat such marginal cases without additional checks or human help. Another reason that the CQHC DMA did not perform Type 3 corrections was the fact that Type 3 suspicions could result from hydrostatic checking in more complicated combinations of errors, when different corrections are needed.

The situation is quite different with the CQCHT DMA: using the whole complex of checks, it performs or, to be more exact, tries to perform, all Type 3 corrections, as it did in Example 11. The presence of a Type 3 error is strongly suggested by the quick recognition pattern, and the corrections have been performed by the DMA. It is also able to treat the marginal cases, when only one of the two parameters should be corrected. This may be illustrated by Example 12. Due to some difference between the hydrostatic residuals (in terms of temperature), the hydrostatic check suspected Type 3 errors in this case, but the DMA realized that only the temperature was in error and corrected it, leaving the height value unchanged. Cases like this are included into the

MOD file, giving a specialist the opportunity to supervise a DMA decision and, if necessary, to override it. (Compare with Table 4.4.)

Example 11
Type 3 correction

ID: 98223 LAT: 18.18 LON: 120.53 TIME: 92/04/11/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	-	-	-	-	-	-	-			
500	0	0	2	1	0	0	0			
400	2	2	2	2	2	2	3			
300	0	0	1	1	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	1	0	1	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
500	5860	-5.9	3	-0.5			**94**	**10.5**	8	0.1
					-63	**-19.3**				
400	7380	-55.7	**-196**	**-39.0**			**-202**	**-38.9**	**-186**	**-39.0**
					371	**88.2**				
300	9680	-32.5	15	0.5			**75**	**8.5**	37	0.7

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
400	T	-15.5	40.2	1	3	1
400	Z	7580	200	1	3	1

Example 12
Type "3=2" correction: HSC suspected both Z and T at 200 HPa, but DMA rehabilitated Z and corrected only T

ID: 94750 LAT: -34.95 LON: 150.53 TIME: 92/04/08/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	1	0	0	0			
200	0	2	0	2	0	2	3			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
250	10510	-51.7	2	0.2			-15	**6.9**	6	0.9
					116	**35.6**				
200	11980	-80.1	33	**-26.4**			23	**-26.5**	30	**-27.1**
					110	**26.1**				
150	13820	-55.3	27	0.1			8	**6.3**	24	0.1

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
200	T	-50.8	29.3	1	3	1
200	Z	11980	0	2	3	1

The CQCHT DMA is even capable of dealing with rather complicated cases of many communication-related errors in the same report, when the hydrostatic check suspects two or more Type 3 errors in a row. Example 13 provides a good illustration of such combinations of errors. As many as three Type 3 errors in a row were suspected by the hydrostatic check, followed immediately by a Type 1 error. The DMA proved to be quite successful in dealing with this combination of hydrostatic suspicions. The "first" suspected Type 3 error (at 300 HPa) was actually a Type 2 error. It was hydrostatically suspected as a Type 3 error because of the hydrostatic residual created by the neighboring Type 3 errors at 250 HPa. The Type 3 hydrostatic suspicion at 200 HPa was the consequence of the errors at 250 HPa in combination with another, Type 1, error at 150 HPa, There was no error at all at 200 HPa. The DMA correctly recognized what actually happened with this report and corrected all the errors.

Example 13
Successful multiple corrections by scan 1 in spite of inexact hydrostatic diagnosis.

ID: 40745 LAT: 36.27 LON: 59.63 TIME: 92/03/27/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	1	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	2	0	0	0			
300	0	2	2	2	0	2	3			
250	2	2	2	1	2	2	3			
200	0	0	2	1	0	0	3			
150	2	0	2	0	2	0	1			
100	0	0	2	0	0	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
400	7150	-38.5	8	0.3			3	-16.0	-11	-0.6
					-338	-80.2				
300	9060	26.0	9	79.6			1962	70.2	11	79.5
					-4882	-1829.5				
250	5640	-24.5	-4571	31.4			-4581	8.5	-4585	31.3
					4484	1373.0				
200	11650	-54.5	16	0.9			-259	-7.7	-18	-0.7
					6008	1426.9				
150	19500	-54.3	6036	2.5			6008	2.1	6002	2.0
					-6000	-1011.0				
100	16080	-57.3	65	1.4			-2868	1.0	20	1.5

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	T	-56.5	-82.5	1	3	1
250	T	-54.8	-30.3	1	3	1
250	Z	10222	4582	1	3	1
150	Z	13500	-6000	1	1	1

As will be shown by some other examples, the CQCHT DMA is capable of dealing with even more complicated combinations of errors. At the same time, it fails to introduce corrections in comparatively simple situations, as may be seen from Example 14. The hydrostatic check suspected a Type 6 error, that is an error in thickness computation, for the 300-250 HPa layer, but the DMA rejected this suspicion and made no correction. At the same time, even the quick recognition part shows that there is a

Type 3 error at 250 HPa. A manual inspection of the main part confirms this diagnosis and indicates that the reported 250 HPa height of 10640 m should be corrected to 10840 m, and the temperature of +25.0° should be -45.0°. Corresponding errors of -200 m and 70° are large enough to be detected and confidently corrected. Instead, the DMA has just rejected both values in its second scan proving itself unable to deal properly with this comparatively simple case. Why did this happen?

There exists a subtle effect that we call compensation. Each of two hydrostatic residuals caused by errors in both height and temperature at the same level is a linear combination of these errors. It may happen with one of these residuals that, although the contributions of both errors to it are large, they have opposite signs and about the same absolute value, thus resulting in a small residual. That is exactly what happened with the 250-200 HPa layer residual in Example 14. The equation for this residual in terms of height, s, is

$$s = -z' - BT',$$

where z' and T' are the errors and B is the coefficient in the hydrostatic equation equal to 3.27 mK^{-1} for the layer in question. Thus, for the errors estimated above,

$$s = 200 - 3.27*70 = 200 - 227 = -27 \text{ m},$$

so that the residual is about 10 times smaller than each of the two contributions to it and very close to the actual hydrostatic residual of -20 m. The smallness of this residual prevented the hydrostatic check from suspecting a Type 3 error . It instead diagnosed that only one hydrostatic residual was large, so that a thickness computation error should be suspected.

Example 14
Type 6 suspected instead of Type 3 because of hydrostatic residual compensation. The errors could be easily recognized and corrected by a specialist

ID: 42379 LAT: 26.67 LON: 88.37 TIME: 92/04/09/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	1	0			
400	0	0	0	0	0	0	0			
300	0	0	2	2	0	0	0			
250	2	2	2	2	1	2	6			
200	0	0	1	2	0	0	0			
150	0	0	0	0	0	0	0			

100	0	0	0	0	0	0	0

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
300	9600	-34.9	4	-0.6			90	-20.7	21	-1.0
					-391	-146.6				
250	10640	25.0	-208	68.1			-206	68.5	-185	66.5
					-20	-6.0				
200	12310	-53.9	-8	-1.1			77	-18.8	-2	-1.2

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
250	Z	10640	0	2	6	1

Why could the CQCHT DMA not recognize that there was a compensation effect in Example 14? The answer to this question is simple: the DMA does not contain a special provision needed to achieve this aim. It would not be very difficult, at least in principle, to generalize the DMA by including an investigation of possible compensation effects. However such a generalization would hardly be desirable. As will be demonstrated later in this section, there exist many other subtle effects, caused by various combinations of two or more non-isolated errors, which also cannot be recognized by the DMA, unless it is generalized to deal with that particular combination. Each such combination occurs so seldom, that it is much better to use human help in such rare cases than to try to make the existing, already quite complicated, Decision Making Algorithm more and more complicated. This is particularly so because, however complicated the DMA can be made, there will always be cases requiring its further complication--or human help.

8.4. Computational errors.

The last type of error, which could be corrected by the hydrostatic check alone but was not corrected by the CHQC DMA, is that of Type 6, i.e., an error in thickness computation at a station (or elsewhere). As long as the heights of mandatory isobaric surfaces are computed by accumulating the computed thicknesses of all layers between pairs of neighboring surfaces, an error in such computation leads to errors in all heights above the layer in question. To correct all these heights based on only one hydrostatic suspicion would be rather risky, particularly if we take into account that a Type 6 hydrostatic suspicion may be caused by something quite different, as happened in Example 14.

The situation is quite different for the CQCHT DMA due to the availability of other, statistical, checks. So, despite the fact that the hydrostatic suspicion of a Type 6 error in Example 15 was based on a rather small residual, the CQCHT DMA recognized the error and corrected it, because both incremental and horizontal check residuals for all involved heights confirmed its existence. The absence of large increments and/or residuals for temperature is "negative evidence" supporting this decision, as are the small values of vertical check residuals for all heights in question except for the first. (Compare with Table 4.17.)

Example 15
Type 6 correction

ID: 91643 LAT: -8.52 LON: 179.22 TIME: 92/04/01/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	-	-	-
850	-	-	-	-	-	-	-			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	1	0	0			
250	0	0	0	0	1	0	0			
200	0	0	0	0	0	0	0			
150	1	0	1	0	1	0	6			
100	1	0	0	0	1	0	0			
70	1	0	0	0	1	0	0			
50	2	1	1	1	2	1	0			
30	-	-	-	-	-	-	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
200	12510	-53.1	52	-1.2			-14	-0.6	51	-1.1
					104	24.6				
150	14400	-68.9	**137**	-2.4			**73**	-1.7	**137**	-2.4
					-18	-3.1				
100	16730	-81.7	**132**	-3.2			31	-3.6	**132**	-3.1
					-14	-2.6				
70	18740	-76.9	**144**	4.5			11	3.1	**143**	4.4
					-11	-2.2				
50	20720	-65.1	**229**	10.6			155	9.6	**227**	10.4
					5	0.7				
30	23890	-57.9	-	-			-	-	-	-

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
150	Z	14300	-100	1	6	1
100	Z	16630	-100	1	0	1
70	Z	18640	-100	1	0	1
50	Z	20620	-100	1	0	1
30	Z	23790	-100	1	0	1

It often happens that a computation error distorts the heights only up to 100 HPa, while all heights at 70 HPa and above are not influenced by this error. Such "restoration of truth", illustrated by Example 16, may be explained by the fact that Part C of rawinsonde reports, containing mandatory surface data at 70 HPa and above, is transmitted later than Part A with information up to 100 HPa. It is possible that by the time Part C is sent, the error in the thickness computation has been discovered at the station and corrected. However, the station may not transmit the corrected Part A or, at least, it may not reach the data file at NMC.

Example 16
Type "6-6" correction

ID: 58665 LAT: 28.65 LON: 120.08 TIME: 92/05/12/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	2	0	0	0	0			
300	2	0	2	0	2	0	6			
250	2	0	2	0	2	0	0			
200	2	0	2	0	2	0	0			
150	2	0	2	0	2	0	0			
100	2	0	2	0	2	0	0			
70	0	0	2	0	0	0	6			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
400	7550	-17.1	21	1.0			**-864**	0.6	5	0.3
					2457	583.6				
300	12110	-32.1	**2489**	1.9			**1412**	1.2	**2461**	0.2
					1	0.5				
250	13360	-42.5	**2502**	1.6			**572**	0.4	**2464**	0.1
					-9	-2.8				
200	14830	-50.9	**2509**	2.6			**594**	1.6	**2459**	-0.2
					9	2.1				
150	16670	-60.5	**2544**	3.0			**679**	2.8	**2456**	-0.7
					-13	-2.2				
100	19120	-70.7	**2577**	-2.0			**1674**	-1.6	**2494**	0.6
					-2467	-472.5				
70	18770	-70.1	**61**	-4.6			**-895**	-4.7	**-8**	-1.5
					21	4.3				
50	20840	-60.1	**80**	2.2			49	3.2	**-5**	0.5
					6	0.8				
30	24090	-52.3	-	-			-	-	-	-
					4	0.7				
20	26720	-51.5	-	-			-	-	-	-

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	Z	9640	-2460	1	0	6
250	Z	10900	-2460	1	0	1
200	Z	12370	-2460	1	0	1
150	Z	14210	-2460	1	0	1
100	Z	16660	-2460	1	0	1
70	Z	16310	-2460	1	6	1
50	Z	18380	-2460	1	0	1
30	Z	21630	-2460	1	0	1
20	Z	24260	-2460	1	0	1
70	Z	18780	10	1	6	1
50	Z	20850	10	1	0	1
30	Z	24100	10	1	0	1
20	Z	26730	10	1	0	1

Example 16 shows that the CQCHT DMA has no difficulties in handling such situations, although it does not contain any special provisions for them (the latter may be recognized by the fact that the DMA made corrections of 10 m, instead of 0, at 70 HPa and above). The DMA made all the corrections within the first scan, first correcting all heights above the 400-300 HPa layer and then "recorrecting back" the Part C heights.

This does not mean, however, that the DMA is capable of correcting every combination of Type 6 errors in one report. The most difficult situation of this kind emerges when there are several such errors in a row. The case presented in Example 17 deserves to be called a champion in computational errors.

Example 17
"Type 66666" errors corrections by scans 1 and 2

ID: 40848 LAT: 29.53 LON: 52.48 TIME: 92/05/17/00

SCAN 1

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	2	0	0	0	0			
500	2	0	0	0	2	0	3			
400	2	0	2	0	2	0	3			
300	2	0	2	0	2	0	3			
250	0	0	1	0	0	0	3			
200	2	0	0	0	2	0	3			
150	2	0	2	0	2	0	3			
100	2	0	1	0	2	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	3148	10.2	0	-1.1			**-80**	1.0	-3	-2.5
					250	50.8				
500	6080	-11.9	**246**	-1.6			**-9**	-1.5	**226**	-1.5
					366	112.0				
400	8120	-21.7	**606**	0.1			**582**	0.7	**586**	0.1
					-815	-193.6				
300	9350	-38.9	**-215**	-0.6			**-421**	-0.7	**230**	-1.2
					220	82.5				
250	10800	-46.5	5	0.2			**-62**	-0.4	-19	-1.1
					398	121.2				
200	12660	-52.1	**417**	3.2			**36**	3.0	**381**	1.1
					634	150.5				
150	15130	-58.1	**1073**	0.8			**683**	0.9	**1026**	1.1
					-376	-63.4				
100	17230	-70.9	**674**	-5.0			**153**	-5.2	**642**	-1.7

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
500	Z	5844	-236	1	3	1
400	Z	7523	-597	1	3	1
300	Z	9572	222	1	3	1
200	Z	12261	-399	1	3	1

SCAN 2

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			

400	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0
200	0	0	2	0	0	0	0
150	2	0	2	0	2	0	3
100	2	0	1	0	2	0	0

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
200	12261	-52.1	18	3.2			-363	3.0	-18	1.3
					1033	245.3				
150	15130	-58.1	1073	0.8			846	0.9	1026	1.1
					-376	-63.4				
100	17230	-70.9	674	-5.0			153	-5.2	642	-1.7

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
500	Z	5844	-236	1	3	1
400	Z	7523	-597	1	3	1
300	Z	9572	222	1	3	1
200	Z	12261	-399	1	3	1
150	Z	14370	-760	1	3	2
100	Z	17230	0	4	0	2

Some controversy in suspicions can be immediately seen in the quick recognition section: while the Type 3 hydrostatic suspicions imply the presence of errors in both heights and temperatures, the results of all statistical checks indicate that only heights contain errors. Inspection of the main part of this output confirms this impression. All increments and statistical residuals for temperatures are rather small.

A careful inspection of height increments and hydrostatic residuals shows that each hydrostatic residual is very close to the difference between corresponding increments: 250 is close to 246-0, 366 to 606-246, -815 to -215-606, and so on. This proves that each layer thickness above 700 HPa was computed wrongly!

The DMA tried to correct all these errors. It almost succeeded; only the very last height was rejected by scan 2 instead of being corrected. It would have been corrected as well if there were a scan 3.

Certainly, this example is rather exceptional. We came across only one more such case during an entire year of the CQCHT monitoring. Cases with multiple errors of various kinds are, however, not so rare, and the CQCHT DMA proved to be quite effective in correcting such errors. Some examples of this kind will be presented below.

At the same time, the DMA is unable to properly recognize and correct comparatively simple combinations of errors including Type 6 ones, because a special provision would be needed in the DMA to achieve this aim, just as for the case in Example 14 above. One such combination, a "Type 2 + 6" error, is presented in Example 18. There is a communication error, most probably a simple sign error, in the 300 HPa temperature in combination with a computation error of 100 m or so in the 400-300 HPa thickness. It would be rather easy for a trained specialist to correct, using the CQCHT output, all erroneous values in this report.

