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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 351

THE HYDROSTATIC CHECKING OF RADIOSONDE HEIGHTS AND TEMPERATURES, PART II

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I. Introduction

This Office Note documents improvements to the new NMC hydrostatic check of radiosonde data. It brings up-to-date Office Note 344, in which the basic theory was presented and early results were shown. The hydrostatic check of radiosonde temperatures and heights relies on the redundancy of the data. The radiosonde instrument measures temperatures, and the heights are determined from the temperatures by use of the hydrostatic equation. There is the possibility to measure the radiosonde height independently, but this opportunity is not presently used. Following the hydrostatic integration, the data are encoded and transmitted as a message. If the heights and temperatures decoded by NMC do not agree hydrostatically within certain limits, the decoded value of height(s) or temperature(s) must be in error. The new hydrostatic check (HSC) inspects the pattern of disagreement numbers, called hydrostatic residuals, to determine the value(s) that is(are) in error, and some new improvements try to determine the most likely original value. The logic of the code has also been improved to try to better handle more complicated error patterns. Recently, a check of the agreement of the low-level mandatory level heights and the reported surface pressure has been added. These improvements and the monitoring system will be described in Section II.

The extensive testing of the modifications will be described in Section III. Section IV will present the results of those tests and Section V will detail some specific questions. The final Section VI will describe plans for the future.

The HSC was implemented in the FINAL cycle, 4 times a day, beginning December 14, 1988. Following a period of examination and determination of robustness within the NMC operations, the HSC was then implemented into operations at all places where the old hydrostatic check, HYDROCHK, is executed (about 20 per day).

II. Improvements

The improvements from the documentation in Office Note 344 fall into two categories: improvements to the corrected values, and improvements to the monitoring of the system. Among the improvements to the corrected values, likewise, there are two categories: improvement to the exact value of the correction, and better determination of which values are in error. The improvements to the corrected values will be considered first.

Determination of correction value

The hydrostatic errors determined by HSC are 'human' errors. They have been introduced because a person has in some way made an error in handling the data. Only in extremely rare cases is the error due to communication or computer error. A list of possible errors includes a manual computation error, sign error, transcription error or typing error. The errors are not due to errors in the value received at the ground from the radiosonde, for there are not yet any heights for the temperatures to be inconsistent with. Since the errors are 'human' errors, and deal with the data in decimal form, we expect certain types of corrections to be predominantly necessary, namely: sign correction, single digit correction, or interchange of digits correction. The HSC code first determines a provisional correction from the pattern of hydrostatic residuals (see Office Note 344 for the basic theory). Then sign (for temperature), single digit or interchange of digit corrections ('simple' corrections) are sought within a range of the provisional value of the correction. The range for temperature is 5 degrees and for height is 15 meters. The closest 'simple' correction is accepted if one exists. Otherwise, the provisional value is used.

Correction pairs

A single error in height or temperature leads to a pair of hydrostatic residuals for the layer above and below. The previous note described how corrections are made in this case. The last section described modifications to make the corrected value more likely to be the original value of the data. When there are errors at adjacent layers, the pattern of residuals is more complicated. There are generally three residuals of moderate size for two adjacent errors. Figure 1 shows the arrangement of variables. Heights are denoted by z, temperatures by T, and residuals by s. It is possible to determine the nature of the errors by examination of the residuals. We note that if two errors occur at the same level, the error cannot be reliably determined. However, even in this case a correction pair is suggested (Type 3 error).

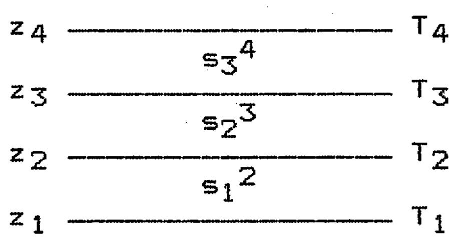

Figure 1.--Arrangement of variables for hydrostatic check.

The theory for the correction to variables when three residuals must be considered will be developed in this section. If we assume that there are no errors in height or temperature, that we can neglect the difference between temperature and virtual temperature, and assume that the temperature varies linearly with the logarithm of pressure between mandatory levels, then the hydrostatic equation gives

$$0 = z_{i+1} - z_i - A_i^{i+1} - B_i^{i+1}(T_i + T_{i+1}) \qquad (1)$$

with

$$A_i^{i+1} = (RT_o/g)\ \ln(p_i/p_{i+1})$$

$$B_i^{i+1} = (R/2g)\ \ln(p_i/p_{i+1})$$

R is the gas constant, T_o = 273.15 K and g is the acceleration of gravity. If there are errors in height, dz, and temperature, dT, then the equation for the residuals is

$$s_i^{i+1} = z_{i+1}+dz_{i+1}-z_i-dz_i-A_i^{i+1}-B_i^{i+1}(T_i+dT_i+T_{i+1}+dT_{i+1}) \qquad (2)$$

By subtraction of (1) from (2), we obtain an equation for the residuals and errors.

$$s_i^{i+1} = dz_{i+1} - dz_i - B_i^{i+1}(dT_i + dT_{i+1}),\ i=1,2,3 \qquad (3)$$

We are considering errors at the interior levels, 2 and 3 in Figure 1, without errors at the bounding levels. Therefore, (3) expanded for the three layers is

$$s_1^2 = dz_2 - B_1^2 dT_2$$

$$s_2^3 = dz_3 - dz_2 - B_2^3(dT_2 + dT_3) \qquad (4)$$

$$s_3^4 = -dz_3 - B_3^4 dT_3$$

Four special cases of (4) are considered. The details of one will be shown; the others follow a similar line of reasoning.

<u>Special case -- two height errors</u> (Type 7)

In this case, it is assumed that $dT_2 = dT_3 = 0.$, while dz_2 and dz_3 are nonzero. Then equations (4) become

$$s_1^2 = dz_2$$

$$s_2^3 = dz_3 - dz_2 \qquad (4a)$$

$$s_3^4 = -dz_3$$

It can be seen that in this case, $s_1^2 + s_2^3 + s_3^4 = 0$. However, this strict equality does not account for any of the assumptions made earlier, primarily the nonlinearity of T with respect to ln(pressure). Therefore, the equality must be relaxed somewhat. In terms of temperature deviations, we may write

$$s_1^2 + s_2^3 + s_3^4 = -B_1^2 dT_2 - B_2^3(dT_2 + dT_3) - B_3^4 dT_3$$
$$= -(B_1^2 + B_2^3)dT_2 - (B_2^3 + B_3^4)dT_3 \qquad (5)$$

We choose a limiting value of 5 degrees Celsius to be the maximum error in the resulting layer temperatures from the height corrections. Each temperature error in (5) is replaced by dT_{lim} and we consider the limit for random, independent errors with magnitudes less than or equal to dT_{lim}. This leads to the following inequality to define the conditions under which we define an error to be of the type assumed, namely, two height errors:

$$|s_1^2 + s_2^3 + s_3^4| < \sqrt{(B_1^2 + B_2^3)^2 + (B_2^3 + B_3^4)^2}\, dT_{lim} \qquad (6)$$

The corrections are taken from (4a). Namely,

$$dz_2 = s_1^2 \quad \text{and} \quad dz_3 = -s_3^4. \qquad (6a)$$

The conditions for the other cases are stated without comment.

