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A Guide to WMO Code Form FM 94 BUFR

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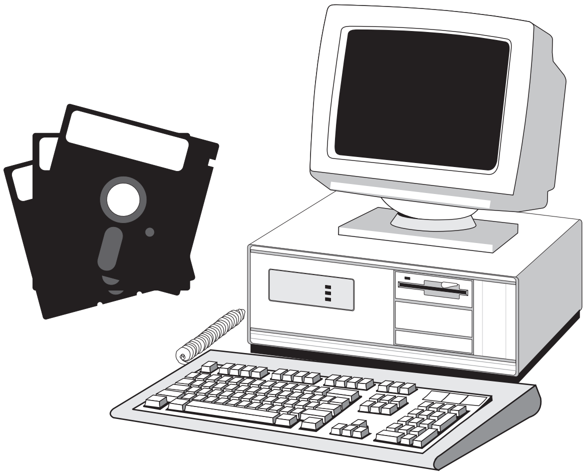

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A GUIDE TO THE WMO CODE FORM
FM 94 BUFR

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A GUIDE TO WMO CODE FORM FM 94 BUFR

FCM-I6 1995

FOREWORD

This guide documents and defines the unique self-descriptive characteristics of FM-94 BUFR and serves to greatly improve the user-friendliness of this widely used code form.

The development and global implementation of BUFR code has been on-going for the past several years. In 1988, the World Meteorological Organization adopted BUFR code as a test code and recently adopted it as an operational code. The Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) Working Group for Meteorological Information Management (WG/MIM) recognized the need for an improved guide to the code that provided examples and detailed explanations on how to encode the BUFR code. This recognition led to the development of this document under the WG/MIM's guidance. The WG/MIM has been instrumental in encouraging, reviewing and guiding the development of this document.

The OFCM recognizes that we are in a time period marked by rapid world-wide growth and enhancement of meteorological communications systems. OFCM believes that this document, **A Guide to WMO Code Form FM 94 BUFR: FCM-I6 1995,** will have positive impact on the acceptance and use of the BUFR code. We commend Mr. Wayne Thorpe, Dr. John D. Stackpole, and the WG/MIM for their most significant contributions.

Julian M. Wright, Jr.
Federal Coordinator for
Meteorological Services and
Supporting Research

A GUIDE TO THE WMO CODE FORM FM 94 BUFR

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INTRODUCTION

The World Meteorological Organization (WMO) code form FM 94 BUFR(Binary Universal Form for the Representation of meteorological data) is a binary code designed to represent, employing a continuous binary stream, any meteorological data. There is, however, nothing uniquely meteorological about BUFR. The meteorological emphasis is the result of the origin of the code. The code form may be applied to any numerical or qualitative data type.

BUFR is the result of a series of informal and formal "expert meetings" and periods of experimental usage by several meteorological data processing centers. The WMO Commission for Basic Systems (CBS) approved BUFR at its January/February 1988 meeting. Changes were introduced at the meetings of the CBS Working Group on Data Management, Sub-Group on Data Representation in May, 1989 and October 1990. The changes introduced at the October 1990 meeting were of such magnitude that BUFR, Edition 2 was defined, with an effective date of November 7, 1991.

The key to understanding the power of BUFR is the code's self-descriptive nature. A BUFR "message" (or record, the terms are interchangeable in this context) containing observational data of any sort also contains a complete description of what those data are: the description includes identifying the parameter in question, (height, temperature, pressure, latitude, date and time, whatever), the units, any decimal scaling that may have been employed to change the precision from that of the original units, data compression that may have been applied for efficiency, and the number of binary bits used to contain the numeric value of the observation. This data description is all contained in tables which are the major part of the BUFR documentation.

The strength of this self-descriptive feature is in accommodating change. For example, if new observations or observational platforms are developed, there is no need to invent a new code form to represent and transmit the new data; all that is necessary is the publication of additional data description tables. Similarly for the deletion of possibly outdated observations: instead of having to send "missing" indicators for a long period while awaiting a change to a fixed format code, the "missing" data are simply not sent in the message and the data description section is adjusted accordingly. The data description tables are not changed, however, so that archives of old data may be retrieved.

This self-descriptive feature leads to another advantage over character oriented codes - the relative ease of decoding a BUFR message. Where a large number of specialized and complex programs are now needed to decode the plethora of character codes in current use, it is entirely feasible to write a single "universal BUFR decoder" program capable of decoding any BUFR message. It is not a trivial task to write such a BUFR decoder, but once it is done, it is done for all time. The program will not have to change with changes in observational practices; only the tables will need to be augmented, a relatively trivial task.

The development of BUFR has been synonymous with the development of the data description language that is integral to it. Indeed the major portion of the full description of BUFR is a description of the vocabulary and syntax of the data description language. The definition of the data description language, and the "descriptors" that are its vocabulary, are what give BUFR its "universal" aspect. Any piece of information can be described in the language, not just meteorological observations.

The other major aspect of BUFR is reflected in the first initial, "B". BUFR is a purely binary or bit oriented form, thus making it both machine dependent and, at the same time, machine independent. The dependency comes in the construction or interpretation of BUFR messages. There is not much for a human to look at (unless a person is very patient) as all the numbers in a message, whether data descriptors or the data themselves, are binary integers. And that, of course, leads to the machine independence: with BUFR consisting entirely of binary integers any brand of machine can handle BUFR as well as any other.

The binary nature of BUFR leads to another advantage over character codes: the ease and speed of converting the message into an internally useful numeric format. With character codes the conversion from ASCII (or EBCDIC) to integer or floating point is expensive relative to the conversion from binary integers to floating point. The latter is all that BUFR requires. In some tests, the European Centre for Medium-Range Weather Forecasts found a speedup of better than 6 times in decoding BUFR messages over the corresponding TEMP (WMO Radiosonde character code FM 35-IX Ext.) messages. The BUFR data also required about half the machine memory as the character data.

All of this does assume the availability of well designed computer programs that are capable of parsing the descriptors, which can be a complex task, matching them to the bit stream of data and extracting the numbers from the stream, responding properly to the arrival of new (or the departure of old) data descriptors, and reformatting the numbers in a way suitable for subsequent calculations. The bit oriented nature of the message also requires the availability of bit transparent communications systems such as the x.25 protocol. Such protocols have various error detecting schemes built in so there need be little concern about the corruption of information in the transmission process.

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CHAPTER 1

SECTIONS OF A BUFR MESSAGE

1.1 Introduction. The term "message" refers to BUFR being used as a data transmission format; however, BUFR can be, and is, used in several meteorological data processing centers as an on-line storage format as well as a data archiving format.

1.2 Specifications of Octets Within Each Section. For transmission of data, each BUFR message consists of a continuous binary stream comprising 6 sections.

<table>
<tr><th colspan="6">CONTINUOUS BINARY STREAM</th></tr>
<tr><td>section
0</td><td>section
1</td><td>section
2</td><td>section
3</td><td>section
4</td><td>section
5</td></tr>
</table>

Section Number	Name	Contents
0	indicator section	"BUFR" (coded according to the CCITT International Alphabet No. 5, which is functionally equivalent to ASCII), length of message, BUFR edition number.
1	identification section	length of section, identification of the message.
2	optional section	length of section and any additional items for local use by data processing centers.
3	data description section	length of section, number of data subsets, data category flag, data compression flag, and a collection of data descriptors which define the form and content of individual data elements.
4	data section	length of section and binary data.
5	end section	"7777" (coded in CCITT International Alphabet No. 5).

Each of the sections of a BUFR message is made up of a series of octets. The term octet, meaning 8 bits, was coined to avoid having to continually qualify byte as an 8-bit byte. Also, in French, the words "byte" and "bit" are pronounced the same (as "beet"), "octet" clearly avoids that problem, too. An individual section shall always consist of an even number of octets, with extra bits added on and set to zero when necessary. Within each section, octets are numbered 1, 2, 3, etc., starting at the beginning of each section. Bit positions within octets are referred to as bit 1 to bit 8, where bit 1 is the most significant, leftmost, or high order bit. An octet with only bit 8 set would have the integer value 1.

Theoretically there is no upper limit to the size of a BUFR message but, by convention, BUFR messages are restricted to 15000 octets or 120000 bits. This limit is to allow an entire BUFR message to be contained within memory of most computers for decoding. It is also a limit set by the capabilities of the Global Telecommunications System (GTS) of the WMO. The BLOK feature, described elsewhere, can be used to break very long BUFR messages into parts, if necessary.

Figure 1-1 is an example of a complete BUFR message containing 52 octets. This particular message contains 1 temperature observation of 295.2 degrees K from WMO block/station 72491. (Note that optional Section 2 is not included.) Figures 1-2 through 1-7 illustrate decoding of the individual sections. The spaces between octets in Figures 1-2 through 1-7 were added to improve readability.

```
                                                end of section 0
010000100101010101000110010100100000000000000000001101000000001000000000000000

000001001000000000000000000000011100000000000000000000001000000000000000100000
                                    end of section 1
000101011101000001000001110100001100000000000000000000000000000000000000111000

000000000000000000000110000000000000001000000010000000100000010000011000000010 0
         end of section 3                                  end of section 4
000000000100000000000000000010000000000010010000111101011101110001000000001101
     end of section 5
11001101110011011100110111
```

Figure 1-1. Example of a complete BUFR message containing 52 octets

1.2.1 Section 0 - Indicator Section.

CONTINUOUS BINARY STREAM					
SECTION 0	section 1	section 2	section 3	section 4	section 5

Octet No.	Contents
1 - 4	"BUFR" (coded according to the CCITT International Alphabet No. 5)
5 - 7	Total length of BUFR message, in octets (including Section 0)
8	BUFR edition number (currently 2)

The earlier editions of BUFR did not include the total message length in octets 5-7. Thus, in decoding BUFR Edition 0 and 1 messages, there was no way of determining the entire length of the message without scanning ahead to find the individual lengths of each of the sections. Edition 2 eliminates this problem by including the total message length right up front. By design, in BUFR Edition 2, octet 8, containing the BUFR Edition number, is in the same octet position relative to the start of the message as it was in Editions 0 and 1. By keeping the relative position fixed, a decoder program can determine, at the outset, which BUFR version was used for a particular message and then behave accordingly. This means, for example, that archives of old (pre-Edition 2) records need not be updated.

OCTET NO.	1	2	3	4	5	6	7	8
BINARY	01000010	01010101	01000110	01010010	00000000	00000000	00110100	00000010
HEXADECIMAL	4 2	5 5	4 6	5 2	0 0	0 0	3 4	0 2
DECODED	B	U	F	R			52	2

length of message in octets

BUFR Edition

Figure 1-2. Decoding Section 0

1.2.2 Section 1 - Identification Section.

<table>
<tr><td colspan="6">CONTINUOUS BINARY STREAM</td></tr>
<tr><td>section 0</td><td>SECTION 1</td><td>section 2</td><td>section 3</td><td>section 4</td><td>section 5</td></tr>
</table>

Octet No.	Contents
1 - 3	Length of section, in octets
4	BUFR master table (zero if standard WMO FM 94 BUFR tables are used - provides for BUFR to be used to represent data from other disciplines which may have their own versions of master tables and local tables)
5 - 6	Originating centre: code table 0 01 031
7	Update sequence number (zero for original BUFR messages; incremented for updates)
8	Bit 1 = 0 no optional section = 1 optional section included Bits 2 - 8 set to zero (reserved)
9	Data category type (BUFR Table A)
10	Data category sub-type (defined by local ADP centres)
11	Version number of master tables used (currently 2 for WMO FM 94 BUFR tables)
12	Version number of local tables used to augment the master table in use
13	Year of century
14	Month
15	Day
16	Hour
17	Minute
18 -	Reserved for local use by ADP centres

```
OCTET NO.           1        2        3        4        5        6        7        8

BINARY          00000000 00000000 00010010 00000000 00000000 00111010 00000000 00000000

  HEXADECIMAL       0   0    0   0    1   2    0   0    0   0    3   A    0   0

    DECODED                               18       0                 58
                   length of section
                          standard BUFR tables
                              originating center (US Navy - FNOC)
                                          flag indicating Section 2 not included


OCTET NO.           9       10       11       12       13       14       15       16

BINARY          00000010 00000000 00000010 00000001 01011110 00000100 00011101 00001100

HEXADECIMAL       0   2    0   0    0   2    0   1    5   E    0   4    1   D    0   C

                 DECODED              2       0        2        1       94        4       29        12
                      data category
                     data category sub-type
                           version of master tables
                                     version of local tables
                                                      year of century
                                                                   month
                                                                              day
                                                                                      hour
                 OCTET NO.          17       18

                 BINARY          00000000 00000000

                   HEXADECIMAL       0   0    0   0

                     DECODED              0        0

                               minute
                                     local use
```

Figure 1-3. Decoding Section 1

The length of Section 1 can vary between BUFR messages. Beginning with octet 18, a data processing center may add any type of information they choose. A decoding program may not know what that information may be. Knowing what the length of the section is, as indicated in octets 1-3, a decoder program can skip over the information that begins at octet 18 and position itself at the next section, either Section 2, if included, or Section 3. Bit 1 of octet 8 indicates if Section 2 is included. If there is no information beginning at octet 18, one octet must still be included (set to 0) in order to have an even number of octets within the section.

1.2.3 Section 2 - Optional Section.

CONTINUOUS BINARY STREAM					
section 0	section 1	**SECTION** **2**	section 3	section 4	section 5

Octet No.	Contents
1 - 3	Length of section, in octets
4	set to zero (reserved)
5 -	Reserved for use by ADP centres

Section 2 may or may not be included in any BUFR message. When it is contained within a BUFR message, bit 1 of octet 8, Section 1, is set to 1. If Section 2 is not included in a message then bit 1 of octet 8, Section 1 is set to 0. Section 2 may be used for any purpose by an originating center. The only restrictions on the use of Section 2 are that octets 1 - 3 are set to the length of the section, octet 4 is set to zero and the total length of the section contains an even number of octets.

A typical use of this optional section could be in a data base context. The section might contain pointers into the data section of the message, pointers which indicate the relative location of the start of individual sets of observations (one station’s worth, for example) in the data. There could also be some sort of index term included, such as the WMO block and station number. This would make it quite easy to find a particular observation quickly and avoid decoding the whole message just to find one or two specific data elements.

1.2.4 Section 3 - Data Description Section.

CONTINUOUS BINARY STREAM					
section 0	section 1	section 2	**SECTION 3**	section 4	section 5

Octet No.	Contents
1 - 3	Length of section, in octets
4	set to zero (reserved)
5 - 6	number of data subsets
7	Bit 1 = 1 observed data
	= 0 other data
	Bit 2 = 1 compressed data
	= 0 non-compressed data
	Bit 3 - 8 set to zero (reserved)
8 -	A collection of descriptors which define the form and content of the individual data elements which comprise one data subset in the data section.

If octets 5-6 indicate that there is more than one data subset in the message then multiple sets of observations, all with the same format (as described by the data descriptors) will be found in Section 4. This is a means of building "collectives" of observations. Doing so realizes a large portion of the potential of efficiency in BUFR.

In the flag bits of octet 7, "observed data" is taken to mean just that; "other data", is by custom, if not explicit statement, presumed to be forecast information, or possibly some form of "observation," indirectly derived from "true" observations. The nature of "data compression" will be described in Chapter 4.

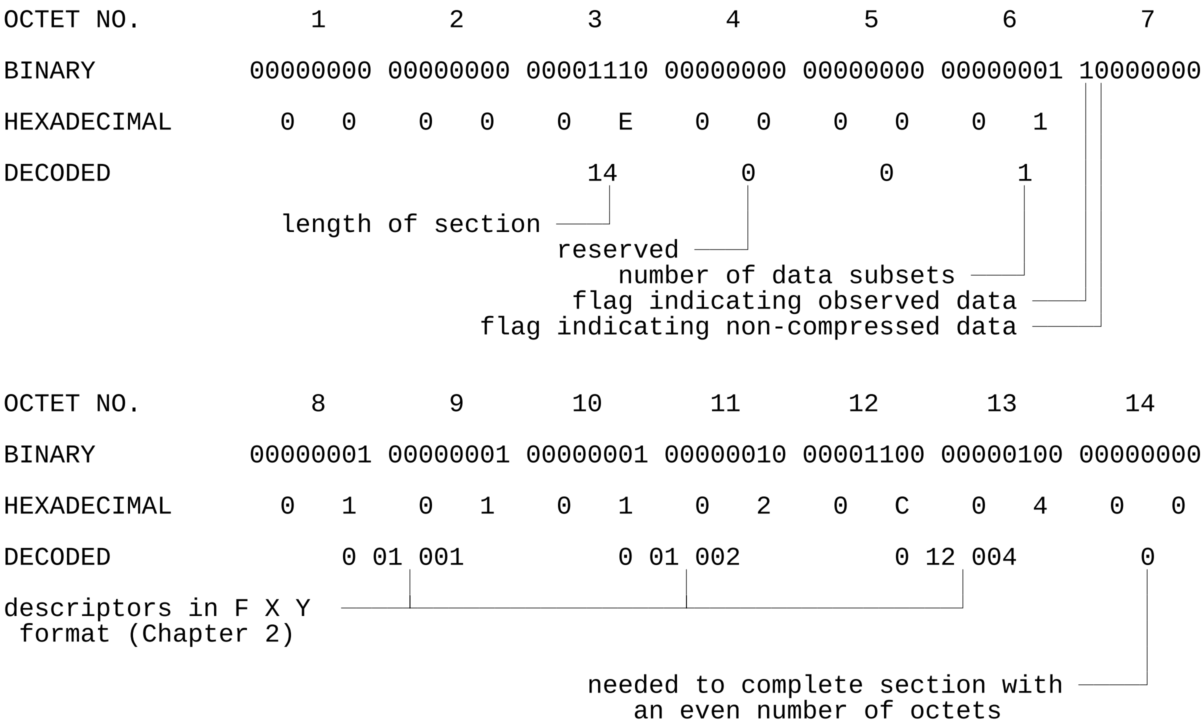


Figure 1-4. Decoding Section 3

1.2.5 Section 4 - Data Section.

CONTINUOUS BINARY STREAM					
section 0	section 1	section 2	section 3	**SECTION** **4**	section 5

Octet No.	Contents
1 - 3	Length of section, in octets
4	set to zero (reserved)
5	Binary data as defined by descriptors which begin at octet 8, Section 3.

1.2.6 Section 5 - End Section.

CONTINUOUS BINARY STREAM					
section 0	section 1	section 2	section 3	section 4	**SECTION** **5**

Octet No.	Contents
1 - 4	"7777" (coded according to the CCITT International Alphabet No. 5)

1.2.7 Required Entries. In any BUFR message there will be a minimum number of bits to represent even the smallest amount of data.

CONTINUOUS BINARY STREAM					
section 0 64 bits	section 1 144 bits	section 2 (optional)	section 3 80 bits	section 4 48 bits	section 5 32 bits

368 bits

The required entries for each section are:

Section 0 - octets 1 - 8

Section 1 - octets 1 - 18

```
OCTET NO.             1        2        3        4        5        6        7        8

BINARY            01000000 00000000 00001000 00000000 10010000 11110101 11011100 01000000

HEXADECIMAL         0   0    0   0    0   8    0   0

DECODED                                8        0      data as described by descriptors
                                                          in Section 3 (Figure 1-6)
                 length of section
                                  reserved
```

Figure 1-5. Decoding Section 4

```
OCTET NO.                5                6                7                8

BINARY           1 0 0 1 0 0 0 0  1 1 1 1 0 1 0 1  1 1 0 1 1 1 0 0  0 1 0 0 0 0 0 0

HEXADECIMAL            48              1EB                   B88                                DECODED

                       72              491                   2952
                                                  3 bits of zero to end octet
```

Figure 1-6. Section 4 data as described by descriptors

Section 2 -	optional, but if included, octets 1 - 4 are required with any information to begin in octet 5.
Section 3 -	octets 1 - 7 The data descriptors begin in octet 8. A single data descriptor occupies 16 bits, or 2 octets. Since the section must contain an even number of octets, there will be a minimum of 10 octets in the section 3. Section 3 will always conclude with 8 bits set to zero since all descriptors are 16 bits in length and the first descriptor begins in octet 8.
Section 4 -	octets 1 - 4 The data begins in octet 5. Since the section must contain an even number of octets there must be at least 2 octets after octet 4.
Section 5 -	octets 1 - 4

Figure 1-8 is the same BUFR message as in Figures 1-1 to 1-7. The shaded areas in Figure 1-8 are those octets which are required in any BUFR message. Not included in the shaded areas are descriptors contained in octets 8 - 14 of Section 3 and the data in octets 5 - 8 of Section 4.

1.2.8 BUFR and Data Management. Sections 3 and 4 of BUFR contain all of the information necessary for defining and representing data. The remaining sections are defined and included purely as aids to data management. Since key information for data management is available from fixed locations relative to the start of each section, it is possible to categorize and classify the main attributes of BUFR data without decoding the data description in Section 3 and the data in Section 4.

OCTET NO.	1	2	3	4
BINARY	00110111	00110111	00110111	00110111
HEXADECIMAL	3 7	3 7	3 7	3 7
DECODED	7	7	7	7

Figure 1-7. Decoding Section 5

```
                                           end of section 0 ───┐
01000010010101010100011001010010000000000000000000110100000000100


00000000000000000010010000000000000000000011100000000000000000000


00001000000000000000100000000101011101000001000001110100001100000

            ┌── end of section 1
00000000000000000000000000000000011100000000000000000000000011000

                                        end of section 3 ──┐
00000000000100000001000000010000001000001100000001000000000001000
    │  8       9       10      11      12      13      14  │
    └────────────────────── octets ────────────────────────┘

                                       end of section 4 ──┐
00000000000000010000000000010010000111101011101110001000000001101
                           │  5       6      7        8   │
                           └────────── octets ────────────┘

      end of section 5 ──┐
11001101110011011100110111
```

Figure 1-8. Required entries in sample BUFR message

CHAPTER 2

BUFR TABLES

2.1 Introduction. BUFR employs 3 types of tables: BUFR tables, code tables and flag tables. It also provides for the use of local tables.

The tables in BUFR that contain information to describe, classify and define the contents of a BUFR message are called BUFR tables. There are 4 BUFR tables defined: Tables A, B, C and D. Code tables and flag tables are defined and discussed in paragraph 2.7. Local tables are defined and discussed in paragraph 2.8.