Example 18
Type "2+6" correction, not provided by the DMA. The errors could be easily recognized and corrected by a specialist.

ID: 48407 LAT: 15.25 LON: 104.87 TIME: 92/03/18/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	1	2	0	0	0			
300	1	2	1	2	1	2	3			
250	1	0	0	2	1	0	0			
200	1	0	0	0	1	0	0			
150	1	0	0	0	1	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
400	7580	-16.5	-9	-0.3			**-45**	**-12.3**	-7	-0.1
					-145	**-34.5**				
300	9790	29.6	**107**	**61.8**			**60**	**61.9**	**110**	**60.9**
					-153	**-57.5**				
250	11060	-42.5	**117**	0.3			**27**	**-17.5**	**120**	-4.0
					5	1.4				
200	12530	-55.1	**128**	-0.6			40	-0.2	**127**	-1.0
					-3	-0.7				
150	14310	-67.7	**112**	-0.9			44	-0.7	**115**	-1.3

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	T	29.6	0	3	3	2

8.5. Hydrostatically suspected errors at highest or lowest reported levels.

A communication-related error in either temperature or height of the highest mandatory surface among those reported (Type 5 error) influences only one hydrostatic residual, that for the highest layer. It is impossible therefore for the hydrostatic check alone to decide which of the two parameters is in error (or, maybe, both are). Consequently, the CHQC DMA only provided human specialists with its Type 5 error suspicion outputs, and it was up to the specialist to decide what to do in each such case.

The situation with the CQCHT is quite different: using information from other, statistical, checks, its DMA almost always diagnoses the error and automatically corrects it, as it did in Example 19. The temperature increment and residuals of its statistical checks at 250 HPa are quite large in this example, close to each other and close in absolute value to, and of opposite sign of, the hydrostatic check residual (in terms of temperature). The DMA thus concluded that only the temperature was in error, and found a simple correction--of its sign only. No information about this correction was given operationally to any specialist (just as for confident corrections at an intermediate level). Only in cases, when the DMA has not performed any correction, either because it decided that no correction was needed or because no correction(s) resulting in sufficiently small values of all increments and residuals could be found, is a specialist provided with the CQCHT results and asked to make the decision. (Compare with Table 4.9.)

Example 19
Type "5=2" correction

ID: 47041 LAT: 39.93 LON: 127.55 TIME: 92/03/31/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	1	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	1	0			
400	0	0	0	0	0	0	0			
300	0	0	0	2	0	0	0			
250	0	2	0	2	0	2	5			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
300	9160	-46.3	-49	-1.6			-11	**-34.5**	-42	-2.5
					-308	**-115.4**				
250	10340	57.6	-60	**112.6**			-31	**113.1**	-70	**111.2**

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
250	T	-57.6	-115.2	1	5	1

Some further examples of Type 5 error corrections will be presented below, in connection with more complicated cases.

Although the situation with Type 4 errors, those influencing the hydrostatic residual only for the lowest layer, is analogous to that just considered, there are some important differences. First, a Type 4 hydrostatic suspicion may be caused not only by communication error(s), but also by an error in computing the thickness of the lowest layer. (Strictly speaking, the same is true for Type 5 errors: such error may be a result of wrongly computed thickness of the highest layer. However, such an error cannot, and does not need to, be distinguished from a communication error in the height of the highest level). Secondly, there exists an additional check, the baseline check, and it increases the chances for the DMA to properly diagnose and correct Type 4 errors.

So, the DMA diagnosis in Example 20 that it was a height error is based not only on the fact that the hydrostatic residual for the 1000-850 HPa layer is of opposite sign and close in absolute value to the 1000 HPa height increment and to residuals of its statistical checks, which are close to each other. The baseline check residual in terms of this height also confirms this diagnosis. If that were not the case, then the DMA would try to find a different solution. (Compare with Table 4.5.)

Example 20
Type "4=1" correction

ID: 08594 LAT: 16.73 LON: 337.05 TIME: 92/04/11/12

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	1	0	1	0	1	0	4	2	0	0
850	0	0	1	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

FULL VALUES Ps	Zs	SURF PRESSURE INCR	HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
1008.0	54	-0.4	-0.8	12.9	120	**-114**	-2409

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	8	22.2	**-114**	2.6			**-110**	2.6	**-118**	3.7
					94	39.7				
850	1494	16.6	-8	0.1			**41**	-0.8	-10	0.3

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	98	90	1	4	1

A more complicated situation, when the DMA diagnosed and corrected both the height and the temperature of the lowest surface is illustrated by Example 21. Again, the presence of the baseline check results was useful; its residual in terms of Z1 confirms that the "partitioning" of the contributions of height and temperature errors to the hydrostatic residual has been performed reasonably well by the DMA on the basis of statistical residuals. (Compare with Table 4.7.)

Example 21
Type "4=3" correction

ID: 97014 LAT: 1.53 LON: 124.92 TIME: 92/05/07/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	1	2	1	2	1	2	4	2	0	0
850	0	0	1	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	1	0	1	0	1	0			
50	1	-	1	-	0	-	0			
30	-	-	-	-	-	-	0			

FULL VALUES Ps	Zs	SURF PRESSURE INCR	HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
1002.0	80	0.5	0.4	-10.5	-99	**98**	-7905

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	**0**	**0.0**	**-89**	**-30.4**			**-89**	**-29.9**	**-89**	**-30.0**
					162	**68.2**				
850	1504	17.8	1	-1.5			**38**	**8.0**	1	-1.2

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	T	30.3	30.3	1	4	1
1000	Z	90	90	1	4	1

It is easy to see what has actually happened in this case: both height and temperature at 1000 HPa were erroneously put equal to zero. Most probably, these data were just missing in the report, but they were coded not as missing but as zeros. Errors of such kind happen often. There is no need to search for simple corrections for such errors.

Another point to be mentioned about these, Type "4=3", errors is that a possible compensation effect, like that which occurred in Example 14 above, is even more dangerous when communication-related errors in both height and temperature take place at the lowest or highest reported level. A Type 3 error usually results in two large hydrostatic residuals, and a compensation can make only one of them small, while the other is still large and signals that something is wrong. As to a Type "4=3" or "5=3" error, it leads to only one large hydrostatic residual, and a compensation effect would make this residual small, so there is no hydrostatic suspicion at all. As a result, the DMA does not recognize communication errors in such cases, suspecting observational errors instead, as it did in examples 22 and 23. It is a human specialist who faces the not very easy task of identifying and correcting the errors using the CQCHT outputs.

Example 22

Type "5=3" error, not recognized because of compensation

ID: 24817 LAT: 61.27 LON: 108.02 TIME: 92/07/09/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	1	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	1	0	0			
50	2	2	2	2	2	2	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
70	18950	-49.1	93	1.2			-38	-3.8	110	1.3
					42	8.6				
50	21320	-24.5	266	24.7			218	24.5	282	24.9

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
50	T	-24.5	0.0	3	0	2
50	Z	21320	0	3	0	2

Example 23

Type "4=3" correction not made because of compensation

ID: 42361 LAT: 26.23 LON: 78.25 TIME: 92/07/17/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	0	2	1	2	1	2	102	2	0	0
850	0	0	1	0	0	0	0			
700	0	0	0	0	1	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	1	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	1	0	1	0	1	0			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
972.0	207	-3.0	-0.7	-9.7	-82	**100**	465

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
1000	53	-0.5	**58**	**-37.3**			**82**	**-35.7**	**78**	**-37.3**
					-10	-4.1				
850	1388	19.6	**-42**	-4.6			**-49**	**6.6**	-33	-5.0

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	53	0	5	102	1

A proper identification and correction of Type 7-10 errors also becomes difficult when one of the two error-containing levels is the lowest or the highest one, because three hydrostatic residuals are needed in order to diagnose errors of any of these types, but only two residuals are available. As a rule, human help is necessary in such situations, as in Example 24.

Example 24
Type "boundary 9" errors

ID: 82900 LAT: -8.07 LON: 325.12 TIME: 92/06/15/12

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	1	0	2	0	1	0	102	2	0	0
850	0	2	1	2	0	2	3			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			

FULL VALUES Ps	Zs	SURF PRESSURE INCR	HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
1016.0	19	3.1	3.8	16.1	153	**-139**	1541

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	18	25.0	**-112**	-2.8			**-123**	**7.6**	**-107**	-2.0
					204	**85.9**				
850	1549	-13.5	18	**-29.8**			56	**-28.8**	23	**-29.2**
					85	**30.0**				
700	3172	8.4	19	-0.4			15	**8.6**	24	-0.5

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	18	0	5	102	1
850	T	-13.5	0	3	3	2

A hydrostatic suspicion of a Type 4 error may also be caused by a computational error in the thickness of the lowest layer. Such a computational error results in wrong values of all heights except that of the lowest level. The CQCHT DMA is capable of diagnosing and correcting such "Type 4=6" errors, as in Example 25. One can see that the increments and horizontal check residuals for both height and temperature of 1000 HPa are rather small, while those for all other heights are large and close to the hydrostatic residual. Such a pattern, reflected also by the quick recognition section, is analogous to that for Type 6 errors, as discussed in Subsection D, except that there is a Type 4, not 6, hydrostatic suspicion.

Example 25
Type "4=6" correction

ID: 46734 LAT: 23.57 LON: 119.62 TIME: 92/04/29/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	0	0	0	0	0	0	4	0	0	0
850	1	0	1	0	2	0	0			
700	1	0	0	0	1	0	0			
500	1	0	0	0	1	0	0			
400	1	0	0	0	1	0	0			
300	1	0	0	0	0	0	0			
250	1	0	0	0	0	0	0			
200	1	0	0	0	0	0	0			
150	1	0	0	0	0	0	0			
100	1	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			
10	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	107	24.2	11	-2.0			**-53**	-1.2	7	0.4
					106	44.5				
850	1615	19.0	**108**	-2.5			**68**	-1.6	**101**	-2.7
					0	-0.1				
700	3250	10.2	**96**	-1.0			16	-0.5	**82**	-1.7
					11	2.1				
500	5970	-6.3	**101**	1.1			23	0.9	**75**	-0.3
					5	1.5				
400	7680	-17.9	**111**	1.4			31	1.0	**87**	-0.1
					-7	-1.7				
300	9760	-32.7	**110**	0.6			24	0.2	**61**	0.2
					3	1.3				
250	11020	-42.7	**113**	0.5			27	0.8	**64**	0.0
					0	0.0				
200	12480	-56.5	**115**	-2.1			31	-2.2	**63**	-1.1
					4	1.0				
150	14270	-65.7	**108**	0.0			16	0.8	**60**	-0.7
					-9	-1.5				
100	16670	-74.7	**137**	-1.8			65	-1.3	**54**	-0.1
					-9	-1.8				
70	18740	-73.3	**93**	-2.9			6	-3.1	**53**	2.2
					-3	-0.5				
50	20750	-64.3	**100**	2.6			53	3.2	**55**	0.0
					4	0.5				
30	23950	-54.5	-	-			-	-	-	-
					-1	-0.2				
20	26570	-50.1	-	-			-	-	-	-
					-1	-0.1				
10	31200	-39.7	-	-			-	-	-	-

DMA results						
P	Variable	New value	Correction	Decision	Type	Scan
1000	T	24.1	0.0	2	4	1
1000	Z	107	0	2	4	1
850	Z	1515	-100	1	0	1
700	Z	3150	-100	1	0	1
500	Z	5870	-100	1	0	1
400	Z	7580	-100	1	0	1
300	Z	9660	-100	1	0	1
250	Z	10920	-100	1	0	1
200	Z	12380	-100	1	0	1
150	Z	14170	-100	1	0	1
100	Z	16570	-100	1	0	1
70	Z	18640	-100	1	0	1
50	Z	20650	-100	1	0	1
30	Z	23850	-100	1	0	1
20	Z	26470	-100	1	0	1
10	Z	31100	-100	1	0	1

8.6. Errors correctable by the complex containing baseline checks.

Although the Comprehensive Hydrostatic Quality Control code contained a baseline check, it was impossible without other, statistical, checks to diagnose what actually happened in each case with a large baseline check residual. Therefore, the CHQC DMA just displayed the baseline check results for such cases, not even trying to recognize which data was in error and why.

The situation with the CQCHT is quite different: the presence of statistical check residuals, particularly of those for the surface-air pressure, makes it possible for the CQCHT DMA to examine the origin of each error causing a large baseline and/or surface pressure check residual and to correct most such errors.

As illustrated by examples 20 and 21 in the previous subsection, the baseline check residual is used by the CQCHT DMA when a Type 4 error is suspected by the hydrostatic check. In those cases, however, the baseline check provides auxiliary information to confirm (or deny) a diagnosis reached on the basis of other checks. The main use of the baseline checks is different: to correct errors which otherwise could not be even diagnosed confidently. There are four types of such errors.

Among them, Type 100 errors happen most often. This type of error is, as a rule, a communication-related error in the surface-air pressure, as in Example 26. The DMA identifies a Type 100 error when the baseline residual in terms of surface pressure is large and close to the surface pressure increment (and its horizontal residual), and there are no large mandatory height increments nearby. This check or, better to say, this complex of checks proves to be very sensitive, particularly over plain terrain (or over sea) in non-polar regions: the DMA is capable of detecting and correcting Type 100 errors as small as 6 HPa, as in Example 27. (Compare with Table 4.11)

Example 26
Large type 100 correction

```
ID: 40758   LAT: 36.27   LON: 59.63 TIME: 92/06/16/12
----------------------------------------------------------
PRES   IINC   IVOI   IHOI   IHSC  IBAS   IIPL   IHPL
       Z  T   Z  T   Z  T
1000   0  -   0  -   0  -    100    2      2      2
 850   0  0   0  0   0  0      0
 700   0  0   0  0   0  0      0
 500   0  0   0  0   0  0      0
 400   0  0   0  0   0  0      0
 300   0  0   0  0   0  0      0
 250   0  0   0  0   0  0      0
 200   0  0   0  0   0  0      0
 150   0  0   0  0   0  0      0
 100   0  0   0  0   0  0      0
  70   0  0   0  0   0  0      0
----------------------------------------------------------
 FULL VALUES    SURF PRESSURE    BASELINE CHECK RESIDUALS
   Ps     Zs    INCR  HORRES     inPs    inZs    inZ1   inZ2
  990.0  989    88.4   88.1      89.4     849    -906  13531
----------------------------------------------------------
   DMA results
   P  Variable New value Correction Decision   Type  Scan
           Ps     900.0     -90.0          1      100    1
```

Example 27
Type 100 correction

ID: 08508 LAT: 38.75 LON: 332.93 TIME: 92/04/01/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	0	0	0	0	0	0	100	2	1	1
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	-	-	-	-	-	-	-			
200	-	-	-	-	-	-	-			
150	-	-	-	-	-	-	-			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
1004.0	55	-6.4	-6.4	-6.9	-58	57	2329

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
	Ps	1010.5	6.5	1	100	1

Although the surface pressure correction, performed by the DMA, was quite reasonable, what actually happened in Example 27 was not a communication error of this pressure but an error in the elevation of the station 08508 in the NMC list of upper-air sounding stations, the so-called station dictionary. That was clear because, unlike communication errors, the Type 100 error at this station was permanent: it occurred in each report from the station. Our experience shows that such station elevation errors occur not very seldom. Most probably, they are caused by changes in station positions. The CQCHT DMA provides a good tool for detection and correction of these errors.

One could suspect station elevation errors even by the baseline check alone, and we came across such cases when monitoring the CHQC results. Under those conditions, however, one could not be absolutely sure about the nature of each permanent baseline error. At least in principle, such errors might be caused by a permanent error (a scale shift) of the station barometer measurements. The situation is quite different when the baseline check residuals are analyzed in a complex with other residuals, as it is done by the CQCHT DMA. An observational error in surface pressure (Type 106 error) results in residual pattern substantially different from that resulting from a Type 100 error. As illustrated by Example 28, the surface pressure increment and horizontal residual are large for a Type 106 error as they are for a Type 100 error, but the baseline residual is small and, most important, there are large increments and horizontal residuals of isobaric heights, beginning at the lowest reported level. They are approximately equal to each other and to the surface pressure increment multiplied by the vertical gradient of pressure (i.e., by about 8 m/HPa). Consequently, in order to correct a surface pressure measurement error it is necessary not only to correct the pressure, as in the case of a Type 100 error, but also to make corresponding corrections to all heights, as the DMA did in Example 28. These corrections look like those of a thickness computation (Type 6) error, but are applied to all heights beginning with the lowest one. (Compare with Table 4.22.)