Two temperature errors (Type 8)

Assumptions: $dz_2 = dz_3 = 0.$; dT_2 and dT_3 not zero. Type 8 is diagnosed if

$$\left|\frac{s_1^2}{B_1^2} + \frac{s_3^4}{B_3^4} - \frac{s_2^3}{B_2^3}\right| < \sqrt{\left[\frac{1}{B_1^2} + \frac{1}{B_2^3}\right]^2 + \left[\frac{1}{B_2^3} + \frac{1}{B_3^4}\right]^2}\, dz_{lim} \qquad (7)$$

with dz_{lim} = 15 meters. The temperature corrections are

$$dT_2 = s_1^2/B_1^2 \quad \text{and} \quad dT_3 = s_3^4/B_3^4. \qquad (7a)$$

Lower height error, upper temperature error (Type 9)

Assumptions: $dT_2 = dz_3 = 0.$; dz_2 and dT_3 not zero.

$$|B_3^4(s_1^2 + s_2^3) - B_2^3 s_3^4|$$
$$< \sqrt{(B_1^2 + B_2^3)^2 (B_3^4)^2 dT_{lim}^2 + (B_2^3 + B_3^4)^2 dz_{lim}^2} \qquad (8)$$

The height and temperature corrections are

$$dz_2 = -s_1^2 \quad \text{and} \quad dT_3 = s_3^4/B_3^4. \qquad (8a)$$

Lower temperature error, upper height error (Type 10)

Assumptions: $dz_2 = dT_3 = 0.$; dT_2 and dz_3 not zero.

$$|B_1{}^2(s_2{}^3 + s_3{}^4) - B_2{}^3 s_1{}^2|$$

$$< \sqrt{(B_2{}^3 + B_3{}^4)^2 (B_1{}^2)^2 dT_{lim}{}^2 + (B_1{}^2 + B_2{}^3)^2 dz_{lim}{}^2} \qquad (9)$$

The temperature and height corrections are

$$dz_3 = s_3{}^4 \quad \text{and} \quad dT_2 = s_1{}^2/B_1{}^2. \qquad (9a)$$

Reconsideration of logic of error determination

Our first concern has been to find those errors that can be most confidently corrected. In order to do this, the pairs of residuals with the largest values were considered first, followed by lesser residuals, until all layers are inspected. In the new logic, the error determination always begins with the lowest layer and proceeds upward to the top. Confident height and temperature corrections are always sought first, followed by pairs of somewhat less confident pairs of corrections (Types 7 to 10). Any correctable errors are corrected and a second pass of the data is made from the bottom to top. This new logic is not incorporated in operations, since only the confident corrections are made to height and temperature (Types 1 and 2). However, recent tests have been made which show the new error determination strategy to be generally superior. It may be decided in the future to incorporate Types 7 to 10 error corrections operationally if they are found to be highly reliable.

In the Complex Quality Control strategy, several checks are combined to make decisions of data quality. Within that system, the revised logic of the hydrostatic check will become not merely another option, but necessary, since checks may be repeated several times, based upon provisional modifications to the data.

Baseline check

Sometimes there is an error in the lowest reported height which cannot be determined by the hydrostatic check. However, the two lowest level heights and the reported surface pressure should be consistent with the station height. This consistency can be checked by assuming a standard structure to the temperature profile in the lower atmosphere. The check uses the lowest two heights to determine a layer mean temperature and assumes a standard lapse rate to hold downward to the surface of -6.5 degrees/kilometer. Then the computed value of the station height is obtained from the following equations.

$$b = -.0065$$

$$z_{lay} = \tfrac{1}{2}(z_1 + z_2)$$

$$\alpha_{lay} = (p_2/p_1)^{-Rb/g}$$

$$T_{lay} = -\tfrac{1}{2}b(z_2 - z_1)\left[\frac{1+\alpha_{lay}}{1-\alpha_{lay}}\right]$$

$$\alpha = (p_s/p_1)^{-Rb/g}$$

$$z_s^c = z_1 + [(\alpha-1)/b] * [T_{lay} + b(z_1 - z_{lay})] \qquad (10)$$

The computed value of the surface height, z_s^c should agree with the station height to within 10 to 20 meters at most. Stations with greater disagreement are printed out for consideration by the MOD analysts.

Error and correction summaries

Detailed information is available daily from the HSC. All profiles containing errors are listed in full, and then the errors and corrections are summarized by error type. TABLE 1 contains a sample of this information.

A Monthly Summary is produced from the daily summaries. It contains tables of errors stratified by 1) error type and pressure, 2) WMO station block, 3) WMO station block for each error type, and 4) error types listed separately for each station having an error. The table of errors for December 1988, by WMO block is shown in Table 2. Note the large number of errors for stations in blocks 20-38, 42-43, 50-59, 71 and 94. These blocks are for U.S.S.R., India, China, Canada and Australia. Table 3 shows a summary for these countries. And Table 4 shows a summary of the errors detected, classified by error type.

III. Testing of the HSC

The HSC has undergone extensive testing, both by the authors and by Valerie Thompson and Bill Whitmore of NMC's Meteorological Operations Division. The MOD evaluation extended from October 1, 1988 to October 31, 1988. During this period there were 995

TABLE 1 -- DAILY SUMMARY OF ERRORS AND CORRECTIONS

IDENT	PRESS	HEIGHT	TEMP	RESID1	RESID2	HGT COR	TMP COR	NEW HGT
12425	100	13220.	-55.1	-2986.1	2998.2	3000.	0.0	16220.
10410	250	10140.	-31.5	-61.9	-69.5	0.	-21.6	10140.
42410	400	7350.	29.0	-150.4	-1684.9	-60.	-63.7	7350.
28661	1000	80.	82.8	0.0	-205.6	-206.	-86.4	80.
48601	30	26960.	8.0	2772.6	0.0	-2770.	370.6	26960.

Table 1 continued--

NEW TMP	NEW S1	NEW S2	CTYP	DATE/TIME
-55.1	13.9	-1.8	1	89011300
-53.1	-4.2	1.1	2	89011300
29.0	-150.4	-1684.9	3	89011300
82.8	0.0	-205.6	4	89011300
8.0	2772.6	0.0	5	89011300

KEY

RESID1,2 - residuals
HGT COR - ht correction
TMP COR - temp. corr.
NEW S1 - new residual 1
NEW S2 - new residual 2
CTYP - correction type
NEW HGT - new height
NEW TMP - new temp.

TABLE 2--Error Counts by Station Block for December 1988

The total number of hydrostatic errors detected: 4121

tens ↓ / units-->	0	1	2	3	4	5	6	7	8	9
00	0	4	9	3	7	0	3	17	5	1
10	22	3	21	13	0	52	26	36	0	0
20	32	23	15	43	91	59	11	20	30	33
30	75	83	28	19	31	30	32	71	94	0
40	48	66	317	274	145	0	53	64	172	0
50	39	111	72	60	105	23	92	98	24	66
60	78	76	31	26	15	10	0	53	4	0
70	14	233	24	0	8	0	64	0	40	0
80	12	4	58	34	4	16	3	73	0	21
90	0	62	0	68	113	0	88	18	0	0

confident height corrections and 628 confident temperature corrections made by HSC, out of a total of 3380 hydrostatic errors. Of the confident corrections, 262 underwent an examination by MOD for "reasonableness". A further 184 underwent a visual test, involving comparison on maps with surrounding data. And finally, 12 error corrections were examined in great detail. There were a few cases where the hydrostatic correction did not lead to the correct value, but in no case was this due to a flaw in the hydrostatic correction algorithm itself. In one case the baseline was in error. In the second case, the profile contained two isolated errors which canceled each other. On December 14, 1988 the HSC was put into operations, just preceding HYDROCHK in the FINAL cycle four times daily. (HYDROCHK is the present check, which flags some bad data, based upon hydrostatic, wind shear, and lapse rate considerations.) HSC's results have been scrutinized daily since that time, with results sent to a file from which the monthly summaries are obtained. On January 11, 1989 the HSC began operations in all places that HYDROCHK is run, being run just prior to it. In this way, the data corrected by HSC will not be flagged by HYDROCHK. The operational modifications to the data by HSC are only made for confident height and temperature corrections, but the other corrections are listed for evaluation.

TABLE 3--Countries with Large Number of Errors for December 1988

U.S.S.R.	820	20%
China	690	17%
Indian subcontinent	591	14%
Canada	233	6%
Australia	113	3%

TABLE 4--Summary of Hydrostatic Errors by Type for December 1988

(Summary for 61 observation times, about 37,000 observations.)

Classification of Errors

Type	Description		number	percent
1	confident height correction		984	23.9
2	confident temperature correction		769	18.7
3	correction pair (z,T)		321	7.8
4	error at lowest level		418	10.1
5	error at top level		763	18.5
6	isolated large residual		399	9.7
7	two height errors	using three large residuals	47	partial month about 5 percent
8	two temp. errors		13	
9	lower z, upper T		14	
10	lower T, upper z		28	
11	small height correction		296	7.2
12	temp. corr. giving unstable layer		69	1.7

The restructured code, described in the section Reconsideration of logic of error determination, has also undergone continuous testing. All modifications which the authors wish to test are executed routinely twice a day on the FINAL data. In this way it is possible to collect and build up a library of particularly difficult cases.

IV. Examples and Special Problems

In about half the cases of large hydrostatic residuals, an error is isolated and the hydrostatic residual pattern makes it evident what the correction is to be. In the other cases, however, we have found many possible difficulties. Correction types 7-10 are designed to correct some of these more complicated cases. To date, we do not make corrections to the data in these cases, but merely list what the correction should be. Some of these interesting cases will be shown below.

