WORLD METEOROLOGICAL ORGANIZATION

THE WMO TABLE DRIVEN CODES:

THE 21ST CENTURY UNIVERSAL OBSERVATION CODES

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ABSTRACT

The table driven codes **BUFR** (**B**inary **U**niversal **F**orm for the **R**epresentation of meteorological data) and **CREX** (**C**haracter form for the **R**epresentation and **EX**change of data) offer great advantages in comparison with the traditional alphanumeric codes. The main features of these codes are self-description, flexibility and expandability, which are fundamental in times of fast scientific and technical evolution. The advantages of Table Driven Codes versus traditional Alphanumeric Codes are demonstrated. The principles of the structure of the codes are developed. Specific and Common features of BUFR and CREX are explained. Examples related to the coding of a SYNOP message and an ozone sounding are given. In summary, the self description, the flexibility and the expandability render these data representation forms easy to maintain. In addition, BUFR allows condensation (packing), quality flags and associated values. CREX permits simple readability. These codes are universal permitting the representation of any type of observations. They are the ideal codes for coding observations and the most adapted to the fast scientific and technological evolution of the 21st Century. They are the last observation codes that WMO had to design. BUFR and CREX can be easily expanded to satisfy all observational requirements, without deviating from WMO recommendations, even to answer national needs for specific domestic data exchange, as it is presently the case in many Countries.

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INTRODUCTION

1. The table driven codes **BUFR** (**B**inary **U**niversal **F**orm for the **R**epresentation of meteorological data) and **CREX** (**C**haracter form for the **R**epresentation and **EX**change of data) offer great advantages in comparison with the traditional alphanumeric codes. The main features of these codes are self-description, flexibility and expandability, which are fundamental in times of fast scientific and technical evolution. In addition, BUFR offers condensation (packing). The alphanumeric code CREX provides simple readability but no packing, although compression could be applied to it by usually available commercial packages. BUFR has been approved for operational use in 1988. It has been used mainly, so far, for satellite, aircraft and wind profiler observations, but also for tropical cyclone information and for archiving of all types of observational data. CREX had been approved as an experimental Code by CBS Ext.94, starting on 2 November 1994. CBS Ext. 98 recommended CREX as an operational data representation code form from 3 May 2000. This was endorsed by EC-LI (1999). CREX is already used among centres for exchange of ozone data, radiological data, hydrological data, tide gauge data and soil temperature data. BUFR should always be used to exchange observations internationally. CREX should be used only if binary transmission is not possible. These two codes are the only codes that WMO needs for observation coding and are recommended for all present and future WMO applications.

2. THE DIFFERENCE BETWEEN THE FIXED ALPHANUMERIC CODES AND THE TABLE DRIVEN CODES

2.1 What does this character string mean in an alphanumeric codes?: **32325 11027?**
Nddff **$1s_nTTT$?**

N = Total cloud cover, dd = wind direction from which it is blowing, ff = wind speed

The position and the coding convention (the symbolic form) define the data: **ddffN or ffddN or Nddff**?

In a table driven code, there are also position rules, but those apply only to the frame, to the shape of the «container» rather than to the content itself. The presence of a datum is described in the message itself: it is the self-description feature. There will be a section at the beginning of the report, which defines what data are transmitted in this message. That section will in fact contain pointers towards elements in predefined and internationally agreed tables (stored in the official WMO Manual on Codes). Once this section (the Data Description Section) is read, the following part of the message containing the data (the Data Section) can be understood. Indeed, the characteristics of the parameters to be transmitted must already be defined in the tables of the WMO Manual. The "pointers" in the Data Description Section are in fact numbers called descriptors, which correspond to entries in the BUFR/CREX tables (see paragraph 3).

2.2 The layout of the BUFR and CREX codes are the following:

BUFR

SECTION 0 Indicator Section
SECTION 1 Identification Section
SECTION 2 **(Optional Section)**
SECTION 3 Data Description Section
SECTION 4 Data Section
SECTION 5 End Section

CREX

SECTION 0 Indicator Section
SECTION 1 Data Description Section
SECTION 2 Data Section
SECTION 3 **(Optional Section)**
SECTION 4 End Section

Sections 0 and 1 in BUFR and Section 0 in CREX are short sections, which identify the message. Section 2 in BUFR and Section 3 in CREX are optional sections that can be used to transmit any information or parameters for national purpose. It is somehow the equivalent of national groups in traditional alphanumeric codes.

2.3 In CREX and BUFR the parameters are simply listed as required by the user of the codes (in fact the data producer). CREX and BUFR offer flexibility and self-description. The datum are laid out one after the other, thus, it is very simple to read a CREX message. An item (the data value of a parameter to be transmitted in a report) will be translated in a set of characters (bytes) in CREX. It will be translated in a set of bits in BUFR. CREX is the image in characters of BUFR bit fields.