Example 28
Type 106 correction

ID: 94302 LAT: -22.23 LON: 114.08 TIME: 92/04/06/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	1	0	0	0	1	0	106	0	2	2
850	1	0	0	0	1	0	0			
700	1	0	0	0	1	0	0			
500	1	0	0	0	1	0	0			
400	1	0	0	0	1	0	0			
300	1	0	0	0	1	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
1019.0	6	**10.6**	**10.8**	0.5	4	-4	36

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	168	23.6	**88**	-3.4			36	-3.2	**90**	-2.6
					7	3.1				
850	1579	20.2	**88**	-0.5			19	0.6	**87**	-0.6
					8	2.8				
700	3220	8.2	**90**	-0.4			22	-0.3	**87**	-0.2
					9	1.9				
500	5910	-10.1	**91**	0.0			26	0.2	**88**	-0.2
					0	0.1				
400	7590	-21.9	**83**	-0.3			13	-0.3	**80**	-0.5
					8	2.0				
300	9650	-37.1	**92**	0.0			24	-0.5	**90**	0.1
					-3	-1.0				
250	10890	-43.5	**95**	1.9			22	2.1	**92**	1.8
					-3	-1.0				
200	12350	-54.7	**97**	-0.9			27	-1.1	**93**	-1.2
					0	0.0				
150	14150	-64.1	**90**	-1.2			25	-0.6	**86**	-0.8
					-14	-2.3				
100	16570	-72.1	**79**	-2.9			21	-2.3	**75**	-2.1
					12	2.3				
70	18680	-72.3	**70**	-2.1			5	-2.3	**73**	-0.9
					6	1.1				
50	20701	-62.9	**99**	3.9			62	4.4	**93**	2.3
					-1	-0.1				
30	23910	-55.3	-	-			-	-	-	-

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	76	-92	1	106	1
850	Z	1487	-92	1	0	1
700	Z	3128	-92	1	0	1
500	Z	5818	-92	1	0	1
400	Z	7498	-92	1	0	1
300	Z	9558	-92	1	0	1
250	Z	10798	-92	1	0	1
200	Z	12258	-92	1	0	1
150	Z	14058	-92	1	0	1
100	Z	16478	-92	1	0	1
70	Z	18588	-92	1	0	1
50	Z	20618	-92	1	0	1
30	Z	23818	-92	1	0	1
	Ps	1008.3	-10.7	1	106	1

Corrections of this kind are also needed when there is no communication or observation error in surface pressure, but an error has been made in computing the height of the lowest mandatory level (Type 116 error, illustrated by Example 29). (Compare with Table 4.18.)

Example 29
Type 116 correction

ID: 28952 LAT: 53.22 LON: 63.62 TIME: 92/05/08/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	1	0	116	2	0	0
850	1	0	0	0	1	0	0			
700	1	0	0	0	2	0	0			
500	2	0	1	0	2	0	0			
400	2	0	0	0	2	0	0			
300	2	0	1	0	2	0	0			
250	2	0	1	0	2	0	0			
200	1	0	1	0	1	0	0			
150	1	0	0	0	1	0	0			
100	0	0	0	0	0	0	5			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
990.0	171	-1.5	-2.0	-9.0	**-76**	81	1210

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
1000	163	8.6	**65**	4.0			14	2.6	**66**	4.1
					8	3.4				
850	1500	3.8	**86**	3.8			21	1.6	**81**	4.3
					-5	-1.8				
700	3040	-6.3	**104**	3.9			18	2.2	**101**	4.3
					6	1.2				
500	5600	-21.3	**148**	3.6			43	2.0	**144**	4.3
					4	1.1				
400	7210	-33.1	**168**	3.4			39	1.9	**171**	3.5
					0	0.0				
300	9170	-47.7	**195**	2.9			51	2.6	**199**	3.4
					1	0.3				
250	10350	-56.7	**205**	-1.1			58	-0.5	**212**	-1.0
					-10	-3.1				
200	11740	-60.9	**184**	-5.7			59	-4.7	**192**	-5.5
					-4	-1.0				
150	13540	-56.9	**119**	-3.5			36	-2.1	**132**	-3.4
					-89	**-15.0**				
100	16020	-56.5	**24**	**-0.7**			-34	-0.1	**21**	**-1.0**

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	87	-76	1	116	1
850	Z	1424	-76	1	0	1

700	Z	2964	-76	1	0	1
500	Z	5524	-76	1	0	1
400	Z	7134	-76	1	0	1
300	Z	9084	-76	1	0	1
250	Z	10274	-76	1	0	1
200	Z	11664	-76	1	0	1
150	Z	13464	-76	1	0	1
100	Z	15944	-76	1	0	1
100	T	-50.6	5.9	1	5	1
100	Z	16003	-17	1	5	1

Such an error does not lead, unlike a Type 106 error, to large surface pressure residuals. It results instead in a large baseline check residual in terms of the station elevation, which is of opposite sign and close in absolute value to all height increments. Correspondingly, the DMA corrects all the heights by this value. As may be seen in Example 29, these corrections are very much like those of Type 106 error corrections (Example 28), except that there is no pressure correction.

Comparison of the CQCHT DMA actions concerning these two types of errors gives a good illustration of what may be called the CQC ideology, namely of its attempts to diagnose the **cause** of each rough error. Although resulting in quite analogous patterns of residuals, Type 106 and 116 errors are of substantially different origin, and the origin of each error is investigated by the DMA. This is important not only because corresponding corrections are different for errors of these two types, but also because an analogous residual pattern may be caused by observation errors when no correction is possible.

Example 30 illustrates the last type of error that can be detected and corrected only with the help of the baseline check, the Type 101. This is a communication error in the lowest level height which, however, cannot be suspected by the hydrostatic check just because the temperature at this level is missing. This happens comparatively often, particularly for elevated stations. A Type 101 error leads to a large increment and a large horizontal check residual for the lowest level height (more exactly, to large algebraic differences between them and their values at the next level), which are approximately equal to the baseline check residual in terms of this height. Using these values, the DMA computes the error and corrects it. (Compare with Table 4.12.)

Example 30
Type 101 correction

ID: 06610 LAT: 46.82 LON: 6.95 TIME: 92/04/01/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	2	0	2	0	2	0	101	2	2	2
850	0	0	1	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
933.0	501	9.7	8.5	-9.3	-72	**127**	168

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
1000	67	-	**161**	-	-	-	**153**	-	**149**	-
850	1243	-1.1	13	-1.8			-55	-1.7	10	-0.4

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	-69	-136	1	101	1

It should be mentioned that the DMA behavior with errors detected with the aid of baseline check differs essentially from its treatment of hydrostatically suspected errors. No such thing as a baseline check suspicion which may be found right or wrong exists. Each error of any of four types considered above is not only suspected but automatically corrected by the DMA. This is because, in order to diagnose any of these errors, the DMA uses the baseline residual in combination with those of other checks.

There exist some cases when, despite large residuals of the baseline and/or surface pressure checks, the DMA finds itself unable to meet criteria for any of types 100, 101, 106 or 116 error. This often happens with reports from elevated stations because errors in the extrapolation of temperature to the sea level may distort results of the baseline and surface pressure checks for such stations. Therefore the DMA just ignores such error suspicions from stations with elevation exceeding 800 m. As to reports of that kind from stations with lower elevation, the DMA makes the decision 5, "human help needed". It transfers the CQCHT information to the MOD specialists, assigning the error type 102 to either the lowest height or the surface pressure, meaning that something is probably wrong, according to the baseline check results, in the report, but the DMA was unable to confidently detect and correct the error(s).

It is usually not difficult for a qualified specialist to recognize what actually happened when a Type 102 error has been diagnosed and, if necessary, to make corrections. A small Type 116 error is most probable in Example 31, and it is up to a specialist to decide whether or not to correct all heights by about 40 m. In some rare cases, however, a great deal of knowledge and even imagination is needed in order to make the proper decision, as happened in Example 32. Although the reported surface pressure was definitely wrong in this case, the DMA could not diagnose a Type 100 error because the baseline check indicated a substantially smaller error than the surface pressure checks did. Neither was it diagnosed as a Type 106 error because the baseline residual in terms of surface pressure was large, and because the height increments were much smaller than eight times the surface pressure increments.

Example 31
Type 102 suspicion

ID: 42700 LAT: 23.37 LON: 85.33 TIME: 92/04/15/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	0	-	0	-	0	-	102	1	2	1
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	-	0	-	0	-	1	-			
100	0	0	0	0	0	0	0			

FULL VALUES Ps	FULL VALUES Zs	SURF PRESSURE INCR	SURF PRESSURE HORRES	BASELINE CHECK RESIDUALS inPs	BASELINE CHECK RESIDUALS inZs	BASELINE CHECK RESIDUALS inZ1	BASELINE CHECK RESIDUALS inZ2
943.0	647	8.9	7.7	4.2	40	62	108

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	86	-	**45**	-			25	-	**37**	-
					-	-				
850	1516	24.4	**32**	-2.0			3	-1.5	17	-2.6

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
	Ps	943.0	0	5	102	1

Example 32
Type 102 suspicion - most probably, a combination of Type 100 and 106 errors

ID: 07240 LAT: 47.35 LON: 0.72 TIME: 92/05/13/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	1	-	0	-	1	-	102	2	2	2
850	0	0	0	0	1	0	0			
700	0	0	0	0	1	0	0			
500	0	0	0	0	1	0	0			
400	1	0	0	0	1	0	0			
300	0	0	0	0	1	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	1	0	1	0	1	0			
100	0	0	0	0	0	0	0			

FULL VALUES Ps	FULL VALUES Zs	SURF PRESSURE INCR	SURF PRESSURE HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
904.0	106	**-107.6**	**-109.2**	**-97.8**	891	-2374	-1427

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	122	-	**-81**	-			**-51**	-	**-89**	-
					-	-				
850	1523	15.6	**-50**	4.3			-3	4.9	**-58**	4.4
					7	2.5				
700	3132	1.8	**-39**	-2.0			2	-2.8	**-50**	-2.1
					0	0.0				
500	5750	-16.5	**-60**	-2.6			-12	-1.8	**-73**	-2.2
					3	0.9				
400	7390	-28.5	**-83**	-1.9			-29	-1.4	**-91**	-1.6
					-2	-0.5				
300	9390	-42.3	**-85**	0.9			-23	0.7	**-94**	0.8

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	Z	122	0	5	102	1

To solve this puzzle, one has to imagine what would happen if there were both measurement and communication errors in the surface pressure! Having made this assumption, it will be comparatively easy to recognize that the surface pressure was first measured with an error of about -10 HPa and then transmitted with an additional error of -100 HPa. To correct the report, it is necessary to add about 110 HPa to reported surface pressure and about 80 m to each reported height.

8.7. Observational errors.

The CHQC DMA is unable to detect observational errors in rawinsonde reports because, as long as the mandatory level heights are computed from observed temperature profiles by the hydrostatic equation, the hydrostatic check simply does not react to any observational error.

In contrast, the CQCHT DMA is not only capable of detecting observational errors, like many other QC methods, it is much more sensitive in doing so, just because of the presence of the hydrostatic check: if there are large residuals of statistical checks and no large hydrostatic residuals, this clearly indicates that the errors are of observational origin. Moreover, although it would be, generally speaking, better if the isobaric heights were determined independently, the fact that they are computed from temperature data plays a positive role in detecting observational errors: it allows the CQCHT DMA to recognize rather small errors of this kind if they are persistent vertically.

Example 33 illustrates such a situation. The temperature increments and horizontal residuals are very small in this example (although still larger than the hydrostatic residuals), but they are all positive. Their accumulated influence resulted in large height errors, and that made it possible for the DMA to detect these observational errors. (Compare with Table 4.21.)

Example 33
Small but persistent observation errors

ID: 59981 LAT: 16.83 LON: 112.33 TIME: 92/04/06/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	1	0	0	0	1	0	0			
100	2	0	1	0	1	0	0			
70	1	0	0	1	1	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	3134	11.4	3	2.2			3	1.8	6	2.2
					-3	-0.6				
500	5860	-3.5	25	2.8			12	1.7	29	3.1
					-5	-1.4				
400	7580	-14.7	29	2.6			2	1.4	25	1.8
					-2	-0.6				
300	9700	-27.5	47	2.4			10	1.1	39	2.4
					4	1.5				
250	10990	-36.9	63	2.6			12	1.1	56	2.7
					3	1.1				
200	12500	-48.1	85	3.3			17	1.8	80	3.4
					4	0.9				
150	14340	-62.1	121	4.2			15	2.9	114	4.0
					-5	-0.9				
100	16780	-72.1	**217**	3.6			103	4.5	202	4.8
					1	0.1				
70	18820	-83.5	194	-8.2			84	-9.0	172	-5.5

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
100	Z	16780	0	4	0	2

Observational errors may be quite large, like those in Examples 34 and 35. In such cases the DMA detects possible errors not only in heights, but either in both temperature and height as in Example 34, or even only in temperature, if the errors are not very large and not very persistent, as happened in Example 35. (Compare with Table 4.20.)

Example 34
Large observational errors

ID: 72247 LAT: 32.35 LON: 265.35 TIME: 92/04/13/12

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	20			
700	0	0	0	0	0	0	10			
500	0	2	1	1	0	2	6			
400	1	2	0	1	1	2	0			
300	2	2	1	1	2	2	0			
250	2	2	2	1	2	2	0			
200	2	0	2	0	2	0	0			
150	2	0	0	0	2	1	0			
100	2	0	2	0	2	0	0			
70	2	1	1	1	2	1	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
700	3184	2.4	11	-1.6			11	1.2	12	-1.6
					56	**11.5**				
500	5810	-26.9	-9	**-14.5**			36	**-10.4**	-11	**-13.9**
					-5	-1.4				
400	7370	-40.3	-117	**-14.8**			-26	-7.6	-114	**-15.0**
					5	1.2				
300	9260	-58.3	**-247**	**-17.1**			-63	-9.9	**-242**	**-16.8**
					-8	-3.0				
250	10380	-65.3	**-340**	**-14.5**			-102	-9.7	**-337**	-14.2
					8	2.5				
200	11760	-60.9	**-376**	0.2			-115	4.8	**-369**	2.2
					10	2.5				
150	13530	-67.5	**-349**	-4.0			-54	-3.9	**-358**	-7.4
					-13	-2.1				
100	15970	-65.5	**-434**	-0.6			-187	-1.9	**-436**	-1.3
					10	1.9				
70	18170	-61.3	**-336**	10.3			-117	10.5	**-367**	8.4

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
850	T	13.0	0.0	3	20	1
700	Z	3184	0	2	10	1
500	Z	5810	0	2	6	1
850	T	13.0	0.0	3	20	2
700	Z	3184	0	2	10	2
500	T	-26.8	0	3	6	2
500	Z	5810	0	2	6	2
400	T	-40.3	0.0	3	0	2
300	T	-58.3	0.0	3	0	2
300	Z	9260	0	4	0	2

250	Z	10380	0	4	0	2
200	Z	11760	0	4	0	2

P	Variable	New value	Correction	Decision	Type	Scan
150	Z	13530	0	4	0	2
100	Z	15970	0	4	0	2
70	Z	18170	0	4	0	2

Example 35
Isolated observational errors

ID: 52267 LAT: 41.98 LON: 101.07 TIME: 92/04/13/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	-	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	1	0	0	0	1	0			
250	1	1	0	1	0	1	0			
200	1	0	1	0	1	0	0			
150	1	0	0	0	0	0	0			
100	1	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
400	7310	-31.7	32	2.3			-8	0.2	4	1.4
					5	1.1				
300	9300	-43.1	80	**8.3**			11	5.0	40	**7.0**
					4	1.6				
250	10510	-51.3	135	**9.5**			37	6.6	83	**7.6**
					-2	-0.5				
200	11930	-59.7	179	2.2			64	0.3	116	-0.2

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
300	T	-43.1	0	3	0	2
250	T	-51.3	0	3	0	2

Errors of observational origin in temperatures and/or heights of mandatory surfaces cannot be corrected because the reported values are those computed in the course of data processing at stations, not the observed values themselves. There exist therefore two options concerning data distorted by observational errors: either to automatically exclude them from consideration by the data assimilation system, or to ask a specialist to decide what to do with each such datum. It was decided to have the CQCHT output MOD file include all reports diagnosed as containing observational errors. The DMA decision concerning each such datum is either 3 (likely bad), or 4 (definitely bad), or 5 (Type 102 error, i.e., undetermined probable baseline error).