The first four examples will show profile fragments to illustrate how correction Types 7 to 10 perform. Table 5 shows a Type 7 correction--two height errors. The table shows the reported heights and temperatures and their corrected values, the residuals before and after correction (RESID and NEW-S), the corrections (ZCOR and TCOR) and the error type (TYP). In many cases, one of the height errors will be smaller than 100 meters, but is given credence by the residual pattern of the adjacent error.

TABLE 5--Two height errors, Type 7 correction.

Station: 38750 Date/Time: 89010712

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
500	5560.	5560.	-23.7	-23.7			0.	0.0	0
					-987.3	12.7			
400	6160.	7160.	-36.9	-36.9			1000.	0.0	7
					1199.8	-0.2			
300	9300.	9100.	-48.9	-48.9			-200.	0.0	7
					-192.1	7.9			
250	10290.	10290.	-54.7	-54.7			0.	0.0	0

Table 6 shows an example of corrections to two temperatures (Type 8 correction). The 400 mb temperature has a sign error plus an error to one digit. The 300 mb temperature has an error in one digit.

TABLE 6--Two temperature errors, Type 8 correction.

Station: 51644 Date/Time: 89010912

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
500	5490.	5490.	-34.7	-34.7			0.	0.0	0
					-145.0	11.9			
400	7030.	7030.	4.0	-44.0			0.	-48.0	8
					-65.2	10.7			
300	8940.	8940.	-81.5	-51.5			0.	30.0	8
					87.8	7.7			
250	10110.	10110.	-59.5	-59.5			0.	0.0	0

Table 7 shows an example of a Type 9 correction; there is an error to the lower height and upper temperature. In this case, there is a relatively small error to the 250 mb height and a sign error to the 200 mb temperature. This sign error is quite evident, but would not have been detected automatically without looking at all three layers, because the 250-200 mb and 200-150 mb residuals, divided by the "B"s, differ too much from each other.

TABLE 7--Lower height error, upper temperature error, Type 9 correction.

Station: 44288 Date/Time: 89011000

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
300	8850.	8850.	-56.3	-56.3			0.	0.0	0
					65.5	-4.5			
250	10080.	10080.	-53.9	-53.9			-70.	0.0	9
					-410.4	2.1			
200	11450.	11450.	52.4	-52.4			0.	-104.8	9
					-441.3	0.3			
150	13310.	13310.	-52.5	-52.5			0.	0.0	0

Table 8 shows an example of a Type 10 correction; there are errors to the lower temperature and upper height. In this example, there is a sign error to the 500 mb temperature and a single digit error to the 400 mb height. Again, it is necessary to consider the three large residuals together to be able to diagnose either error.

TABLE 8--Lower temperature error, upper height error, Type 10 correction.

Station: 47158 Date/Time: 88121512

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
700	2866.	2866.	-23.7	-23.7			0.	0.0	0
					-287.3	-15.2			
500	5290.	5290.	27.6	-27.6			0.	-55.2	10
					-910.0	-10.6			
400	6050.	6850.	-38.1	-38.1			800.	0.0	10
					798.9	-1.1			
300	8800.	8800.	-45.1	-45.1			0.	0.0	0

The next case is shown to illustrate the complexity of some reports. In this case, there are 8 large residuals which become small after the corrections are applied! However, there still remains a large residual for the lowest layer. Table 9 shows the reported heights and temperatures and their corrected values.

The corrections for this station are described as follows. There is a large residual between 850 and 700 mb. The suggested corrections are 40. meters or 14.2 degrees to the 850 mb data. Since the temperature correction does not look likely, the error is probably to the 850 mb height. However, it is possible that the 850-700 mb thickness is in error, in which case, all the heights above 850 mb would need to be corrected. However, the final decision must await a horizontal quality control check. Proceeding upward, large residuals are encountered for the layers

TABLE 9--Example of Complicated Corrections

Station: 42779 Date/Time: 88121100

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
1000	182.	182.	9999.9	9999.9			0.	.0	0
850	1552.	1552.	7.0	7.0			40.	14.2	4
					40.4	40.4			
700	3185.	3185.	6.8	6.8			0.	.0	0
					9.5	9.5			
500	5890.	5890.	-6.1	-6.1			0.	.0	0
					2.7	2.7			
400	7610.	7610.	-14.7	-14.7			0.	.0	0
					-73.1	10.7			
300	9740.	9740.	-8.7	-28.6			0.	-20.0	10
					846.8	-.1			
250	11920.	11020.	-38.3	-38.3			-900.	.0	10
					-904.3	-4.3			
200	12520.	12520.	-47.7	-47.7			0.	.0	0
					-124.7	1.2			
150	14370.	14370.	-29.9	-59.8			0.	-30.0	2
					-197.7	-20.1			
100	16800.	16800.	-73.9	-73.9			0.	.0	0
					-83.3	21.2			
70	18930.	18930.	-48.7	-68.7			0.	-20.0	10
					874.9	-26.5			
50	21950.	20950.	-62.3	-62.3			-1000.	.0	10
					-1007.1	-7.1			
30	24180.	24180.	-51.3	-51.3			0.	.0	0
					2.8	2.8			
20	26850.	26850.	-44.9	-44.9			0.	.0	0

400-300 mb, 300-250 mb and 250-200 mb. These three residuals are used to diagnose a Type 10 correction (lower temperature, upper height). The corrections are -20.0 degrees to the 300 mb temperature and -900. meters to the 250 mb height, resulting in much improved residuals for the three layers. Next, we encountered large residuals for the layers 200-150 mb and 150-100 mb. They support a Type 2 confident temperature correction to

150 mb of -30.0 degrees. Again, the new residuals are small. Proceeding upward, there are large residuals in the 100-70 mb, 70-50 mb and 50-30 mb layers. These residuals support a Type 10 correction pair of -20.0 degrees to the 70 mb temperature and -1000. meters to the 50 mb height. The residuals are greatly improved by these corrections.

The success of our algorithm in this case is no accident. This is a complicated case, but in a sense it is an easy case for the following reasons. First, all correction types are well-determined; there is little ambiguity. And second, the errors are separated enough so that their residual patterns do not overlap too much. In other cases that prove to be really difficult, one or more of these conditions is lacking. An example is provided by Table 10, in which the sequential nature of the new strategy is essential. Only the lower part of the profile is reproduced. On the first pass, the 400 mb height is corrected by 500 meters. Then the recalculated 500-400 mb residual, and the 700-500 mb residual are used to define the temperature correction at 500 mb.

TABLE 10--Example of Corrections Needing Two Passes

Station: 31538 Date/Time: 89011700

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
1000	233.	233.	9999.9	9999.9			0.	.0	0
850	1431.	1431.	-16.7	-16.7			0.	.0	0
					5.6	5.6			
700	2874.	2874.	-24.1	-24.1			0.	.0	0
					-50.9	-2.1			
500	5250.	5250.	-29.7	-39.6			0.	-10.0	2
					-532.4	0.0			
400	6250.	6750.	-47.7	-47.7			500.	.0	1
					496.5	-3.5			
300	9770.	9770.	-54.9	-54.9			0.	0.0	0

Data gaps

Not all errors in the radiosonde data show up as hydrostatic inconsistencies. There are frequent errors which make it impossible for the present decoding routines to properly decode a report. In many cases, the lower part of a report is properly decoded, but the upper part is lost. At a later time, the part C transmission may be entirely alright. This gives the impression of a report with missing data from some low level to 100 mb--a data "hole". Some of these holes are detected by the HSC, because of the implied linearity of the temperature profile in our check. Others are only detected by special code written by Automation Division personnel. Following their detection, these cases may be examined by Meteorological Operations Division personnel for manual correction. Many reports are salvaged, but many could be corrected automatically.

Correctable errors in the bottom and top layers

Hydrostatic errors at the lowest and highest level can often be corrected by inspection of the reported values and proposed corrections. The HSC suggests alternative height or temperature corrections. In many cases it is clear which datum is in error, so it clear which correction to use. In other cases, the application of one of the corrections leads to an absurd value, leaving the other correction as the more reasonable. Further evaluation can be done by comparison of corrected values with climatology or surrounding data. For a test period, types 4 and 5 error information were provided to MOD. It was decided that corrections could be make in many cases if the information were provided early enough. Since January 11, 1989 the type 4 and 5 error information has been routinely available at about 0500 Z and 1700 Z.

Examples of the reasoning that can be used in many cases to determine a likely correction is provided by Tables 11 and 12. Table 11 show an error at the top of a profile. The suggested corrections are either 1090. meters or -107.9 degrees. The reported temperature of 55.6 degrees at 10 mb is clearly wrong and a correction of -107.9 gives a reasonable value. It is most likely that the temperature sign is in error. In this case, the application of one of the suggested corrections leads to a positive result.