2.2 Table A - Data Category. Table A is referred to in Section 1 and provides a quick check for the type of data represented in the message. Of the 256 possible entries for Table A, 17 are currently defined:

Table 2-1. BUFR Table A - data category

Code Figure	Meaning
0	Surface data - land
1	Surface data - sea
2	Vertical soundings (other than satellite)
3	Vertical soundings (satellite)
4	Single level upper-air data (other than satellite)
5	Single level upper-air data (satellite)
6	Radar data
7	Synoptic data
8	Physical/chemical constituents
9	Dispersal and transport
10	Radiological data
11	BUFR tables, complete replacement or update
12	Surface data (satellite)
13-19	Reserved
20	Status information
21	Radiances
22-30	Reserved
31	Oceanographic data
32-100	Reserved
101	Image data
102-255	Reserved

Placing one of the code figures from Table A (Table 2-1) in octet 9 of Section 1 is actually redundant. The descriptors used in

Section 3 of a message fully define the data in Section 4, regardless of the Table A code figure in Section 1. Decoding programs may, however, wish to reference Table A in order to obtain a general classification of the data available prior to actually decoding the information and/or passing it on to some subsequent application program.

2.3 **Table B - Classification of Elements.** Table B is referenced in Section 3 of a BUFR message and contains descriptions of parameters encoded in Section 4. Table B, as set forth in the WMO Manual On Codes, Volume 1, Part B (reference 4), is reproduced in its entirety in Appendix B. Table B entries consist of 6 entities:

- a descriptor consisting of the 3 parts F X and Y
- element name
- units: basic (SI) units for the element
- scale: factor (equal to 10 to the power [scale]) by which the element has been multiplied prior to encoding
- reference value: a number to be subtracted from the element, after scaling, (if any), and prior to encoding
- data width, in bits, the element requires for representation in Section 4

A Table B descriptor consists of 16 bits (2 octets) divided into 3 parts, F, X and Y.

F	X	Y
2 bits	6 bits	8 bits

F (2 bits) indicates the type of descriptor. In 2 bits there are 4 possibilities, 0, 1, 2 and 3. The numeric value of the 2 bit quantity F, indicates the type of descriptor.

F = 0 Element descriptor   (Table B entry)
F = 1 Replication operator
F = 2 Operator descriptor (Table C entry)
F = 3 Sequence descriptor (Table D entry)

X (6 bits) indicates the class or category of descriptor. There are 64 possibilities, classes 00 to 63. Thus far, 28 classes have been defined.

Y (8 bits) indicates the entry within an X class. The 8 bits will yield 256 possibilities within each of the 64 classes. There are a varying number of entries within each of the 28 classes that are currently defined.

It is the F X Y descriptors in Section 3 that refer to data represented in Section 4. The 16 bits of F, X and Y are not to be treated as a 16 bit numeric value, but rather as 16 bits divided into 3 parts, where each part (F, X and Y) are in themselves 2, 6 and 8 bit numeric values. Some examples of descriptors with their corresponding bit settings:

Descriptor	F	X	Y	
0 01 001	00	000001	00000001	(Figure 1-4)
1 02 006	01	000010	00000110	
2 01 131	10	000001	10000011	
3 07 002	11	000111	00000010	

If the following descriptors were contained in Section 3,

0 01 001   0 01 002   0 02 001   0 04 001   0 04 002
0 04 003   0 04 004   0 04 005   0 05 002   0 06 002,

they would refer to the following extracts from BUFR Table B.

Table Reference F X Y	Element Name	Units	Scale	Reference Value	Data Width (Bits)
0 01 001	WMO block number	numeric	0	0	7
0 01 002	WMO station number	numeric	0	0	10
0 02 001	Type of station	code table	0	0	2
0 04 001	Year	Year	0	0	12
0 04 002	Month	Month	0	0	4
0 04 003	Day	Day	0	0	6
0 04 004	Hour	Hour	0	0	5
0 04 005	Minute	Minute	0	0	6
0 05 002	Latitude (coarse accuracy)	Degree	2	-9000	15
0 06 002	Longitude (coarse accuracy)	Degree	2	-18000	16

The element name is a plain language description of the element entry of the table.

The units of Table B entries refer to the format of how the data in Section 4 is represented. The data may be numeric as in the case of a WMO block number or character data as in the case of an aircraft identifier. When data is in character form, the character representation is always according to the CCITT International Alphabet No. 5. The units may also refer to a code or flag table, where the code or flag table is described in the WMO Manual On

Codes using as the code or flag table number the same number as the F X Y descriptor. For example, from page I-Bi--123 of the manual:

0 02 001
Type of station

Code Figure	
1	Automatic station
2	Manned station
3	Reserved
4	Missing value

Other units are in Standard International (SI) units, such as meters or degrees Kelvin.

The scale refers to the power of 10 by which the element in Section 4 has been multiplied in order to retain the desired precision in the transmitted data. For example, the units of latitude are whole degrees in Table B. This is not precise enough, however, for most uses. Therefore, the elements are to be multiplied by 100 (10^2) so that the transmitted precision will be centidegrees, a more useful precision. On the other hand, the (SI) unit of pressure in Table B is Pascals, a rather small unit that would result in unnecessarily precise numbers being transmitted. The BUFR Table B calls for pressure to be divided by 10 (10^-1) resulting in a transmitted unit of 10ths of hPa, or tenths of millibars, a more reasonable precision for meteorological usage. These precisions can be changed on the fly, so to speak, if the table values are not appropriate in special cases. This is done through the use of "data description operators" - see paragraph 2.4 below.

The reference value is a value that is to be subtracted from the data after multiplication by the scale factor, if any, before encoding into Section 4 in order to produce, in all cases, a positive value. In the case of latitude and longitude, south latitude and west longitude are negative before applying the reference value. If, for example, a position of 35.50 degrees south latitude were being encoded, multiplying -35.50 by 100 (scale of 2) would produce -3550. Subtracting the reference value -9000 would give 5450 that would be encoded in Section 4. To obtain the original value in decoding Section 4, adding back the -9000 reference value to 5450 would result in -3550, then dividing by the scale (100) would obtain -35.50.

The data width of Table B entries is a count of how many bits the largest possible value of an individual data item of Section 4 occupies.

In those instances where a Table B descriptor defines an element of data in Section 4, where that element is missing for a given subset, then all bits for that element will be set to 1’s in Section 4.

Obviously, without an up-to-date Table B, a decoder program would not be able to determine the form or content of data appearing in Section 4.

2.3.1 Data Replication. A special descriptor called the replication operator (F = 1) is used to define a range of subsequent descriptors, together with a replication factor. This enables the appropriate descriptors to be considered to be repeated a number of times. In general for data replication, X indicates the number of immediately following descriptors that are to be replicated as a repeated set, and Y indicates the total number of replications. This, of course, implies, that the same pattern will be found in Section 4, the data section. This ability to describe a repeated pattern in the data by a single set of descriptors contributes to the efficiency of BUFR.

As an example, consider that the following sequence appears in Section 3:

1 02 006   0 07 004   0 01 003

The meaning of 1 02 006 is that the next 2 descriptors are repeated 6 times, or the equivalent set of descriptors:

0 07 004   0 01 003   0 07 004   0 01 003   0 07 004   0 01 003
0 07 004   0 01 003   0 07 004   0 01 003   0 07 004   0 01 003

A special form of the replication operator allows the replication factor to be stored with the data in Section 4, rather than with the descriptor in Section 3. This special form is called delayed replication. It is indicated by Y = 0. It allows the data to be described in a general way, with the number of replications being different from subset to subset. Since the data now contains an additional data element, the actual replication count, a descriptor must be added to Section 3 to account for, and describe, this (special) data element. The appropriate descriptor is found in Class 31. Special note: the 0 31 YYY (delayed replication factor) descriptor follows immediately after the 1 X 000 (delayed replication) descriptor but is NOT included in the count (X) of the following descriptors to be replicated.

Another form of delayed replication enables both the data description and the corresponding data item or items to be repeated. Entries in Class 31 of Table B (see Appendix B) are used in association with the delayed replication operator to enable this to be done.

2.4 Table C - Data Description Operators. Table C (F = 2) data description operators (Chapter 5) are used when there is a need to redefine Table B attributes temporarily, such as to change data width, scale or reference value of a Table B entry. Table C is also used to add associated fields such as quality control information, indicate characters as data items, and signify data width of local descriptors.

2.5 Table D - Lists of Common Sequences. Table D (F = 3) contains descriptors which describe additional descriptors. A single descriptor used in Section 3 with F = 3 is a pointer to a Table D entry which contains other descriptors. If the Table D descriptor 3 01 001 were used in Section 3, the expansion of that descriptor is two Table B descriptors, 0 01 001 and 0 01 002.

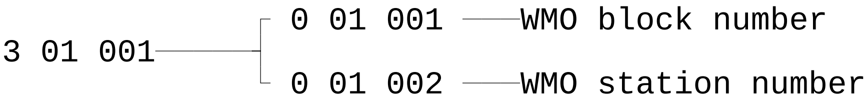
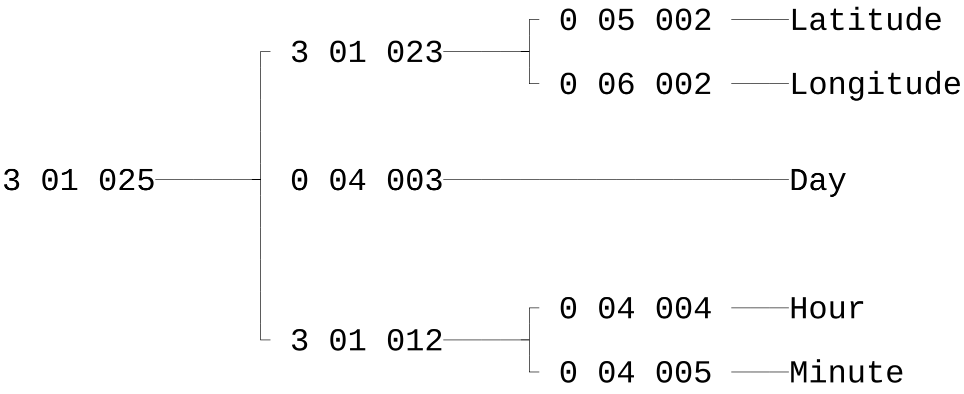


Table D descriptors may also refer to an expansion list of descriptors that contain additional Table D descriptors. The descriptor 3 01 025 expands to 3 01 023, 0 04 003 and 3 01 012. In the expansion, 3 01 023 additionally expands to 0 05 002 and 0 06 002. The remaining descriptor 3 01 012 expands to 0 04 004 and 0 04 005. Thus, the single Table D descriptor 3 01 025 expands to a total of 5 separate Table B entries.



The order of the data in Section 4 is then according to the following sequence of Table B entries: 0 05 002, 0 06 002, 0 04 003, 0 04 004, 0 04 005.

There are currently 19 categories of common sequences defined in BUFR Table D (Table 2-2 below).

Table 2-2. BUFR Table D list of common sequences

F	X	Category of Sequences
3	00	BUFR table entries sequences
3	01	Location and identification sequences
3	02	Meteorological sequences common to surface data
3	03	Meteorological sequences common to vertical sounding data
3	04	Meteorological sequences common to satellite observations
3	05	Reserved
3	06	Meteorological or oceanographic sequences common to oceanographic observations
3	07	Surface report sequences (land)
3	08	Surface report sequences (sea)
3	09	Vertical sounding sequences (conventional data)
3	10	Vertical sounding sequences (satellite data)
3	11	Single level report sequences (conventional data)
3	12	Single level report sequences (satellite data)
3	13	Sequences common to image data
3	14	Reserved
3	15	Oceanographic report sequences
3	16	Synoptic feature sequences
3	18	Radiological report sequences
3	21	Radar report sequences

Any BUFR message may be encoded without using Table D. The data description contained within Section 3 can be accomplished entirely by using only element descriptors of Table B and operator descriptors of Table C. To do so, however would involve considerable overhead in terms of the length of the Section 3 data description. The use of Table D is another major contributor to the efficiency of BUFR.

2.6 Message Layout. Figure 2-1 illustrates how the single descriptor 3 07 002 expands into 2 more Table D descriptors, 3 01 032 and 3 02 011. The descriptor 3 01 032 further expands into 5 more descriptors 3 01 001, 0 02 001, 3 01 011, 3 01 012 and 3 01 024. As is shown in Figure 2-1, descriptors in Table D may themselves refer to Table D, provided no circularity results on repeated expansion. Completion of the expansion process leads to a total of 31 Table B descriptors. The 16 bits in Section 3 taken by the descriptor 3 07 002 results in a savings of 480 bits (30 x 16 bits) over what the 31 Table B descriptors would occupy in bits.

Table D has been limited to lists of descriptors likely to be most frequently used. Table D was not designed to be comprehensive of all sequences likely to be encountered. To do so would require an excessively large Table D and would considerably reduce flexibility when encoding minor differences in reporting practices. More flexibility is retained if the Data Description Section contains several descriptors.

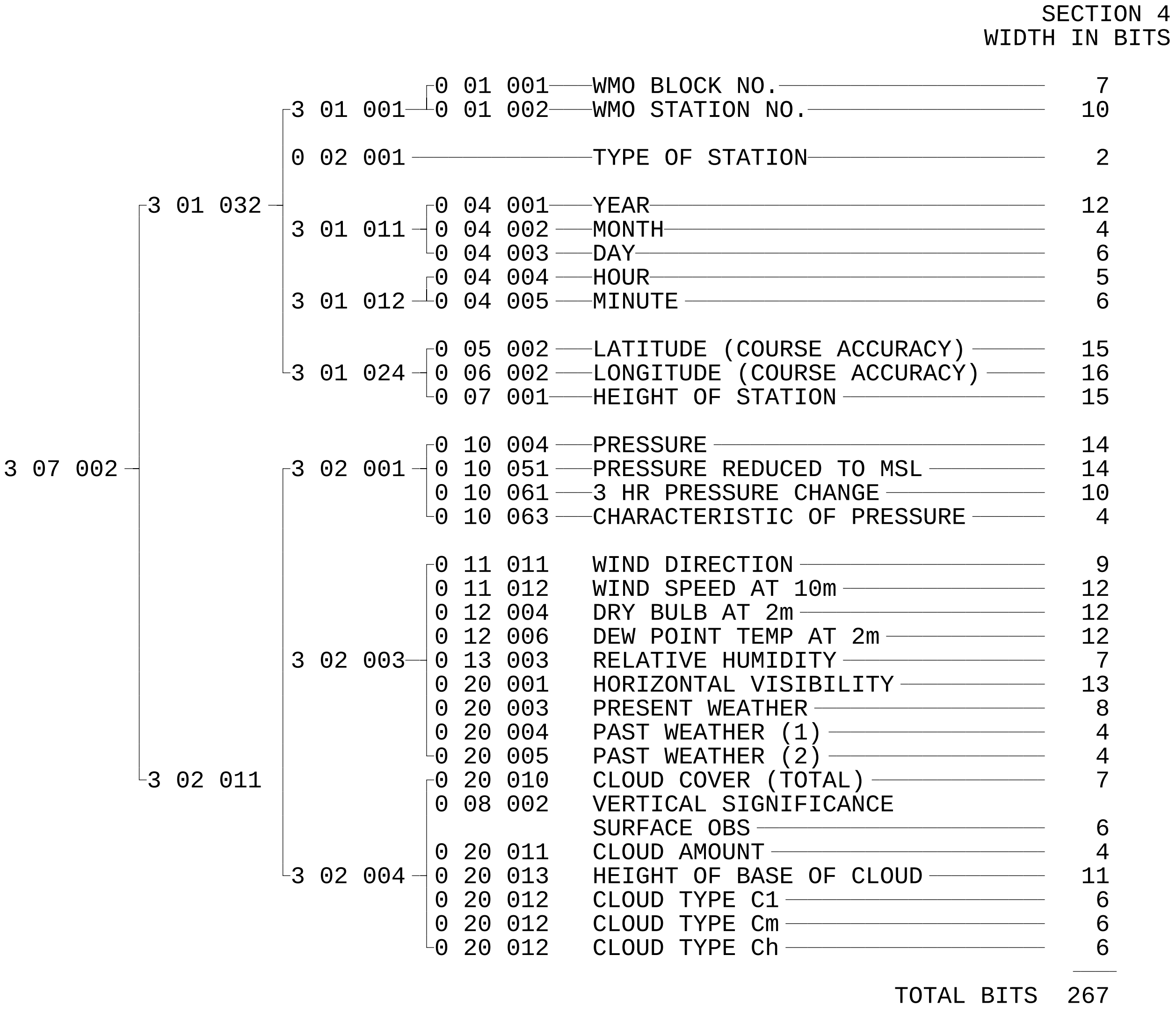
A complete layout of a BUFR message containing just 1 surface observation is illustrated in Figure 2-2. As indicated in octets 5-7 of Section 1, there are a total of 78 octets in the message, or 624 bits. Of the 624 bits, 267 are for the actual parameters of data (Figure 2-1) and the remaining 357 bits are BUFR overhead. BUFR overhead in this context is the number of bits that are not actual surface data. In this example there are more bits used for the overhead than for the surface data.

Figure 2-3 is a complete layout of a BUFR message containing the maximum number of 448 subsets to fit within the 15000 octet limit. This message would contain 14996 octets or 119968 bits. Of these 119968 bits, 119616 are data and 352 bits are BUFR overhead. The 5 bit difference in overhead from Figure 2-2 (357 bits) and Figure 2-3 (352 bits) is due to the number of bits set to 0 at the end of Section 4 in order to complete the section at the end of an even numbered octet. For 1 subset of 267 bits, 5 additional bits are needed to complete the octet. For 448 subsets, or 119616 bits, no additional bits are needed to complete the last octet.

2.6.1 Comparison of BUFR and Character Code Bit Counts. The surface observations illustrated in Figures 2-1 to 2-3 are the equivalent of the following parameters in the WMO code form FM 12-IX Ext. SYNOP:

YYGGi_w IIiii $i_R i_x$hVV Nddff 1s_nTTT 2$s_n T_d T_d T_d$ 3$P_o P_o P_o P_o$
4PPPP 5appp 7ww$W_1 W_2$ 8$N_h C_L C_M C_H$

Data encoded in this form would consist of 55 characters plus 10 spaces between each group of 5 characters for a total of 65 characters. For transmission purposes these 65 characters would require a total number of 520 bits (65 X 8 bits per character). A complete BUFR message with 1 observation (Figure 2-2) requires 78 octets or 624 bits, 104 more than the corresponding character representation. Of these 624 bits, 267 are taken by the surface observation and 357 as BUFR overhead. If, however, 448 observations in character form were transmitted, the total number of bits would be 232960 (520 X 448). The corresponding BUFR representation (Figure 2-3) would require 14996 octets, or 119968 bits, a savings of 112992 bits over the character representation. The 112992 bits is equivalent to 217 observations in character form or 423 observations in BUFR, not counting the BUFR overhead. While these numbers may be viewed in different ways, the real significance is that BUFR is far more efficient, in terms of number of bits to represent a set of meteorological observations, than character forms.



					SECTION 4 WIDTH IN BITS
3 07 002	3 01 032	3 01 001	0 01 001	WMO BLOCK NO.	7
			0 01 002	WMO STATION NO.	10
		0 02 001		TYPE OF STATION	2
		3 01 011	0 04 001	YEAR	12
			0 04 002	MONTH	4
			0 04 003	DAY	6
		3 01 012	0 04 004	HOUR	5
			0 04 005	MINUTE	6
		3 01 024	0 05 002	LATITUDE (COURSE ACCURACY)	15
			0 06 002	LONGITUDE (COURSE ACCURACY)	16
			0 07 001	HEIGHT OF STATION	15
	3 02 011	3 02 001	0 10 004	PRESSURE	14
			0 10 051	PRESSURE REDUCED TO MSL	14
			0 10 061	3 HR PRESSURE CHANGE	10
			0 10 063	CHARACTERISTIC OF PRESSURE	4
		3 02 003	0 11 011	WIND DIRECTION	9
			0 11 012	WIND SPEED AT 10m	12
			0 12 004	DRY BULB AT 2m	12
			0 12 006	DEW POINT TEMP AT 2m	12
			0 13 003	RELATIVE HUMIDITY	7
			0 20 001	HORIZONTAL VISIBILITY	13
			0 20 003	PRESENT WEATHER	8
			0 20 004	PAST WEATHER (1)	4
			0 20 005	PAST WEATHER (2)	4
		3 02 004	0 20 010	CLOUD COVER (TOTAL)	7
			0 08 002	VERTICAL SIGNIFICANCE SURFACE OBS	6
			0 20 011	CLOUD AMOUNT	4
			0 20 013	HEIGHT OF BASE OF CLOUD	11
			0 20 012	CLOUD TYPE C1	6
			0 20 012	CLOUD TYPE Cm	6
			0 20 012	CLOUD TYPE Ch	6
				TOTAL BITS	267

Figure 2-1. Example of surface observations sequence using Table D descriptor 3 07 002

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	78	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originating center (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator that Section 2 not included
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number of octets for section
Section 3 (Data description section)	1-3	27-29	10	length of section (octets)
	4	30	0	reserved
	5-6	31-32	1	number of data subsets
	7	33	bit 1=1	flag indicating observed data
	8-9	34-35	3 07 002	Table D descriptor for surface land in F X Y format
	10	36	0	need to complete section with an even number of octets
Section 4 (Data section)	1-3	37-39	38	length of section (octets)
	4	40	0	reserved
	5-38	41-74	data	continuous bit stream of data for 1 observations, 267 bits plus 5 bits to end on even octet (see Figure 2-1 for expansion)
Section 5 (End section)	1-4	75-78	7777	encoded CCITT International Alphabet No. 5

Figure 2-2. BUFR message of 1 surface observation using Table D descriptor 3 07 002

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	14996	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originating center (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator that Section 2 not included
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master table
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number of octets for section
Section 3 (Data description section)	1-3	27-29	10	length of section (octets)
	4	30	0	reserved
	5-6	31-32	448	number of data subsets
	7	33	bit 1=1	flag indicating observed data
	8-9	34-35	3 07 002	Table D descriptor for surface land in F X Y format
	10	36	0	need to complete section with an even number of octets
Section 4 (Data section)	1-3	37-39	14956	length of section (octets)
	4	40	0	reserved
	5-14956	41-14992	data	continuous bit stream of data for 448 observations, 267 bits per observation with no added bits to end on an even octet
Section 5 (End section)	1-4	14993-14996	7777	encoded CCITT International Alphabet No. 5

Figure 2-3. BUFR message of 448 surface observations using Table D descriptor 3 07 002

2.7 Code Tables and Flag Tables. Since some meteorological parameters are qualitative or semi-qualitative, they are best represented with reference to a code table.