Decisions 4 may be, though usually are not, overridden by a specialist. As to the likely bad data (decisions 3 and 5), it is up to a specialist to decide what to do with each such datum. To make well-motivated decisions of this kind is a rather difficult task, particularly under operational conditions.

First, there usually are several levels in a row with likely bad data, and it is necessary to decide which of them (if any) should be rejected. Secondly, not much may be achieved by looking at the output itself, just because the report has been already examined by the CQCHT algorithms. It is highly desirable therefore to use every available additional information, like results from other observing means or significant level data, and/or to involve graphical aid: vertical profiles and cross-sections, maps etc. It is hardly possible without special software to produce such graphs in operationally acceptable time.

One has also to have in mind that the decision whether to reject or to preserve some data should depend on the presence or absence of other data not far from the station. In a region with a dense network one can easily reject even slightly questionable data, while even more strongly suspected data should be retained in a data poor region.

There exists, at least in principle, a possibility to make an intermediate decision: to retain a questionable datum but to assimilate it with smaller weight. This may be done by assigning a larger root mean square observation error to such datum. This way, assigning different RMS observational errors to different data, depending on their estimated quality, is already used in both global and regional Data Assimilation Systems at the NMC.

Not every DMA decision 3, or 4, or 5 means, of course, that an observational error is diagnosed or suspected. In every case, when the DMA detects some large errors but is unable to correct them (or to rehabilitate the data), it either rejects erroneous data or, at least, includes them as suspected data into the MOD file. This happens, as a rule, in complicated cases, when there are several rough errors in a report, and not all of them (or even none of them) could have been corrected automatically. In such situations, like those in examples 14 and 32 above, a well-qualified specialist is often able to properly correct the report.

It also happens often that a report is distorted by both observational and non-observational errors. This does not cause much harm if the observational errors are very large, like those in Example 36. Whether first corrected or not, the erroneous data would be finally rejected anyway. The situations illustrated by Example 37 are much more unfavorable. As can be easily seen, there was a computational error in this case, which resulted in wrong heights at 100 HPa and above. However, a small observational error in the 100 HPa temperature prevented the DMA from diagnosing and correcting this error. It is up to human specialists to perform necessary corrections in such cases.

Example 36
Large observational errors, rejections included corrected datum.

```
ID: 40230   LAT: 32.55   LON: 35.85 TIME: 92/07/19/00

SCAN 1
PRES   IINC   IVOI   IHOI   IHSC   IBAS   IIPL   IHPL
        Z  T   Z  T   Z  T
1000    -  -   -  -   -  -     -      -      -      -
 850    0  2   0  1   0  1     0
 700    2  2   1  2   2  2     0
 500    2  2   2  2   2  2     5

  P     Observ      Increment   Hydrost     Vertical   Horizont
          Z    T       Z    T   inZ  inT     Z    T     Z    T
 850   1440   4.2    -48 -17.2              28 -12.9   -39 -14.6
                                  2   0.6
 700   3000  -2.1   -132 -13.7             -32 -19.6  -118 -13.1
                             -368  -74.8
 500   5610  60.6   -243  64.0            -176  66.8  -236  64.9

   DMA results
   P  Variable New value Correction Decision   Type  Scan
 500     T       -14.1      -74.7       1         5    1
```

SCAN 2

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	-	-	-	-	-	-	-	-	-	-
850	0	2	0	1	0	1	0			
700	2	2	1	0	2	2	0			
500	2	1	2	1	2	1	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
850	1440	4.2	-48	**-17.2**			28	**-12.9**	-39	**-14.6**
					2	0.6				
700	3000	-2.1	**-132**	**-13.7**			**-32**	**-6.9**	**-118**	**-13.1**
					0	-0.1				
500	5610	-14.1	**-243**	**-10.7**			**-176**	**-7.9**	**-236**	**-9.8**

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
500	T	-14.1	-74.7	1	5	1
850	T	4.2	0.0	3	0	2
700	T	-2.1	0.0	3	0	2
700	Z	3000	0	4	0	2
500	T	-14.1	0.0	3	0	2
500	Z	5610	0	4	0	2

Example 37
Small observational error prevented Type 6 error corrections.

ID: 60680 LAT: 22.78 LON: 5.52 TIME: 92/07/12/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IJPL
1000	-	-	-	-	-	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	0	0	1	0	0	0	0			
100	2	0	1	0	2	0	6			
70	2	0	1	0	2	0	0			
50	2	0	1	0	2	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
150	14260	-64.7	1	-1.5			104	-0.7	0	-1.5
					-323	-54.5				
100	16330	-78.3	-330	-5.2			-177	-5.1	-330	-5.2
					-36	-7.0				
70	18380	-68.3	-405	-0.5			-145	0.2	-405	0.5
					-18	-3.6				
50	20430	-58.1	-380	6.8			-172	6.7	-381	6.8

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
100	Z	16330	0	2	6	1
100	Z	16330	0	4	6	2
70	Z	18380	0	3	0	2
50	Z	20430	0	3	0	2

8.8. Data holes

If a report does not contain height or temperature at some mandatory level, or both are missing, then this level is a missing one for the hydrostatic check. It just skips this level and goes to the next one. If there are two or more missing levels in a row (or if the missing level is 100 HPa), then the DMA diagnoses a data hole (Type 13 or 14 error suspicion) and performs some additional testing. The reason for doing so is the possibility that a large hydrostatic residual in such thick layer was caused not by any errors but by the nonlinearity of the temperature profile (with respect to the logarithm of pressure) within the layer. In other words, it may happen--and actually happens very often--that, despite a large hydrostatic residual in a data hole, there are no errors at the lower or upper boundary of the hole.

The presence of many data holes in operationally received (and decoded) rawinsonde reports was discovered at NMC about four years ago, and several measures were undertaken since then in order to make them less frequent. However, data holes still occur comparatively often, though more seldom than several years ago. Among them, Type 13 suspected errors, which occur when one or more upper levels of the Part A are missing (i.e., when the hole contains the 100 HPa level), happen most often. The main reason for them is the fact that Parts C of reports, containing mandatory levels 70 HPa and less, are transmitted separately from Parts A.

Unlike the CHQC DMA, the CQCHT DMA not only detects the data holes, it investigates whether there are rough errors at the lower and/or upper boundary of each hole. It does not take into account, when doing so, the hydrostatic residual within the hole (because of its unreliability), analyzing instead hydrostatic residuals for layers neighboring the hole in a complex with increments and horizontal residuals for the hole boundaries. Quite naturally, the DMA decides in most cases that there were no errors, as it did in Example 38. From a formal point of view, the CQCHT results in such a case do not differ from the CHQC ones: the data hole was discovered and nothing was changed. In the essence , however, the CQCHT DMA did much more, it confirmed that the data at the hole boundaries did not contain rough errors.

Example 38
Data hole, no errors

ID: 71722 LAT: 46.38 LON: 284.03 TIME: 92/04/13/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	-	-	-	-	-	-	-			
250	-	-	-	-	-	-	-			
200	-	-	-	-	-	-	-			
150	-	-	-	-	-	-	-			
100	-	-	-	-	-	-	-			
70	0	0	0	0	0	0	13			
50	0	0	0	0	0	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
400	6800	-41.9	-44	-1.6			-35	-0.6	-60	-1.2
					-	-				
300	-	-	-	-			-	-	-	-
....										
100	-	-	-	-			-	-	-	-
					-122	-4.8				
70	18170	-53.9	-30	-1.1			-13	-0.2	-30	-0.2

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
400	T	-41.9	0.0	2	0	1
400	Z	6800	0	2	0	1
70	T	-53.9	0.0	2	0	1
70	Z	18170	0	2	0	1

Example 39 illustrates a situation with a rough error at the hole's lower boundary. This may be denoted as Type 5' error, because, attempting to find such errors, the DMA behaves just like it would do if there were no data above the hole. Analogously to Type 5, one may distinguish between Type "5'=1", "5'=2" and "5'=3" errors. Example 39 is a "Type "5'=2" error.

Example 39
Before-the-hole correction (Type "5'=2" correction)

ID: 37549 LAT: 41.68 LON: 44.95 TIME: 92/09/08/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	0	-	0	0	1	1
850	0	1	0	1	1	1	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	1	0	0	0			
250	0	2	0	2	0	2	3			
200	-	-	-	-	-	-	-			
150	-	-	-	-	-	-	-			
100	-	-	-	-	-	-	-			
70	0	0	0	0	0	0	13			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
300	9590	-37.9	35	-0.3			14	**-9.6**	29	-0.4
					-89	**-33.3**				
250	10820	-14.1	28	**30.6**			8	**30.7**	16	**30.2**
					-	-				
....										
100	-	-	-	-			-	-	-	-
					-757	-40.6				
70	18840	-61.1	27	-0.2			14	-0.1	-4	-0.9

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
250	T	-44.5	-30.4	1	3	1
70	T	-61.1	0.0	2	0	1
70	Z	18840	0	2	0	1

Analogously, a situation with rough error(s) at the upper boundary of a hole, like that in Example 40, may be denoted as a Type 4' error, because the DMA ignores all data below the hole while detecting and correcting such error. It may correct either the height of the hole's upper boundary ("Type 4'=1" correction), or its temperature ("Type 4'=2"), or both ("Type 4'=3"), or even all the heights above this boundary ("Type 4'=6" correction).

Example 40
After-the-hole correction. (Type "4'=1" error correction.)

ID: 28275 LAT: 58.15 LON: 68.18 TIME: 92/07/10/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	0	0	0	0	0	0	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	0	0	0	0	0	0	0			
150	-	-	-	-	-	-	-			
100	-	-	-	-	-	-	-			
70	0	0	0	0	0	0	13			
50	0	0	0	0	0	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
200	12120	-57.5	66	-2.4			37	-3.3	32	-1.7
					-	-				
150	-	-	-	-			-	-	-	-
					-	-				
100	-	-	-	-			-	-	-	-
					95	6.2				
70	18940	-51.1	**97**	1.8			**94**	1.1	**70**	0.9
					-122	-24.7				
50	21020	-48.1	6	3.3			**-44**	2.9	-38	2.6

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
200	T	-57.5	0.0	2	0	1
200	Z	12120	0	2	0	1
70	Z	18840	-100	1	13	1

Certainly, the presence of a hole diminishes the DMA capability to properly detect and correct errors at its boundary. That is why all information concerning data holes is included into MOD files. It is also necessary to realize that it is practically impossible or, at least, it would be very risky to automatically detect and correct a computational error in the hole's thickness, just because the hydrostatic residual for a data hole cannot be believed. A specialist can help to resolve such cases, and even more complicated ones, like that in Example 41.

Example 41
After-the-hole corrections rejected because of an additional computational error in the thickness of the hole

```
SCAN 1
ID: 43003  LAT: 19.08  LON: 72.85  TIME: 92/07/14/00

PRES  IINC   IVOI   IHOI   IHSC  IBAS  IIPL  IJPL
      Z  T   Z  T   Z  T
1000  0  -   0  -   0  -     -     0     0     0
 850  0  0   0  0   0  0     0
 700  0  0   0  0   0  0     0
 500  0  0   0  0   0  0     0
 400  0  0   0  0   0  0     0
 300  0  0   0  0   0  0     0
 250  0  0   0  0   0  0     0
 200  -  -   -  -   -  -     -
 150  -  -   -  -   -  -     -
 100  2  2   2  2   2  2    14
  70  2  0   2  2   2  0     0
  50  2  0   1  0   2  0     0
  30  -  -   -  -   -  -     0

  P     Observ     Increment    Hydrost    Vertical    Horizont
         Z    T      Z     T   inZ   inT    Z     T     Z     T
 250 11000 -38.6    -1  -0.4               -4  -0.2    -1   0.1
                             -2838 -211.6
 100 15240  20.2 -1403  95.6            -1290  96.3 -1411  95.9
                               715  136.9
  70 18520 -75.1  -224  -3.6              364 -20.6  -216  -4.1
                                 5    1.0
  50 20530 -68.1  -225  -0.8             -110   0.0  -227  -0.9

  DMA results
  P  Variable New value Correction Decision   Type  Scan
 250     T      -38.6       0.0       2         0     1
 250     Z    11000         0         2         0     1
 100     T      -80.7    -100.8       1        14     1
 100     Z    16426      1186         1        14     1
```

SCAN 2

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	0	-	0	-	0	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	0	0	0	0			
300	0	0	0	0	0	0	0			
250	0	0	0	0	0	0	0			
200	-	-	-	-	-	-	-			
150	-	-	-	-	-	-	-			
100	2	0	1	0	2	0	14			
70	2	0	0	0	2	0	0			
50	2	0	1	0	2	0	0			
30	-	-	-	-	-	-	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
250	11000	-38.6	-1	-0.4			-3	-0.2	-1	0.1
					-300	-22.4				
100	16426	-80.7	**-217**	-5.3			**-104**	-4.6	**-225**	-5.0
					56	10.6				
70	18320	-75.1	**-224**	-3.6			**-62**	-2.5	**-216**	-4.1
					5	1.0				
50	23640	-61.9	**-225**	-0.8			**-110**	0.0	**-227**	-0.9

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
250	T	-38.6	0.0	2	0	1
250	Z	11000	0	2	0	1
100	T	-80.7	-100.8	1	14	1
100	Z	16426	1186	1	14	1
250	T	-38.6	0.0	2	0	2
250	Z	11000	0	2	0	2
100	T	-80.7	0.0	3	14	2
100	Z	16426	0	4	14	2
70	Z	18520	0	3	0	2
50	Z	20510	0	3	0	2

There were communication-related errors in both height and temperature at the upper boundary of the hole, 100 HPa, and both were corrected by the CQCHT first scan. At the second scan, however, the CQCHT DMA recommended rejecting all heights above the hole and even rejecting data corrected by the first scan.

Analyzing the second scan output, a specialist may see that the three height increments above the hole are very close to each other, as are the horizontal check residuals. Most probably, there was an additional error of about -220 m in the hole thickness computation. If this, "Type 6_{hole}" error is corrected, there will be no more CQCHT suspicions for this report.

8.9. Multiple error corrections.

As illustrated above, computational errors (Types 6 and 116), as well as those in surface pressure measurement (Type 106), usually result in wrong values of several mandatory level heights in a row, and all these values should be corrected. Nevertheless, each such error may be considered as a single error, because all wrong values have been caused, so to say, by a single wrongdoing: either by a wrong computation, or by a wrong measurement.

Some other kinds of errors, also considered above, are in fact multiple errors in the sense that there were two or more wrong actions resulting in erroneous values, like two communication-related errors in cases of Type 3, 7, 8, 9 or 10 errors.

Several more complicated cases, like those in Examples 13 and 17, were also considered above in order to illustrate some general points. The purpose of this, last subsection is to demonstrate further examples of multiple errors and to draw some general conclusions.

The CHQC DMA had no problems when coming across so-called isolated multiple errors, that is, errors divided from each other by one or more error-free levels. The same is true for the CQCHT DMA, as illustrated by Example 42. The three error-containing levels in this example, 850, 300 and 100 HPa, are isolated, and the DMA was able therefore to analyze and correct errors at each level independently. This example also illustrates essential superiority of the CQCHT over the CHQC. The latter would not be able to correct any of the six erroneous values because it is unable to make Type 3 and Type 4 error corrections.

Example 42

Successful multiple corrections by scan 1.