TABLE 11--Example of Error at the Top (Positive Argument)

Station: 31300 Date/Time: 89020112

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
20	26070.	26070.	-54.7	-54.7			0.	.0	0
					-1094.9	-1094.9			
10	30530.	30530.	55.6	55.6			1090.	-107.9	5

Table 12 shows an example where a different kind of reasoning must be applied to determine the likely correction. It shows an error at the lowest layer. Adding the proposed temperature correction to the reported temperature leads to a definitely wrong temperature. Therefore, the likely error is in the lowest level height. A height correction of 100. meters seems reasonable. In this case, a negative argument is used to obtain the likely correction.

TABLE 12--Example of Error at the Bottom (Negative Argument)

Station: 15730 Date/Time: 89020212

PRESS	HEIGHT	NEW-HT	TEMP.	NEW-T	RESID	NEW-S	ZCOR	TCOR	TYP
1000	296.	296.	9999.9	9999.9			0.	.0	0
850	1530.	1530.	1.0	1.0			98.	34.4	4
					97.9	97.9			
700	3177.	3177.	-2.5	-2.5			0.	.0	0

VI. Plans for the Future

The corrections that can be made most confidently, Types 1 and 2, are now made routinely, operationally. Also, corrections are made manually for the bottom and top layers. With further testing and refinement, we may feel confident to introduce the Types 7 to 10 corrections as well. However, no decision has as yet been made. When the other components of the Complex Quality Control are available, it will then not be as important to try to make as many corrections to the data as possible, based only upon the HSC. When the horizontal and vertical checks are available, then their results can be used to confirm, reject, or modify the HSC conclusions and many more tentative corrections of the HSC will become confident. Development work has begun on the horizontal check of heights and temperatures.

Monitoring and exchange of information

The hydrostatic corrections are monitored daily by MOD. In addition, they examine the errors at the bottom and top for manual corrections to the data. Further, the developers monitor most of the corrections and proposed corrections for subtle difficulties in the performance requiring modification. These kinds of monitoring will continue and slowly change as the present code becomes validated and as new elements of the Complex Quality Control are introduced.

We are exchanging Monthly Summaries of performance of HSC with the ECMWF. There has also been correspondence regarding consistent problems noted with another country, helping to let them know that their difficulty is of importance to others.

REFERENCES

Collins, W.G. and L.S. Gandin, 1988: The hydrostatic checking of radiosonde heights and temperatures. NOAA, National Weather Service, National Meteorological Center, Office Note 344.

Gandin, L.S., 1988: Complex quality control of meteorological observations. Mon. Wea. Rev., 116 (5), 1137-1156.

DiMego, G.J., P.A. Phoebus and J.E. McDonell, 1985: Data processing and quality control for optimum interpolation analyses at the National Metrorological Center. NOAA, National Weather Service, National Meteorological Center, Office Note 306.

APPENDIX A -- Modified Table for Office Note 29.
TABLE 101 (ON 29) for Category 08 (Additional Data)

Code Figure	Specification
001	Stability index.....000$i_s i_s$
002	Low-level mean wind for surface to 5,000-foot layer in knots.....ddfff
003	Low-level mean wind for 5,000- to 10,000-foot layer in knots.....ddfff
004	Vertical wind shear data in knots.....4$v_b v_b v_a v_a$ (99 is used when solidi (//) were encoded for $v_b v_b$ and/or $v_a v_a$)
101	Code figure from "101" group.....000xx
104	Release time in hundredths of hours.....0hhhh
105	Receipt time* in hundredths of hours.....0hhhh
106	Instrument type, radiation correction code figures $r_s r_s s_r s_a s_a$ (99 is used when solidi (//) were encoded for $s_a s_a$
107	Original value of corrected data.....vvvvv vvvvv in meters if geopotential height vvvvv in tenths of degrees C if temperature 1st Category 08 Marker indicates data type: Z = geopotential height T = temperature 2nd Category 08 Marker indicates level in mb: 1 = 1000 9 = 150 2 = 850 A = 100 3 = 700 B = 70 4 = 500 C = 50 5 = 400 D = 30 6 = 300 E = 20 7 = 250 F = 10 8 = 200

* Table Q.8 will be utilized to indicate Part A, B, C, or D of the TEMP, PILOT, TEMP SHIP, or PILOT SHIP reports.