2.7.1 Code Tables. BUFR code tables and flag tables refer to elements defined within BUFR Table B. They are numbered according to the X and Y values of the corresponding Table B reference. For example, the Table B entry 0 01 003, WMO Region number, geographical area, indicates in the Unit column that this is a BUFR code table, the number of that code table being 0 01 003.

Many of the code tables included in the BUFR specification are similar to existing WMO code tables for representing character data. Attachment II of the WMO Manual on Codes, Volume 1, Part B is a list of the code tables associated with BUFR Table B and the existing specifications and code tables of the WMO Manual on Codes, Volume 1, Part A.

There is no one-to-one BUFR code table relationship to the character code tables. The character Code Table 3333, Quadrant of the Globe, for example, has no meaning in BUFR, as all points on the globe in BUFR are completely expressed as latitude and longitude values.

2.7.2 Flag tables. In a flag table, each bit indicates an item of significance. A bit set to 1 indicates an item is included, or is true, while a bit set to 0 indicates omission, or false. In any flag table, when all bits are set it is an indication of a missing value. Flag tables additionally enable combinations to be identified. In all flag tables within the BUFR specification, bits are numbered from 1 to N from most significant to least significant within a data width of N bits, i.e., from left (bit 1) to right (bit N). For example, from page I-Bi--135 of the manual:

0 08 001
Vertical sounding significance

Bit No.	
1	Surface
2	Standard level
3	Tropopause level
4	Maximum wind level
5	Significant level, temperature
6	Significant level, wind
All 7	Missing value

2.7.3 Flags. Flags, without reference to a flag table, are also used within Sections 1 and 3 of a BUFR message. In Section 1, octet 8, if bit 1 = 0 this is an indication that the optional Section 2 is not contained within the message. If bit 1 = 1, then Section 2 is included.

```
      Section 1                      Section 1
       Octet 8                        Octet 8

      00000000                       10000000
      |                              |
      └ Section 2 not included       └ Section 2 included
```

Similarly, the two flag bits in Section 3, octet 7 have these meanings:

```
      Section 3                      Section 3
       Octet 7                        Octet 7
      00000000                       11000000
      ||                             ||
      |└ non-compressed data         |└ compressed data
      |                              |
      └ other data                   └ observed data
```

2.8 Local Tables. Since a data processing center may need to represent data conforming to a local requirement and such local data may not be defined within Table B, specific areas of Table B and D are reserved for local use (Figure 2-4). These areas are defined as descriptor part Y entries 192 to 255 inclusive of all descriptor part X classes. Also, centers defining descriptor part X classes for local use should restrict their use to the range 48 to 63 inclusive.

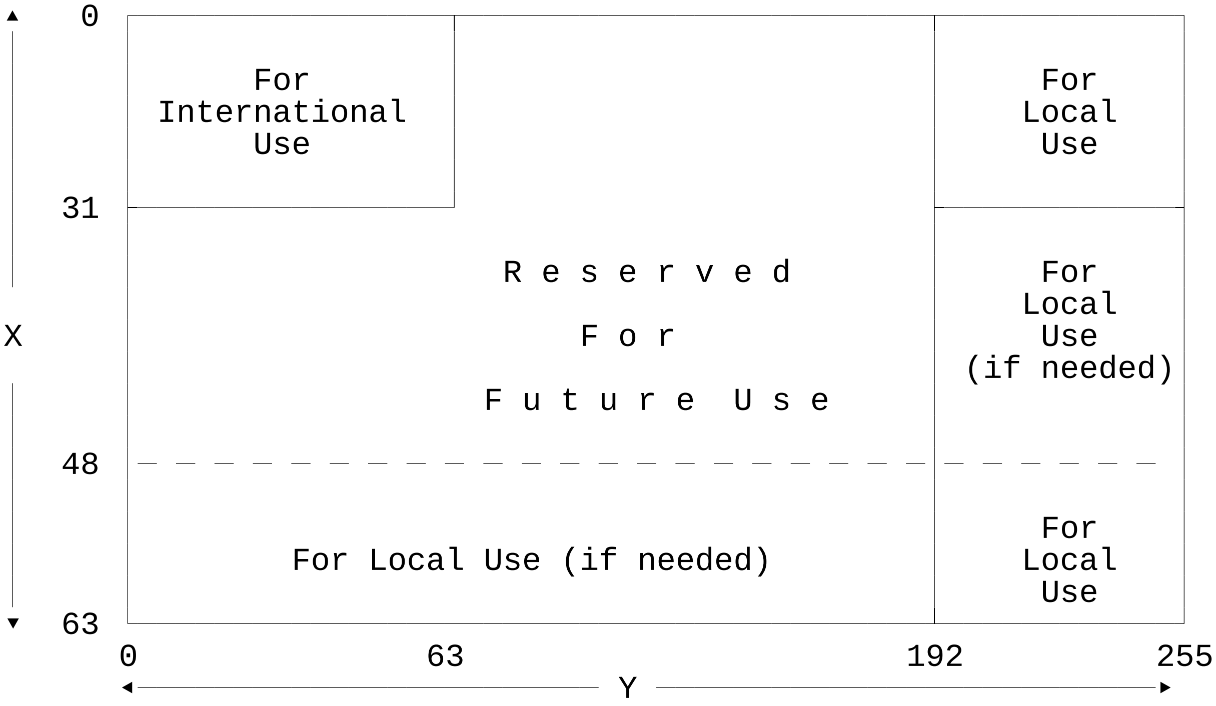


Figure 2-4. Table reservations

If a data processing center had multiple sources of data receipt, for example, it may be necessary to indicate the source of an observation by encoding the circuit from which the data was received. A local Table B descriptor such as 0 54 192 could be used which may be a code table specifying circuits of transmission. The Table B entry could be:

Table Reference	Element Name	Units	Scale	Reference Value	Data Width (Bits)
0 54 192	Circuit	code table	0	0	3

The corresponding local code table could be:

0 54 192
Circuit designators for data receipt

Code Figure	Circuit
0	GTS
1	AWN
2	AUTODIN
3	ANTARCTIC
4-7	Reserved

Using the same Table D descriptor, 3 07 002, as in Figure 2-1, adding the local descriptor 0 54 192 would produce the expansion as in Figure 2-5. The following modifications would have to be made to the BUFR message if the local descriptor 0 54 192 were to be included in a message (Figure 2-6):

> Section 0, octets 5-7, the total length of the message, increases from 14996 octets to 14998 octets.
>
> Section 1, octet no. 12 (octet 20 within the message) would have the version number of the local tables in use.
>
> Section 3, octets 1-3, the encoded value would increase from 10 octets to 12 octets. If one descriptor were being added, the length of the section increases by 2 in order to keep the section an even number of octets. Octets 5-6, number of data subsets decreases from 448 to 443. The number of data subsets have been reduced to keep the total message length under the 15000 octet maximum.
>
> Also in Section 3, the descriptors will occupy octets 8-11 vice octets 8-9 to accommodate the added descriptor.

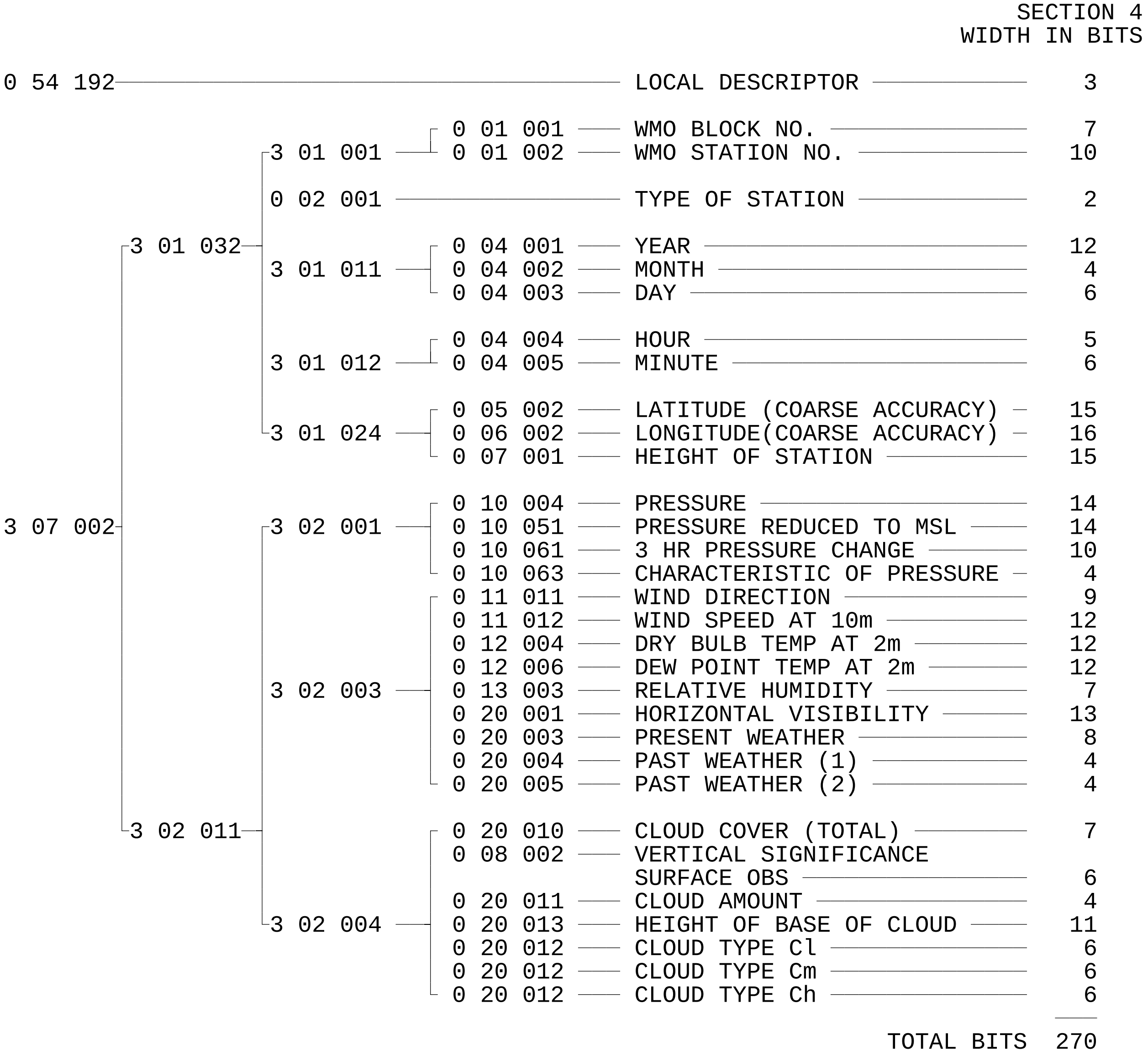


Figure 2-5. Example of surface observations sequence using Table D descriptor 3 07 002 and a local descriptor.

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	14998	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originating center (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator that Section 2 not included
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	1	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also need to complete even number of octets
Section 3 (Data description section)	1-3	27-29	12	length of section (octets)
	4	30	0	reserved
	5-6	31-32	443	number of data subsets
	7	33	BIT 1=1	flag indicating observed data
	8-11	34-37	0 54 192 3 07 002	local and Table D descriptors in F X Y format
	10	38	0	need to complete section with an even number of octets
Section 4 (Data section)	1-3	39-41	14956	length of section (octets)
	4	42	0	reserved
	5-14956	43-14994	data	continuous bit stream of data for 443 observations, 270 bits per observation plus 6 bits to end on even octet
Section 5 (End section)	1-4	14995-14998	7777	encoded CCITT international Alphabet No. 5

Figure 2-6. BUFR message of 443 surface observations using 2 descriptors, local descriptor 0 54 192 and Table B descriptor 3 07 002.

Note that in Section 4, octets 1-3, the encoded value for length of section remains the same at 14956 octets. The number of bits needed for 448 subsets without a local descriptor is 119616 (448 X 267), or exactly 14952 octets. For 443 subsets with 3 bits added to each subset for the local information, 119610 bits are needed (443 X 270). Adding 6 bits to complete the octet brings the total bit count for all 443 subsets to 119616, the same number of bits as 448 subsets without the added local information.

CHAPTER 3

USING DATA REPLICATION

3.1 Introduction. When encoding a series of parameters a fixed number of times for all reports represented in Section 4, it may be possible to choose from one of several methods for using Section 3 descriptors.

3.2 Data Replication Examples. If there were 4 elements of cloud information that were described by the Table B descriptors 0 08 002, 0 20 011, 0 20 012, 0 20 013, and these elements were to be repeated 4 times, these 16 total elements of data in Section 4 may be described in the following ways:

1. Long and cumbersome method, each element described individually:

```
0 08 002   0 20 011   0 20 012   0 20 013
0 08 002   0 20 011   0 20 012   0 20 013
0 08 002   0 20 011   0 20 012   0 20 013
0 08 002   0 20 011   0 20 012   0 20 013
```

2. Using the replication operator:

```
1 04 004   0 08 002   0 20 011   0 20 012   0 20 013
```

   The meaning of the descriptor 1 04 004 is that the F portion (1) is indicating this is a replication operator, the X portion (04) means the following 4 descriptors are to be repeated Y (004) times.

3. Combine replication operator and Table D descriptor:

```
1 01 004   3 02 005
```

   In this particular example of Table B descriptors there is defined a Table D descriptor 3 02 005 which expands to the 4 descriptors 0 08 002 0 20 011 0 20 012 0 20 013. The replication operator 1 01 004 followed by 3 02 005 means the data in Section 4, defined by the Table D descriptor 3 02 005, is repeated 4 times.

Using either a replication operator followed by a Table B descriptor or a replication operator followed by a Table D descriptor, if it exists, produces the same definition of data as repeating Table B descriptors. Note, in example 3, that the count of the number of descriptors to be replicated (X, 01) applies to the single Table D descriptor that is actually in the message, and NOT to the set of possibly very many descriptors that the single type 3 descriptor represents.

A special form of the replication operator allows the replication factor to be stored with the data in Section 4, rather than with the descriptor in Section 3. This is particularly useful when describing data such as TEMP or BATHY observations where the number of levels differs from observation to observation. The delayed replication operator is of the form F X Y where F = 1, X indicates how many descriptors are to be replicated, and Y = 000. This operator is to be followed by a Table B descriptor from Class 31. The Class 31 descriptor is not included in the count (X) of the number of following descriptors to be replicated. Thus, if the following sequence of descriptors appeared in Section 3: 1 01 000 0 31 001 0 03 014, the meaning of these descriptors is:

1 01 000 F = 1 replication operator
X = 01 1 descriptor is replicated, not counting, i.e., skipping over, the 0 31 001 descriptor
Y = 000 delayed replication

0 31 001 F = 0 Table B descriptor
X = 31 Class 31 - data description operator qualifiers
Y = 001 delayed descriptor replication factor occupying 8 bits in Section 4 (Table B, Class 31 definition)

3 03 014 F = 3 Table D descriptor
X = 03 Category 03 - meteorological sequences common to vertical sounding data
Y = 014 entry 14 of Category 03

The Table D descriptor 3 03 014 expands into seven descriptors. The Section 4 data width for the expansion of 3 03 014 is 83 bits.

			Section 4 Width in Bits	
1 01 000		Delayed Rep. 1 Descriptor	0	
0 31 001		Replication Factor	8	
3 03 014	0 07 004	Pressure	14	83 bits
	0 08 001	Vertical Sounding Sig	7	
	0 10 003	Geopotential	17	
	0 12 001	Temperature	12	
	0 12 003	Dew Point	12	
	0 11 001	Wind Direction	9	
	0 11 002	Wind Speed	12	

For each observation encoded into Section 4 the 8 bits preceding the pressure data indicates how many times the following 7 elements are replicated.

Figure 3-1 is an example of TEMP observations sequence using a single Table D descriptor which expands to include delayed replication. In this example, the replication factor indicates how many levels are contained within the observation. The bit count of 245 bits is for 1 level, each additional level would require 83 bits.

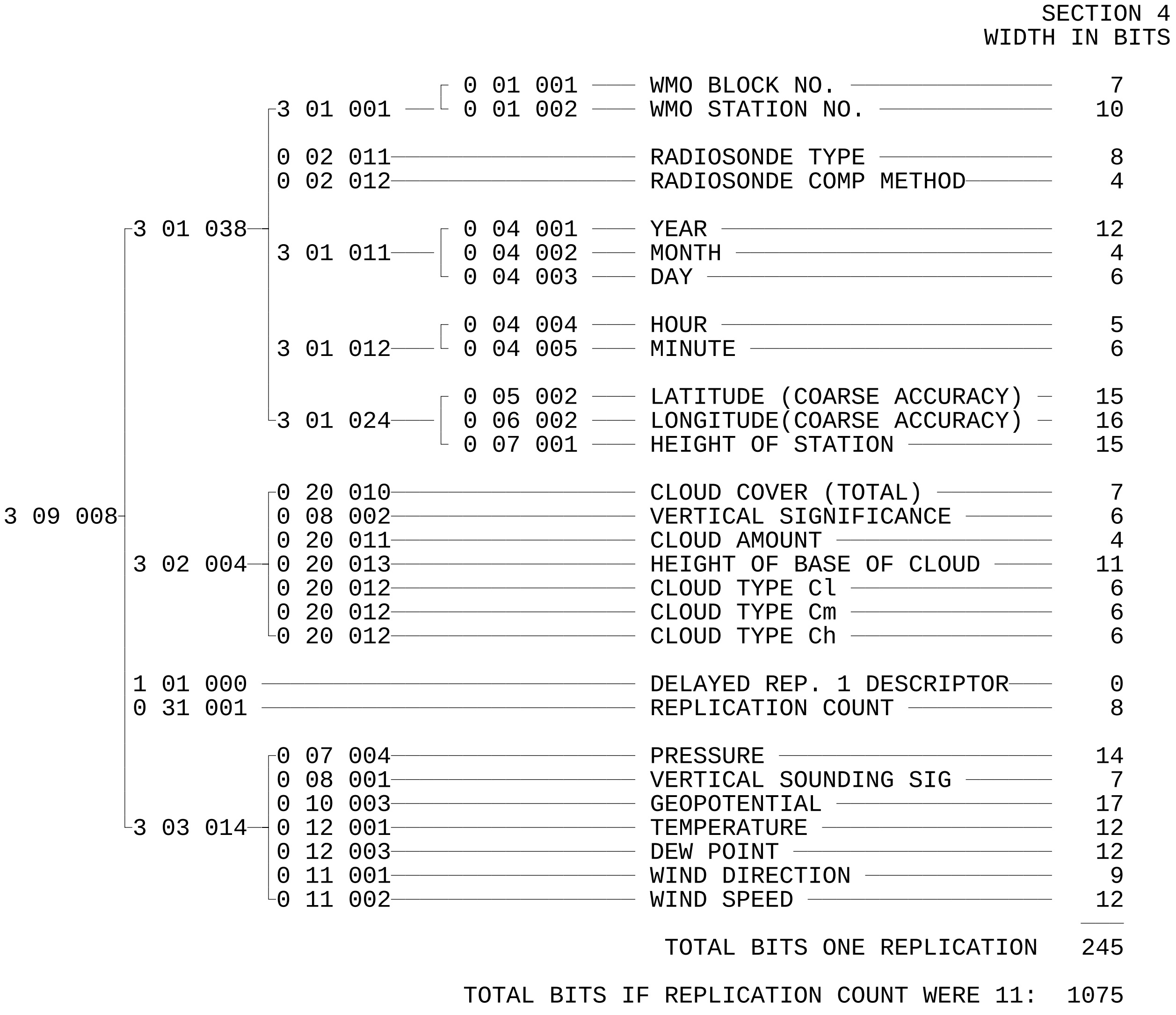


Figure 3-1. Example of TEMP observations sequence using delayed replication

CHAPTER 4

DATA COMPRESSION

4.1 Introduction. Even though BUFR makes efficient use of space by virtue of binary numbers that take only as many bits as are necessary to hold the largest expected value, a further compression may be possible. Data compression is indicated by setting the second bit of octet 7 in Section 3 to a value of one.

4.2 Method Used for Data Compression. The method employed by BUFR for data compression is similar to that used in the WMO Code FM 92 GRIB (GRidded Binary fields). Like elements from the full set of observations are collected together, their minimum values subtracted out, and the difference from the minimum are then encoded with a bit length selected to hold the largest difference from the minimum value. This is repeated for all the elements.

Using the following group of identically defined data subsets:

	Station Number	Station Height	Pressure	Temperature	Dew Point
subset 1	**101**	296	10132	122	110
subset 2	103	**291**	10122	121	110
subset 3	107	310	**10050**	105	099
subset 4	112	295	missing	110	102
subset 5	114	350	10055	**095**	**089**
subset 6	116	325	10075	101	091

Extraction of the minimum value of each element gives:

101	291	10050	095	089

Each value can now be represented as the difference from these minimum values:

	Station Number	Station Height	Pressure	Temperature	Dew Point
subset 1	0	5	82	27	21
subset 2	2	0	72	26	21
subset 3	5	19	0	10	10
subset 4	11	4	missing	15	13
subset 5	13	59	5	0	0
subset 6	15	34	25	6	2

After each difference from the minimum value has been determined for each element, the number of bits necessary to store the largest of the difference values for each element is established. For the station number column above, the largest difference is 15 which is equivalent to 1111_2, or 4 bits. However this presents a small problem. All four bits being set on, as is the case for the number 15, is properly interpreted as "missing," not as a numeric value of 15. What is done in such cases is to simply add one bit to the number needed to store the largest difference value; thus 15 gets stored in 5 bits, as 01111. It is not necessary to add one bit to the bit lengths for all the elements; it is only necessary when one of the numbers to be encoded "fills" the available space; that is, if the number 3 is to be stored in 2 bits, 7 in 3 bits, 15 in 4 bits, 31 in 5 bits, etc. A convenient way to do this and assure that there is always room for "missings" (if needed) is to add 1 to the largest difference value and figure the number of bits based on this larger-by-one value.