ID: 32540 LAT: 53.02 LON: 158.72 TIME: 92/07/29/00

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	2	2	2	2	2	2	4	2	0	0
850	0	0	2	0	0	0	0			
700	0	0	2	0	0	0	0			
500	2	1	2	1	2	1	3			
400	0	0	2	0	0	0	0			
300	0	0	2	2	0	0	0			
250	2	2	2	2	2	2	3			
200	0	0	2	2	0	0	0			
150	0	0	0	0	0	0	0			
100	0	0	0	0	0	0	0			
70	0	0	0	0	0	0	0			
50	0	0	0	0	0	0	0			
30	-	-	-	-	-	-	0			
20	-	-	-	-	-	-	0			

FULL VALUES Ps	Zs	SURF PRESSURE INCR	HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
999.0	78	0.4	-1.4	27.1	275	-277	-43988

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
1000	-207	-13.5	-261	-25.7			-264	-24.4	-274	-24.0
					334	140.6				
850	1400	2.2	5	-3.8			114	4.2	-1	-3.2
					3	1.2				
700	2960	-0.7	-9	-1.3			-1284	1.4	-18	-0.4
					4014	815.2				
500	9560	-20.5	3956	-9.4			3957	-9.8	3945	-9.3
					-3919	******				
400	7290	-20.9	6	2.5			-1609	4.5	-2	2.0
					2	0.4				
300	9350	-36.5	23	2.0			240	-38.7	13	1.9
					-906	-339.4				
250	10040	88.2	-512	135.7			-533	135.5	-522	136.6
					96	29.3				
200	12030	-54.5	32	-1.6			228	-37.0	16	-3.3

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
1000	T	12.9	26.4	1	4	1
1000	Z	64	271	1	4	1
500	T	-10.8	9.7	1	3	1
500	Z	5600	-3960	1	3	1
250	T	-48.3	-136.5	1	3	1
250	Z	10580	-540	1	3	1

The errors in Example 43, unlike those in the previous one, are not isolated. They are present at three levels in a row. Several conclusions may be drawn from this example. First, the DMA successfully corrected only the heights, leaving the temperatures unchanged, despite the absence of a special provision for such errors and despite the hydrostatic suspicions of Type 3 errors implying that the temperatures might be wrong as well. Secondly, a well trained specialist can easily realize what has actually happened in this case: the person who coded the report for transmission was aware of the coding requirement to skip the first digit in 850 and 700 HPa heights, as well as in those of 250 HPa and above, but he (or she) erroneously "extrapolated" this rule to the heights of 500, 400 and 300 HPa surfaces. The actual values of these heights were thus 5830, 7530 and 9620 m respectively, which is very close to the values computed by the DMA. This gives a realistic estimate of the degree of accuracy achievable by the CQCHT DMA in the course of automatic correction of three data even without a special provision for such cases.

Example 43
"Type 77" corrections of coding errors.

ID: 67774 LAT: -17.83 LON: 31.02 TIME: 92/06/01/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	0	0	0
850	0	0	1	0	0	0	0			
700	0	0	2	0	0	0	0			
500	2	0	2	0	2	0	3			
400	2	0	2	0	2	0	3			
300	2	0	2	0	2	0	3			
250	0	0	2	0	0	0	0			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	3155	5.0	9	-2.5			**-781**	-0.7	8	-2.6
					2430	493.5				
500	8260	-8.1	**2437**	1.3			**3371**	2.1	**2435**	1.1
					-4674	*******				
400	5290	-16.5	**-2227**	2.5			**-2010**	2.2	**-2229**	2.5
					-1201	-285.3				
300	6180	-33.1	**-3417**	0.1			**-2678**	-0.6	**-3419**	0.1
					3443	1290.3				
250	10880	-42.1	29	0.5			**2022**	0.5	26	0.4

DMA results						
P	Variable	New value	Correction	Decision	Type	Scan
500	Z	5823	-2437	1	3	1
400	Z	7517	2227	1	3	1
300	Z	9598	3418	1	3	1

The accuracy may be worse with a larger number of errors, as in Example 44, where all eight reported values, four heights and four temperatures, were corrected by the DMA. Two CQCHT scans were needed to do this. On the first scan, two Type 3 errors at intermediate levels, 500 and 400 HPa, were hydrostatically suspected, which resulted in correction of all four values at these levels. Using these corrected values at the second scan, the hydrostatic check suspected errors at the lower and upper levels (among those reported), i.e., Type 4 and 5 errors, and that led to correction of four remaining values.

Example 44
"Shift errors", all data corrected by two scans

ID: 42867 LAT: 21.10 LON: 79.05 TIME: 92/07/08/12

SCAN 1

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	-	-	-	-	-	-	-	-	-	-
850	-	-	-	-	-	-	-			
700	2	2	2	1	2	2	0			
500	2	2	2	2	2	2	3			
400	2	2	2	0	2	2	3			
300	2	2	2	2	2	2	0			

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
700	1460	30.2	-1634	17.7			-254	13.9	-1645	20.1
					-1231	-249.9				
500	3143	15.2	-2685	18.0			-1445	11.3	-2688	18.5
					933	285.6				
400	5910	0.2	-1655	13.6			151	5.3	-1636	14.7
					-501	-119.0				
300	7670	-9.5	-2025	17.9			-1140	14.7	-2009	19.9

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
500	T	-5.0	-20.2	1	3	1
500	Z	5829	2686	1	3	1
400	T	-10.9	-11.1	1	3	1
400	Z	7555	1645	1	3	1

SCAN 2

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	-	-	-
850	-	-	-	-	-	-	-			
700	2	2	2	2	2	2	4			
500	0	0	2	1	0	0	0			
400	0	0	2	0	0	0	0			
300	2	2	2	2	2	2	5			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	1460	30.2	**-1634**	**17.7**			**-1634**	**18.2**	**-1645**	**20.1**
					1555	**315.7**				
500	5829	-5.0	1	-2.2			**548**	**-6.0**	-2	-1.7
					-6	-1.9				
400	7555	-10.9	-10	2.5			**705**	**-0.6**	9	3.6
					-2099	**-498.6**				
300	7670	-9.5	**-2025**	**17.9**			**-2020**	**17.3**	**-2009**	**19.9**

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
500	T	-5.0	-20.2	1	3	1
500	Z	5829	2686	1	3	1
400	T	-10.9	-11.1	1	3	1
400	Z	7555	1645	1	3	1
700	T	10.4	-19.7	1	4	2
700	Z	3101	1641	1	4	2
300	T	-29.2	-19.7	1	5	2
300	Z	9670	2000	1	5	2

It is not difficult to realize what happened most probably to this report. There actually were errors not in height or temperature, but in pressure values. They were shifted by one mandatory level upwards: 850 HPa data were reported as 700 HPa ones, 700 as 500, and so on. Using this explanation, one can compare automatically corrected values of height and temperature at 700, 500 and 400 HPa with those in the report shifted back to correct levels, and thus to evaluate the accuracy of corrections. Not unexpectedly, the accuracy is comparatively low, particularly for height corrections.

It is desirable therefore that every case with multiple CQCHT corrections (such cases are very rare; there are usually not more than 1 or 2 of them per main observation time) be investigated by a specialist in an attempt to realize what has actually happened and to make better corrections. This human help is particularly important in cases when the CQCHT could not, due to one or another reason, make all necessary corrections of non-isolated errors, like those in Example 45. This, again, was a shifting error, with 700

HPa data repeating 850 HPa ones. The CQCHT DMA corrected only a small part of errors and proposed therefore to reject all other erroneous data. The specialist's help would allow the whole report to be preserved instead of rejecting most of it.

Example 45
"Repshift" error, only small part corrected

ID: 51243 LAT: 45.60 LON: 84.85 TIME:92/07/13/12

SCAN 1

PRES	IINC Z	IINC T	IVOI Z	IVOI T	IHOI Z	IHOI T	IHSC	IBAS	IIPL	IHPL
1000	-	-	-	-	-	-	-	2	2	2
850	0	0	2	0	0	0	102			
700	2	2	2	1	2	2	3			
500	2	2	2	1	2	2	3			
400	2	1	2	0	2	1	3			
300	2	2	2	1	2	2	1			
250	-	1	-	0	-	1	0			
200	2	1	0	0	2	1	1			
150	2	1	2	0	2	0	3			
100	2	0	2	0	2	0	0			

FULL VALUES Ps	Zs	SURF PRESSURE INCR	HORRES	BASELINE CHECK RESIDUALS inPs	inZs	inZ1	inZ2
960.0	426	**781.5**	**781.6**	**110.0**	**-1090**	**662**	**-1688**

P	Observ Z	Observ T	Increment Z	Increment T	Hydrost inZ	Hydrost inT	Vertical Z	Vertical T	Horizont Z	Horizont T
850	1516	25.0	9	0.9			955	-3.6	2	0.9
					-1694	-596.3				
700	1516	25.0	-1637	14.4			-777	11.4	-1655	14.7
					-1202	-244.0				
500	3175	9.6	-2686	15.9			-1438	10.8	-2720	15.1
					931	285.1				
400	5890	-9.7	-1672	10.0			143	2.9	-1710	9.5
					-437	-113.3				
300	7590	-19.5	-2049	14.7			-898	10.2	-2093	13.4
					-	-				
250	-	-32.7	-	9.0			-	2.7	-	7.9
					463	78.0				
200	10940	-40.3	-1438	8.7			-40	4.6	-1504	7.4
					-428	-101.6				
150	12440	-48.1	-1789	8.9			-402	6.0	-1865	7.6
					-765	-128.9				
100	14300	-55.9	-2452	6.5			-1583	4.9	-2535	5.8

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
850	Z	1516	0	5	102	1
700	T	5.4	-19.6	1	3	1
700	Z	3162	1646	1	3	1
300	Z	7590	0	3	1	1
200	Z	10940	0	3	1	1

SCAN 2

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	1	0	0
850	0	0	0	0	0	0	0			
700	0	0	2	1	0	0	0			
500	2	2	2	2	2	2	3			
400	2	1	2	0	2	1	3			
300	2	2	2	1	2	2	1			
250	-	1	-	0	-	1	0			
200	2	1	0	0	2	1	1			
150	2	1	2	0	2	1	3			
100	2	0	2	0	2	0	0			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
960.0	426	-3.5	-2.9	-2.9	-27	16	-42

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	3162	5.4	9	0.9			869	-8.2	-9	-4.9
					-2751	-558.7				
500	3175	9.6	-2686	15.9			-1985	14.2	-2720	15.1
					931	285.1				
400	5890	-9.7	-1672	10.0			143	2.9	-1710	9.2
					-477	-113.3				
300	7590	-19.5	-2049	14.7			-898	10.2	-2093	13.4
					-	-				
250	-	-32.7	-	9.0			-	2.7	-	7.9
					463	78.0				
200	10940	-40.3	-1438	8.7			-40	4.6	-1504	7.4
					-428	-101.6				
150	12440	-48.1	-1789	8.9			-402	6.0	-1865	7.6
					-765	-128.9				
100	14300	-55.9	-2452	6.5			-1583	4.9	-2535	5.8

DMA results

P	Variable	New value	Correction	Decision	Type	Scan
850	Z	1516	0	5	102	1
700	T	5.4	-19.6	1	3	1
700	Z	3163	1646	1	3	1
300	Z	7590	0	3	1	1
200	Z	10940	0	3	1	1
500	T	9.6	0	3	3	2
500	Z	3175	0	4	3	2

400	T	-9.7	0	3	3	2
400	Z	5890	0	4	3	2
300	T	-19.5	0	3	1	2
300	Z	7590	0	4	1	2
250	T	-32.6	0	3	0	2
200	T	-40.3	0	3	1	2
200	Z	10940	0	4	1	2
150	T	-48.1	0	3	3	2
150	Z	12440	0	4	3	2
100	Z	14330	0	4	0	2

Unfortunately, this aim is not always achievable. It is sometimes very difficult, if not impossible, to diagnose the origin of multiple non-isolated errors in a report. Example 46 provides a good illustration of such rare event. It is absolutely clear that all reported temperatures at 300 HPa and above are completely wrong, and so are the heights at 250 HPa and above. It is, however, unclear what has caused these errors. The DMA succeeded in correcting all 9 erroneous values, 7 by the first scan and remaining 2 by the second scan. As long as the cause of all these errors can not be understood, it is impossible to decide whether it would be better just to reject the upper part of this report (as any other QC method would do) instead of correcting it.

Example 46
"Successfully" corrected trash

ID: 68512 LAT: -29.67 LON: 17.87 TIME: 92/05/03/00

SCAN 1

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	-	-	-	-	-	-	-	0	0	0
850	0	0	0	0	0	0	0			
700	0	0	0	0	0	0	0			
500	0	0	0	0	0	0	0			
400	0	0	0	1	0	0	0			
300	0	2	2	2	0	2	3			
250	2	2	2	2	2	2	3			
200	2	2	2	2	2	2	3			
150	2	2	2	2	2	2	3			
100	2	2	2	2	2	2	0			

```
  P     Observ      Increment    Hydrost    Vertical    Horizont
        Z    T       Z     T    inZ   inT    Z      T     Z     T
 400  7440 -22.9     18   -1.3                5   -9.0    21  -0.3
                             -164  -38.9
 300  9500   0.0     11   37.8              185   26.2    22  38.4
                             -640 -239.8
 250 10300  -6.7   -421   39.9            -3273   16.8  -403  41.4
                             7867 2409.0
 200 19920  -2.9   7751   52.4             5992   29.0  7778  53.5
                            -2786 -661.8
 150 19430   2.0   5463   65.2             1545   41.8  5496  65.5
                            -3996 -673.4
 100 18740   8.8   2331   75.9             -323   64.2  2357  75.9
```

```
  DMA results
   P  Variable New value Correction Decision    Type  Scan

 300      T        -40.1      -40.1        1        3     1
 250      T        -46.2      -39.5        1        3     1
 250      Z      10712        412          1        3     1
 200      T        -52.8      -49.9        1        3     1
 200      Z      12155      -7765          1        3     1
 150      T        -62.3      -64.3        1        3     1
 150      Z      13940      -5490          1        3     1
```

```
SCAN 2
PRES   IINC   IVOI   IHOI   IHSC   IBAS   IIPL   IHPL
       Z  T   Z  T   Z  T
1000   -  -   -  -   -  -     -      0      0      0
 850   0  0   0  0   0  0     0
 700   0  0   0  0   0  0     0
 500   0  0   0  0   0  0     0
 400   0  0   0  0   0  0     0
 300   0  0   0  0   0  0     0
 250   0  0   0  0   0  0     0
 200   0  0   0  0   0  0     0
 150   0  0   2  1   0  0     0
 100   2  2   2  2   2  2     5
```

```
  P     Observ      Increment    Hydrost    Vertical    Horizont
        Z    T       Z     T    inZ   inT    Z      T     Z     T
 150 13940 -62.3    -23    0.9             -783  -11.5     6   1.2
                             1876  316.1
 100 18740   8.8   2331   75.9             2344   75.8  2357  75.9
```

```
 DMA results
  P  Variable New value Correction Decision    Type  Scan
 300      T        -40.1      -40.1        1        3     1
 250      T        -46.2      -39.5        1        3     1
 250      Z      10712        412          1        3     1
 200      T        -52.8      -49.9        1        3     1
 200      Z      12155      -7765          1        3     1
 150      T        -62.3      -64.3        1        3     1
```

150	Z	13940	-5490	1	3	1
100	T	-68.1	-76.9	1	5	2
100	Z	16401	-2339	1	5	2

This kind of "over-work", or "over-productivity" of the CQCHT DMA is inevitable, just because the main aim of the DMA is to detect and correct all confidently correctable errors. The CQCHT DMA never tries, unlike some other QC methods, to "invent" any missing data, and that is, of course, very good. If, however, the DMA detects errors, suspected by hydrostatic and/or baseline check, it always tries to correct the erroneous data. It does so even with very short reports (Example 47) and with reports having many missing data (Example 48). Nothing can be said against an overwhelming majority of corrections made by the DMA. It happens, however, though very seldom, that the erroneous data, corrected by the DMA, have no meaning at all, as, most probably, in examples 46-48. In such cases, the DMA actions do not essentially differ from the restoration of missing data, and one may prefer to reject meaningless information instead of correcting it. The above-mentioned human assistance in cases with multiple non-isolated errors may help to solve this problem as well. It is necessary, however, to understand that it is practically never harmful just to accept the corrections of meaningless data performed by the CQCHT DMA.