APPENDIX B -- HYDROSTATIC ERROR CORRECTION SUBROUTINES

```
      SUBROUTINE CORECT(Z,T,ZCOR,TCOR,ZC,TC,S,DUM,LEV,ICTYP,IDUM)
C$$$  SUBPROGRAM DOCUMENTATION BLOCK
C
C SUBPROGRAM:    CORECT       HYDROSTATIC CORRECTION TO DATA
C   PRGMMR: W.COLLINS         ORG: W/NMC22    DATE: 88-09-14
C
C ABSTRACT:  MAKES CORRECTIONS TO HEIGHTS AND
C   TEMPERATURES IN A RADIOSONDE REPORT BASED UPON
C   A HYDROSTATIC CHECK. THIS VERSION WILL MAKE CORRECTIONS
C   FOR THREE LARGE RESIDUALS IN A ROW.
C
C PROGRAM HISTORY LOG:
C   88-09-14  ORIGINAL    W. COLLINS
C   89-02-02              W. COLLINS  RESTRUCTURED CODE
C
C USAGE:    CALL CORECT(Z, T, ZCOR, TCOR, ZC, TC, S, DUM,
C                       LEV, ICTYP, IDUM)
C   INPUT ARGUMENT LIST:
C           Z      - HEIGHT PROFILE (METERS)
C           T      - TEMPERATURE PROFILE (CELSIUS)
C           DUM    - DUMMY VARIABLE (PLACESAVER)
C           LEV    - NUMBER OF LEVELS TO CONSIDER
C
C   OUTPUT ARGUMENT LIST:
C           ZCOR   - HEIGHT CORRECTION (METERS)
C           TCOR   - TEMPERATURE CORRECTION (KELVIN/CELSIUS)
C           ZC     - CORRECTED HEIGHT PROFILE (METERS)
C           TC     - CORRECTED TEMPERATURE PROFILE (CELSIUS)
C           S      - NEW HYDROSTATIC RESIDUAL FOR LAYER (M)
C           ICTYP  - CORRECTION TYPE CODE
C               0 = NO CORRECTION
C               1 = CONFIDENT HEIGHT CORRECTION
C               2 = CONFIDENT TEMPERATURE CORRECTION
C                   NOTE!  ONLY TYPES 1 AND 2 GIVE CONFIDENT
C                     CORRECTIONS THAT ARE ACTUALLY APPLIED
C                     TO THE DATA.
C               3 = Z, T CORRECTIONS TO MAKE RESIDS = 0.
C               4 = BOTTOM LAYER CORRECTION CHOICE
C               5 = TOP LAYER CORRECTION CHOICE
C               6 = ISOLATED LARGE RESIDUAL
C               7 = TWO CONFIDENT HEIGHT CORRECTIONS IN A ROW
C               8 = TWO CONFIDENT TEMPERATURE CORRECTIONS IN A ROW
C               9 = TWO CONFIDENT CORRECTIONS IN A ROW
C                     LOWER HEIGHT, UPPER TEMPERATURE
C              10 = TWO CONFIDENT CORRECTIONS IN A ROW
C                     LOWER TEMPERATURE, UPPER HEIGHT
C              11 = HEIGHT CORRECTION .LT. 100 M
C              12 = TEMPERATURE CORRECTION, GIVING INSTABILITY
C              22 = TEMPERATURE CORRECTION LESS THAN 5 DEGREES
C              99 = TYPE 9 OR 10 WITH RESULTING INSTABILITY
C           IDUM  - DUMMY VARIABLE (PLACE SAVER)
C
C ATTRIBUTES:
C   LANGUAGE: VS FORTRAN
C   MACHINE:  NAS
C
C$$$
```

```
C
C     MAKE HYDROSTATIC CORRECTIONS.
C
C     (Z,T)          - INPUT (HEIGHT,TEMPERATURE)
C     (ZC,TC)        - OUTPUT(HEIGHT,TEMPERATURE)
C     (ZI,TI)        - INTERMEDIATE VALUES OF (HT.,TEMP.)
C     (ZCOR,TCOR)    - OUTPUT HT., TEMP. CORRECTIONS
C     (ZCORI,TCORI)  - INTERMEDIATE HT., TEMP. CORRECTIONS
C     LL'S           - VALUES OF L'S FOR EACH SCAN.
C
      DIMENSION Z(1), T(1), ZC(1), TC(1), ICTYP(1),
     &  ZCOR(1), TCOR(1), S(1), DUM(1), IDUM(1),
     &  ALLZ(5), ALLT(101), ALLZL(31)
      COMMON /CORCT/ SI(54,3), ICTYPI(54,3),
     &  ZI(55,3), TI(55,3), ZCORI(55,3), TCORI(55,3),
     &  LL1(55,3), LL2(55,3), LL3(55,3), LL4(55,3)
      COMMON /CONSTS/ R, G, TO, A(54), B(54), SS(54)
      COMMON /LEVEL/ MBOGUS,NPLVL,IPLVL(55)
      DATA ZMSG /99999./, TMSG /9999.9/, ZMAX /90000./,
     &  TMAX /9000./, DZALL /15./, DTALL /5./,
     &  CP /1004.5/,
     &  ALLZ /0.,-10.,10.,-20.,20./,
     &  ALLZL /0.,-1.,1.,-2.,2.,-3.,3.,-4.,4.,-5.,5.,
     &    -6.,6.,-7.,7.,-8.,8.,-9.,9.,-10.,10.,-11.,
     &    11.,-12.,12.,-13.,13.,-14.,14.,-15.,15./
C
C     DUM, IDUM ARE MERELY PLACE-HOLDERS TO MAKE CALL
C     SEQUENCE THE SAME AS AN EARLIER VERSION.
C
      DUM(1) = 0.
      IDUM(1) = 0
      DO 5 I=1,101
        IMOD = MOD(I,2) + 1
        ALLT(I) = (-1.)**IMOD * AINT((I+.1)/2.)
    5 CONTINUE
      DO 8 K=1,LEV
        DO 7 I=1,3
          ZI(K,I) = ZMSG
          TI(K,I) = TMSG
          LL1(K,I) = -9
          LL2(K,I) = -9
          LL3(K,I) = -9
          LL4(K,I) = -9
    7   CONTINUE
    8 CONTINUE
      DO 10 K=1,LEV
        ZI(K,1) = Z(K)
        TI(K,1) = T(K)
   10 CONTINUE
      LEVM = LEV - 1
      DO 20 K=1,LEVM
        ICTYP(K) = 0
        DO 15 I=1,3
          ICTYPI(K,I) = 0
   15   CONTINUE
   20 CONTINUE
      DO 30 K=1,NPLVL
```

```
          ZCOR(K) = 0.
          TCOR(K) = 0.
          S(K) = 0.
          DO 25 II=1,3
            ZCORI(K,II) = 0.
            TCORI(K,II) = 0.
   25     CONTINUE
   30 CONTINUE
C
C     FIND INDEX OF LAST COMPLETE LEVEL.
C
      DO 32 K=1,LEV
        KK = LEV - K + 1
        IF(ZI(KK,1).NE.ZMSG.AND.TI(KK,1).NE.TMSG) GO TO 35
   32 CONTINUE
   35 LTOP = KK
C
C     BEGIN CALCULATIONS. GET FOUR LEVELS OF DATA.
C
      ISCAN = 1
      CON = 0.4
   40 CONTINUE
      ISCAN = ISCAN + 1
C
C     RESET COUNTER FOR RESIDUAL LAYER.
C
      IS = 0
C
C     SET BEGINNING VALUES FOR THIS SCAN TO BE THE
C     SAME AS THEY ENDED LAST SCAN.
C
      IF(ISCAN.GT.3) GO TO 300
      DO 42 K=1,LEV
        ZI(K,ISCAN) = ZI(K,ISCAN-1)
        TI(K,ISCAN) = TI(K,ISCAN-1)
   42 CONTINUE
      IF(ISCAN.EQ.3) CON = 0.8
      ISTRT = 0
      LAST = 0
      CALL FIRST(LAST,ZI(1,ISCAN),TI(1,ISCAN),
     &  ZL1,ZL2,ZL3,ZL4,TL1,TL2,TL3,TL4,
     &  L1,L2,L3,L4,LEV,IER)
      LL = L1
      IF(LL.GT.55.OR.LL.LT.0) LL = 1
      LL1(LL,ISCAN) = L1
      LL2(LL,ISCAN) = L2
      LL3(LL,ISCAN) = L3
      LL4(LL,ISCAN) = L4
      IF(IER.EQ.1) GO TO 300
   50 CONTINUE
      IF(ISTRT.EQ.0) THEN
        LB = LAST
        ISTRT = 1
        LAST = 0
        GO TO 60
      ENDIF
      CALL FNLEV(LAST,ZI(1,ISCAN),TI(1,ISCAN),
```

```
     &  ZL1,ZL2,ZL3,ZL4,TL1,TL2,TL3,TL4,
     &  L1,L2,L3,L4,LEV,IER)
      LL = L1
      IF(LL.GT.55.OR.LL.LT.0) LL = 1
      LL1(LL,ISCAN) = L1
      LL2(LL,ISCAN) = L2
      LL3(LL,ISCAN) = L3
      LL4(LL,ISCAN) = L4