In the example above, the station height would be placed in 6 bits; the pressure in 7 (with the "missing" indicated as 1111111), etc., as in the following table:

	Station Number	Station Height	Pressure	Temperature	Dew Point
largest difference value +1	16	60	83	28	22
number of bits	5	6	7	5	5

Whereas in the non-compressed storage of data in Section 4 there is a continuous bit stream for all parameters for an entire observation, in the compressed form all elements of the same parameter from each observation form a continuous stream (Figure 4-1). In order to determine what the minimum value is that has to be added back to each of the following elements, and how many bits are being used for the storage of these elements, there are two additional items appearing in the compressed form of storage in Section 4 that do not appear in the non-compressed form.

These items are:

(1) the minimum value of this parameter and,
(2) the number of bits that are being used for the storage of each element.

These items of information precede the element values. The Section 4 representation for compressed data for each parameter used in the example above is:

> Station number minimum value (101) occupying 10 bits as specified by the Table B data width for entry 0 01 002 followed by:

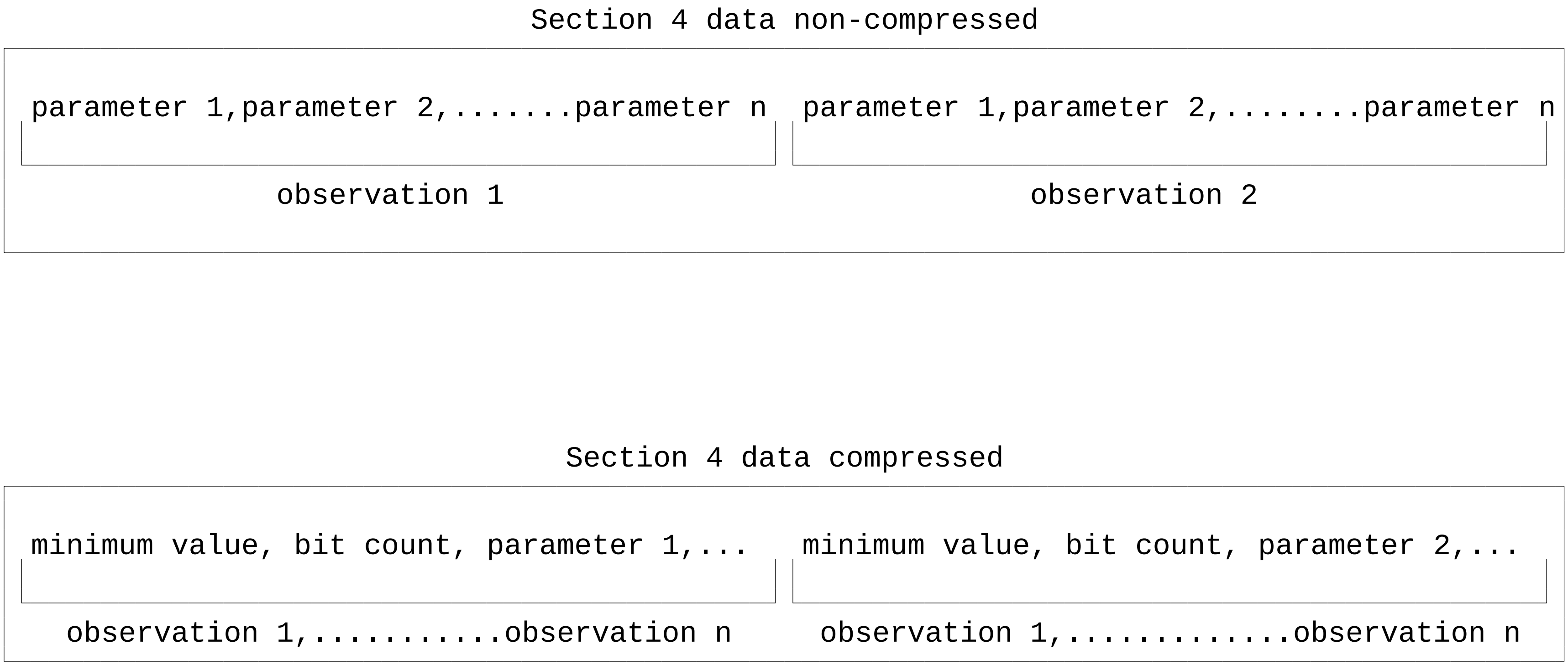


Figure 4-1. Comparison of non-compressed and compressed data in Section 4

> 6 bits containing the count in bits (5) that each of the station numbers will occupy, followed by: the 6 station number differences from the minimum values (0, 2, 5, 11, 13 and 15), where each value occupies 5 bits.

After the last station number difference (15), the next 15 bits (Table B data width for entry 0 07 001) will be taken by the minimum value for station height (291) followed by the count of bits to represent the differences (6) and then each of the elements occupying 6 bits apiece (5, 0, 19, 4, 59, 34).

Continuing the process for all 5 parameters would produce within Section 4 the following bit counts:

	station number	station height	pressure	temperature	dew point
Table B descriptor	0 01 002	0 07 001	0 10 004	0 12 004	0 12 006
data width to contain minimum value	10	15	14	12	12
6 bits containing bit count of parameter	6	6	6	6	6
Total bits preceding each parameter	16	21	20	18	18
data width to represent difference from minimum	5	6	7	5	5
compressed data representation for 6 subsets	30	36	42	30	30
total bit count for 6 subsets including compression bit counts	46 +	57 +	62 +	48 +	48 = 261

To represent all 6 subsets in compressed form in Section 4, 261 bits are necessary.

Using the same set of values for the 6 subsets in non-compressed form, the bit counts in Section 4 would be as follows:

	station number	station height	pressure	temperature	dew point
Table B descriptor data width	10	15	14	12	12
total bit count for 6 subsets	60 +	90 +	84 +	72 +	72 = 378

A total of 378 bits are necessary to represent all 6 subsets in non-compressed form.

There are other conditions that can occur when encoding compressed data. If all elements of a set of parameters are missing, the minimum value occupying the specified Table B data width in Section 4 will be set to all 1's, the 6 bits specifying how many bits are used for each value will be set to 0, and the difference values will be omitted. If, for example, all the dew points were missing from the 6 subsets, the number of bits to represent dew point would be reduced to include only the Table B data width for dew point (12 bits) and the 6 bits specifying the bits used for each value.

	station number		station height		pressure		temperature		dew point	
Table B descriptor	0 01 002		0 07 001		0 10 004		0 12 004		0 12 006	
data width to contain minimum value	10		15		14		12		12	
6 bits containing bit count parameter will occupy	6		6		6		6		6	
Total bits preceding each parameter	16		21		20		18		18	
compressed data (difference from minimum)	5		6		7		5		0	
compressed data representation for 6 subsets	30		36		42		30		0	
total bit count for 6 subsets including compression identifiers	46	+	57	+	62	+	48	+	18	= 231

In the non-compressed form, storage of the missing dew point values would still occupy 12 bits each, with all bits set to 1.

	station number		station height		pressure		temperature		dew point	
Table B descriptor data width	10		15		14		12		12	
total bit count for 6 subsets	60	+	90	+	84	+	72	+	72	= 378

The other condition that may occur is, if all the difference values are identical, then, the 6 bits specifying the count of bits for each difference value will set to 0, and difference values will be omitted. This condition would produce the same bit count as if all elements were missing. In summary:

Set of parameters missing:

> minimum value occupying number of bits as indicated in Table B set to all 1’s
>
> 6 bits specifying how many bits are used for each value set to 0
>
> difference values omitted

Set of identical parameters:

> minimum value occupying number of bits as indicated in Table B set to minimum value (actual value for all parameters)
>
> 6 bits specifying how many bits are used for each value set to 0
>
> difference values omitted

Data compression is most effective when the range of values for the parameters is small. In the example of the 6 subsets, each parameter has a difference from the minimum value, where the number of bits to represent the difference is half, or less than half, the number of bits required in non-compressed form for storage in Section 4, as indicated by the Table B entry data width. If the 6 subsets were put into a message where compression was not applied, the length of the message would be 100 octets (Figure 4-2). By applying compression, the length of the message would be reduced to 86 octets (Figure 4-3).

Using the range of values for the same 6 subsets, not realistic, but to show the effect of compression for a large data set, a total of 4267 subsets could be put into a BUFR message not exceeding 15000 octets (Figure 4-4). In non-compressed form there would be only 1898 subsets within the 15000 octet limit (Figure 4-5).

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	100	total length of message (octets)
Section 1 (identification section)	8	8	2	BUFR edition number
	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originator (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator for no Section 2
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number octets for section
Section 3 (Data description section)	1-3	27-29	18	length of section (octets)
	4	30	0	reserved
	5-6	31-32	6	number of data subsets
	7	33	bit 1=1	flag indicating observed data
			bit 2=0	**flag indicating no compression**
	8-17	34-43	0 01 002	WMO station no.
			0 07 001	height of station
			0 10 004	pressure
			0 12 004	temperature
			0 12 006	dew point
	18	44	0	needed to complete section with an even number of octets
Section 4 (Data section)	1-3	45-47	52	length of section (octets)
	4	48	0	reserved
	5-52	49-96	data	continuous bit stream of data for 6 subsets, 63 bits per subset plus 6 bits to end on even octet
Section 5 (End section)	1-4	97-100	7777	encoded CCITT international Alphabet No. 5

Figure 4-2. BUFR message of 6 subsets in non-compressed form

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	86	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originator (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator for no Section 2
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number octets for section
Section 3 (Data description section)	1-3	27-29	18	length of section (octets)
	4	30	0	reserved
	5-6	31-32	6	number of data subsets
	7	33	bit 1=1	flag indicating observed data
			bit 2=1	**flag indicating compression**
	8-17	34-43	0 01 002	WMO station no.
			0 07 001	height of station
			0 10 004	pressure
			0 12 004	temperature
			0 12 006	dew point
	18	44	0	needed to complete section with an even number of octets
Section 4 (Data section)	1-3	45-47	38	length of section (octets)
	4	48	0	reserved
	5-52	49-82	data	261 continuous bits of compressed data plus 11 bits to end on even octet
Section 5 (End section)	1-4	83-86	7777	encoded CCITT international Alphabet No. 5

Figure 4-3. BUFR message of 6 subsets in compressed form

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	15000	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originator (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator for no Section 2
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number octets for section
Section 3 (Data description section)	1-3	27-29	18	length of section (octets)
	4	30	0	reserved
	5-6	31-32	4267	number of data subsets
	7	33	bit 1=1	flag indicating observed data
			bit 2=1	**flag indicating compression**
	8-17	34-43	0 01 002	WMO station no.
			0 07 001	height of station
			0 10 004	pressure
			0 12 004	temperature
			0 12 006	dew point
	18	44	0	needed to complete section with an even number of octets
Section 4 (Data section)	1-3	45-47	14952	length of section (octets)
	4	48	0	reserved
	5-52	49-14996	data	119569 continuous bits of compressed data plus 15 bits to end on even octet
Section 5 (End section)	1-4	14997-15000	7777	encoded CCITT international Alphabet No. 5

Figure 4-4. BUFR message of 4267 subsets in compressed form

	Section Octet No.	Octet in Message	Encoded Value	Description
Section 0 (indicator section)	1-4	1-4	BUFR	encoded international CCITT Alphabet No. 5
	5-7	5-7	15000	total length of message (octets)
	8	8	2	BUFR edition number
Section 1 (identification section)	1-3	9-11	18	length of section (octets)
	4	12	0	BUFR master table
	5-6	13-14	58	originator (U.S. Navy - FNOC)
	7	15	0	update sequence number
	8	16	0	indicator for no Section 2
	9	17	0	Table A - surface land data
	10	18	0	BUFR message sub-type
	11	19	2	version number of master tables
	12	20	0	version number of local tables
	13	21	92	year of century
	14	22	4	month
	15	23	18	day
	16	24	0	hour
	17	25	0	minute
	18	26	0	reserved for local use by ADP centers (also needed to complete even number octets for section
Section 3 (Data description section)	1-3	27-29	18	length of section (octets)
	4	30	0	reserved
	5-6	31-32	1898	number of data subsets
	7	33	bit 1=1	flag indicating observed data
			bit 2=0	**flag indicating no compression**
	8-17	34-43	0 01 002	WMO station no.
			0 07 001	height of station
			0 10 004	pressure
			0 12 004	temperature
			0 12 006	dew point
	18	44	0	needed to complete section with an even number of octets
Section 4 (Data section)	1-3	45-47	14952	length of section (octets)
	4	48	0	reserved
	5-52	49-14996	data	continuous bit stream of data for 1898 subsets, 63 bits per subset plus 10 bits to end on even octet
Section 5 (End section)	1-4	14997-15000	7777	encoded CCITT international Alphabet No. 5

Figure 4-5. BUFR message of 1898 subsets in non-compressed form

CHAPTER 5

TABLE C DATA DESCRIPTION OPERATORS

5.1 Introduction. Table C data description operators (Table 5-1) are used when there is a need to redefine Table B attributes temporarily, such as the need to change the data width, scale or reference value of a Table B entry.

5.2 Changing Data Width, Scale, and Reference Value. If data from a DRIFTER observation (FM 18-IX Ext., Report of a drifting-buoy observation) were being encoded into BUFR, there are no Table B entries to correspond to latitude and longitude in thousandths of degrees. The Table B entries for latitude and longitude are high accuracy (hundred thousandths of a degree) and coarse accuracy (hundredths of a degree). There are several possible methods to handle the encoding of latitude and longitude for DRIFTER in thousandths of degrees. One method would be to choose the high accuracy Table B entries for latitude and longitude in hundred thousandths of degrees. There would be no loss of accuracy, but a lot of unused bits for each observation would be encoded in Section 4. The high accuracy latitude requires 25 bits for representation, high accuracy longitude 26 bits. To represent latitude and longitude to thousandths of degrees would require 18 and 19 bits respectively. If the extra bits from using high accuracy were not deemed a concern, this would be the easiest method. If, however, it were desirable to use only the bits required to represent latitude and longitude in thousandths of degrees, there are two ways for this to be accomplished. First, and the least desirable of any method, would be to create local descriptors for Table B with the appropriate scale and reference values for thousandths of degrees. This is the least desirable method because if the BUFR message were to be transmitted to another center, the receiving center would have to have available to their BUFR decoder program the correct definition of the local descriptors. The other method would be to use the Table C data description operators 2 01 Y to change the data width of the Table B descriptor for latitude and longitude, 2 02 Y to change the scale and 2 03 Y to change the reference values.

There is now a choice to be made between temporarily changing latitude and longitude from hundredths of degrees to thousandths, or, from changing them from hundred thousandths to thousandths. It doesn’t matter which is done, as the only difference between the choices will be the Y operand entries of the data description operators.

Table 5-1. BUFR Table C - data description operators

Table Reference F	X	Operand	Operator Name	Operation Definition
2	01	Y	Change data width	Add (Y-128) bits to the data width for each data element in Table B, other than CCITT IA5 (character) data, code or flag tables
2	02	Y	Change scale	Multiply scale given for each non-code data elements in Table B by 10^(Y-128)
2	03	Y	Change reference values	Subsequent element descriptors define new reference values for corresponding Table B entries. Each new reference value is represented by Y bits in the Data Section. Definition of new reference values is concluded by encoding this operator with Y=255. Negative reference values shall be represented by a positive integer with the left-most bit (bit 1) set to 1
2	04	Y	Add associated field	Precede each data element with Y bits of information This operation associates a data field (e.g., quality control information) of Y bits with each data element.
2	05	Y	Signify character	Y characters (CCITT international Alphabet No. 5) are inserted as a data field of Y x 8 bits in length
2	06	Y	Signify data width for the immediately following local descriptor	Y bits of data are described by the immediately following descriptor

If it were decided to change the data width of latitude and longitude from hundredths to thousandths of degrees, it must first be determined how many bits are necessary to represent individually latitude and longitude in thousandths of a degree. The maximum value for latitude to be represented in the data in Section 4 must take into consideration the old reference value of -9000. The new reference value will be -90000 to accommodate thousandths of degrees. The maximum value of a reported latitude to be encoded into BUFR bits is 180000. This value is arrived at by a reported latitude of 90.000 North which must then be scaled to 10^3 (also to be changed from 10^2) to retain the desired precision, then subtracting the reference value of -90000, producing 180000. The number of bits to accommodate 180000_{10} is 18. To change the data width of the Table B entry for latitude (coarse accuracy) from 15 bits to 18 bits would require the Table C entry 2 01 131. The Y operand 131 is determined by the Operation Definition of adding Y-128 bits to the data width given for the element 0 05 002. The number 128 is the midpoint between 1 and 255 which is the range of values for the 8 bits of Y. Numbers between 1 and 127 will produce a negative value for changing data width, 129 to 255 a positive value.

The next step would be to change the scale from 10^2 to 10^3 in order to properly decode the reported latitude which will be encoded in Section 4 with 18 bits. The WMO BUFR definition for change scale, "Multiply scale given for each non-code data element in Table B by 10^(Y-128)," is referring to the result of 10^scale. For Table B entry 0 05 002, the scale is 2. In this case it is the resultant value 100 which is to be multiplied by 10^(Y-128), not the scale 2. Thus, the data description operator to change the scale for Table B entry 0 05 002 would be 2 02 129.

To complete the necessary changes for Table B, the reference value also needs to be modified from -9000 to -90000. Here again it must be determined how many bits are necessary to accommodate the new value, as the new reference value itself is encoded into Section 4. The number of bits to accommodate 90000 (positive value) is 17. It is, however, necessary to indicate this is to be a negative value which will require an additional bit. To indicate a new reference value as negative, the left most bit of the reference value encoded into Section 4 is set to 1. The sequence of operators needed to redefine or change a reference value is:

1) the 2 03 018 "change reference values operator," which announces a change and states how many bits are set aside for the new reference value in the data section (18 in this example)

2) one or more regular (F=0) data descriptors to indicate which variable(s) are to have new reference values. There are, of course, as many 18-bit values in the data as there are data descriptors following the 2 03 018 descriptor.

In this particular case it will not be necessary to have separate Data Description operators to modify longitude data width and change of scale. The increase in number of bits for data width to accommodate longitude to thousandths of degrees is also 3. The change of scale also remains the same. There will, however, be a required change of reference value from -18000 to -180000. By following the same steps as when changing the latitude Table reference value, the Data Description operator for changing the longitude reference value would be 2 03 019 followed by the data descriptor 0 06 002, followed by the descriptor 2 03 255 to indicate the end of the list of descriptors for which reference values are being changed.

Once Data Description operators 2 01 Y, 2 02 Y and 2 03 Y have been used in Section 3, they remain in effect for the rest of whatever follows in the Section 3 data descriptions. To cancel operator 2 01, and 2 02, the additional entries 2 01 000 and 2 02 000 must be included in Section 3. To cancel the reference value change indicated by the operator 2 03 018, there must be included in Section 3 an operator 2 03 000.

The data description operators encoded into Section 3 for DRIFTER observations would then be as shown on the following page.

0 01 005	buoy/platform identifier
0 02 001	type of station
3 01 011	Table D descriptor which expands to descriptors for year, month and day
3 01 012	Table D descriptor which expands to descriptors for hour and minute
2 01 131	increase data width by 3
2 02 129	multiply scale by 10^1
2 03 018	change reference value - new value contained in 18 bits in Section 4
0 05 002	new reference value applies to latitude - coarse accuracy
2 03 255	terminate reference value definition 203018
2 03 019	change reference value - new value contained in 19 bits in Section 4
0 06 002	new reference value applies to longitude - coarse accuracy
2 03 255	terminate reference value definition
2 02 000	cancel change scale
2 01 000	cancel change data width
2 03 000	Cause all redefined reference values to revert back to standard Table B values
	OTHER ADDITIONAL DATA DESCRIPTORS TO COMPLETE DRIFTER DESCRIPTION

The order for cancellation of nested Data Description operators follows the above pattern; that is, the last change defined is the first canceled.

If instead of changing latitude and longitude from hundredths to thousandths, it were to be changed from hundred thousandths to thousandths the following descriptions would be used:

0 01 005	buoy/platform identifier
0 02 001	type of station
3 01 011	Table D descriptor which expands to descriptors for year, month and day
3 01 012	Table D descriptor which expands to descriptors for hour and minute
2 01 121	**decrease data width by 7**
2 02 127	**multiply scale by -1**
2 03 018	change reference value - new value contained in 18 bits in Section 4
0 05 001	**new reference value applies to latitude - high accuracy**
2 03 255	terminate reference value definition 203018
2 03 019	change reference value - new value contained in 19 bits in Section 4
0 06 001	**new reference value applies to longitude - high accuracy**
2 03 255	terminate reference value definition
2 02 000	cancel change scale
2 01 000	cancel change data width
2 03 000	Cause all redefined reference values to revert back to standard Table B values
	OTHER ADDITIONAL DATA DESCRIPTORS TO COMPLETE DRIFTER DESCRIPTION

Which would be the better of the methods? Again, use of local descriptors to define latitude and longitude is not a good idea as their use may cause a BUFR message to be undecodable in some other center. Of the two other methods, (1) using high accuracy latitude and longitude, or (2) using Data Description operators to change latitude and longitude definitions to thousandths of degrees, each will produce the same results. In terms of number of bits saved by changing to thousandths of degrees over high accuracy, a DRIFTER observation containing data equivalent to the DRIFTER code (FM 18-IX Ext. Sections 0 through Section 2) would require 214 bits per observation using high accuracy latitude and longitude. If latitude and longitude were changed by Data Description operators to thousandths of degrees then the observation would require 200 bits per observation, or a savings of 14 bits per observation - hardly worth the effort!

The preceding example does not imply that changing data width, scale and reference values should not be done, but it does point out that to do so to lower the number of bits within the data section for a given parameter is probably not that beneficial. In those instances where none of the possible Table B entries provide enough significance for new technologies, then the flexibility is provided within BUFR to handle those situations. If, for example, satellites were to measure latitude and longitude to millionths of degrees, then, to maintain significance of those measurements would require changing data width, scale and reference values, at least until (or if) there is a new Table B entry.