Example 47
Multiple corrections of a short report by Scan 1

ID: 91334 LAT: 7.47 LON: 151.85 TIME: 92/06/09/12

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IHPL
	Z	T	Z	T	Z	T				
1000	0	0	0	2	0	0	100	2	2	2
850	1	2	2	2	2	2	3			
700	2	1	2	2	2	1	5			

FULL VALUES		SURF PRESSURE		BASELINE CHECK RESIDUALS			
Ps	Zs	INCR	HORRES	inPs	inZs	inZ1	inZ2
1090.0	3	**82.1**	**82.0**	**80.4**	725	-470	1335

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
1000	93	26.5	20	-4.8			**-42**	**32.4**	20	-4.8
					-94	**-39.6**				
850	1594	98.0	**105**	**78.7**			**157**	**83.1**	**105**	**78.7**
					-456	**-160.1**				
700	2969	0.0	**-159**	**-11.6**			**-220**	**-36.4**	**-160**	**-11.7**

DMA results						
P	Variable	New value	Correction	Decision	Type	Scan
1000	PS	1008.5	-81.5	1	100	1
850	T	18.3	-79.7	1	3	1
850	Z	1494	-100	1	3	1
700	T	10.0	10.0	1	5	1
700	Z	3130	161	1	5	1

Example 48

Successful multiple corrections by scan 1 in spite of all data holes

ID: 48042 LAT: 21.98 LON: 96.10 TIME: 92/05/07/00

PRES	IINC		IVOI		IHOI		IHSC	IBAS	IIPL	IJPL
	Z	T	Z	T	Z	T				
1000	0	-	0	-	1	-	-	-	-	-
850	-	-	-	-	-	-	-			
700	0	0	0	1	0	0	0			
500	0	2	2	2	0	2	3			
400	-	-	-	-	-	-	-			
300	2	2	2	2	2	2	3			
250	2	2	2	2	2	2	3			
200	-	-	-	-	-	-	-			
150	-	-	-	-	-	-	-			
100	0	0	2	0	0	0	14			

P	Observ		Increment		Hydrost		Vertical		Horizont	
	Z	T	Z	T	inZ	inT	Z	T	Z	T
700	3108	8.4	-13	-1.5			-1	**-8.5**	-16	0.9
					-153	**-31.0**				
500	5820	27.0	2	**33.2**			**-1248**	**26.2**	6	**32.6**
					3472	**464.4**				
300	13780	27.0	**4124**	**56.8**			**4400**	**35.4**	**4136**	**56.4**
					-5001	******				
250	10350	15.4	**-573**	**56.4**			**-2979**	**37.8**	606	**55.6**
					-200	**-14.9**				
100	16630	-78.5	52	-3.2			**244**	-7.8	-16	-3.2

DMA results						
P	Variable	New value	Correction	Decision	Type	Scan
500	T	-7.8	-34.8	1	3	1
300	T	-29.5	-56.5	1	3	1
300	Z	9649	-4131	1	3	1
250	T	-45.6	-61.0	1	3	1
250	Z	10939	589	1	3	1
100	T	-78.5	0.0	3	14	1
100	Z	16630	0	3	14	1

9. Summary and Conclusions

Table 9.1 contains some statistics on the CQCHT performance obtained in the course of its quasi-operational monitoring in August 1992 by the authors. The numbers of reports in the Table are those averaged over 54 main observation times and rounded to closest integers. In order to compare the CQCHT performance with that of the "old" code (CHQC), we also computed analogous statistics for it, as if it were applied to the same data. These statistics are presented in the lower part of the Table.

Table 9.1

Statistics of CQCHT performance in August 1992
(numbers of reports per main observation time)

	Hydro-static	Base-line	Hole	Obser-vation
Suspected	50	8	7	22
Completely corrected	41	5	1	0
Partly rehabilitated	4	0	0	0
Rehabilitated	5	0	6	0
Passed to MOD	9	3	7	22
CHQC would: suspect	50	6	7	0
correct	27	0	0	0
pass to MOD	23	0	0	0

Among the four categories of errors, those detectable by the hydrostatic check happen most often: there are about 50 such reports, on average, per observation time, which amounts to more than 7% of all arriving reports. The old code would be able to correct 54% of these reports, providing MOD specialists with information about remaining cases and requesting their help. As a rule, it would be easy for a specialist to decide what should be done in each such case. In contrast to that, the CQCHT DMA treats all cases with hydrostatic suspicions. In 82% of these cases, its corrected error type is in complete agreement with the hydrostatic suspicion, while in remaining 18% of them it decides either to rehabilitate one of two suspected values, or to make no correction at all. All these decisions are made entirely automatically, and only information about reports with decisions including rehabilitation is put into the MOD file. The average number of such reports, 9, is much less than 23 reports sent by the CHQC.

As to the errors detectable and correctable with the aid of the baseline check, the CHQC detected many of them but was unable to univaluedly determine the error origin and, thus, to correct any of such errors. The CQCHT DMA automatically corrects a majority of these errors, providing the MOD specialists with information about the remaining, unindentified cases.

The situation with data holes is analogous to that just described. The CHQC just detected all of them. In contrast to that, the CQCHT investigates, for each data hole, whether there is any communication-related error at its lower and/or upper boundary, and corrects every diagnosed error. The result is most often negative, but the CQCHT DMA passes its information about each data hole to MOD, because the sensitivity of the hydrostatic check over a hole is low and because there may be a computational error in its thickness.

Errors of the last group, the observational ones, could not even be detected by the CHQC, only the CQCHT does it. Table 9.1 shows that a comparatively large number of reports are distorted by observational errors. One has to take into account, however, that such errors have a strongly uneven geographical distribution: as illustrated by Table 9.2, an overwhelming majority of them occur over the Indian Subcontinent (WMO Blocks 42 and 43). It is impossible to correct any of these errors, and the CQCHT DMA flags such data either for rejection from the data assimilation set or for assimilation with diminished weight. At the same time, all information about detected observational errors is given to MOD, so that a specialist may override the DMA decision as to which particular data in every such report should be rejected and which should remain.

One may see from this comparison that the CQCHT is substantially more productive than the "old" CHQC was: it automatically corrects about twice as many errors, and it additionally detects many other errors. The main CQCHT advantage is, however, different: while the CHQC DMA is unable, without human help, to correct up to 50% of errors detected by it, the CQCHT DMA performs almost entirely automatically (with an exception for small number of unidentified errors suspected with the aid of the baseline check). It thus makes redundant any subjective quality control of rawinsonde height and temperature, unless the CQCHT results indicate the desirability of human help.

Table 9.2

Statistics of CQCHT-detected rawinsonde observation errors in height and temperature of mandatory isobaric surfaces

Absolute numbers (N) of observational errors per main observation time over different regions, averaged over 50 observation times in December 1991, and their ratios to the overall number of reports with observational errors (r_1 in %) and to mean numbers of all reports over the region (r_2 in %)

Region	WMO Blocks	N	r_1	r_2
Western and Central Europe	01-17	0.8	4.4	0.9
CIS (former USSR)	20-38	3.4	18.8	2.3
Indian Subcontinent	42-43	7.0	38.7	30.0
China	50-59	2.1	11.6	1.9
Other regions of Asia	40-41, 44-48	1.1	6.0	1.8
Africa	60-68	0.8	4.4	2.7
North America	70-74	0.9	5.0	0.7
Central America	76,78	0.5	2.8	3.3
South America and Antarctica	80-89	0.6	3.3	2.6
Pacific Islands, Australia and New Zealand	91-98	0.9	5.0	1.7

At the same time, the CQCHT algorithm produces plenty of information essential for the MOD specialists. The CQCHT DMA automatically produces such information, and it is up to the MOD specialists how to use it in the best possible way.

We hope very much that the situation in that respect will substantially improve when the Interactive Quality Control (IQC) software, designed recently by Jack Woollen, becomes operational. Undoubtedly, this will bring the quality control at NMC, and particularly the MMM actions, to a new, much higher level. In order to perform this rather difficult and interesting work on a sufficiently high level, the MOD specialists have to achieve, with the aid of this Office Note and other training, the necessary understanding of the Complex Quality Control of rawinsonde data on Height and Temperature.

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Appendix A. Baseline Error Conditions and Corrections, Constants, Notation Dictionary

The Appendices use notation taken directly from the CQCHT code. For their easier understanding, a Notation Dictionary is introduced here.

A.1 Notation Dictionary

Some terms are used, with different endings to the spelling, for the variables z or T and for different levels or layers. The notation convention for those cases is to put the various choices in parentheses.

baseline(in z_1, in p_s)	baseline residual in terms of (lowest mandatory level height, surface pressure)
BASRES	normalizing constant for baseline residual
CHQC	Complex Hydrostatic Quality Control
CORECT	subroutine to perform corrections, main subroutine of DMA
CORRECTION	difference between NEW-VALUE and VALUE
CQCHT	Complex Quality Control of Heights and Temperatures
DMA	Decision Making Algorithm
DOZ	vertical deviation of height increment
DTALL	RMS hydrostatic residual, in terms of temperature, when there are no hydrostatic errors
HINCPS	horizontal residual of surface pressure
HOIRES	vector of values: limiting absolute values for height and temperature horizontal residuals
hor (z,T)	horizontal residual of (z,T)
hor p_{msl}	horizontal residual of surface pressure reduced to mean-sea level
HSCRES	vector of values: limiting absolute values for height and temperature hydrostatic residuals
hyres	hydrostatic residual
HYRES (HEIGHT,TEMP) or Hydrost (in z, in T)	hydrostatic residual in terms of (height, temperature)
IBAS	indicator for baseline residual
IHOI(,Z,T)(2,3)	indicator for horizontal check residual for (,z,T) at levels (k+1,k+2)

IHPL	indicator for mean-sea-level horizontal check residual
IHSC	indicator for hydrostatic residual
IHSC(1,2,3)	indicator for hydrostatic residual for layers (k-1 to k,k to k+1,k+1 to k+2)
IINC(,Z,T)(,2,3)	indicator for increment for (,z,T) at level (k,k,k+1)
IIPL	indicator for mean-sea-level increment
inc(z,T)	observed increment of (z,T)
inc p_{msl}	increment of surface pressure reduced to mean-sea level
IVOI(,Z,T)(2,3)	indicator for vertical check residual for (,z,T) at levels (k+1,k+2)
lev	integer referring to mandatory level
MOD	Meteorological Operations Division
NEW-VALUE	modified values of listed values, each modification making, by itself, the baseline residual equal to zero
OINCPS	observed increment of surface pressure
PRESSURE, PRES, P	mandatory level pressure
PS	surface pressure
PSCOR	surface pressure correction implied by baseline residual
PSRES	normalizing constant for surface pressure indicators
TCLIM	correction limit for absolute value of temperature corrections
TCMIN	used in testing temperature corrections
TSTCOR	subroutine to test proposed corrections
VALUE	reported values
vert(z,T)	vertical residual of (z,T)
VOIRES	vector of values: limiting absolute values for height and temperature vertical residuals
XINC	vector of values: limiting absolute values for height and temperature increments
Z1, Z2	first and second reported mandatory surface heights
ZCLIM1	correction limit for absolute value of height corrections at 1000, 850, and 700 HPa
ZCLIM2	correction limit for absolute value of height corrections at 500 HPa and above
ZCMIN	multiples are used in testing of height corrections
ZS	station elevation above sea level
ZZCOR	height correction

The conditions for diagnosis of each baseline error type and the corrections will be given in this Appendix. The information is given in compact form, so that explanation of the notation used is needed. The notation, max(a,b), has the value of the maximum of a and b, |a| means the absolute value of a, and avg(a,b,...) has the value of the average of the values listed in parentheses.

Whenever a Type 106, 100, 101, or 116 error is diagnosed, a correction is made. Therefore, the existence and magnitude conditions are combined.

A.2 Constants for error determination

There are empirical constants that are used for determination of baseline and other errors. They are collected here for easy reference. Wherever possible, SI units are used (m,kg,s,A,K).

AA = 0.3 DTALL = $\bar{t}_{all}$ = 3.5K ECON1 = 0.25 ECON2 = 0.20

ZCLIM1 = 30m ZCLIM2 = 85m TCLIM = 10K

ZCMIN = 8m TCMIN = 5K BASRES = 40m PSRES = 8HPa

Some physical constants are also used.

$R = 287.05\ \mathrm{J\ kg^{-1}\ K^{-1}}$ $g = 9.80665\ \mathrm{m\ s^{-2}}$ $T_0 = 273.15\ \mathrm{K}$

Values of XINC:

pressure (HPa)	for z (m)	for T (K)
1000	160	17
850	120	17
700	120	13
500	130	11
400	160	11
300	180	12
250	190	13
200	210	15
150	210	17
100	210	17
70	210	17
50	210	17
30	210	17
20	210	17
10	210	17

Values of HOIRES:

pressure (HPa)	for z (m)	for T (K)
1000	120	17
850	90	15
700	90	13
500	130	10
400	150	11
300	180	12
250	190	12
200	210	12
150	210	11
100	210	14
70	210	15
50	210	17
30	210	17
20	210	17
10	210	17

Values of VOIRES:

pressure (HPa)	for z (m)	for T (K)
1000	120	17
850	70	17
700	60	14
500	70	11
400	80	11
300	90	11
250	90	12
200	90	15
150	120	16
100	180	17
70	210	17
50	210	17
30	210	17
20	210	17
10	210	17

Values of HSCRES:

pressure (HPa)	HSCRES (m)
1000-850	65
850-700	65
700-500	35
500-400	50
400-300	35
300-250	40
250-200	35
200-150	40
150-100	50
100-70	85
70-50	70
50-30	70
30-20	80
20-10	70

A.3 Type 106 Error--Surface Pressure Measurement Error

Existence/magnitude conditions:

5 $|i_{k-1}|/XINC_{k-1} \geq 2$ where i_{k-1} is the height increment

11 $|DOZ_k|/XINC_{k-1} < 2$, where DOZ is the vertical deviation of height

11 $|i_{k-1} - i_k|/(XINC_{k-1} + XINC_k) < 2$

$2|p_s^c|/PSRES < 1$

$2|s_{k,k+1}|/HSCRES_{k-1} < 2$

Surface pressure $\neq 0$ (reported value non-zero)

$|i_{ps}| > PSRES$ or $|s^h_{ps}| > PSRES$, where $|i_{ps}|$ is the surface pressure increment and $|s^h_{ps}|$ is the surface pressure horizontal residual

Corrections:

$PSCOR = avg(i_{ps}, s^h_{ps})$ is the surface pressure correction

$ZZCOR_{k-1} = (R/g)(T_k + T_0) \ln[(p_s + PSCOR)/p_s]$ is the correction to all heights

A.4 Type 100 Error--Surface Pressure Communication Error

Existence/magnitude conditions:

$|i_{ps}| > 6$ or $|s^h_{ps}| > 6$ (units are HPa)

$2|i_{ps} + PSCOR|/PSRES < 2$

$2|s^h_{ps} + PSCOR|/PSRES < 2$

$|DOZ_k/z_1^c| < 0.4$

Correction to surface pressure:

$PSCOR = avg(-i_{ps}, -s^h_{ps}, p_s^c)$

A.5 Type 101 Error--Communication Error in Lowest Mandatory Level Height with Missing Temperature

Existence/magnitude conditions:

$$\left|\frac{z_1^c + DOZ_k}{z_1^c - DOZ_k}\right| < \max(1.2\times10^{-4}\, z_s + .02\, ,\, .08)$$

hydrostatic error type = 0

T_k is missing

$5|i_{k-1}|/XINC_{k-1} \geq 2$, where i_{k-1} is the increment of z

height correction:

$ZZCOR_k = avg(DOZ_k, z_1^c)$

A.6 Type 116 Error--Computational Error in the Height of the Lowest Mandatory Level.

Existence/magnitude conditions:

IIPL = 0 (surface pressure increment small)

IHPL = 0 (surface pressure horizontal residual small)

IHSC = 0

$$\frac{11|i_{k-1} - i_k|}{XINC_{k-1} + XINC_k} < 1$$, where i_k is the height increment

$$\frac{4|i_k + z_1^c|}{XINC_{k-1} + XINC_k} < 1$$

$5|i_k|/XINC_{k-1} \geq 2$

Height correction:

$ZZCOR_k = s^b$

A.7 Type 102 Error--Undetermined Baseline Error

A Type 102 error is diagnosed when one of the baseline check quantities is large, but no other type is satisfied. The variable that likely has a problem is identified. No correction is possible.

lowest height likely bad:

IBAS = 2 baseline residual large

IHSC = 0 (original diagnosis of Type 0)

$z_s < 1000$m

surface pressure likely bad:

IIPL = 2 and/or IHPL = 2 surface pressure increment and/or surface pressure residual large

IHSC = 0 (original diagnosis of Type 0)

$z_s < 850$m

Appendix B. Details of Decisions and Criteria for Hydrostatically Detected Errors

This Appendix will consider the details of the criteria for determining the acceptability of a correction (decision = 1). It will also give the criteria for other decisions: = 4 for bad data, uncorrected, =3 for likely bad data, and =2 for good data. The general strategy of dealing with each error type is given in section 6.