      IF(IER.EQ.1) GO TO 200
      IF(L3.GE.LTOP) GO TO 200
   60 CONTINUE
C
C     CALCULATE THE RESIDUALS.
C
      IF(L1.EQ.99) THEN
        S1 = 0.
        BSUM1 = 0.
        SBIG1 = 0.
      ELSE
        CALL RES(ZL1,ZL2,TL1,TL2,L1,L2,A,B,SS,S1,BSUM1,SBIG1)
      ENDIF
      CALL RES(ZL2,ZL3,TL2,TL3,L2,L3,A,B,SS,S2,BSUM2,SBIG2)
      FSHAT1 = FSHAT(S1,S2,SBIG1,SBIG2)
C
C     FOR LOWEST LAYER, FILL TWO VALUES OF SI. FIRST HERE...
C
      IF(L1.EQ.99) THEN
        IS = IS + 1
        SI(IS,ISCAN-1) = S2
      ENDIF
      CALL RES(ZL3,ZL4,TL3,TL4,L3,L4,A,B,SS,S3,BSUM3,SBIG3)
      FSHAT2 = FSHAT(S2,S3,SBIG2,SBIG3)
C
C     FILL SECOND VALUE OF SI ALWAYS.
C
      IS = IS + 1
      SI(IS,ISCAN-1) = S3
C
C     CHECK FOR CONFIDENT HEIGHT CORRECTION.
C
      SHGT = ABS(S2+S3)
      SSHGT = (BSUM2+BSUM3) * DTALL * FSHAT2
      IF(((ABS(S2).GT.SBIG2.AND.ABS(S3).GT.0.5*SBIG3)
     &  .OR.(ABS(S3).GT.SBIG3.AND.ABS(S2).GT.0.5*SBIG2))
     &  .AND.(L4-L3.LT.3)
     &  .AND.(L3-L2.LT.3)
     &  .AND.(SHGT.LT.SSHGT)) THEN
        ZCORI(L3,ISCAN) = -0.5*(S2-S3)
        CALL ZCORR(ZL3,ZCORI(L3,ISCAN),L3,ALLZL,31,
     &    ALLZ,5,ICTYPI(L3,ISCAN),1)
        ZI(L3,ISCAN) = ZL3
        TCORI(L3,ISCAN) = 0.
        GO TO 50
      ENDIF
C
C     CHECK FOR CONFIDENT TEMPERATURE CORRECTION.
C
```

```
      STMP = ABS(S2/BSUM2 - S3/BSUM3)
      SSTMP = (1./BSUM2 + 1./BSUM3) * DZALL * FSHAT2
      IF(((ABS(S2).GT.SBIG2.AND.ABS(S3).GT.0.5*SBIG3)
     &  .OR.(ABS(S3).GT.SBIG3.AND.ABS(S2).GT.0.5*SBIG2))
     &  .AND.(L4-L3.LT.3)
     &  .AND.(L3-L2.LT.3)
     &  .AND.(STMP.LT.SSTMP)) THEN
        TCORI(L3,ISCAN) = 0.5 * (S2/BSUM2 + S3/BSUM3)
        CALL TCORR(TL2,TL3,TL4,TCORI(L3,ISCAN),ZL2,ZL3,ZL4,
     &    ALLT,101,ICTYPI(L3,ISCAN),0,2)
        TI(L3,ISCAN) = TL3
        ZCORI(L3,ISCAN) = 0.
        GO TO 50
      ENDIF
C
C     NO CONFIDENT TYPE 1 OR 2 CORRECTIONS.
C     IF THERE IS NO 4TH LEVEL DATA,
C     OR NEAR THE TOP, CHECK FOR ERRORS OF
C     TYPES 3, 4, 5, AND 6 (STATEMENT NO. 150).
C
      IF(L1.LT.2.OR.L1.EQ.99) GO TO 150
      IF(L4.GE.LTOP) GO TO 150
C
C     CHECK FOR TWO ERRORS GIVING LARGE RESIDUALS.
C     PERFORM THE TESTS ONLY FOR SUFFICIENTLY LARGE RESIDUALS.
C
      R1 = ABS(S1)/SBIG1
      R2 = ABS(S2)/SBIG2
      R3 = ABS(S3)/SBIG3
      IF(((R1.GT.1.AND.(R2.GT.0.5.OR.R3.GT.0.5))
     &  .OR.(R2.GT.1.AND.(R1.GT.0.5.OR.R3.GT.0.5))
     &  .OR.(R3.GT.1.AND.(R1.GT.0.5.OR.R2.GT.0.5)))
     &  .AND.(L2-L1.LT.3)
     &  .AND.(L3-L2.LT.3)
     &  .AND.(L4-L3.LT.3)) THEN
C
C     TEST FOR TWO HEIGHT ERRORS.
C
      ZZ = ABS(S1 + S2 + S3)
      ZZR = CON * DTALL * SQRT((BSUM1+BSUM2)**2 +
     &  (BSUM2+BSUM3)**2)
      IF(ZZ.LT.ZZR) THEN
        ZCORI(L2,ISCAN) = -S1
        ZCORI(L3,ISCAN) = S3
        ZOLD2 = ZL2
        ZOLD3 = ZL3
        CALL ZCORR(ZL2,ZCORI(L2,ISCAN),L2,ALLZL,31,ALLZ,5,
     &    ICTYPI(L2,ISCAN),7)
        CALL ZCORR(ZL3,ZCORI(L3,ISCAN),L3,ALLZL,31,ALLZ,5,
     &    ICTYPI(L3,ISCAN),7)
        IF(L2.GE.3.AND.ABS(ZCORI(L2,ISCAN)).LT.100.
     &    .AND.ABS(ZCORI(L3,ISCAN)).LT.100.) THEN
          ZL2 = ZOLD2
          ZL3 = ZOLD3
          ZCORI(L2,ISCAN) = 0.
          ZCORI(L3,ISCAN) = 0.
          ICTYPI(L2,ISCAN) = 11
```

```
            ICTYPI(L3,ISCAN) = 11
          ENDIF
          ZI(L2,ISCAN) = ZL2
          ZI(L3,ISCAN) = ZL3
          TCORI(L2,ISCAN) = 0.
          TCORI(L3,ISCAN) = 0.
          GO TO 50
        ENDIF
C
C       TEST FOR TWO TEMPERATURE ERRORS.
C
        TT = ABS(S1/BSUM1 - S2/BSUM2 + S3/BSUM3)
        TTR = CON * DZALL * SQRT((1./BSUM1 + 1./BSUM2)**2
     &  + (1./BSUM2 + 1./BSUM3)**2)
        IF(TT.LT.TTR) THEN
          TCORI(L2,ISCAN) = S1/BSUM1
          TCORI(L3,ISCAN) = S3/BSUM3
          CALL TCORR(TL1,TL2,TL3,TCORI(L2,ISCAN),ZL1,ZL2,ZL3,
     &      ALLT,101,ICTYPI(L2,ISCAN),-1,8)
          CALL TCORR(TL2,TL3,TL4,TCORI(L3,ISCAN),ZL2,ZL3,ZL4,
     &      ALLT,101,ICTYPI(L3,ISCAN),0,8)
          TI(L2,ISCAN) = TL2
          TI(L3,ISCAN) = TL3
          ZCORI(L2,ISCAN) = 0.
          ZCORI(L3,ISCAN) = 0.
          GO TO 50
        ENDIF
C
C       TEST FOR ERROR TO LOWER HEIGHT, UPPER TEMPERATURE.
C
        ZT = ABS(BSUM3*(S1+S2) - BSUM2*S3)
        ZTR = SQRT(((BSUM1+BSUM2)*BSUM3*CON*DTALL)**2
     &  + ((BSUM2+BSUM3)*CON*DZALL)**2)
        IF(ZT.LT.ZTR) THEN
          ZCORI(L2,ISCAN) = -S1
          TCORI(L3,ISCAN) = S3/BSUM3
          ZOLD = ZL2
          TOLD = TL3
          CALL ZCORR(ZL2,ZCORI(L2,ISCAN),L2,ALLZL,31,
     &      ALLZ,5,ICTYPI(L2,ISCAN),9)
          CALL TCORR(TL2,TL3,TL4,TCORI(L3,ISCAN),ZL2,ZL3,ZL4,
     &      ALLT,101,ICTYPI(L3,ISCAN),0,9)
          IF(ICTYPI(L3,ISCAN).EQ.12) THEN
            ICTYPI(L2,ISCAN) = 99
            ICTYPI(L3,ISCAN) = 99
            ZL2 = ZOLD
            TL3 = TOLD
            ZCORI(L2,ISCAN) = 0.
            TCORI(L3,ISCAN) = 0.
          ENDIF
          ZI(L2,ISCAN) = ZL2
          TI(L3,ISCAN) = TL3
          ZCORI(L3,ISCAN) = 0.
          TCORI(L2,ISCAN) = 0.
          GO TO 50
        ENDIF
C
```

```
C     TEST FOR ERROR TO LOWER TEMPERATURE, UPPER HEIGHT.
C
      TZ = ABS(BSUM1*(S2+S3) - BSUM2*S1)
      TZR = SQRT(((BSUM2+BSUM3)*BSUM1*CON*DTALL)**2
     &  + ((BSUM1+BSUM2)*CON*DZALL)**2)
      IF(TZ.LT.TZR) THEN
        ZCORI(L3,ISCAN) = S3
        TCORI(L2,ISCAN) = S1/BSUM1
        ZOLD = ZL3
        TOLD = TL2
        CALL ZCORR(ZL3,ZCORI(L3,ISCAN),L3,ALLZL,31,ALLZ,5,
     &    ICTYPI(L3,ISCAN),10)
        CALL TCORR(TL1,TL2,TL3,TCORI(L2,ISCAN),ZL1,ZL2,ZL3,
     &    ALLT,101,ICTYPI(L2,ISCAN),0,10)
        IF(ICTYPI(L2,ISCAN).EQ.12) THEN
          ICTYPI(L2,ISCAN) = 99
          ICTYPI(L3,ISCAN) = 99
          ZL3 = ZOLD
          TL2 = TOLD
          ZCORI(L3,ISCAN) = 0.
          TCORI(L2,ISCAN) = 0.
        ENDIF
        ZI(L3,ISCAN) = ZL3
        TI(L2,ISCAN) = TL2