This example also shows that, when changing data width, scale and reference values, a single Table D descriptor cannot be used in Section 3. The reason is that changing data width and scale apply to all descriptors in Table B until the change data width and/or change scale is canceled. Since the descriptor to be affected may be deep within the Table D expansion process, there is no way to include the Data Descriptor operators in that expansion. A change in reference value, however, can be accomplished while still using a single Table D entry. This is possible because, after the entry for change reference value, 2 03 YYY, there must also be included the Table B descriptor or multiple descriptors that are to have new reference values.

5.2.1 Changing Reference Value Only. The Table B entries for geopotential, 0 07 003 and 0 10 003 have a reference value of -400 which is too restrictive for very low pressure systems. The Table C-Data Description operator 2 03 YYY can be placed as the first descriptor in Section 3, followed by the Table B descriptor(s) to which it applies. Placing 2 03 010, followed by 0 10 003 before the Table D descriptor means that each time data is encountered in Section 4 for 0 10 003, the new reference value indicated by the count of 10 bits specified by YYY applies. Within 10 bits the limit of the new reference value as a negative number is -511. The descriptor to conclude the list of descriptors for which new reference values are supplied follows immediately, and is followed in turn by the Table D descriptor. See Figure 5-1 where the order of the Section 3 descriptors is:

2 03 010 0 10 003 2 03 255 3 09 008

The Section 4 data will be in the order indicated by that figure.

5.3 Add Associated Field. The Data Description operator 2 04 Y permits the inclusion of quality control information of Y bits attached to each following data element. The additional YYY bits of the associated field appear in the data section as prefixes to the actual data elements. The Add Associated Field operator, whenever used, must be immediately followed by the Class 31 Data Description Operator Qualifier 0 31 021 (data width 6 bits; see code table below) to indicate the meaning of the associated fields.

0 31 021
Associated field significance

Code Figure		
0	Reserved	
1	1 bit indicator of quality	0 = good 1 = suspect or bad
2	2 bit indicator of quality	0 = good 1 = slightly suspect 2 = highly suspect 3 = bad
3-6	Reserved	
7	Percentage confidence	
8-20	Reserved	
21	1 bit indicator of correction	0 = original value 1 = substituted/corrected value
22-62	Reserved for local use	
63	Missing value	

If quality control information were to be added to a single parameter such as pressure, Table B descriptor 0 07 004, the following sequence would appear in Section 3:

2 04 007 0 31 021 0 07 004 2 04 000

```
                                                                  SECTION 4
                                                              WIDTH IN BITS

2 03 010 ---------------------------------- CHANGE REFERENCE VALUE
                                             (ACTUAL REFERENCE VALUE
                                             IN SECTION 4) ------------   0

0 10 003 --------------------------------- REFERENCE VALUE TO CHANGE:
                                           GEOPOTENTIAL --------------   10

2 03 255 --------------------------------- TERMINATE CHANGE REFERENCE
                                           VALUE ---------------------    0

                           ┌ 0 01 001 -- WMO BLOCK NO. ---------------    7
                ┌3 01 001 -└ 0 01 002 -- WMO STATION NO. -------------   10
                │
                │0 02 011----------------- RADIOSONDE TYPE -----------    8
                │0 02 012----------------- RADIOSONDE COMP METHOD-----    4
                │
       ┌3 01 0 8┤              ┌ 0 04 001 -- YEAR --------------------   12
       │        │3 01 011 -  │ 0 04 002 -- MONTH -------------------    4
       │        │              └ 0 04 003 -- DAY ---------------------    6
       │        │
       │        │              ┌ 0 04 004 -- HOUR --------------------    5
       │        │3 01 012 -  └ 0 04 005 -- MINUTE ------------------    6
       │        │
       │        │              ┌ 0 05 002 -- LATITUDE (coarse accuracy) -   15
       │        └3 01 024 -  │ 0 06 002 -- LONGITUDE(coarse accuracy) -   16
       │                       └ 0 07 001 -- HEIGHT OF STATION -------   15
       │
       │        ┌0 20 010----------------- CLOUD COVER (TOTAL) -------    7
3 09 008┤        │0 08 002----------------- VERTICAL SIGNIFICANCE -----    6
       │        │0 20 011----------------- CLOUD AMOUNT --------------    4
       │3 02 004┤0 20 013----------------- HEIGHT OF BASE OF CLOUD ---   11
       │        │0 20 012----------------- CLOUD TYPE Cl -------------    6
       │        │0 20 012----------------- CLOUD TYPE Cm -------------    6
       │        └0 20 012----------------- CLOUD TYPE Ch -------------    6
       │
       │1 01 000 -------------------------- DELAYED REP. 1 FACTOR -----    0
       │0 31 001 -------------------------- REPLICATION FACTOR --------    8
       │
       │        ┌0 07 004----------------- PRESSURE ------------------   14
       │        │0 08 001----------------- VERTICAL SOUNDING SIG -----     7
       │        │0 10 003----------------- GEOPOTENTIAL --------------   17
       └3 03 014┤0 12 001----------------- TEMPERATURE ---------------   12
                │0 12 003----------------- DEW POINT -----------------   12
                │0 11 001----------------- WIND DIRECTION ------------    9
                └0 11 002----------------- WIND SPEED ----------------   12

2 03 000 --------------------------------- CAUSE REDEFINED REFERENCE
                                           VALUE TO REVERT BACK TO
                                           STANDARD TABLE B VALUE ----    0
                                                                       ----
                                                         TOTAL BITS   255
```

Figure 5-1. Change reference value of geopotential

The meaning of the above sequence is:

2 04 007 - indicator that 7 bits of data precede all following Table B entries

0 31 021 - code table entry for the meaning of the 7 bits preceding the Table B entry

0 07 004 - Table B entry for pressure

2 04 000 - cancellation of the Add Associated Field operator

The Section 4 data width for this sequence is 27 bits. The operators 2 04 007 and 2 04 000 do not occupy any bits within Section 4. The 27 bits are taken by 0 31 021 (6 bits) and 0 07 004 (21 bits, 7 bits of associated field plus 14 bits of pressure value)

When multiple Table B entries are preceded by 2 04 YYY as in:

2 04 007 0 31 021 0 07 004 0 31 021 0 10 003 2 04 000

the Add Associated Field operator 2 04 007 and the Data Description Operator Qualifier 0 31 021 both apply to the Table B descriptors 0 07 004 and 0 10 003. The Section 4 data width for the sequence is then:

2 04 007	0	bits
0 31 021	6	
0 07 004	21	(7 associated bits plus bits 14 data)
0 31 021	6	(change meaning of associated field)
0 10 003	24	(7 associated bits plus 17 bits data)
2 04 000	0	

Note that the associated fields are not prefixed onto the data described by 0 31 YYY descriptors. **This is a general rule: none of the Table C operators are applied to any of the Table B, Class 31 descriptors.**

If quality control information were to be added to the following sequence of parameters as described by the Table D descriptor 3 03 014 the following will result:

			SECTION 4 WIDTH IN BITS
3 03 014	0 07 004	PRESSURE	14
	0 08 001	VERTICAL SOUNDING SIG	7
	0 10 003	GEOPOTENTIAL	17
	0 12 001	TEMPERATURE	12
	0 12 003	DEW POINT	12
	0 11 001	WIND DIRECTION	9
	0 11 002	WIND SPEED	12
			83

By placing in Section 3 the operators 2 04 YYY and 0 31 021 immediately preceding 3 03 014, and the cancellation operator 2 04 000 following 3 03 014, the following sequence would be produced:

		SECTION 4 WIDTH IN BITS
2 04 007	ADD ASSOCIATED FIELD	0
0 31 021	ASSOCIATED FIELD SIG	6
	ASSOCIATED FIELD	7
0 07 004	PRESSURE	14
	ASSOCIATED FIELD	7
0 08 001	VERTICAL SOUNDING SIG	7
	ASSOCIATED FIELD	7
0 10 003	GEOPOTENTIAL	17
	ASSOCIATED FIELD	7
0 12 001	TEMPERATURE	12
	ASSOCIATED FIELD	7
0 12 003	DEW POINT	12
	ASSOCIATED FIELD	7
0 11 001	WIND DIRECTION	9
	ASSOCIATED FIELD	7
0 11 002	WIND SPEED	12
2 04 000	CANCEL ADD ASSOCIATED FIELD	0
		138

Adding associated fields to a data sequence that is described by a Table D descriptor means the associated fields are placed before all data items in the sequence. If quality control information were to be applied only to the pressure and geopotential parameters, the Table D descriptor could not be used but instead each individual parameter would have to be listed in Section 3.

2 04 007	ADD ASSOCIATED FIELD	0
0 31 021	ASSOCIATED FIELD SIG	6
	ASSOCIATED FIELD	7
0 07 004	PRESSURE	14
2 04 000	CANCEL ADD ASSOCIATED FIELD	0
0 08 001	VERTICAL SOUNDING SIG	7
2 04 007	ADD ASSOCIATED FIELD	0
0 31 021	ASSOCIATED FIELD SIG	6
	ASSOCIATED FIELD	7
0 10 003	GEOPOTENTIAL	17
2 04 000	CANCEL ADD ASSOCIATED FIELD	0
0 12 001	TEMPERATURE	12
0 12 003	DEW POINT	12
0 11 001	WIND DIRECTION	9
0 11 002	WIND SPEED	12
		109

If quality control information were to be added to the pressure and geopotential parameters in the TEMP observations as described in

Figure 3-1, the following adjustments would have to be made. The single Table D descriptor 3 09 008 could no longer be used as the expansion includes the additional Table D descriptor 3 03 014 which further expands to those parameters where quality control information would need to be inserted. The actual order of the Section 3 descriptors would now be (as illustrated in Figure 5-2):

```
 3 01 038   3 02 004   1 13 000   0 31 001   2 04 007   0 31 021
 0 07 004   2 04 000   0 08 001   2 04 007   0 31 021   0 10 003
 2 04 000   0 12 001   0 12 003   0 11 001   0 11 002
```

5.4 <u>Encoding Character Data</u>. There may be occasions when it is necessary to encode character data into BUFR. An observation encoded into BUFR that originated from the character code FM 13-IX Ext. SHIP, for example, has within that code form the optional inclusion of plain language. If this character information were carried over for encoding into BUFR, the Data Description operator 2 05 Y would be used in Section 3 to indicate the inclusion of character data in Section 4 of the BUFR message. The Y operand of the Data Descriptor indicates the number of characters, encoded CCITT International Alphabet No. 5, inserted as a data field in Section 4.

The following parameters from the FM 13-IX Ext. SHIP code form:

$$\left(\begin{bmatrix} 6I_sE_sE_sR_s \\ \text{or ICING +} \\ \text{plain language} \end{bmatrix}\right)$$

described by BUFR descriptors would be:

0 20 033	cause of ice accretion
0 20 031	ice deposit (thickness)
0 20 032	rate of ice accretion

It would have to be determined in advance how many characters would be allowed for the plain language. If only the word ICING were to be placed in Section 4, the Data Descriptor 2 05 005 would be used. If it were determined that ICING plus 25 additional characters, including spaces, were to be described then the descriptor would be 2 05 030. The data descriptors and data width in Section 4 would then be:

		data width in bits
0 20 033	cause of ice accretion	4
0 20 031	ice deposit (thickness)	7
0 20 032	rate of ice accretion	3
2 05 030	character information	240

				SECTION 4 WIDTH IN BITS
3 01 038	3 01 001	0 01 001	WMO BLOCK NO.	7
		0 01 002	WMO STATION NO.	10
	0 02 011		RADIOSONDE TYPE	8
	0 02 012		RADIOSONDE COMP METHOD	4
	3 01 011	0 04 001	YEAR	12
		0 04 002	MONTH	4
		0 04 003	DAY	6
	3 01 012	0 04 004	HOUR	5
		0 04 005	MINUTE	6
	3 01 024	0 05 002	LATITUDE (COARSE ACCURACY)	15
		0 06 002	LONGITUDE(COARSE ACCURACY)	16
		0 07 001	HEIGHT OF STATION	15
3 02 004	0 20 010		CLOUD COVER (TOTAL)	7
	0 08 002		VERTICAL SIGNIFICANCE	6
	0 20 011		CLOUD AMOUNT	4
	0 20 013		HEIGHT OF BASE OF CLOUD	11
	0 20 012		CLOUD TYPE Cl	6
	0 20 012		CLOUD TYPE Cm	6
	0 20 012		CLOUD TYPE Ch	6
1 13 000			DELAYED REP. 13 DESCRIPTORS	0
0 31 001			REPLICATION FACTOR	8
2 04 007			ADD ASSOCIATED FIELD	0
0 31 021			ASSOCIATED FIELD SIG.	6
			ASSOCIATED FIELD	7
0 07 004			PRESSURE	14
2 04 000			CANCEL ADD ASSOCIATED FIELD	0
0 08 001			VERTICAL SOUNDING SIG	7
2 04 007			ADD ASSOCIATED FIELD	0
0 31 021			ASSOCIATED FIELD SIG.	6
			ASSOCIATED FIELD	7
0 10 003			GEOPOTENTIAL	17
2 04 000			CANCEL ADD ASSOCIATED FIELD	0
0 12 001			TEMPERATURE	12
0 12 003			DEW POINT	12
0 11 001			WIND DIRECTION	9
0 11 002			WIND SPEED	12
			TOTAL BITS (ONE REPLICATION)	277

Figure 5-2. Example of TEMP observations sequence using delayed replication and quality control information.

Since an observation in FM 13-IX EXT. SHIP code would have either the parameters for ice reported, or ICING + plain language, but not both, then if there were no plain language the character information would be set to spaces. If the ICING + plain language were reported, then the data for descriptors 0 20 033, 0 20 031 and 0 20 032 would be set to missing, all bits set. Since Section 3 indicates a count of how many subsets (observations) are included in Section 4, the above descriptors apply to all subsets, even if an individual observation does not contain any icing information. In that case the entire set of icing data for an observation would be set to missing and spaces.

5.5 **Signifying Length of Local Descriptors**. Local Descriptors were provided in BUFR to enable a data processing center the capability of describing information of any type within BUFR for the center's internal use (Figure 2-4). There does exist, however, the possibility that once data is described in BUFR it may be necessary to transmit a BUFR message to another center, where the BUFR message would contain local information. Since a receiver of the BUFR message may or not know the meaning of the local descriptor, it could be impossible to be able to decode the message, as the receiver would not know the data width in Section 4 of the local information (Figure 2-5). While it could be argued that BUFR messages containing local information should never be transmitted to another center, it may require a separate set of software to remove local information before the message is ready for transmission. To overcome this situation the Data Description operator 2 06 Y was developed to allow local information to be contained within a transmitted message and to give information to the receiver that indicates the length in bits of the local data. The meaning of the Data Description operator 2 06 Y is that the following local descriptor is describing Y bits of data in Section 4. Knowing the width in bits of data in Section 4 then allows the receiver of the message to bypass that number of bits and permits proper decoding of Section 4. For example, see Figure 5-3.

The operator 2 06 Y can only be used when it precedes a local descriptor with F = 0. While it is within the rules of BUFR to create local descriptors with F = 3 (sequence descriptor), the Data Description operator 2 06 Y cannot be used to bypass whatever number of bits are being described by a sequence descriptor. Since a sequence descriptor expands to other descriptors and in the expansion process other local descriptors or delayed replication may be encountered, there is no way of knowing in advance how many total bits are covered by a sequence descriptor.

					SECTION 4 WIDTH IN BITS
2 06 003				3 BITS ARE DESCRIBED BY THE FOLLOWING LOCAL DESCRIPTOR	0
0 54 192				LOCAL DESCRIPTOR	3
3 07 002	3 01 023	3 01 001	0 01 001	WMO BLOCK NO.	7
			0 01 002	WMO STATION NO.	10
		0 02 001		TYPE OF STATION	2
		3 01 011	0 04 001	YEAR	12
			0 04 002	MONTH	4
			0 04 003	DAY	6
		3 01 012	0 04 004	HOUR	5
			0 04 005	MINUTE	6
		3 01 024	0 05 002	LATITUDE (coarse accuracy)	15
			0 06 002	LONGITUDE(coarse accuracy)	16
			0 07 001	HEIGHT OF STATION	15
	3 02 011	3 02 001	0 10 004	PRESSURE	14
			0 10 051	PRESSURE REDUCED TO MSL	14
			0 10 061	3 HR PRESSURE CHANGE	10
			0 10 063	CHARACTERISTIC OF PRESSURE	4
		3 02 003	0 11 011	WIND DIRECTION	9
			0 11 012	WIND SPEED AT 10m	12
			0 12 004	DRY BULB TEMP AT 2m	12
			0 12 006	DEW POINT TEMP AT 2m	12
			0 13 003	RELATIVE HUMIDITY	7
			0 20 001	HORIZONTAL VISIBILITY	13
			0 20 003	PRESENT WEATHER	8
			0 20 004	PAST WEATHER (1)	4
			0 20 005	PAST WEATHER (2)	4
		3 02 004	0 20 010	CLOUD COVER (TOTAL)	7
			0 08 002	VERTICAL SIGNIFICANCE SURFACE OBS	6
			0 20 011	CLOUD AMOUNT	4
			0 20 013	HEIGHT OF BASE OF CLOUD	11
			0 20 012	CLOUD TYPE Cl	6
			0 20 012	CLOUD TYPE Cm	6
			0 20 012	CLOUD TYPE Ch	6
				TOTAL BITS	270

Figure 5-3. Example of surface observations with local descriptor and data descriptor operator 2 06 Y

CHAPTER 6

QUIRKS, ADVANCED FEATURES, AND SPECIAL USES OF BUFR

(contributed by: J.D. Stackpole)

6.1 Introduction. This chapter is a slightly disparate collection of odds and ends about BUFR. It discusses some of the advanced features that are sometimes overlooked in a casual reading of the WMO Manual, some of the special uses to which data represented in BUFR has been (or can be) put, and offers a fuller explanation of some of the rather obscure portions of the WMO description of the data representation system.

It also details some of the conventions adopted on an ad hoc basis in those (few) cases where the current specifications of BUFR are a little bit ambiguous. It is expected that what is described in this context will all eventually find its way into the published specifications.

In part, this chapter is necessary because it is turning out, with experience, that BUFR is indeed a very powerful data representation system. As people work with the system, they recognize new possibilities that were not thought of in the original design. Sometimes these new possibilities fit right into the existing system, as though they were implicitly present from the beginning. At other times, they require a slight (or not so slight) augmentation of the BUFR rules and/or descriptors to implement the ideas. The latter must be done with care, of course, so as not to build any (violent) inconsistencies into BUFR. Some of the more promising proposals for change are discussed in this chapter and these are clearly indicated as such.

Also, this chapter is (unfortunately) necessary because some of the features (advanced or not) of BUFR are none too clearly spelled out in the necessarily limited confines of the WMO Manual. Experience has shown that some of the rules and regulations get overlooked and/or misinterpreted in their application. It is hoped that this chapter, and this guide in general, will help to alleviate these sorts of problems.

BUFR sets out to do a lot and this, in turn, leads to complexity. There is no free lunch.

As an organizing structure, each section of a BUFR message/record will be dealt with in its regular order.

6.2 Section 0 - Indicator Section.

6.2.1 Edition Number Changes. There hasn't been any particular difficulty with this section except perhaps for the "edition number", currently 2, of the BUFR system. The edition number will change only if there is a structural change to the data representation system such that an existing and functioning BUFR decoder would fail to work properly if given a "new" record to decode. A change or augmentation to Tables A, B, D, or the code and flag tables would not involve defining a new Edition for BUFR; one would, of course, be required to change corresponding tables in a computer program but the logic of the program would not have to be changed. Changing tables is easy; changing program logic is not so easy. This difference is, indeed, what BUFR is all about.

Edition changes can come about in three main ways. For one, if the basic bit or octet structure of the BUFR record was changed, by the addition of something new in one of the "fixed format" portions of the record, say, this would obviously require computer program changes to work properly. The change from Edition 1 to 2 involved just such a change - see the remarks at the end of par. 1.2.1. These types of changes are expected to be kept to a bare minimum by the WMO community.

A second way that an edition change can come about is if the data description operators, in Table C, are augmented. These operator descriptors are qualitatively different from simple data descriptors: where the data descriptors just passively describe the data in the record, the operator descriptors are, in effect, instructions to the decoding program to undertake some particular action - just what actions are possible are those defined by Table C. Descriptors of type 1 (F=1), the replication operators, are also in this category - they tell the computer program to do something - but there is little room for change as they are currently defined. Clearly, if some new (and presumably useful) "operation" is defined, by inclusion of an operator in Table C, any decoding programs will have to be modified to respond properly. The descriptor 2 06 YYY (the "skip local descriptor" operator) was one such addition made in the conversion from Edition 1 to Edition 2.

Unfortunately, not all of the "operator" descriptors are collected in Table C. Some of the nominal data descriptors, in particular the "increment" descriptors found in Table B, Classes 4, 5, 6, and 7, take on the character of operators in conjunction with data replication (Regulation 94.5.4) and the operator qualifiers in Table B, Class 31. This is expanded on further below. However, it is clear that changes or augmentations to the general process of replication, including increments, would involve defining a new edition of BUFR.

A third change that would require a new edition would be a change of the regulations and/or many of the various notes scattered through the documentation. (The "notes", by the way, are as important as the "regulations" in formally defining BUFR - they contain many of the details that flesh out the rather sparse regulations. Ignore them at your peril.) This is not apt to happen - more likely there will be clarifications to the regulations or notes that will serve to make the rules more precise in cases that currently seem ambiguous. This may result in a tightening of a rule (or an interpretation) that may require a current "inappropriate" practice to be eliminated. Whether this should be considered as requiring an edition number change is a matter of some judgment. The WMO will be the final arbiter.

6.2.2 Maximum Size of BUFR Records. As noted elsewhere, there is no theoretical limit to the size of a BUFR message. The largest that can be accommodated by octets 5-7 would be almost 17 mega-octets (megabytes) but a single bulletin of that size would be a bit much for the WMO Global Telecommunications System (GTS). By general international agreement, as specified in the Manual on the GTS, WMO Publication 386, single messages should be kept to less than 15,000 octets (15 kilobytes); 10,000 octets is a good safe number to use to be assured that GTS switching centers won’t inadvertently truncate the bulletins as they pass them on. A new GTS specification for breaking up very large bulletins, using the new BBB parameter in the WMO Abbreviated Heading, has recently been promulgated. It is better, however, that such large records not be generated in the first place.