B.1 Type 1 Errors--Communication Error in Mandatory Level Height

Normalized sums of increment and residuals are defined before and after correction. These will be used to test the acceptability of a correction. In all cases, the sums include terms for data that are not missing. For the available checks

$B = b^i + b^h + b^v$ sums of normalized increment, residuals before correction

$A = a^i + a^h + a^v$ sums of normalized increment, residuals after correction

$r = B/A$

where

$$b^i = \left(\frac{1}{ECON1}\right)\left(\frac{i}{XINC_k\left|\frac{7i}{XINC_k}\right|^{AA}}\right), \quad a^i = \left(\frac{1}{ECON2}\right)\left(\frac{i + ZZCOR_k}{XINC_k\left|\frac{7i}{XINC_k}\right|^{AA}}\right).$$

where i is the height increment. If available, the vertical deviation of the height increment replaces the increment. See A.1 for values of the constants.

$$b^h = \left(\frac{1}{ECON1}\right)\left(\frac{s^h}{HOIRES_k\left|\frac{7s^h}{HOIRES_k}\right|^{AA}}\right), \quad a^h = \left(\frac{1}{ECON2}\right)\left(\frac{s^h + ZZCOR_k}{HOIRES_k\left|\frac{7s^h}{HOIRES_k}\right|^{AA}}\right)$$

where s^h is the horizontal height residual. Again, the vertical deviation of s^h replaces s^h if available.

$$b^v = \left(\frac{1}{ECON1}\right)\left(\frac{s^v}{VOIRES_k\left|\frac{7s^v}{VOIRES_k}\right|^{AA}}\right), \quad a^v = \left(\frac{1}{ECON2}\right)\left(\frac{s^v + ZZCOR_k}{VOIRES_k\left|\frac{7s^v}{VOIRES_k}\right|^{AA}}\right)$$

where s^v is the vertical height residual.

For the lowest level, check the agreement of the proposed correction with z_1^c:

$|z_1^c - ZZCOR_k| \leq ECON2 * XINC_k$ is required in addition to conditions listed below.

At all levels, the following is required for correction (decision = 1). (Here and for other error types, the conditions are listed in several lines. This is used to signify that all the conditions must be satisfied, unless the word "or" is specifically used.)

Number of available checks, n, is at least 1.

$B > n$

$A < n$ or ($r > 3$ and $A < 1.5n$)

Datum is marked as bad (decision = 4) if

not decision 1

$n \geq 1$

$B > n$

scan > 1

Datum is marked as doubtful (decision = 3) if

not decision 1 or 4

$n \geq 1$

$B > 0.5n$

Otherwise, mark datum as all right (decision = 2).

B.2 Type 2 Errors--Communication Error in Mandatory Level Temperature

Section 6.3.2 describes in a general way how temperature errors are determined. The specific criteria will be described here. One characteristic error for temperature is a sign error, and it is tested for specifically. The basic idea is to test what would be the lapse rate under the assumption of a sign error. Some quantities are defined:

$\lambda_0 = -g/c_p$ dry adiabatic lapse rate

Using the reported temperatures and heights--

$\lambda^- = (T_k - T_{k-1})/(z_k - z_{k-1})$ $\lambda^+ = (T_{k+1} - T_k)/(z_{k+1} - z_k)$

Under the assumption of a sign error, the correct lapse rates are--

$\lambda^{s-} = (-T_k - T_{k-1})/(z_k - z_{k-1})$ $\lambda^{s+} = (T_{k+1} + T_k)/(z_{k+1} - z_k)$

In checking, the absolute value of the difference of these lapse rates from the dry adiabatic lapse rate is used. These differences are defined as--

$\delta^- = |\lambda^- - \lambda_0|$ $\delta^{s-} = |\lambda^{s-} - \lambda_0|$

$\delta^+ = |\lambda^+ - \lambda_0|$ $\delta^{s+} = |\lambda^{s+} - \lambda_0|$

A sign correction is accepted if

$|2T_k + TTCOR_k| < 5K$

$\lambda^{s-} \geq 1.1\lambda_0$ or $\lambda^{s-} < \delta^-$

$\lambda^{s+} \geq 1.1\lambda_0$ or $\lambda^{s+} < \delta^+$

If a sign correction is not acceptable, then the proposed temperature correction is rounded to the nearest 0.1 degree and a simple correction is found. The criteria for acceptance are similar to those for a Type 1 correction. Normalized sums of the increment and residuals are defined for before and after the correction.

$B = b^i + b^h + b^v$ sums of normalized increment, residuals before correction

$A = a^i + a^h + a^v$ sums of normalized increment, residuals after correction

$r = B/A$

where

$$b^i = \left(\frac{1}{ECON1}\right)\left(\frac{i}{XINC_k\left|\dfrac{7i}{XINC_k}\right|^{AA}}\right), \quad a^i = \left(\frac{1}{ECON2}\right)\left(\frac{i + ZZCOR_k}{XINC_k\left|\dfrac{7i}{XINC_k}\right|^{AA}}\right)$$

where i is the temperature increment. For temperature, the vertical deviation never replaces the increment.

$$b^h = \left(\frac{1}{ECON1}\right)\left(\frac{s^h}{HOIRES_k\left|\dfrac{7s^h}{HOIRES_k}\right|^{AA}}\right), \quad a^h = \left(\frac{1}{ECON2}\right)\left(\frac{s^h + ZZCOR_k}{HOIRES_k\left|\dfrac{7s^h}{HOIRES_k}\right|^{AA}}\right)$$

where s^h is the horizontal temperature residual.

$$b^v = \left(\frac{1}{ECON1}\right)\left(\frac{s^v}{VOIRES_k\left|\dfrac{7s^v}{VOIRES_k}\right|^{AA}}\right), \quad a^v = \left(\frac{1}{ECON2}\right)\left(\frac{s^v + ZZCOR_k}{VOIRES_k\left|\dfrac{7s^v}{VOIRES_k}\right|^{AA}}\right)$$

where s^v is the vertical temperature residual.

The proposed correction is accepted if (decision =1) the number of available checks, n, is at least 1

$B > n$

$A < n$ or $(R > 3$ and $A < 1.5n)$

The decision = 4 if

decision not 1

$n \geq 1$

$B > n$

scan > 1

The decision = 3 if

decision is not 1 or 4

$n \geq 1$

$B > 0.5n$

Otherwise, the decision = 2.

B.3 Type 3 Error--Communication Errors to Both Height and Temperature at the Same Mandatory Level

Details of the decisions for a Type 3 correction follow. First, TSTCOR is called for height at level k, returning IHSC1, IHSC2, IHSC3, IINCZ2, IINCZ3, IHOIZ2, IHOIZ3, IVOIZ2, and IVOIZ3. (See Appendix C for the details of TSTCOR. The returned values have a range of 0, 1, or 2. They are returned for the hydrostatic residual for layers (k-1,k), (k,k+1) and (k+1,k+2), for the increments at levels k, k+1, for the horizontal residuals at levels k, k+1, and for the vertical residuals at levels k, k+1.) TSTCOR is also called for temperature at level k, returning IHSC1, IHSC2, IHSC3, IINCT2, IINCT3, IHOIT2, IHOIT3, IVOIT2, and IVOIT3.

The following are used in the decisions:

$IZ = IINCZ2 + IHOIZ2 + IVOIZ2$

$IT = IINCT2 + IHOIT2 + IVOIT2$

$$ZCMIN1 = \begin{cases} 30. & k \le 3 \\ 85. & k > 3 \end{cases}$$

$$ZCMIN2 = 4\bar{t}_{all} B_{k-1,k}$$

The notation min(a,b,...) means that the minimum of (a,b,...) is to be chosen.

ZCMIN = min(ZCMIN1,ZCMIN2) (minimum of values is used)

$$IHSC = \begin{cases} 1 & \text{if adjacent hydrostatic level types} = 0 \\ & \text{and } (IHSC1 = 2 \text{ or } IHSC2 = 2) \\ 0 & \text{otherwise} \end{cases}$$

The decision = 1 for both height and temperature (Type "3=3") if

$IZ < 2$

$|ZZCOR_k| \ge ZCMIN$

$IT < 2$

$|TTCOR_k| \ge 5$

$IHSC = 0$

Make height correction only (Type "3=1") if

previously considered corrections not accepted

$IZ < 2$

$|ZZCOR_k| \ge ZCMIN$

$IHSC = 0$

Make temperature correction only (Type "3=2") if previously considered corrections not accepted

IT < 2

$|TTCOR_k| \geq 5$

IHSC = 0

Otherwise, make no correction.

B.4 Type 6 Error--Computation Error in Thickness

Quantities as they would be after correction are defined and used in the decision process. Define

$DINC1 = i_k - i_{k-1} + ZZCOR_k$

$DINC2 = i_{k+1} - i_k$

$DHOR1 = s^h{}_k - s^h{}_{k-1} + ZZCOR_k$

$DHOR2 = s^h{}_{k+1} - s^h{}_k$

Do not make a correction (set decision = 2) if

$|DINC1| > 0.25\ XINC_k$

or $|DINC2| > 0.25\ XINC_k$

or $|DHOR1| > 0.25\ XINC_k$

or $|DHOR2| > 0.25\ XINC_k$

Otherwise, continue with the checking:

Call TSTCOR for height at level k, returning IHSC1, IHSC2, IHSC3, IINC2, IINC3, IHOI2, IHOI3, IVOI2, IVOI3. (See Appendix C for the details of TSTCOR. The returned values have a range of 0, 1, or 2. They are returned for the hydrostatic residual for layers (k-1,k), (k,k+1) and (k+1,k+2), for the increments at levels k, k+1, for the horizontal residuals at levels k, k+1, and for the vertical residuals at levels k, k+1.)

Define

ISUM = IINC2 + IHOI2 + IVOI2

Corrections are made (decision = 1) if

ISUM < 2

IHSC1 < 2

Otherwise, set decision = 2.

B.5 Error Types 7 to10--Communication Errors at Adjacent Levels

The decision methodology for Types 7 to 10 is nearly identical. They begin by calling TSTCOR for the relevant variables (z for Types 7, 9 and 10, T for Types 8, 9 and 10). Next, define

$$\text{ISUM} = \begin{cases} \left.\begin{array}{ll} \text{IINC2+IHOI2+IVOI2} & \text{at } k \\ \text{IINC3+IHOI3+IVOI3} & \text{at } k+1 \end{array}\right\} \text{for } z \\ \left.\begin{array}{ll} \text{IINC2+IHOI2} & \text{at } k \\ \text{IINC3+IHOI3} & \text{at } k+1 \end{array}\right\} \text{for } T \end{cases}$$

The decisions for levels k and k+1 are:

Decision	level k conditions	level k+1 conditions
1	ISUM < 2	ISUM < 2
	IHSC1 < 2	IHSC2 < 2
	IHSC2 < 2	IHSC3 < 2
3	ISUM < 4	ISUM < 4
	IHSC1 < 2	IHSC2 < 2
	IHSC2 < 2	IHSC3 < 2
4	ISCAN > 1	ISCAN > 1
	(ISUM ≥ 4	(ISUM ≥ 4
	or ISHC1 = 2	or ISHC2 = 2
	or IHSC2 = 2)	or IHSC3 = 2)
2	otherwise	otherwise

Appendix C. Routine to Test Proposed Corrections (TSTCOR)

The routine to test proposed corrections (TSTCOR) is called for each error type except Types 1, 11, 2 and 22. It calculates integers reflecting the size of the increments and residuals after a proposed correction is applied. The steps for calculating these integers, called indicators, is outlined below.

Calculate new increments for all template levels.

Calculate vertical deviations of increments at 2nd and 3rd template levels (k and k+1)

Calculate revised hydrostatic residuals for template layers.

If k is the lowest level, recalculate the baseline quantities.

Perform the horizontal check for the 4 template levels:

- collect data from influencing stations
- form terms of weight equation matrix
- solve equation for residual weights
- calculate the horizontal residual

Calculate the vertical deviations of horizontal residuals at the 2nd and 3rd template levels.

Calculate the new vertical residuals.

Calculate indicators of revised quantities at template levels 2 and 3 (also template layers 1, 2 and 3 for hydrostatic indicators). These indicators have the value 0, 1 or 2 and represent normalized values of the new increments or residuals.

In the following, the notation min(a,b,...) means that the minimum of the values (a,b,...) is to be chosen.

Consider the indicators for the vertical check first. They are

$$IVOI2 = \min(2|s^v_{k,k+1}|/VOIRES_k\ ,\ 2)$$

and

$$IVOI3 = \min(2|s^v_{k+1,k+2}|/VOIRES_{k+1}\ ,\ 2)$$

where s^v is the new vertical residual, VOIRES values are given in A.1, and min(k,l) has an integer value equal to the smaller value of k and l.

The indicators for the increment and horizontal residual consider the deviations in addition to the values. For the increments, the indicators are

$$IINC2 = \min(2|i_{k,k+1}|/f^i\ XINC_{k,}\ ,\ 2|i_{k,k+1}|/d^i\ XINC_k\ ,\ 2)$$

and

$$IINC3 = \min(2|i_{k+1,k+2}|/f^i\ XINC_{k+1,}\ ,\ 2|i_{k+1,k+2}|/d^i\ XINC_{k+1}\ ,\ 2)$$

where i is the new increment, d^i is the deviation for new values of the increment, and the values of XINC are given in A.1. The parameter, f, is included so that the values of the terms are relatively reduced for large values of the new increment. Appropriate variations of f are used also for the horizontal and hydrostatic indicators. It is given by

$$f(x) = 1 + (\log_{10} g(x))^{1.5}$$

with

$$g(x) = \begin{cases} 1 & , |x| < XMAX/2 \\ 2|x|/XMAX, & \text{otherwise} \end{cases}$$

In the use of f above, x = i and XMAX = $XINC_k$. The function is also shown in Fig. C.1 for the range of x = 0 to x = 5 XMAX.

For the horizontal residuals, the indicators are

$$IHOI2 = \min(2|s^h{}_{k,k+1}|/f^h\ HOIRES_{k,}\ ,\ 2|d^h{}_{k,k+1}|/f^h\ HOIRES_k\ ,\ 2)$$

and

$$IHOI3 = \min(2|s^h{}_{k+1,k+2}|/f^h\ HOIRES_{k+1,}\ ,\ 2|d^h{}_{k+1,k+2}|/f^h\ HOIRES_{k+1}\ ,\ 2)$$

where s^h is the new horizontal residual, d^h is the deviation for new values of the horizontal residual, and the values of HOIRES are given in A.1. The values of f^h are calculated with x = s^h and XMAX = HOIRES.

For the hydrostatic residuals, the indicators are calculated for the three template layers. They are given by

$$IHSC1 = \min(2|s_{k-1,k}|/HSCRES_{k-1,k}\ ,\ 2)$$
$$IHSC2 = \min(2|s_{k,k+1}|/HSCRES_{k,k+1}\ ,\ 2)$$
$$IHSC3 = \min(2|s_{k+1,k+2}|/VOIRES_{k+1,k+2}\ ,\ 2)$$

where s are the new hydrostatic residuals and the values of HSCRES are given in C.1. The function f is calculated with x = s and XMAX = $HSCRES_{k,k+1}$.