        TCORI(L3,ISCAN) = 0.
        ZCORI(L2,ISCAN) = 0.
        GO TO 50
      ENDIF
      ENDIF
  150 CONTINUE
C
C     CHECK FOR TYPE 3 ERRORS.
C
      IF((ABS(S1).GT.SBIG1.AND.ABS(S2).GT.0.5*SBIG2)
     &  .OR.(ABS(S2).GT.SBIG2.AND.ABS(S1).GT.0.5*SBIG1)) THEN
        ZCORI(L2,ISCAN) = (BSUM1*S2 - BSUM2*S1)/(BSUM1+BSUM2)
        IF(L2.LE.3) ZCORI(L2,ISCAN) = ANINT(ZCORI(L2,ISCAN))
        IF(L2.GT.3) ZCORI(L2,ISCAN) = 10.*ANINT(ZCORI(L2,ISCAN)/10.)
        TCORI(L2,ISCAN) = (S1+S2)/(BSUM1+BSUM2)
        TCORI(L2,ISCAN) = 0.1 * ANINT(10.*TCORI(L2,ISCAN))
        ICTYPI(L2,ISCAN) = 3
        GO TO 50
      ENDIF
C
C     CHECK FOR ERROR(S) AT THE BOTTOM.
C
      IF(L2.EQ.LB.AND.ABS(S2).GT.SBIG2.
     &  AND.ABS(S3).LT.0.5*SBIG3) THEN
        ZCORI(L2,ISCAN) = S2
        IF(L2.LE.3) ZCORI(L2,ISCAN) = ANINT(ZCORI(L2,ISCAN))
        IF(L2.GT.3) ZCORI(L2,ISCAN) = 10. * ANINT(ZCORI(L2,ISCAN)/10.)
        TCORI(L2,ISCAN) = S2/BSUM2
        TCORI(L2,ISCAN) = 0.1 * ANINT(10.*TCORI(L2,ISCAN))
        ICTYPI(L2,ISCAN) = 4
        GO TO 50
      ENDIF
C
```

```
C     CHECK FOR ISOLATED LARGE RESIDUAL.
C
      IF(ABS(S2).GT.1.5*SBIG2.AND.ABS(S1).LT.0.5*SBIG1.
     &  AND.ABS(S3).LT.0.5*SBIG3) THEN
        ICTYPI(L3,ISCAN) = 6
        GO TO 50
      ENDIF
C
C     NO ERRORS FOUND.  GO BACK TO 50 TO GET
C     NEXT LEVELS OF DATA.
C
      GO TO 50
C
C     CHECK FOR ERROR(S) AT THE TOP.  THEN RETURN
C     FOR SECOND PASS (TO STATEMENT 40).
C
  200 CONTINUE
C
C     NOTE THAT S2, S3 ARE NOT RECLACULATED IN THIS SPECIAL CASE.
C     HOWEVER, THE L'S HAVE BEEN RECALCULATED.
C
C     CHECK FOR ERROR AT THE TOP.
C
      IF(ABS(S3).GT.SBIG3.
     &  AND.ABS(S2).LT.0.5*SBIG2) THEN
        ZCORI(L3,ISCAN) = -S3
        IF(L3.LE.3) ZCORI(L3,ISCAN) = ANINT(ZCORI(L3,ISCAN))
        IF(L3.GT.3) ZCORI(L3,ISCAN) = 10. * ANINT(ZCORI(L3,ISCAN)/10.)
        TCORI(L3,ISCAN) = S3/BSUM3
        TCORI(L3,ISCAN) = 0.1 * ANINT(10.*TCORI(L3,ISCAN))
        ICTYPI(L3,ISCAN) = 5
      ENDIF
      GO TO 40
  300 CONTINUE
C
C     COME HERE TO FILL IN OUTPUT FIELDS.
C
      DO 320 K=1,LEV
        ZC(K) = ZI(K,3)
        TC(K) = TI(K,3)
        S(K) = SI(K,2)
        ICTYP(K) = 0
        ZCOR(K) = 0.
        TCOR(K) = 0.
        DO 310 II=1,3
          IF(ICTYPI(K,II).NE.0) ICTYP(K) = ICTYPI(K,II)
          IF(ZCORI(K,II).NE.0.) ZCOR(K) = ZCORI(K,II)
          IF(TCORI(K,II).NE.0.) TCOR(K) = TCORI(K,II)
  310   CONTINUE
  320 CONTINUE
      END
```

```
C*********************************************************************
      SUBROUTINE RES(Z1,Z2,T1,T2,L1,L2,A,B,SS,S,BSUM,SBIG)
C$$$ SUBPROGRAM DOCUMENTATION BLOCK
C
C SUBPROGRAM:    RES     CALCULATE HYDROSTATIC RESIDUALS
C   PRGMMR: W. COLLINS    ORG: W/NMC22    DATE: 89-02-02
C
C ABSTRACT:  CALCULATE HYDROSTATIC RESIDUAL FOR MANDATORY
C            LAYERS.  ACCOUNT FOR MISSINGS.
C
C PROGRAM HISTORY LOG:
C   89-02-02  ORIGINAL    W. COLLINS
C
C USAGE:      CAL RES(Z1,Z2,T1,T2,L1,L2,A,B,SS,S,BSUM,SBIG)
C
C
C   INPUT ARGUMENT LIST:
C         (Z1,T1) - LOWER HEIGHT (M) AND TEMPERATURE (CELCIUS)
C         (Z2,T2) - UPPER HEIGHT AND TEMPERATURE
C         (L1,L2) - INDICES FOR TWO LEVELS
C         A,B     - ARRAYS OF COEFFICIENTS
C         SS      - ARRAY OF ADMISSIBLE RESIDUALS
C
C   OUTPUT ARGUMENT LIST:
C         S       - RESIDUAL FOR LAYER
C         BSUM    - B FOR LAYER
C         SBIG    - ADMISSIBLE RESIDUAL FOR LAYER
C
C ATTRIBUTES:
C   LANGUAGE: VS FORTRAN
C   MACHINE:  NAS
C
C$$$
      DIMENSION A(1), B(1), SS(1)
      ASUM = 0.
      BSUM = 0.
      SSUM = 0.
      L2M = L2 - 1
      DO 10 L=L1,L2M
        ASUM = ASUM + A(L)
        BSUM = BSUM + B(L)
        SSUM = SSUM + SS(L)**2
   10 CONTINUE
      SBIG = SQRT(SSUM)
      S = Z2 - Z1 - ASUM - BSUM*(T1+T2)
      RETURN
      END
```

```
C*******************************************************************
      SUBROUTINE FNLEV(LAST,Z,T,ZL1,ZL2,ZL3,ZL4,TL1,TL2,TL3,
     &  TL4,L1,L2,L3,L4,NLEV,IER)
C
C     FIND NEXT COMPLETE LEVEL OF DATA.
C       LAST     - INPUT: LAST LOWEST OF 4 COMPLETE LEVELS
C                  OUTPUT: NEXT LOWEST OF 4 COMPLETE LEVELS
C       Z        - ARRAY OF INPUT HEIGHTS (M)
C       T        - ARRAY OF INPUT TEMPERATURES (CELCIUS)
C       (ZL,TL)  - VALUES OF Z, T AT NEXT 4 COMPLETE LEVELS
C       L'S      - INDEX FOR NEXT 4 COMPLETE LEVELS
C                  SET EQUAL TO 99 FOR NO MORE COMPLETE LEVEL
C       NLEV     - NUMBER OF LEVELS OF Z, T.
C       IER      = 0     4 MORE COMPLETE LEVELS FOUND
C                = 1     LESS THAN 4 MORE COMPLETE LEVELS
C
      DIMENSION Z(1), T(1), ZL(4), TL(4), L(4)
      DATA ZMAX /90000./, TMAX /9000./
      DATA ZMSG /99999./, TMSG /9999.9/, LMSG /99/
      IER = 0
      DO 5 I=1,4
        L(I) = LMSG
        ZL(I) = ZMSG
        TL(I) = TMSG
    5 CONTINUE
      LL = LAST + 1
      DO 30 I=1,4
        DO 20 J=LL,NLEV
          JJ = J
          IF(Z(J).LT.ZMAX.AND.T(J).LT.TMAX) GO TO 25
   20   CONTINUE
        IER = 1
        GO TO 40
   25 CONTINUE
        ZL(I) = Z(JJ)
        TL(I) = T(JJ)
        L(I) = JJ
        IF(I.EQ.1) LAST = JJ
        LL = JJ + 1
   30 CONTINUE
   40 CONTINUE
      L1 = L(1)
      L2 = L(2)
      L3 = L(3)
      L4 = L(4)
      ZL1 = ZL(1)
      ZL2 = ZL(2)
      ZL3 = ZL(3)
      ZL4 = ZL(4)
      TL1 = TL(1)
      TL2 = TL(2)
      TL3 = TL(3)
      TL4 = TL(4)
      RETURN
      END
```

```
C*****************************************************************
      SUBROUTINE FIRST(LAST,Z,T,ZL1,ZL2,ZL3,ZL4,TL1,TL2,TL3,
     &  TL4,L1,L2,L3,L4,NLEV,IER)
C
C     FIND FIRST 3 COMPLETE LEVEL OF DATA.
C       LAST    - OUTPUT: LOWEST 3 COMPLETE LEVELS
C       Z       - ARRAY OF INPUT HEIGHTS (M)
C       T       - ARRAY OF INPUT TEMPERATURES (CELCIUS)
C       (ZL,TL) - VALUES OF Z, T AT NEXT 4 COMPLETE LEVELS
C       L'S     - INDEX FOR NEXT 4 COMPLETE LEVELS