6.3 Section 1 - Identification Section.

6.3.1 Master Tables, Version Numbers, and Local Tables. At present there are no (known) Master Tables for BUFR other than the meteorological set published in the WMO Manual On Codes. That is not to say that such could not exist. It is one of the major strengths of BUFR that any scientific discipline interested in transmitting, storing, or even data-basing its unique information may define its own set of tables and take advantage of meteorological experience in using the BUFR system.

As is noted elsewhere in this document, only the upper left portion of the (Class by Entry) matrix of descriptors has been defined in the current Master Table B - Classes 00 through 31, variable number of entries in each class - in the current WMO documentation. Classes 48 through 63 are for local use. This means that any group may define anything they please for those classes; the same is true for Entries 192 through 255 in any class. The other classes, and whatever unused entries are not spoken for in each class, are set aside for future international usage. Some of the Classes, Class 2 - Instrumentation in particular, are getting alarmingly crowded.

Elements can be added to the international portion of the tables on rather short notice by eliciting the coordinating cooperation of the WMO Working Group on Data Management (WGDM), Sub-Group on Data Representation and Codes (SGDR&C). International notification of such additions is accomplished by the World Weather Watch (WWW)

Operational Newsletter. The WMO body that is parent to the WGDM, the Commission on Basic Systems (CBS), meets every two years or so and, upon CBS approval, the additions to the tables will be published by the WMO. This relatively informal method of adding to the tables is possible because the BUFR community is, at present, rather small. It is also possible because of the agreed upon convention that ONLY additions will be made to Tables B or D by this method and that descriptors will neither be deleted nor changed. Thus, existing messages and decoding tables will not be affected as long as they have no need to make use of the new data descriptors. Changes to the tables which involve only additions do not require that the version number of the tables be changed. Also, changes which are in the nature of "trivial" corrections (typographical errors, more precise definitions of terms, etc.) do not engender new version numbers. The SGDR&C will define what is "trivial" and what is not. At present, the tables stand at Version 2.

The SGDR&C meets from time to time to study and recommend changes that may involve the structure of BUFR or more substantial changes to the tables, such as the addition of new operator descriptors, wholesale reorganization of the tables, or the possible elimination of old and unused descriptors. The latter two steps will be taken with great care, however, so as to not make old archives of BUFR data inaccessible. Such recommendations will wend their way through the WMO system, eventually appearing as new editions of BUFR, or new versions of the tables, upon approval of the CBS. Because both the BUFR edition number and the version number of the tables are part of the BUFR message, it is only a programming task for a decoding program to note the BUFR edition number of a message and the version number for the tables and then extract the appropriate table version from some computer files. The WMO publications will always contain the latest version of the tables. It is up to the various meteorological computer centers to maintain their own files of previous versions as well as their own local tables, of course.

The local portions of the tables can be updated, changed, augmented, etc. at will by the local group concerned. No international notice is required or expected. It is presumed that bulletins containing local descriptors will not usually be sent out internationally (but see the discussion of descriptor 2 06 YYY in paragraph 5.5 for the way to handle any exception).

"Local," although not defined in the BUFR documentation, is generally taken to mean "within the processing center that is generating the BUFR messages," and not necessarily one country. The U. S. has a number of processing centers (the civilian weather service, Air Force, Navy, and other groups as well, each potentially identified by a unique processing center number and sub-number) each one of which is free to use the "local" portions of the BUFR tables as they see fit.

6.3.2 Originating Center. The method of specifying the number of the originating center has been changed from what is described in the (current) Manual on Codes (Supplement 3, 1991). Here is a little historical background as to how things have evolved. GRIB (FM 92) was developed first and adopted a pre-existing WMO table of meteorological centers for "originating centers". It is a list of mainly large world and regional meteorological centers that could be expected to have the computer facilities required to generate GRIB bulletins if they had occasion to do so. When BUFR was developed it was realized that observational data could originate from far more locations that the GRIB table could accommodate. Thus, in BUFR, two octets were set aside for numerical specification of those locations, where GRIB used but one. A proposal was developed to enumerate those additional locations based upon International Civil Aviation Organization (ICAO) Location Indicators and this was published in the 1991 supplement as part of the BUFR specifications. Since then, however, it was realized that confusion and inconsistencies could result from separate GRIB and BUFR originating center tables and a recent proposal was accepted to construct tables that were common to GRIB, BUFR and any other WMO code. To do this it was, in turn, necessary to drop the ICAO numbering system from BUFR. Fortunately, the two tables have not, up to now, developed any inconsistencies and the "ICAO numbers" are in very limited use. It was concluded that this change could be done without requiring a new edition for BUFR.

The resulting system is simply that octet 6 of Section 1 - Identification Section is used to identify the national (or international) originating centers, using the same common table as is in use for GRIB. This table will be coordinated and maintained by the WMO and published as part of the codes manual. Any national sub-center numbers that may be required are to be generated by the national center in question and that number is to be placed in octet 5. The WMO has expressed a willingness to publish sub-center identification tables as supplied by the national centers.

6.3.3 Update Sequence Number. This feature does not seem to have wide use, as yet, but it is a powerful one. Note that the rule does require one to re-send an entire message if even only one element in the message is a correction of a previous message element. The "associated field" (see more on this later) is used to indicate which element(s) is(are) the corrected one(s) within the total message.

6.3.4 Optional Section 2. This section is not usually sent in international messages but it is put to use in some computer centers that use BUFR, frequently in a data base context. Some samples are given later in this chapter. If it is present, the flag in octet 8 of Section 1 must be set, of course.

6.3.5 BUFR Message Sub-Type. This is purely a local option. As an example, beginning on the following page are listed the sub-types currently in use at the National Meteorological Center, Washington.

BUFR Data Category 0: Surface data - land

Data Sub-type	Description
0	Unassigned
1	Synoptic - manual
2	Synoptic - automatic
3	Aviation - manual
4	Aviation - AMOS
5	Aviation - RAMOS
6	Aviation - AUTOB
7	Aviation - ASOS
8	Aviation - METAR
9	Aviation - AWOS

BUFR Data Category 1: Surface data - sea

Data Sub-type	Description
0	Unassigned
1	Ship - manual
2	Ship - automatic
3	Drifting buoy
4	Moored buoy
5	Land based C-MAN station
6	Oil rig or platform
7	Sea level pressure bogus
8	Moisture bogus
9	SSMI

BUFR Data Category 2: Vertical soundings (other than satellite)

Data Sub-type	Description
0	Unassigned
1	Rawinsonde - fixed land
2	Rawinsonde - mobile land
3	Rawinsonde - fixed ship
4	Rawinsonde - mobile ship
5	Dropwinsonde
6	Pibal
7	Profiler

BUFR Data Category 3: Vertical soundings (satellite)

Data Sub-type	Description
0	Unassigned
1	Geostationary
2	Polar orbiting
3	Sun synchronous

BUFR Data Category 4: Single level upper-air (other than satellite):

Data Sub-type	Description
0	Unassigned
1	Aircraft - manual
2	Aircraft - reconnaissance
3	Aircraft - automatic (ASDAR)
4	Aircraft - automatic (ACARS)
5	Aircraft - automatic (AMDAR)

BUFR Data Category 5: Single level upper-air (satellite):

Data Sub-type	Description
0	Unassigned
1	Cloud-tracked winds
2	Water-vapor-tracked winds

The above sort of information is useful in processing the observational data after it has been decoded from BUFR. By knowing ahead of time, so to speak, in considerable detail just what sort of data is in a BUFR message, it can make the choice of subsequent processors that much easier. It also makes it possible to search through a collection of various data types, encoded in BUFR, and select out only those for which there is a special interest. This has obvious applications in a data base context.

6.3.6 Date/Time. The manual suggests placing the date/time "most typical for the BUFR message contents," whatever that may mean, in the appropriate octets. Obviously for synoptic observations the nominal synoptic time is appropriate. But note that the exact time of the observation can be placed in the body of the message if this is of interest or value to the users of the data. Not only that, but a collection of observation times (and exact locations) could be incorporated into one observation to indicate, for example, the times (and places) that a radiosonde balloon reached particular levels in the atmosphere. This possibility is getting serious attention as very fine mesh numerical models with frequent analysis update cycles are coming into operations. A RAOB can take an hour or more to complete its flight, and travel 40 or 50 km (or more) downwind in that time. That is clearly enough to place the high level parts of the observation into both the next analysis update cycle and at a neighboring gridpoint. Reporting this level of detail would require a major revision to the character based TEMP Code (FM 35) but BUFR can accommodate this additional information with no change whatsoever. [End of commercial for BUFR!]

Collections of satellite observations, which are inherently asynoptic, by convention will have the time of the first observation of the collection in the date/time octets. The exact times for each observation will, of course, be in the body of the message.

6.3.7 "Reserved for use ...". Here again is a playground for the local center. It is not expected that international BUFR messages will contain anything past octet 18 (and that octet will be all zeros per the rule that all sections have an even number of octets) but there is no real damage if Section 1 is "extended" past octet 18. That is because the "Length of Section" in octets 1-3 will (should) indicate the full size of the section. Any operational decoding program worthy of the name will check the number in octets 1-3 and respond accordingly, presumably by skipping the extra material.

6.4 Section 2 - Optional Section - Examples of Data Base Keys.

6.4.1 U. S. National Meteorological Center Usage. At the U.S. National Meteorological Center (NMC), Section 2 - Optional Section is being used, internally, as a very simple data base key. The actual data are stored in data subsets (see below), i.e., individual observations. For each observation/subset there is a short collection of information in Section 2, which looks like this:

Content	Element Size
Displacement from start of BUFR message to start of subset (in units of octets)	2 octets
Latitude	2 octets
Longitude	2 octets
Day & hour	2 octets
Identification	6 octets

The first of these 14 octet packets starts in octet 5 of Section 2, with the others following without any break. This rather minimal set of information is enough to select out individual observations using location and/or time criteria. It is not necessary to decode any of the observations to find the desired ones - the displacement count tells you where to go to get each observation.

The alert reader will have noted a difficulty with the above scheme: in the BUFR system there is no requirement that data subsets each start on an exact octet or word boundary; indeed it is rather unlikely that they would, given the essentially random nature of the bit lengths used to store data elements. Yet the "displacement" is specified in terms of octets. Some sort of padding is clearly necessary, so that as the BUFR record is constructed each subset will start on a word (or half-word, or octet) boundary in whatever machine is in use. The actual padding is easy: one simply invents a local descriptor (NMC uses 0 63 255) which is specified to describe 1 bit of padding in the data section without assigning any other "meaning" to the bit. Then one places a delayed replication descriptor (1 01 000, with its associated 0 31 001 count descriptor) in front of the pad descriptor, with the delayed count giving the number of bits inserted to generate a pad of the proper length. This works but leaves one with local descriptors imbedded in the message - a problem if the message is to be sent out non-locally at some future time. It could be expensive to go through the record, remove the padding, and reconstruct a "pure" BUFR record for all the data.

But this can be resolved with the use of the "skip local descriptor" descriptor, 2 06 YYY. Just place it before the local "pad" descriptor, change the XX of the delayed replication descriptor to a value of 2, and the padded record can then be sent out without causing any problems for recipients. The whole thing would look like this:

	Descriptors	Values
	.	.
Here is a fragment from	.	.
an uncompressed BUFR	ddd1	vvv1
record (ignore blank lines)	ddd2	vvv2
	ddd3	vvv3
end of "real" data subset ------>	ddd4	vvv4
Delayed rep. of two descriptors n times;	1 02 000	-
n is the number of bits in the pad, which follows the 8 bits containing the n value	0 31 001	n
Skip local descriptor	2 06 001	-
Local pad descriptor	0 63 255	(one bit)

And that does it.

Another solution to the padding problem, of course, is to create a new international padding descriptor. But since "padding" is machine dependent it seems better to leave the padding up to the local center and not make a regular practice of exchanging padded BUFR messages.

6.4.1.1 BUFR as a Data Base Storage System. Once the observations/subsets are lined up on octet (or word) boundaries it becomes quite feasible to use BUFR records as a (simple) data base storage format. One restriction applies: all the data subsets must be the same size (i.e., no delayed replications - see below) and must not be compressed. A common use of a meteorological data base system is to extract one particular data element, temperature, say, from all the available observations, for specific time and geographic ranges. To do so with "lined up" BUFR records all that is necessary is to decode the first subset and take note of the relative location of the temperature data in that subset. Then one simply extracts the temperature information from the relative location in the other subsets without having to (expensively) unpack the entire record.

Of course, this does not allow for all the features of a full relational data base management system. But it may well be sufficient for some more limited uses. It does have the advantage that data can be shared from center to center, and used in similar data base systems, without the necessity of decoding the data (or extracting it from an RDBMS) and re-encoding the data to transmit it in a reasonably efficient format. It already is in a reasonably efficient transmission format. It may be necessary to redefine the "pad" on a different machine, but that can be done without unpacking or repacking the entire record.

6.5 Section 3 - Data Description Section.

6.5.1 Data Subsets. "Data subsets" are variously defined in the current BUFR documentation. Conceptually, one subset is a collection of "related meteorological data," quoting from the manual. Continuing: "For observational data, each subset usually corresponds to one observation," where "observation," in this context, could mean one surface synoptic observation of a number of specific elements, one radiosonde ascent, one profiler sounding, one satellite derived sounding with radiances perhaps, or the like. No examples of non-observational data subsets are given, but a typical one would be a message consisting of a collection of numerical model forecasts of "soundings" at grid-points or other specific locations. Each forecast sounding (pressure, temperature, wind, relative humidity, whatever, at the many levels of the model) would then be one data subset.

A more precise (if slightly tautological) "operational" definition shows up later on in Regulation 94.5.2: "A data subset shall be defined as the subset of data described by one single application of this collection of descriptors." In this context, the "collection of descriptors" means ALL the descriptors included in Section 3 of the BUFR message. In other words, one pass through the complete collection of descriptors will allow one to decode one data subset from Section 4. One then loops back in the descriptor list for as many times as the data subsets count calls for. All of the data, in Section 4, are properly described by repeated use of the same set of descriptors.

This does not imply that the data subsets are themselves identical in format. The use of delayed replication, as in a collection of RAOBs with varying numbers of significant levels, could cause variations in format (octet count) among data subsets. But they are still considered "subsets" in that the same set of descriptors will properly describe each individual set. The use of the delayed replication descriptor is what makes this possible, and is what delayed replication was designed for.

As noted in Chapter 5, certain descriptor operators, from Table C, can be used to redefine reference values, data lengths, scale factors, and to add associated fields. There is also a group of descriptors which "remain in effect until superseded by redefinition" (more on them below). By common practice, ALL of these redefinitions or "remain in effect" properties are canceled when one cycles back to reuse a set of descriptors for a new data subset. You wipe the slate clean and start as though it was the first time. This rule is NOT specifically stated in the manual at present, but presumably will be in the next update.

Of course, data subsets can be identical in format, i.e., have the same number of octets in each subset. This will always be the case if delayed replication is avoided. In this case one can compress the data, as described in Chapter 4, and gain considerable efficiency. Chapter 4, in the interest of avoiding overwhelming detail, doesn’t mention that it is perfectly possible to compress data elements to which have been attached associated fields. The catch is that every data element has to have an associated field attached to it for the systematic compression to be possible. This may cut into the efficiency of the compression and should be considered before undertaking such a project.

Even though data subsets may be compressed and, as a result, the individual elements in each data subset are all reordered, the data subset concept still holds. The data subset count must be included in the correct location, and must be correct, of course. It is impossible to decompress a message without that information; and even if the data are not compressed the count is necessary to retrieve all the data subsets in a given message.

A final note about subsets: It is possible, within the BUFR framework, to account for many subsets by the device of placing a replication operator just in front of the set of descriptors that define one subset and have that replication include the count of all the subsets. This in effect reduces the data down to just one subset in that one would no longer cycle back and reuse the complete set of descriptors (now including the replication descriptor). This is NOT a recommended procedure. It is far better to have the subset count "up front", so to speak, in octets 5-6 of Section 3 if for no other reason that it gives the user an indication of how much data he will have to contend with before the decoding gets under way.

6.5.2 Observed or "Other Data". A brief note: the "other data" flagged in octet 7 of Section 3 has been taken to mean forecast information, such as a collection, from a numerical model, of forecast "soundings" of wind, temperature, humidity, whatever, at the various internal layers or levels of the model, at a collection of grid points or interpolated locations. The time significance qualifier (0 08 021) is used to indicate that the hours associated with each sounding are indeed forecast hours. The initial time of the forecast is given as an unqualified date/time group, and it is in the message prior to the 0 08 021 descriptor.

"Other data" need not be limited to forecasts, of course. Statistical, climatological, quality control information, etc. would all fall under the general category of "not observations". This lack of specificity is not of very great concern as the descriptors in the body of the message take care of the precise definition of just what information is in the BUFR record.

6.5.3 Data Descriptors. Here is where we shall discuss some of the advanced, tricky, quirky, or special features about descriptors. Perforce, there will be collateral discussions of the data which those descriptors set out to describe. Much of what is discussed here is in the nature of meta-rules about descriptors, in that it deals with the proper interpretation of some special descriptors and interpretation of special combinations of descriptors.

Descriptors, in isolation, are rather straight-forward: one descriptor describes one piece of data, one to one (or in the case of Class D descriptors, one to many). The special rules discussed here go beyond that - some are, in effect, the rules that an application program needs to "know," given that a set of (presumably decoded) data, with associated descriptors, is presented to it. The application program has to "know" the "meaning" of these special descriptors, or patterns of descriptors, to handle the data properly and deliver to the end user what the constructor of the BUFR message intended. Some of the meta-rules are also in the nature of operator descriptors that the BUFR decoding program itself has to "know" in order to reconstruct the original data. Of course, the creator of such BUFR messages has to know and follow the rules as well.

Perhaps all this generalization will come clearer when we deal with specific examples.

6.5.3.1 Descriptors for "Coordinates". The descriptors in Classes 00 through 09 (with 03 and 09 at present reserved for future use) have a special meaning added to them over and above the specific data elements that they describe. They (or the data they represent) "remain in effect until superseded by redefinition." By this is meant that the data in these classes serve as coordinates (in a general sense) for all the following observations. Once you encounter an 0 04 004 (which describes the "hour") one must assume that the hour (a time coordinate) applies to all the following observations, until either another 0 04 004 descriptor is encountered or you reach the end of the data subset.

Obviously the familiar coordinates (two horizontal dimensions - Classes 05 and 06 - a vertical dimension - 07 - and time - 04) are in this sub-category of descriptors, but so are some features that one might not think of as "coordinates", other than in a general sense. Forms of "identification" of the observing platform (block and station number, aircraft tail number, etc.) are "coordinates" in this sense, in that they most certainly apply to all the observations taken from that platform and they "remain in effect until superseded by redefinition." The instrumentation that is used to take the measurements (Class 02) also falls in the same category - it applies to all the actual observations because all the observations were made with that particular instrument. (A lot of the instrumentation class deals with details of radar - there seems a lot more to say about such equipment than, say, a thermometer. But if reporting details about the thermometer [mercury vs. alcohol vs. bimetallic strips, say] became important this information could be added to Class 2 without difficulty.)

A source of confusion can arise by noting that some parameters (height and pressure, for example) appear twice in the tables: in Class 07 and again in Class 10. Which table descriptor is appropriate depends on the nature of the measurement that involves these parameters. A radiosonde, which measures wind, temperature, and humidity (and geopotential height by calculation) as a function of pressure, would report the pressure values using Class 07 (the vertical coordinate or independent variable) and the other parameters from the non-coordinate classes (10 for geopotential, 11, 12, and 13 for the others). An aircraft radar altimeter, on the other hand, might measure pressure (and use Class 10 to report the value) as a function of height (Class 07).

Yet another kind of "coordinate" is imbedded in Class 8 - Significance Qualifiers. These are a way of reporting various qualitative pieces of information about the (following) data elements, beyond their numeric values, that can be important to the user of the data. A problem of how to "cancel" significance has come up - there are cases where it makes no sense to have a particular kind of significance "remain in effect" for the rest of the message (or to the end of the data subset) but there is no explicit way to cancel it. A convention has been more or less agreed upon that sending a "missing" from the appropriate table has the effect of canceling whatever significance was previously established from that table. Presumably, this convention will become a rule (or footnote) in a future printing of the BUFR manual.

There is an exception to the "remain in effect until redefined" rule: when two identical descriptors, from Classes 04 to 07, are placed back to back, that is to be interpreted as defining a range of coordinates. In this way an area, a volume, a span of time, or all three together, can be defined as needed. If the same descriptor shows up later on in the message, then that appearance does indeed redefine that particular coordinate value even if the original coordinates defined a range. The others still remain in effect for any subsequent data.

Unfortunately some coordinate-like information has appeared in a table outside the Class 00-09 range - it escaped somehow. Class 25 - Processing information, largely dealing (again!) with radar information, contains information that by its nature "remains in effect until superseded." It should be considered as a "coordinate" class and most likely will get such an official designation in the future. This will not involve any changes to the structure of BUFR or the tables, only a change in interpretation, or "meaning," of the data elements.

There is not much a general BUFR decoder program can do with this "coordinate " information, other than decode it and pass the information on to some follow-on applications program. As noted in the introduction to this sub-section, it is up to the applications program (or the human reading a decoded message) to supply the interpretation and the meaning of what is there, and then to act accordingly. Some of the interpretation is straightforward, almost second nature. "Obviously" the station identification applies to the following observations made at that station; "obviously" this pressure level is where the RAOB measured the wind and temperature; perhaps not so obvious is the fact that two consecutive azimuth values define a sector in which a hurricane is located. Making the "obvious" explicit with rules, regulations, and footnotes is part of what BUFR is all about. The developers of BUFR made every effort to EXCLUDE as much "self-evident" information as possible and instead require that "meaning" be specified by definite rules - that is, in part, what makes the system so powerful. [End of second commercial!]

6.5.3.2 Replication, Increments, and "Run-length Encoding". As described in Chapter 3, replication (a descriptor with F=1) is pretty straightforward. Even delayed replication is no real problem (except to someone writing a program to do it correctly). In either case, you just replicate the following X descriptors Y times ("Y" can be either part of the descriptor or found in the data section) and that is it. This allows you to encode and describe a potentially very large amount of data with relatively few descriptors. A very powerful feature.