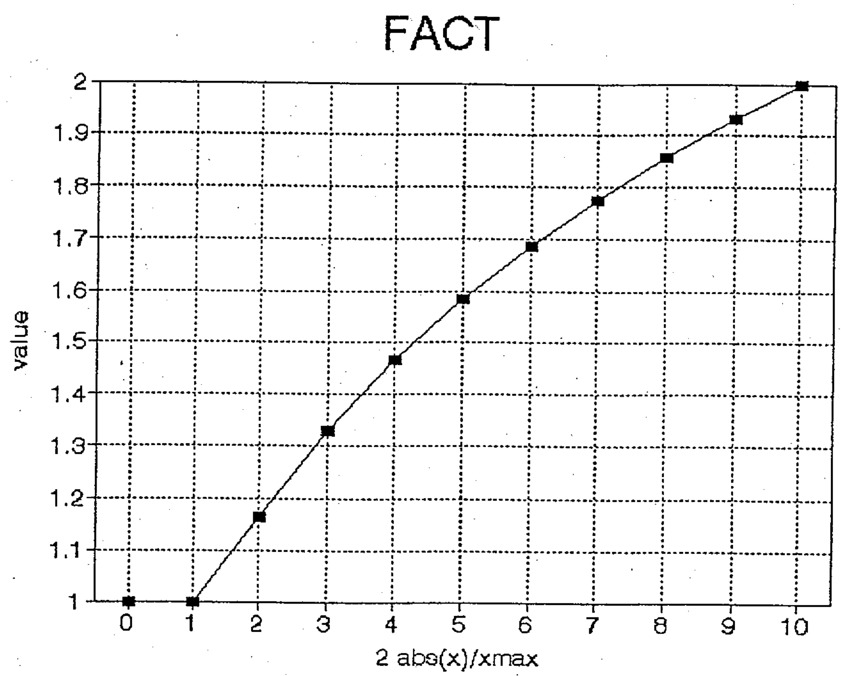

Figure C.1 Parameter f.

Appendix D. Description of Algorithm to Determine Hydrostatic Error Type

This Appendix describes the algorithm to determine the hydrostatic error type (CORECT). The description is in words and pseudo-code.

Set IER = 0.

Define--

$TMIN_k = 2\bar{t}_{all} = 7.0K$ k=1 to NPLVL (NPLVL = 15)

$ZMIN_k = 2\bar{t}_{all}\sqrt{B^2_{k-1,k} + B^2_{k,k+1}}$ k=2 to NPLVL-1

$ZMIN_1 = 1.33\ ZMIN_2$

$ZMIN_{NPLVL} = 1.2\ ZMIN_{NPLVL-1}$

Determine the number of the top complete level (LTOP).

Beginning at the bottom, get 4 levels of data. Two scans through the data are made.

Calculate the hydrostatic residuals, $s_{k-1,k}$ and $s_{k,k+1}$.

Calculate $B_{k-1,k}$ and $B_{k,k+1}$ for the layers, summed across missing data levels.

Calculate the rms hydrostatic residuals, $SBIG_{k-1,k}$ and $SBIG_{k,k+1}$ for the layers.

Test for errors at the top level:

if IER = 0 or k+1 ≥ LTOP then

  if k+1 ≥ 11 and (k+1)-(k) > (k+1)-10 then Type = 13 (hole at top)

    (Remember that k-1, k, k+1, k+2 are indices for levels with both height and temperature not missing. They need not be consecutive.)

  if the number of the level k+1 minus the number of the level k is greater than 2, then Type = 14 (hole at top)

  if ($|s_{k-1,k}| > SBIG_{k-1,k}$ and $|s_{k,k+1}| > 0.7\ SBIG_{k,k+1}$)
   or ($|s_{k-1,k}| > 0.7\ SBIG_{k-1,k}$ and $|s_{k,k+1}| > SBIG_{k,k+1}$)
   and Type = 0 then

    calculate--

    $ZCOR_k = (B_{k-1,k}s_{k,k+1} - B_{k,k+1}s_{k-1,k})/(B_{k-1,k} + B_{k,k+1})$

    $ZCOR_k$ is rounded to nearest meter to 700 HPa and to the nearest 10m above.

$TCOR_k = (s_{k-1,k} + s_{k,k+1})/(B_{k-1,k} + B_{k,k+1})$, rounded to nearest 1/10 degree

$Z2 \equiv 2\bar{t}_{all}\sqrt{B_{k-1,k}^2 + B_{k,k+1}^2}$

$T2 \equiv 2\bar{t}_{all}$

if $|ZCOR_k| > Z2$ or $|TCOR_k| > T2$ then Type = 3 (at top)

elseif $|s_{k,k+1}| > SBIG_{k,k+1}$

and ($|s_{k-1,k}| < 0.75\ SBIG_{k-1,k}$) or ($|s_{k-1,k}/s_{k,k+1}| < 0.33$) then

$ZCOR_{k+1} = s_{k,k+1}$, rounded

$TCOR_{k+1} = s_{k,k+1}/B_{k,k+1}$, rounded

Type = 5

Get third residual, etc.: $s_{k+1,k+2}$, $B_{k+1,k+2}$, $SBIG_{k+1,k+2}$.

Calculate ratios which determine most probable error type.

C = (0.75, 1.0) for scan = (1,2)

Calculated for layers other than the top and bottom are:

$$RZZ = 2C\ \bar{t}_{all}\frac{\sqrt{B_{k-1,k}^2 + B_{k,k+1}^2 + B_{k+1,k+2}^2}}{\left|s_{k-1,k} + s_{k,k+1} + s_{k+1,k+2}\right|}$$ (tests Type 7 existence)

$$RTT = \frac{2\sqrt{3}C\bar{t}_{all}}{\left|X_{k-1,k} - X_{k,k+1} + X_{k+1,k+2}\right|}$$ (tests Type 8 existence)

$$RZT = \frac{2C\bar{t}_{all}\sqrt{B_{k-1,k}^2 + 2B_{k,k+1}^2}}{\left|s_{k-1,k} + s_{k,k+1} - \left(B_{k,k+1} / B_{k+1,k+2}\right)s_{k+1,k+2}\right|}$$ (tests Type 9 existence)

$$RTZ = \frac{2C\bar{t}_{all}\sqrt{B_{k+1,k+2}^2 + 2B_{k,k+1}^2}}{\left|s_{k,k+1} + s_{k+1,k+2} - \left(B_{k,k+1} / B_{k-1,k}\right)s_{k-1,k}\right|}$$ (tests Type 10 existence)

$$RZZM_1 = \frac{\left|s_{k-1,k}\right|}{ZMIN_k},\quad RZZM_2 = \frac{\left|s_{k+1,k+2}\right|}{ZMIN_{k+1}}$$ (tests Type 7 magnitude)

$$RTTM_1 = \frac{\left|s_{k-1,k}\right|}{B_{k-1,k} / TMIN_k},\quad RTTM_2 = \frac{\left|s_{k+1,k+2}\right|}{B_{k+1,k+2} / TMIN_{k+1}}$$ (tests Type 8 magnitude)

$$\text{RZTM}_1 = \frac{|s_{k-1,k}|}{\text{ZMIN}_k}, \quad \text{RZTM}_2 = \frac{|s_{k+1,k+2}|}{B_{k+1,k+2} / \text{TMIN}_{k+1}} \qquad \text{(tests Type 9 magnitude)}$$

$$\text{RTZM}_1 = \frac{|s_{k-1,k}|}{B_{k-1,k} / \text{TMIN}_k}, \quad \text{RTZM}_2 = \frac{|s_{k+1,k+2}|}{\text{ZMIN}_{k+1}} \qquad \text{(tests Type 10 magnitude)}$$

And calculated for all layers are:

$$\text{RZ}_2 = \frac{2\bar{t}_{all}\sqrt{B^2_{k,k+1} + B^2_{k+1,k+2}}}{|s_{k,k+1} + s_{k+1,k+2}|} \qquad \text{(tests Type 1 existence)}$$

$$\text{RZM}_2 = \frac{-0.5(s_{k,k+1} - s_{k+1,k+2})}{\text{ZMIN}_{k+1}} \qquad \text{(tests Type 1 magnitude)}$$

$$\text{RT}_2 = \frac{2\bar{t}_{all}}{|X_{k,k+1} - X_{k+1,k+2}|} \qquad \text{(tests Type 2 existence)}$$

$$\text{RTM}_2 = \frac{0.5|X_{k,k+1} + X_{k+1,k+2}|}{\text{TMIN}_{k+1}} \qquad \text{(tests Type 2 magnitude)}$$

These ratios and the size of the residuals, etc. are examined to determine the error type. The largest of the existence ratios determines the most likely type, and the magnitude ratio is used to test that the magnitude is sufficient to make it likely that an error has actually occurred.

In what follows "no holes" is shorthand for saying that there is at most one missing level above or below the data level in question. And "is maximum" is shorthand for saying that a quantity is the largest of all similar values.

The type determination proceeds as follows, checking first for communication error of height at a single level:

if $\text{RZM}_2 > 1$ and no holes and RZ_2 is maximum then

type = 1

ZCOR_{k+1} is given by Table 5.6

correction is made simple

if $|\text{ZCOR}_{k+1}| < \text{ZLIM}_{k+1}$ then set Type = 11,

where $\text{ZLIM}_{k+1} = \begin{cases} 30., & k+1 \le 3 \\ 85., & k+1 > 3 \end{cases}$

Test for communication error of temperature at a single level:

if $RTM_2 > 1$ and no holes and RT_2 is maximum then

type = 2

$TCOR_{k+1}$ is given by Table 5.6

proposed correction is tested against allowable lapse rates

sign error correction is tested

correction is made simple

if $|TCOR_{k+1}| < 10$ then set Type = 22

Test for Types 7 to 10:

if layers are not bottom or top and if no holes, then

if RZ_2 is maximum and $RZZM_1 > 1$ and $RZZM_2 > 1$ then

type = 7

$ZCOR_k$ and $ZCOR_{k+1}$ are given by Table 5.6

make corrections simple

if $|ZCOR_k| < ZLIM_k$ and $|ZCOR_{k+1}| < ZLIM_{k+1}$ then set Types to 11

if RTT is maximum and $RTTM_1 > 1$ and $RTTM_2 > 1$ and previously determined type $\neq 7$ then

type = 8

$TCOR_k$ and $TCOR_{k+1}$ are given by Table 5.6

check resultant lapse rates

try sign corrections

make corrections simple

if $|TCOR_k| < TCLIM$ and $|TCOR_{k+1}| < TCLIM$ then set types = 22

if RTT is maximum and $RTTM_1 > 1$ and $RTTM_2 > 1$ and previously determined type = 7 then

do not make any corrections (set Type = 0)

if RZT is maximum and $RZTM_1 > 1$ and $RZTM_2 > 1$ then

type = 9

$ZCOR_k$ and $TCOR_{k+1}$ are given by Table 5.6

find simple correction for $ZCOR_k$

check resultant lapse rates

try sign corrections

make $TCOR_{k+1}$ simple

if corrected temperatures give lapse rates exceeding dry adiabatic by 10%, make neither correction and set Type = 99

if $|ZCOR_k| < ZLIM_k$ and $|TCOR_{k+1}| < TLIM$ then set types = 11 and 22 for z_k and T_{k+1}

if RZT is maximum and $RZTM_1 > 1$ and $RZTM_2 > 1$ and previously determined type $\neq 9$ then

type = 10

$TCOR_k$ and $ZCOR_{k+1}$ are given by Table 5.6

find simple correction for $ZCOR_{k+1}$

check resultant lapse rates

try sign corrections

make $TCOR_{k+1}$ simple

if corrected temperatures give lapse rates exceeding dry adiabatic by 10%, make neither correction and set Type = 99

if $|TCOR_k| < TLIM$ and $|ZCOR_{k+1}| < ZLIM_{k+1}$ then set types = 22 and 11 for T_k and z_{k+1}

if RZT is maximum and $RTZM_1 > 1$ and $RTZM_2 > 1$ and previously determined type = 9 then

set types = 0

do not make any corrections

Test for holes:

if pressure is ≤ 100 HPa and at least two of the next higher pressure levels, including 100 HPa, have missing height or temperature, then

Type = 13

if Type $\neq 13$ and at least two of the next higher pressure levels have missing height or temperature or both, then

Type = 14

Test for an error at the lowest level:

if the level is the lowest

and previously determined Type = 0 and

$(|s_{k,k+1}| > SBIG_{k,k+1}$ and $|s_{k+1,k+2}| > 0.5\ SBIG_{k+1,k+2})$

or $(|s_{k,k+1}| > SBIG_{k,k+1}$ and $|s_{k+1,k+2}/s_{k,k+1}| < 1/3)$ then type = 4

$ZCOR_k = s_{k,k+1}$, rounded

$TCOR_k = X_{k,k+1}$, rounded

Test for errors to both height and temperature at the same level:

if $|s_{k,k+1}| > SBIG_{k,k+1}$ and $|s_{k+1,k+2}| > 0.7\ SBIG_{k+1,k+2}$
or $|s_{k,k+1}| > 0.7\ SBIG_{k,k+1}$ and $|s_{k+1,k+2}| > SBIG_{k+1,k+2}$
and previously determined Type = 0, then

$ZCOR_k$ and $TCOR_k$ are given by Table 5.6 for Type 3

$ZCOR_k$ and $TCOR_k$ are rounded.

if $|ZCOR_{k+1}| > 2\bar{t}_{all}\sqrt{B_{k,k+1}^2 + B_{k+1,k+2}^2}$ or $|TCOR_{k+1}| > 2\bar{t}_{all}$ then

type = 3

Test for computation error in thickness:

if $|s_{k,k+1}| > 1.5\ SBIG_{k,k+1}$ and k is not the bottom level and k+1 is not the top level and the previously determined type = 0, then

if $|s_{k-1,k}/s_{k,k+1}| < 1/3$ and $|s_{k-1,k}| < SBIG_{k-1,,k}$
and $|s_{k+1,k+2}/s_{k,k+1}| < 1/3$ and $|s_{k+1,k+2}| < SBIG_{k+1,,k+2}$, then

type = 6

the height corrections are found in Table 5.6

The routine continues moving the template of values upward to the top, and from the lowest level upward for a second scan.

Appendix E. Observational Error Detection

An observational error is an error to the temperature as received at an observing site. This temperature is used in the computation of thicknesses, and therefore the heights and temperatures are hydrostatically consistent. This means that observational errors do not produce large hydrostatic residuals--the hydrostatic type is 0. Typically, a temperature sensor will gradually go bad with elevation, and the resultant heights will go bad more rapidly with elevation. Even a small, consistent temperature error will lead to a large height error at some higher level. This makes the detection of all levels of observational errors difficult, and all profiles with any observational error detected are sent to MOD for further consideration.

The various checks--incremental, horizontal, vertical and baseline--compute indicators of the size of increments and residuals. These have the form

$$\mathrm{IINC} = \min(2|i|/\mathrm{XINC}, 2)$$
$$\mathrm{IHOI} = \min(2|s|/\mathrm{HOIRES}, 2)$$
$$\mathrm{IVOI} = \min(2|s^{v}|/\mathrm{VOIRES}, 2)$$
$$\mathrm{IBAS} = \min(2|s^{b}|/\mathrm{BASRES}, 2)$$
$$\mathrm{IIPL} = \min(2|i^{ps}|/\mathrm{PSRES}, 2)$$
$$\mathrm{IHPL} = \min(2|s^{ps}|/\mathrm{PSRES}, 2)$$

where IINC, IHOI, and IVOI are calculated at the levels k-1, k, and k. IBAS, IIPL, and IHPL apply only to the lowest level. The values of the constants, XINC, HOIRES, VOIRES, BASRES, and PSRES was given in Appendix A. These indicators, along with the hydrostatic diagnosis, are used to detect observational errors.

An observational error in height of a mandatory level is detected if

prior decision $\neq 1$ (no prior confident correction for this height)
hydrostatic type = 0
IINC + IHOI + IVOI ≥ 4 at level k

The decision is 4 for levels up to 100 HPa, and the decision is 3 for levels above 100 HPa.

The detection of a temperature error uses a count of the non-zero indicators: IINC, IHOI, and IVOI at levels k-1, k, and k+1. These indicators are called $NONZ_{k-1}$, $NONZ_k$, and $NONZ_{k+1}$. An observational error in temperature of a mandatory level is detected if

prior decision $\neq 1$ (no prior confident correction for this temperature)
hydrostatic type = 0
[IINC + IHOI + IVOI ≥ 4]
or [($NONZ_k \geq 2$ and $NONZ_{k-1} \geq 2$) or ($NONZ_k \geq 2$ and $NONZ_{k+1} \geq 2$)]

The decision is 3.

Also tested is an observational error in surface pressure. It is detected if

IIPL + IHPL = 4.