C                 SET EQUAL TO 99 FOR NO MORE COMPLETE LEVEL
C       NLEV    - NUMBER OF LEVELS OF Z, T.
C       IER     = 0     AT LEAST 3 MORE COMPLETE LEVELS FOUND
C               = 1     NOT AT LEAST 3 MORE COMPLETE LEVELS
C
      DIMENSION Z(1), T(1), ZL(4), TL(4), L(4)
      DATA ZMAX /90000./, TMAX /9000./
      DATA ZMSG /99999./, TMSG /9999.9/, LMSG /99/
      IER = 0
      DO 5 I=1,4
        L(I) = LMSG
        ZL(I) = ZMSG
        TL(I) = TMSG
    5 CONTINUE
      LL = LAST + 1
      DO 30 I=1,3
        DO 20 J=LL,NLEV
          JJ = J
          IF(Z(J).LT.ZMAX.AND.T(J).LT.TMAX) GO TO 25
   20   CONTINUE
        IF(I.LE.3) IER = 1
        GO TO 40
   25 CONTINUE
        ZL(I+1) = Z(JJ)
        TL(I+1) = T(JJ)
        L(I+1) = JJ
        IF(I.EQ.1) LAST = JJ
        LL = JJ + 1
   30 CONTINUE
   40 CONTINUE
      L1 = L(1)
      L2 = L(2)
      L3 = L(3)
      L4 = L(4)
      ZL1 = ZL(1)
      ZL2 = ZL(2)
      ZL3 = ZL(3)
      ZL4 = ZL(4)
      TL1 = TL(1)
      TL2 = TL(2)
      TL3 = TL(3)
      TL4 = TL(4)
      RETURN
      END
```

```
C*****************************************************************
      SUBROUTINE ZCORR(ZC,ZCOR,J,ALLZL,NZL,ALLZ,NZ,
     &  ICTYP,ITYP)
C
C     FINDS SIMPLE CORRECTION TO HEIGHT AND DOES PROPER ROUNDING.
C
C     INPUT:
C         ZC     - GEOPOTENTIAL HEIGHT (METERS)
C         ZCOR   - HEIGHT CORRECTION (METERS)
C         J      - MANDATORY LEVEL INDEX
C         ALLZL  - ARRAY OF ALLOWABLE DEVIATIONS FROM ZCOR FOR
C                  HEIGHTS BELOW 500MB
C         ALLZ   - ARRAY OF ALLOWABLE DEVIATIONS FROM ZCOR FOR
C                  HEIGHTS AT AND ABOVE 500MB
C         ITYP   - CORRECTION TYPE
C
C     OUTPUT:
C         ZC     - CORRECTED GEOPOTENTIAL HEIGHT (METERS)
C         ZCOR   - HEIGHT CORRECTION APPLIED (METERS)
C         ICTYP  - CORRECTION TYPE
C                  NORMALLY PASSED FROM INPUT, BUT IF CORRECTION IS
C                  LESS THAN 100M, IT IS SET TO 11.
C
      DIMENSION ALLZL(NZL), ALLZ(NZ)
C
C     ROUND TO NEAREST 10 METERS ABOVE 700MB.
C     ROUND TO NEAREST METER BELOW 500MB.
C
      ICTYP = ITYP
      IF(J.LE.3) THEN
        ZCOR = ANINT(ZCOR)
        CALL ONEDIG(ZCOR,ZC,ALLZL,NZL)
      ELSE
        ZCOR = 10.*ANINT(ZCOR/10.)
        CALL ONEDIG(ZCOR,ZC,ALLZ,NZ)
        IF(ABS(ZCOR).LT.100..AND.ITYP.LT.7) THEN
          ZCOR = 0.
          ICTYP = 11
        ENDIF
      ENDIF
      ZC = ZC + ZCOR
      RETURN
      END
```

```
C**********************************************************************
      SUBROUTINE TCORR(TC1,TC2,TC3,TCOR2,ZC1,ZC2,ZC3,
     &  ALLT,NT,ICTYP,IC,ITYP)
C
C     FINDS SIMPLE CORRECTION TO TEMPERATURE AND DOES PROPER
C     ROUNDING.
C
C     INPUT:
C         TC     - TEMPERATURE (CELCIUS)
C         TCOR   - TEMPERATURE CORRECTION (CELCIUS)
C         ZC     - GEOPOTENTIAL HEIGHT (METERS)
C         JP,JM,JMM - MANDATORY LEVEL INDICES
C         ALLT   - ARRAY OF ALLOWABLE DEVIATIONS FROM TCOR
C         ITYP   - CORRECTION TYPE
C
C     OUTPUT:
C         TC     - CORRECTED TEMPERATURE (CELCIUS)
C         TCOR   - TEMPERATURE CORRECTION APPLIED (CELCIUS)
C         IC     - SWITCH WHICH IS NORMALLY 0 OR POSITIVE, BUT
C                  SET TO NEGATIVE IF ONLY LOWER LAPSE IS TO
C                  BE CHECKED
C         ICTYP  - CORRECTION TYPE
C                  NORMALLY PASSED FROM INPUT, BUT IF CORRECTION
C                  GIVES UNSTABLE LAYER(S), IT IS SET TO 12.
C
      DIMENSION ALLT(NT)
      DATA ALAPS /-.010737/, DTALL /5./
      ICTYP = ITYP
      TCOLD = TC2
C     ALLOW FOR 10 PERCENT ERROR IN LAPSE RATE DUE TO
C     RANGE OF ALLOWABLE TEMPERATURES.
C     ALAPS = -(G/CP) * 1.10
C     LAPSES BASED UPON ASSUMPTION OF SIGN ERROR...
      IF(ZC3.NE.ZC2.AND.IC.GE.0) THEN
        ALAPSP = (TC3+TC2)/(ZC3-ZC2)
      ELSE
        ALAPSP = 0.
      ENDIF
      IF(ZC2.NE.ZC1) THEN
        ALAPSM = (-TC2-TC1)/(ZC2-ZC1)
      ELSE
        ALAPSM = 0.
      ENDIF
      IF(ABS(2.*TC2+TCOR2).LT.DTALL
     &  .AND.ALAPSM.GE.ALAPS
     &  .AND.ALAPSP.GE.ALAPS) THEN
        TC2 = -TC2
        TCOR2 = 2. * TC2
      ELSE
C       ROUND THE CORRECTION TO NEAREST TENTH DEGREE
        TCOR2 = .1 * ANINT(10.*TCOR2)
C       ROUND THE TEMPERATURE TO NEAREST TENTH DEGREE
C       (THIS SHOULD BE UNNECESSARY)
        TC2 = .1 * ANINT(10.*TC2)
C
C     FIND SIMPLE CORRECTION FOR VALUES TO TENTHS.
C
```

```
      ICORT = 10. * TCOR2
      ICCT = 10. * TC2
      TCORT = ICORT
      TCT = ICCT
      CALL ONEDIG(TCORT, TCT, ALLT, NT)
      TCOR2 = 0.1 * TCORT
      IF(ABS(TCOR2).LT.5.) THEN
        TCOR2 = 0.
        TC2 = TCOLD
        ICTYP = 22
        RETURN
      ELSE
        TC2 = 0.1 * (TCT + TCORT)
      ENDIF
    ENDIF
C
C     MAKE SURE THAT THE LAPSE RATES ABOVE AND BELOW
C     ARE ADIABATICALLY STABLE.  IF NOT, RESTORE
C     THE ORIGINAL TEMPERATURE, TCOLD.
C
C     ALSO, CHECK FOR TEMPERATURE LAPSES ABOVE AND
C     BELOW OF SAME SIGN.
C
C     ALSO, DO NOT GIVE CORRECTIONS FOR LAYERS WITH
C     MORE THAN ONE LAYER MISSING.
C
      IF(ZC3.NE.ZC2.AND.IC.GE.0) THEN
        ALAPSP = (TC3-TC2)/(ZC3-ZC2)
      ELSE
        ALAPSP = 0.
      ENDIF
      IF(ZC2.NE.ZC1) THEN
        ALAPSM = (TC2-TC1)/(ZC2-ZC1)
      ELSE
        ALAPSM = 0.
      ENDIF
      IF(ALAPSM.GE.ALAPS
     &  .AND.ALAPSP.GE.ALAPS
     &  .AND.JP-JMM.LE.3
     &  .AND.((TC3-TC2)*(TC2-TC1)).GT.-40.)
     &  THEN
        ICTYP = ITYP
      ELSE
        TC2 = TCOLD
        TCOR2 = 0.
        ICTYP = 12
      ENDIF
      RETURN
      END
```

```
C**************************************************************
      FUNCTION FSHAT(S1,S2,SBIG1,SBIG2)
      SHAT = (ABS(S1)+ABS(S2)) / (SBIG1+SBIG2)
      IF(SHAT.LE.1.) THEN
        FSHAT = 1.
      ELSE
        FSHAT = 1. + ALOG10(SHAT)
      ENDIF
      RETURN
      END
```