The only slightly tricky matter is to keep in mind that the 0 31 YYY descriptor that follows the delayed (Y=0) replication descriptor (1 XX 000) is not included in the count of descriptors to be replicated, the XX part of 1 XX YYY. Indeed the descriptors of Class 31 hold a unique position in BUFR. With one (partial) exception, they are never used in isolation, but always in conjunction with some other descriptor in order to "complete" the latter’s function. The exception is 0 31 021 - it can be used alone to redefine the meaning of a previously established associated field. Class 31 descriptors are not included in the replication counts for replication descriptors (nor are they replicated), and their characteristics are not altered by any of the operator descriptors in Table C, even those that change a characteristics of every (other) Table B descriptor. They are "Teflon" descriptors: they stick to other descriptors but nothing sticks to them.

A rather ingenious "extension" to the delayed replication concept has come into use recently. This is one of those "unrecognized possibilities" of BUFR mentioned previously. The idea is simple: set up delayed replication but have the replication count (in the data section) be equal to zero. By a simple extension of the rules, this clearly means that the "following X descriptors shall be replicated zero times", that is, they don’t get used at all, they should be skipped over - there is nothing in the data section corresponding to them. This is quite useful in that it allows one to set up a standard or all inclusive set of descriptors for a variety of observation types but then tailor the use of the descriptors, by setting the replication count to 1 or 0, to fit the actual data in hand. It is considerably more efficient than filling in the "missing" data (all 11111 bits) in the locations in the data section where there is no real observation. A particular example of this is in "vertical soundings," whether generated by RAOBs, satellites, profilers, dropsondes, etc. They all share a basic common structure but some lack whole classes of data - satellite soundings have no winds, for example. The use of "zero count replication" allows one to set up a single set of descriptors for all of these observations with a net saving of space over either setting a lot of "missings" in the data or maintaining a library of different sounding descriptor sets.

The current descriptors allow zero count replication without any changes in current tables. However, to save a little more space, the NMC (Washington) people have defined a 0 31 000 descriptor with a 1-bit data length. This allows a replication count of 1 or 0, all that is needed. This is not yet officially recognized (even though it is within the international portion of the table), but there seems little reason to doubt that it soon will be. It is a very useful idea.

When we turn to the few descriptors that define increments, and in particular discuss the use of increments in conjunction with replication, things get more complex. The rules get quite precise and have to be adhered to closely.

Increments by themselves are not so bad. One first establishes the value of a coordinate that is capable of being incremented. Normally, that coordinate value would "remain in effect until superseded" by the appearance of the same descriptor with a new data value. But the appearance of a descriptor for an increment associated with that coordinate will also change the value of the coordinate by the amount found in the data section. The increment descriptor must be in the same class as the data to be incremented and must have the same units. In the current BUFR tables there is no built-in way to associate an increment uniquely with the descriptor/value that is capable of being incremented. This is unfortunate as it means the decoder program must have special rules encoded for each increment descriptor; it would be better to devise a general rule to associate increments with the thing (or things) to be incremented. This is a project for the future.

A sample is the best way to indicate the descriptor sequence when increments and replication are combined:

Descriptor	Interpretation
0 04 004	Sets the value of the hour. (Should be set to one increment LESS than the starting" value.)
.	
.	
.	
dddd	assorted data may be placed here
dddd	without influencing the replication to come
.	
.	
0 04 014	sets the value of the increment in hours and increments the hour
1 XX 000	set up (delayed) replication of "next" XX descriptors
0 31 001	replication count (not included in the span of replication XX)
.	
.	
.	
XX	descriptors to be replicated
.	
.	

Regulation 94.5.4.3 says that when the increment descriptor just proceeds the replication operator, as in this example, the incrementing action takes place right along with the replication. Every time the descriptors are replicated the hour (in the example) gets incremented, too. Note also, that the hour gets incremented right away, before the first pass through the XX descriptors. That’s why the initial hour value (0 04 004) was given a value one increment’s worth less than the hour value needed for the first iteration.

There is a refinement to this: it is legitimate to place Table C Operator Descriptors between the increment descriptor and the associated replication operator without altering the rule that the incrementing is associated with the replication. This is to allow for (temporary) redefinition of the data width, scale, whatever, of the descriptors within the XX span of replication (and following unless the changes are canceled), if necessary. The class C descriptors cannot be placed after the replication count descriptor as they would then be subject to the replication which might not work very well, nor can the class C descriptors be placed prior to the increment descriptor itself as that means the increment descriptor would have its characteristics changed, also not a good thing. Hence the refinement to the rule. (Don’t forget the other rule, that Class 31 descriptors are not subject to change by Table C descriptors.)

Another feature of replication is "run length encoding." This is enabled by replication followed by the 0 31 011 (or 0 31 012) descriptor. Basically all it says is that in addition to replicating the descriptors a number of times, the data elements present in the data (as described by the set of descriptors to be replicated) should be replicated as well. This is useful, of course, when the original data, as it exists prior to BUFR encoding, contains long runs of identical values, or long runs of identical sets of data elements. This is a familiar and very straightforward form of data compression that can greatly increase the efficiency of data representation in special cases. Of course, the run length encoding replication can be coupled with incrementing of a coordinate; indeed it most likely would be as there is commonly a need to specify the locations of the string of replicated values.

6.5.3.3 The Associated Field. Associated fields are generally for the purpose of "saying something" extra about the particular data element with which they are associated. The most common use is in the arena of "quality control," where some sort of "confidence" indication is given. Other applications are possible and can be established by additions to Code Table 0 31 021.

Creating (or dealing with) an associated field in a message is a two step process. The first is to establish the field and set the number of bits that will precede all the data elements following the appearance of the associated field operator (2 04 YYY). YYY is that number. If 255 bits is not enough (good grief, why?) you can keep adding more bits by repeating the operator. You can also generate compound associated fields by repeating the operator if what you have to "say" about the data elements is complicated.

The second step is to define the meaning of those bits, i.e., how they are to be interpreted by a user of the data. This is done by immediately following each 2 04 YYY descriptor with the usual Class 31 descriptor, 0 31 021, which, by reference to the Code table 0 31 021, establishes that meaning. A little care is required here. Code Table 0 31 021 gives a (small) number of significance code figures (all taking up 6 bits in the data) for different size associated fields; obviously one must be consistent in setting an associated field length and identifying the meaning of the bits in the field.

Once an associated field is established, those extra bits must be (are assumed to be) prefixed to every following data element, until the associated field is canceled. If the quality information has no meaning for some of those following elements, but the field is still there, there is at present no explicit way to indicate "no meaning" within the currently defined meanings. One must either redefine the meaning of the associated field in its entirety (by including 0 31 021 in the message with a data value of 63 - "missing value") or remove the associated field bits by the "cancel" operator: 2 04 000. If multiple or compound associated fields have been defined, each must be canceled separately.

6.5.3.4 Changing Descriptors "On the Fly". A set of descriptors are defined in Class 00 which are used to describe descriptors. These have not had much international (or non-local) use to the best of my knowledge but their purpose, of course, is to send new international (or local) descriptors to interested parties for use prior to some official publication. But another "new possibility" has been suggested, one that would seem to have considerable potential value. This "new possibility" is not defined in the current BUFR specifications and, as will be obvious, would require a new edition number for BUFR as it would require changes in the logic of a decoding program.

The suggestion is simple: it should be considered legitimate to send any descriptor, or collection of descriptors (new or currently defined, international or local), imbedded in a message which otherwise contains data. Then the new descriptor(s), or the redefined old one(s), may then be actually used in the remainder of that message/record. This affords a method of introducing new data on the fly, so to speak, or to change specific descriptor characteristics more selectively that can be done at present with Table C (operator) descriptors. Implementing this would, perforce, require that the decoding program recognize the new descriptor and then either add it to some internal table or use it to alter portions of existing tables. Either option would require new rules to be promulgated and old decoders to be altered. It doesn’t seem to be a very complicated modification. This temporary change to a descriptor would only hold for the one record in which the change is introduced. The next BUFR record would be assumed to contain only "standard" (i.e., published) descriptors until such time as more new ones are introduced.

6.5.3.5 BUFR Records in Archives. A simple extension of the "new possibility" rule in the previous section makes it possible to alleviate a big concern about using BUFR records in long-term archives, that is, the necessity to retain BUFR tables through a number of possible versions for an indefinite time span. The suggestion again is simple and rather obvious. In any file of (presumably many) BUFR records, the first such BUFR record should contain nothing but a collection of all the descriptors that will be used in all the other records in the file. Such a record would have a Table A data category value of 11. The "new rule," then, would be that the descriptors in the first record should be used for decoding all the many records in the file. Individual records could also have redefinitions of descriptors, as above, but they would hold for only the one record. This is really not a rule about the structure of BUFR per se, but is more of a suggestion for good data management where BUFR records and files are involved. Presumably such BUFR archive files would remain intact and only be exchanged in toto.

This archive suggestion would not involve any changes to BUFR itself (and hence no change to the edition number) if the construction of Tables B, C and D, based on what is found in the first Table A = 11 record, was done externally to the decoding process. If the temporary change/addition to a descriptor was allowed that would introduce a new edition to BUFR.

APPENDIX A

REFERENCES

1. Soderman, D. and Gibson, J.K. "The Specification for FM 94 BUFR". FM 94 BUFR Collected Papers and Specification. ECMWF, February 1988.

2. Stackpole, J. "Binary Universal Form for Data Representation (WMO Code FM 94 BUFR)". FM 94 BUFR Collected Papers and Specification. ECMWF, February 1988.

3. World Meteorological Organization Manual on Codes, Volume 1, International Codes, Part A - Alphanumeric Codes. 1988 Edition, Suppl. No. 2 (VII.1991)

4. World Meteorological Organization. Manual on Codes, Volume 1, International Codes, Part B - Binary Codes. 1988 Edition, Suppl. No. 3 (VIII.1991)

APPENDIX B

BUFR TABLE B - CLASSIFICATION OF ELEMENTS

This appendix presents BUFR Table B, copied directly from WMO Manual on Codes, Volume 1, International Codes, Part B, Binary Codes, 1988 Edition, Suppl. No. 3 (VIII.1991). It is reprinted here for the convenience and accessibility of the reader.

BUFR TABLES RELATIVE TO SECTION 3

BUFR Table B — *Classification of Elements*

F	X	Class	Comments
0	00	BUFR table entries	
0	01	Identification	Identifies origin and type of data
0	02	Instrumentation	Defines instrument types used
0	03	Reserved	
0	04	Location (time)	Defines time and time derivatives
0	05	Location (horizontal - 1)	Defines geographical position, including horizontal derivatives, in association with class 06 (first dimension of horizontal space)
0	06	Location (horizontal - 2)	Defines geographical position, including horizontal derivatives, in association with class 05 (second dimension of horizontal space)
0	07	Location (vertical)	Defines height, altitude, pressure level, including vertical derivatives of position

F	X	Class	Comments
0	08	Significance qualifiers	Defines special character of data
0	09	Reserved	
0	10	Vertical elements and pressure	Height, altitude, pressure and derivatives observed or measured, *not* defined as a vertical location
0	11	Wind and turbulence	Wind speed, direction, etc.
0	12	Temperature	
0	13	Hydrographic and hydrological elements	Humidity, rainfall, snowfall, etc.
0	14	Radiation and radiance	
0	15	Physical/chemical constituents	
0	19	Synoptic features	
0	20	Observed phenomena	Defines present/past weather, special phenomena, etc.
0	21	Radar data	
0	22	Oceanographic elements	
0	23	Dispersal and transport	
0	24	Radiological elements	
0	25	Processing information	
0	27	Non-co-ordinate location (horizontal - 1)	Defines geographical positions, in conjunction with class 28, that are not co-ordinates
0	28	Non-co-ordinate location (horizontal - 2)	Defines geographical positions, in conjunction with class 27, that are not co-ordinates
0	29	Map data	
0	30	Image	
0	31	Data description operator qualifiers	Elements used in conjunction with data description operators

(BUFR *Table B — continued)*

Notes:

(1) Where a code table or flag table is appropriate, "code table" or "flag table" respectively is entered in the UNITS column.

(2) The code tables and flag tables associated with Table B are numbered to correspond with the F, X and Y part of the table reference.

(3) To encode values into BUFR, the data (with units as specified in the UNITS column) must be multiplied by 10 to the power SCALE. Then subtract the REFERENCE VALUE to give the coded value found in Section 4 of the BUFR message. For example, a measured latitude is -45.76 degrees. The coarse accuracy descriptor os 0 05 002 and the encoded value is $-45.76 \times 10^2 - (9000) = 4424$.

(4) Where UNITS are given as CCITT IA5, data shall be coded as character data left justified within the field width indicated using CCITT International Alphabet No. 5, and blank filled to the full field width indicated.

(5) Classes 48 to 63 are reserved for local use; all other classes are reserved for future development.

(6) Entries 192 to 255 within all classes are reserved for local use.

(7) First-order statistics are included in Table B only when they are produced, as such, by the observing system.

Class 00 — BUFR table entries

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 00 001	Table A: entry	CCITT IA5	0	0	24
0 00 002	Table A: data category description, line 1	CCITT IA5	0	0	256
0 00 003	Table A: data category description, line 2	CCITT IA5	0	0	256
0 00 005	BUFR edition number	CCITT IA5	0	0	24
0 00 010	F descriptor to be added or defined	CCITT IA5	0	0	8
0 00 011	X descriptor to be added or defined	CCITT IA5	0	0	16
0 00 012	Y descriptor to be added or defined	CCITT IA5	0	0	24
0 00 013	Element name, line 1	CCITT IA5	0	0	256
0 00 014	Element name, line 2	CCITT IA5	0	0	256
0 00 015	Units name	CCITT IA5	0	0	192
0 00 016	Units scale sign	CCITT IA5	0	0	8
0 00 017	Units scale	CCITT IA5	0	0	24
0 00 018	Units reference sign	CCITT IA5	0	0	8
0 00 019	Units reference value	CCITT IA5	0	0	80
0 00 020	Element data width	CCITT IA5	0	0	24
0 00 030	Descriptor defining sequence	CCITT IA5	0	0	40

Class 01 — Identification

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	01	001	WMO block number	Numeric	0	0	7
0	01	002	WMO station number	Numeric	0	0	10
0	01	003	WMO Region number/ geographical area	Code table	0	0	3
0	01	004	WMO Region sub-area	Numeric	0	0	3
0	01	005	Buoy/platform identifier	Numeric	0	0	17
0	01	006	Aircraft identifier	CCITT IA5	0	0	64
0	01	007	Satellite identifier	Code table	0	0	10
0	01	008	Aircraft registration number	CCITT IA5	0	0	64
0	01	011	Ship's call sign	CCITT IA5	0	0	72
0	01	012	Direction of motion of moving observing platform	Degree true	0	0	9
0	01	013	Speed of motion of moving observing platform	m s^{-1}	0	0	10
0	01	014	Platform drift speed (high precision)	m s^{-1}	2	0	10
0	01	021	Synoptic feature identifier	Numeric	0	0	14
0	01	063	ICAO location indicator	CCITT IA5	0	0	64

Class 02 — Instrumentation

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	02	001	Type of station	Code table	0	0	2
0	02	002	Type of instrumentation for wind measurement	Flag table	0	0	4
0	02	003	Type of measuring equipment used	Code table	0	0	4
0	02	004	Type of instrumentation for evaporation measurement or type of crop for which evapotranspiration is reported	Code table	0	0	4
0	02	005	Precision of temperature observation	Degree	2	0	7
0	02	011	Radiosonde type	Code table	0	0	8
0	02	012	Radiosonde computational method	Code table	0	0	4
0	02	013	Solar and infrared radiation correction	Code table	0	0	4
0	02	014	Tracking technique/status of system used	Code table	0	0	7
0	02	015	Radiosonde completeness	Code table	0	0	4
0	02	021	Satellite instrument data used in processing	Flag table	0	0	9
0	02	022	Satellite data-processing technique used	Flag table	0	0	8
0	02	023	Cloud motion computational method	Code table	0	0	4
0	02	024	Integrated mean humidity computational method	Code table	0	0	4
0	02	025	Satellite channel(s) used in computation	Flag table	0	0	25
0	02	026	Cross track resolution	m	2	0	12
0	02	027	Along track resolution	m	2	0	12
0	02	031	Method of current measurement	Code table	0	0	5
0	02	032	Indicator for digitization	Code table	0	0	2
0	02	033	Method of salinity/depth measurement	Code table	0	0	3
0	02	034	Drogue type	Code table	0	0	5

(continued)

(Class 02 — continued)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 02 035	Cable length	m	0	0	9
0 02 036	Buoy type	Code table	0	0	2
0 02 041	Method for estimating reports related to synoptic features	Code table	0	0	6
0 02 061	Aircraft navigational system	Code table	0	0	3
0 02 062	Type of aircraft data relay system	Code table	0	0	4
0 02 063	Aircraft roll angle	Degree	2	–18000	16
0 02 070	Original specification of latitude/longitude	Code table	0	0	4
0 02 101	Type of antenna	Code table	0	0	4
0 02 102	Antenna height above tower base	m	0	0	8
0 02 103	Radome	Flag table	0	0	2
0 02 104	Antenna polarisation	Code table	0	0	4
0 02 105	Maximum antenna gain	dB	0	0	6
0 02 106	3-dB beamwidth	Degree	1	0	6
0 02 107	Sidelobe suppression	dB	0	0	6
0 02 108	Crosspol discrimination (on axis)	dB	0	0	6
0 02 109	Antenna speed (azimuth)	Degree s^{-1}	2	0	12
0 02 110	Antenna speed (elevation)	Degree s^{-1}	2	0	12
0 02 111	Radar incidence angle	Degree	1	0	10
0 02 112	Radar look angle	Degree	1	0	12
0 02 113	Number of azimuth looks	Numeric	0	0	4
0 02 114	Antenna effective surface area	m^2	0	0	15
0 02 121	Mean frequency	Hz	–8	0	7
0 02 122	Frequency agility range	Hz	–6	–128	8
0 02 123	Peak power	W	–4	0	7
0 02 124	Average power	W	–1	0	7
0 02 125	Pulse repetition frequency	Hz	–1	0	8
0 02 126	Pulse width	s	7	0	6
0 02 127	Receiver intermediate frequency	Hz	–6	0	7
0 02 128	Intermediate frequency bandwidth	Hz	–5	0	6

(Class 02 — continued)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 02 129	**Minimum detectable signal**	**dB**	**0**	**–150**	**5**
0 02 130	**Dynamic range**	**dB**	**0**	**0**	**7**
0 02 131	**Sensitivity time control**	**Flag table**	**0**	**0**	**2**
0 02 132	**Azimuth pointing accuracy**	**Degree**	**2**	**0**	**6**
0 02 133	**Elevation pointing accuracy**	**Degree**	**2**	**0**	**6**
0 02 134	**Antenna beam azimuth**	**Degree**	**2**	**0**	**16**
0 02 135	**Antenna elevation**	**Degree**	**2**	**–9000**	**15**

Notes:

(1) This class shall contain elements to describe the instrumentation used to obtain the meteorological elements reported.

(2) This class may also contain elements relating to observational procedures.

(3) Some indication of expected accuracy may be implied in conjunction with certain elements in this class.

Class 04 — Location (time)

TABLE REFERENCE F	X	Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0	04	001	Year	Year	0	0	12
0	04	002	Month	Month	0	0	4
0	04	003	Day	Day	0	0	6
0	04	004	Hour	Hour	0	0	5
0	04	005	Minute	Minute	0	0	6
0	04	006	Second	Second	0	0	6
0	04	011	Time increment	Year	0	–1024	11
0	04	012	Time increment	Month	0	–1024	11
0	04	013	Time increment	Day	0	–1024	11
0	04	014	Time increment	Hour	0	–1024	11
0	04	015	Time increment	Minute	0	–2048	12
0	04	016	Time increment	Second	0	–4096	13
0	04	021	Time period or displacement	Year	0	–1024	11
0	04	022	Time period or displacement	Month	0	–1024	11
0	04	023	Time period or displacement	Day	0	–1024	11
0	04	024	Time period or displacement	Hour	0	–2048	12
0	04	025	Time period or displacement	Minute	0	–2048	12
0	04	026	Time period or displacement	Second	0	–4096	13
0	04	031	Duration of time relating to following value	Hour	0	0	8
0	04	043	Day of the year	Day	0	0	9

Notes:

(1) The significance of time periods or displacements shall be indicated using the time significance code corresponding to table reference 0 08 021.

(2) Where more than one time period or displacement is required to define complex time structures, they shall be defined in immediate succession, and the following ordering shall apply: ensemble period (if required), followed by forecast period (if required), followed by period for averaging or accumulation (if required).

(3) Time periods or displacements and time increments require an initial time location to be defined prior to their use, followed where appropriate by a time significance definition.

(4) The time location, when used with forecast values, shall indicate the time of the initial state for the forecast, or the beginning of the forecast period; when used with ensemble means of forecast values, the time location shall indicate the initial state or the beginning of the first forecast over which ensemble means are derived.

(5) Negative time periods or displacements shall be used to indicate time periods or displacements preceding the currently defined time.

Class 05 — Location (horizontal - 1)

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	05	001	Latitude (high accuracy)	Degree	5	–9000000	25
0	05	002	Latitude (coarse accuracy)	Degree	2	–9000	15
0	05	011	Latitude increment (high accuracy)	Degree	5	–9000000	25
0	05	012	Latitude increment (coarse accuracy)	Degree	2	–9000	15
0	05	021	Bearing or azimuth	Degree true	2	0	16
0	05	022	Solar azimuth	Degree true	2	0	16
0	05	030	Direction (spectral)	Degree	0	0	12
0	05	031	Row number	Numeric	0	0	12
0	05	033	Pixel size on horizontal – 1	m	–1	0	16
0	05	040	Orbit number	Numeric	0	0	24
0	05	041	Scan line number	Numeric	0	0	8
0	05	042	Channel number	Numeric	0	0	6
0	05	043	Field of view number	Numeric	0	0	8
0	05	052	Channel number increment	Numeric	0	0	5
0	05	053	Field of view number increment	Numeric	0	0	5

Notes:

(1) Values of latitude and latitude increments are limited to the range –90 degrees to +90 degrees.

(2) South latitude shall be assigned negative values.

(3) North to south increments shall be assigned negative values.

(4) Bearing or azimuth shall only be used with respect to a stated location, and shall not redefine that location.

(5) The Pixel size on horizontal – 1 is given at location where map scale factor is unity.

Class 06 — Location (horizontal - 2)

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	06	001	Longitude (high accuracy)	Degree	5	−18000000	26
0	06	002	Longitude (coarse accuracy)	Degree	2	−18000	16
0	06	011	Longitude increment (high accuracy)	Degree	5	−18000000	26
0	06	012	Longitude increment (coarse accuracy)	Degree	2	−18000	16
0	06	021	Distance	m	−1	0	13
0	06	030	Wavenumber (spectral)	rad m^{-1}	5	0	13
0	06	031	Column number	Numeric	0	0	12
0	06	033	Pixel size on horizontal – 2	m	−1	0	16

Notes:

(1) Values of longitude are limited to the range −180 degrees to +180 degrees.

(2) West longitude shall be assigned negative values.

(3) East to west increments shall be assigned negative values.

(4) Distance shall only be used with respect to a stated location and a bearing, azimuth or elevation; it shall not redefine that location.

(5) The Pixel size on horizontal – 2 is given at location where map scale factor is unity.

Class 07 — Location (vertical)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 07 001	Height of station	m	0	–400	15
0 07 002	Height or altitude	m	–1	–40	16
0 07 003	Geopotential	$m^2 s^{-2}$	–1	–400	17
0 07 004	Pressure	Pa	–1	0	14
0 07 005	Height increment	m	0	–400	12
0 07 006	Height above station	m	0	0	15
0 07 021	Elevation	Degree	2	–9000	15
0 07 022	Solar elevation	Degree	2	–9000	15
0 07 061	Depth below land surface	m	2	0	14
0 07 062	Depth below sea surface	m	1	0	17

Note: Elevation shall only be used with respect to a stated location and a bearing, azimuth or distance; it shall not redefine that location.

Class 08 — Significance qualifiers

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 08 001	Vertical sounding significance	Flag table	0	0	7
0 08 002	Vertical significance (surface observations)	Code table	0	0	6
0 08 003	Vertical significance (satellite observations)	Code table	0	0	6
0 08 004	Phase of aircraft flight	Code table	0	0	3
0 08 011	Horizontal significance	Code table	0	0	6
0 08 012	Land/sea qualifier	Code table	0	0	2
0 08 021	Time significance	Code table	0	0	5
0 08 022	Total number (with respect to accumulation or average)	Numeric	0	0	16

Note: Where values are accumulated or averaged (for example over a time period), the total number of values from which the accumulated or averaged values are obtained may be represented using reference 0 08 022.

Class 10 — Vertical elements and pressure

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	10	001	Height of land surface	m	0	–400	15
0	10	002	Height	m	–1	–40	16
0	10	003	Geopotential	$m^2 s^{-2}$	–1	–400	17
0	10	004	Pressure	Pa	–1	0	14
0	10	050	Standard deviation altitude	m	2	0	16
0	10	051	Pressure reduced to mean sea-level	Pa	–1	0	14
0	10	052	Altimeter setting (QNH)	Pa	–1	0	14
0	10	060	Pressure change	Pa	–1	–1024	11
0	10	061	3-hour pressure change	Pa	–1	–500	10
0	10	062	24-hour pressure change	Pa	–1	–1000	11
0	10	063	Characteristic of pressure tendency	Code table	0	0	4

Note: Vertical elements and pressure shall be used to define values of these elements independent of the element or variable denoting the vertical co-ordinate.

Class 11 — Wind and turbulence

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 11 001	Wind direction	Degree true	0	0	9
0 11 002	Wind speed	m s^{-1}	1	0	12
0 11 003	u-component	m s^{-1}	1	–4096	13
0 11 004	v-component	m s^{-1}	1	–4096	13
0 11 005	w-component	Pa s^{-1}	1	–512	10
0 11 006	w-component	m s^{-1}	2	–4096	13
0 11 011	Wind direction at 10 m	Degree true	0	0	9
0 11 012	Wind speed at 10 m	m s^{-1}	1	0	12
0 11 013	Wind direction at 5 m	Degree true	0	0	9
0 11 014	Wind speed at 5 m	m s^{-1}	1	0	12
0 11 021	Relative vorticity	1 s^{-1}	9	–65536	17
0 11 022	Divergence	1 s^{-1}	9	–65536	17
0 11 023	Velocity potential	m^2 s^{-1}	–2	–65536	17
0 11 031	Degree of turbulence	Code table	0	0	4
0 11 032	Height of base of turbulence	m	–1	–40	16
0 11 033	Height of top of turbulence	m	–1	–40	16
0 11 034	Vertical gust velocity	m s^{-1}	1	–1024	11
0 11 035	Vertical gust acceleration	m s^{-2}	2	–8192	14
0 11 036	Maximum derived equivalent vertical	m s^{-1}	1	0	10
0 11 041	Maximum wind speed (gusts)	m s^{-1}	1	0	12
0 11 042	Maximum wind speed (10-min mean wind)	m s^{-1}	1	0	12
0 11 050	Standard deviation wind speed	m s^{-1}	1	0	12
0 11 061	Absolute wind shear in 1 km layer below	m s^{-1}	1	0	12
0 11 062	Absolute wind shear in 1 km layer above	m s^{-1}	1	0	12

Notes:

(1) West to east u-components shall be assigned positive values.

(2) South to north v-components shall be assigned positive values.

(3) Upward w-components shall be assigned positive values where units are m s^{-1}.

(Class 11 — continued)

(4) Downward w-components shall be assigned positive values where units are Pa s^{-1}.

(5) Wind reporting standards:

	Speed	*Direction*
No observation	Missing	Missing
Calm	0	0
Normal observation	> 0	1° – 360°
Speed only	> 0	Missing
Direction only	Missing	1° – 360°
"Light and variable"	> 0	0

Class 12 — Temperature

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	12	001	Temperature/dry-bulb temperature	K	1	0	12
0	12	002	Wet-bulb temperature	K	1	0	12
0	12	003	Dew-point temperature	K	1	0	12
0	12	004	Dry-bulb temperature at 2 m	K	1	0	12
0	12	005	Wet-bulb temperature at 2 m	K	1	0	12
0	12	006	Dew-point temperature at 2 m	K	1	0	12
0	12	007	Virtual temperature	K	1	0	12
0	12	011	Maximum temperature, at height and over period specified	K	1	0	12
0	12	012	Minimum temperature, at height and over period specified	K	1	0	12
0	12	013	Ground minimum temperature, past 12 hours	K	1	0	12
0	12	014	Maximum temperature at 2 m, past 12 hours	K	1	0	12
0	12	015	Minimum temperature at 2 m, past 12 hours	K	1	0	12
0	12	016	Maximum temperature at 2 m, past 24 hours	K	1	0	12
0	12	017	Minimum temperature at 2 m, past 24 hours	K	1	0	12
0	12	030	Soil temperature	K	1	0	12
0	12	061	Skin temperature	K	1	0	12
0	12	062	Equivalent black body temperature	K	1	0	12
0	12	063	Brightness temperature	K	1	0	12

Note: Where the expression "at height and over period specified" is entered under ELEMENT NAME, an appropriate vertical location shall be specified using descriptors from class 07, together with an appropriate period using descriptors from class 04.

Class 13 — Hygrographic and hydrological elements

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	13	001	Specific humidity	kg kg^{-1}	5	0	14
0	13	002	Mixing ratio	kg kg^{-1}	5	0	14
0	13	003	Relative humidity	%	0	0	7
0	13	004	Vapour pressure	Pa	–1	0	10
0	13	005	Vapour density	kg m^{-3}	3	0	7
0	13	006	Mixing heights	m	–1	–40	16
0	13	011	Total precipitation/total water equivalent	kg m^{-2}	1	–1	14
0	13	012	Depth of fresh snow	m	2	–2	12
0	13	013	Total snow depth	m	2	–2	16
0	13	014	Rainfall/water equivalent of snow (averaged rate)	kg m^{-2} s^{-1}	4	0	12
0	13	015	Snowfall (averaged rate)	m s^{-1}	7	0	12
0	13	016	Precipitable water	kg m^{-2}	0	0	7
0	13	019	Total precipitation past 1 hour	kg m^{-2}	1	–1	14
0	13	020	Total precipitation past 3 hours	kg m^{-2}	1	–1	14
0	13	021	Total precipitation past 6 hours	kg m^{-2}	1	–1	14
0	13	022	Total precipitation past 12 hours	kg m^{-2}	1	–1	14
0	13	023	Total precipitation past 24 hours	kg m^{-2}	1	–1	14
0	13	031	Evapotranspiration	kg m^{-2}	0	0	7
0	13	032	Evaporation/evapotranspiration	kg m^{-2}	1	0	8
0	13	041	Pasquill-Gifford stability category	Code table	0	0	4

Notes:

(1) A total precipitation value of –1 shall indicate a "trace".

(2) A depth of fresh snow value of –1 shall indicate a little precipitation, non-measurable. A depth of fresh snow value of –2 shall indicate "snow cover not continuous".

(3) A total snow depth value of –1 shall indicate a little precipitation, non-measurable. A total snow depth value of –2 shall indicate "snow cover not continuous".

Class 14 — Radiation and radiance

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	14	001	Long-wave radiation, integrated over 24 hours	$J m^{-2}$	–3	–2048	12
0	14	002	Long-wave radiation, integrated over period specified	$J m^{-2}$	–3	–2048	12
0	14	003	Short-wave radiation, integrated over 24 hours	$J m^{-2}$	–3	–2048	12
0	14	004	Short-wave radiation, integrated over period specified	$J m^{-2}$	–3	–2048	12
0	14	011	Net long-wave radiation, integrated over 24 hours	$J m^{-2}$	–3	–2048	12
0	14	012	Net long-wave radiation, integrated over period specified	$J m^{-2}$	–3	–2048	12
0	14	013	Net short-wave radiation, integrated over 24 hours	$J m^{-2}$	–3	–2048	12
0	14	014	Net short-wave radiation, integrated over period specified	$J m^{-2}$	–3	–2048	12
0	14	015	Net radiation, integrated over 24 hours	$J m^{-2}$	–4	–16384	15
0	14	016	Net radiation, integrated over period specified	$J m^{-2}$	–4	–16384	15
0	14	017	Instantaneous long-wave radiation	$W m^{-2}$	–3	–2048	12
0	14	018	Instantaneous short-wave radiation	$W m^{-2}$	–3	–2048	12
0	14	020	Global solar radiation, integrated over 24 hours	$J m^{-2}$	–4	0	15
0	14	021	Global radiation, integrated over period specified	$J m^{-2}$	–4	0	15
0	14	022	Diffuse solar radiation, integrated over 24 hours	$J m^{-2}$	–4	0	15
0	14	023	Diffuse solar radiation, integrated over period specified	$J m^{-2}$	–4	0	15
0	14	024	Direct solar radiation, integrated over 24 hours	$J m^{-2}$	–4	0	15
0	14	025	Direct solar radiation, integrated over period specified	$J m^{-2}$	–4	0	15
0	14	031	Total sunshine	Minute	0	0	11
0	14	032	Total sunshine	Hour	0	0	10

(Class 14 — continued)

Notes:

(1) Downward radiation shall be assigned negative values.

(2) Upward radiation shall be assigned positive values.

(3) Where the expression "period specified" is entered under ELEMENT NAME, an appropriate period shall be specified using descriptors from class 04.

Class 15 — Physical/chemical constituents

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 15 001	Ozone	Dobson	0	0	10

Class 19 — Synoptic features

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 19 001	Type of synoptic feature	Code table	0	0	6
0 19 002	Effective radius of feature	m	–2	0	12
0 19 003	Wind speed threshold	$m\ s^{-1}$	0	0	8
0 19 004	Effective radius with respect to wind speeds above threshold	m	–2	0	12

Note: The effective radius of feature shall be defined with respect to the radius of the 1000-hPa isobars at mean sea-level.

Class 20 — Observed phenomena

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	20	001	Horizontal visibility	m	−1	0	13
0	20	002	Vertical visibility	m	−1	0	7
0	20	003	Present weather	Code table	0	0	9
0	20	004	Past weather (1)	Code table	0	0	5
0	20	005	Past weather (2)	Code table	0	0	5
0	20	010	Cloud cover (total)	%	0	0	7
0	20	011	Cloud amount	Code table	0	0	4
0	20	012	Cloud type	Code table	0	0	6
0	20	013	Height of base of cloud	m	−1	−40	11
0	20	014	Height of top of cloud	m	−1	−40	11
0	20	015	Pressure at base of cloud	Pa	−1	0	14
0	20	016	Pressure at top of cloud	Pa	−1	0	14
0	20	017	Cloud top description	Code table	0	0	4
0	20	031	Ice deposit (thickness)	m	2	0	7
0	20	032	Rate of ice accretion	Code table	0	0	3
0	20	033	Cause of ice accretion	Flag table	0	0	4
0	20	034	Sea ice concentration	Code table	0	0	5
0	20	035	Amount and type of ice	Code table	0	0	4
0	20	036	Ice situation	Code table	0	0	5
0	20	037	Ice development	Code table	0	0	5
0	20	038	Bearing of ice edge	Degree true	0	0	12
0	20	039	Ice distance	m	−1	0	13
0	20	041	Airframe icing	Code table	0	0	4
0	20	051	Amount of low clouds	%	0	0	7
0	20	052	Amount of middle clouds	%	0	0	7
0	20	053	Amount of high clouds	%	0	0	7
0	20	061	Runway visual range (RVR)	m	0	0	12
0	20	062	State of the ground (with or without snow)	Code table	0	0	5
0	20	063	Special phenomena	Code table	0	0	10

Class 21 — Radar data

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	21	001	Horizontal reflectivity	dB	0	–64	7
0	21	002	Vertical reflectivity	dB	0	–64	7
0	21	003	Differential reflectivity	dB	1	–5	7
0	21	005	Linear depolarisation ratio	dB	0	–65	6
0	21	006	Circular depolarisation ratio	dB	0	–65	6
0	21	011	Doppler mean velocity in X-direction	m s^{-1}	0	–128	8
0	21	012	Doppler mean velocity in Y-direction	m s^{-1}	0	–128	8
0	21	013	Doppler mean velocity in Z-direction	m s^{-1}	0	–128	8
0	21	014	Doppler mean velocity (radial)	m s^{-1}	1	–4096	13
0	21	017	Doppler velocity spectral width	m s^{-1}	1	–4096	8
0	21	021	Echo tops	m	–3	0	4
0	21	030	Signal to noise ratio	dB	0	–32	8
0	21	031	Vertically integrated liquid-water content	kg m^{-2}	0	0	7
0	21	036	Radar rainfall intensity	m s^{-1}	7	0	12
0	21	041	Bright-band height	m	–2	0	8
0	21	051	Signal power above 1 mW	dB	0	–256	8

Class 22 — Oceanographic elements

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 22 001	Direction of waves	Degree true	0	0	9
0 22 002	Direction of wind waves	Degree true	0	0	9
0 22 003	Direction of swell waves	Degree true	0	0	9
0 22 004	Direction of current	Degree true	0	0	9
0 22 011	Period of waves	s	0	0	6
0 22 012	Period of wind waves	s	0	0	6
0 22 013	Period of swell waves	s	0	0	6
0 22 021	Height of waves	m	1	0	10
0 22 022	Height of wind waves	m	1	0	10
0 22 023	Height of swell waves	m	1	0	10
0 22 025	Standard deviation wave height	m	2	0	10
0 22 031	Speed of current	$m\ s^{-1}$	2	0	13
0 22 042	Sea temperature	K	1	0	12
0 22 043	Sea temperature	K	2	0	15
0 22 044	Sound velocity	$m\ s^{-1}$	1	0	14
0 22 050	Standard deviation sea-surface temperature	K	2	0	8
0 22 061	State of the sea	Code table	0	0	4
0 22 062	Salinity	Part per thousand	2	0	14
0 22 063	Total water depth	m	0	0	14

Class 23 — Dispersal and transport

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	23	001	Accident early notification – article applicable	Code table	0	0	3
0	23	002	Activity or facility involved in incident	Code table	0	0	5
0	23	003	Type of release	Code table	0	0	3
0	23	004	Countermeasures taken near border	Code table	0	0	3
0	23	005	Cause of incident	Code table	0	0	2
0	23	006	Incident situation	Code table	0	0	3
0	23	007	Characteristics of release	Code table	0	0	3
0	23	008	State of current release	Code table	0	0	2
0	23	009	State of expected release	Code table	0	0	2
0	23	016	Possibility of significant chemical toxic health effect	Code table	0	0	2
0	23	017	Flow discharge of major recipient	$m^3 s^{-1}$	6	0	20
0	23	018	Release behaviour over time	Code table	0	0	3
0	23	019	Actual release height	m	0	–15000	17
0	23	021	Effective release height	m	0	–15000	17
0	23	022	Distance of release point or site of incident	m	0	0	24
0	23	023	Main transport speed in the atmosphere	$m s^{-1}$	1	0	12
0	23	024	Main transport speed in water	$m s^{-1}$	2	0	13
0	23	025	Main transport speed in ground water	$m s^{-1}$	2	0	13
0	23	027	Main transport direction in the atmosphere	Degree true	0	0	9
0	23	028	Main transport direction in water	Degree true	0	0	9
0	23	029	Main transport direction in ground water	Degree true	0	0	9
0	23	031	Possibility that plume will encounter precipitation in State in which incident occurred	Code table	0	0	2
0	23	032	Plume will encounter change in wind direction and/or speed flag	Code table	0	0	2

Class 24 — Radiological elements

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	24	001	Estimate of amount of radioactivity released up to specified time	Bq*	–11	0	28
0	24	002	Estimated maximum potential release	Bq	–11	0	28
0	24	003	Composition of release	Code table	0	0	5
0	24	004	Element name	CCITT IA5	0	0	16
0	24	005	Isotope mass	Numeric	0	0	9
0	24	011	Dose	mSv*/**	2	0	32
0	24	012	Trajectory dose (defined location and expected time of arrival)	mSv	2	0	32
0	24	013	Gamma dose in air along the main transport path (defined location and time period)	mSv	2	0	32
0	24	021	Air concentration (of named isotope type including gross beta)	Bq m^{-3}	2	0	32
0	24	022	Concentration in precipitation (of named isotope type)	Bq l^{-1}	2	0	32

Note: Useful ranges used above:

10^{11} Bq to 10^{19} Bq for releases;

10^{-2} Bq to 10^{7} Bq and 10^{-2} mSv to 10^{7} mSv for concentration and doses.

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*	*New named unit and symbol*	*In other SI units*	*Old special unit and symbol*	*Relationship, old to new units*
	becquerel (Bq)	s^{-1}	curie (Ci)	1 Ci = 3.7×10^{10} Bq
	sievert (Sv)	J kg^{-1}	rem (rem)	1 rem = 0.01 Sv

** Millisievert.

Class 25 — Processing information

TABLE REFERENCE			ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
F	X	Y					
0	25	001	Range-gate length	m	−1	0	6
0	25	002	Number of gates averaged	Numeric	0	0	4
0	25	003	Number of integrated pulses	Numeric	0	0	8
0	25	004	Echo processing	Code table	0	0	2
0	25	005	Echo integration	Code table	0	0	2
0	25	006	Z to R conversion	Code table	0	0	3
0	25	007	Z to R conversion factor	Numeric	0	0	12
0	25	008	Z to R conversion exponent	Numeric	2	0	9
0	25	009	Calibration method	Flag table	0	0	4
0	25	010	Clutter treatment	Code table	0	0	4
0	25	011	Ground occultation correction (screening)	Code table	0	0	2
0	25	012	Range attenuation correction	Code table	0	0	2
0	25	013	Bright-band correction	Flag table	0	0	2
0	25	015	Radome attenuation correction	Flag table	0	0	2
0	25	016	Clear-air attenuation correction	dB m^{-1}	5	0	6
0	25	017	Precipitation attenuation correction	Flag table	0	0	2
0	25	018	A to Z law for attenuation factor	Numeric	7	0	6
0	25	019	A to Z law for attenuation exponent	Numeric	2	0	7
0	25	020	Mean-speed estimation	Code table	0	0	2
0	25	021	Wind computation enhancement	Flag table	0	0	8

Class 27 — Non-co-ordinate location (horizontal - 1)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 27 001	**Latitude (high accuracy)**	Degree	5	–9000000	25
0 27 002	**Latitude (coarse accuracy)**	Degree	2	–9000	15
0 27 003	**Alternate latitude**	Degree	2	–9000	15
0 27 020	**Satellite location counter**	Numeric	0	0	16

Notes:

(1) The alternate latitude may be used when the computation of the position yields multiple solutions and there is no *a priori* way to distinguish between them.

(2) The Satellite Location Counter is calculated as

counter = superswath no. x 1000 + box no. x 10 + minibox no.

Class 28 — Non-co-ordinate location (horizontal - 2)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 28 001	**Longitude (high accuracy)**	Degree	5	–18000000	26
0 28 002	**Longitude (coarse accuracy)**	Degree	2	–18000	16
0 28 003	**Alternate longitude**	Degree	2	–18000	16

Note: The alternate longitude may be used when the computation of the position yields multiple solutions and there is no *a priori* way to distinguish between them.

Class 29 — Map data

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 29 001	Projection type	Code table	0	0	3
0 29 002	Co-ordinate grid type	Code table	0	0	2

Class 30 — Image

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 30 001	Pixel value (4 bits)	Numeric	0	0	4
0 30 021	Number of pixels per row	Numeric	0	0	12
0 30 022	Number of pixels per column	Numeric	0	0	12
0 30 031	Picture type	Code table	0	0	4
0 30 032	Combination with other data	Flag table	0	0	16

Note: Pixel data width can be changed with descriptor 2 01 YYY.

Class 31 — Data description operator qualifiers

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (BITS)
0 31 001	**Delayed descriptor replication factor**	**Numeric**	**0**	**0**	**8**
0 31 002	**Extended delayed descriptor replication factor**	**Numeric**	**0**	**0**	**16**
0 31 011	**Delayed descriptor and data repetition factor**	**Numeric**	**0**	**0**	**8**
0 31 012	**Extended delayed descriptor and data repetition factor**	**Numeric**	**0**	**0**	**16**
0 31 021	**Associated field significance**	**Code table**	**0**	**0**	**6**

Note: The "delayed descriptor and data repetition factor" is intended for run-length encoding (e.g. scanning an image). It specifies a count N which applies to both descriptor and data, i.e. the value of the single element defined by the following descriptor is repeated N times (at intervals already specified).

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