2.4 When there is a requirement for transmission of new parameters or new data types, new elements are simply added to the WMO BUFR and CREX Tables (to be agreed by CBS). Table driven codes can transmit an infinity of information. There is total flexibility. Definition of new «codes» as such is no more necessary. Expansion of tables is sufficient. Procedures and regulations are fixed. An edition number is associated for every new layout (not a frequent change). Edition number of the format (layout of the message) and version number of the tables are transmitted in the message itself (in Indicator and Identification sections for BUFR, in Data Description section for CREX) and enable the treatment of old archived data.

3. BUFR AND CREX TABLES

3.1 Tables define how the parameters (the elements) shall be coded as data items in a BUFR or CREX message (i.e. units, size, scale). They are recorded in the publication no 306 of WMO, the Manual on Codes, Volume I.2, Part B – Binary Codes and Part C – Common features to Binary and Alphanumeric Codes. The Manual on Codes comprises also Volume I.1 - Part A, Alphanumeric Codes and Volume II: Regional Codes and National Coding Practices. The Tables defining BUFR and CREX coding are the Tables A, B, C, and D.

3.2 **Table A** defines the data category (e.g. Surface data – land, surface data-sea, vertical soundings).

3.3 **Table B**: The list of elements (parameters) is defined in BUFR and CREX Tables B. The same elements are found in BUFR and CREX Tables B but their unit may differ. BUFR units are SI; while CREX units are more user oriented (e.g.: for temperature Kelvin in BUFR, Celsius in CREX). The table reference column lists the descriptors (their identification number) which are defining the elements. The data items transmitted in a report will have their descriptors listed in the Data Description Section. See below, as example, extracts of BUFR and CREX Table B for Temperature:

Temperature (in BUFR)

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

Note: To encode values in BUFR, the data (in the units as specified in the UNIT column) must be multiplied by 10 to the power of SCALE and then, the REFERENCE VALUE must be subtracted to them.

Temperature (in CREX)

Reference	Element name	Unit	Scale	Data width
B 12 001	Temperature/dry-bulb temperature	°C	1	3
B 12 002	Wet-bulb temperature	°C	1	3
B 12 003	Dew-point temperature	°C	1	3
B 12 004	Dry-bulb temperature at 2 m	°C	1	3
B 12 005	Wet-bulb temperature at 2 m	°C	1	3
B 12 006	Dew-point temperature at 2 m	°C	1	3
B 12 007	Virtual temperature	°C	1	3
B 12 011	Maximum temperature, at height and over period specified	°C	1	3
B 12 012	Minimum temperature, at height and over period specified	°C	1	3

Note: To encode values in CREX, the data (in the units as specified in the UNIT column) must be multiplied by 10 to the power of SCALE. In the example above, data will be thus encoded in 10^{th} of Degree Celsius.

3.4 **TABLE D**: A group of data items always transmitted altogether (like a regular SYNOP or TEMP report) can be defined in what is called a common sequence descriptor, so that, the individual element descriptors will not need to be repeated each time in the data description section. It is only the common sequence descriptor, which will be listed in the data description section. The Common Sequences are defined in BUFR and CREX Tables D. An example of BUFR Table D is shown below (the common sequences descriptor number are listed in the Table Reference F X Y column):

- Meteorological sequences common to surface data

TABLE REFERENCE			TABLE REFERENCES			ELEMENT NAME
F	X	Y				
3	02	001	0	10	004	Pressure (at station level)
			0	10	051	Pressure reduced to mean sea level
			0	10	061	3-hour pressure change
			0	10	063	Characteristic of pressure tendency
						(High altitude station)
3	02	002	0	10	004	Pressure (at station level)
			0	07	004	Pressure level
			0	10	003	Geopotential of pressure level
			0	10	061	3-hour pressure change
			0	10	063	Characteristic of pressure tendency
3	02	003	0	11	011	Wind direction (10 m)
			0	11	012	Wind speed (10 m)
			0	12	004	Temperature (2 m)
			0	12	006	Dew point (2 m)
			0	13	003	Relative humidity
			0	20	001	Horizontal visibility
			0	20	003	Present weather
			0	20	004	Past weather (1)
			0	20	005	Past weather (2)

4. COMMON FEATURES TO BUFR AND CREX

4.1 For Tables A, B and D, entries numbering are the same in CREX Tables and BUFR Tables for the same entity represented. Table B entries are listed both in BUFR and CREX. Table D common sequences are not defined in both CREX Table D and BUFR Table D. However, if a CREX Table D sequence is not defined in BUFR Table D, it has a number, which is not used by any BUFR sequences. Similarly, BUFR Table D sequences have numbers, which are not used by any CREX Table D sequences. There are also ranges of numbers for descriptors outside the international agreed range of numbers which can be used to define special descriptors or sequences for national local purpose only, and thus enable the domestic exchange of special national data.

4.2 **Code Table or Flag Table**s: An element based on a Code (e.g. Cloud Type) or a set of conditions defined by flags to be set (i.e. set of bits put to value 1) will have an associated Code Table or Flag Table (in the unit column of Table B, “Code table “ or “Flag table” will be written). BUFR and CREX Code and Flag Tables are identical. In CREX, flag values are coded in octal representation. Examples of Code Table and Flag Table are listed below:

0 20 011

Cloud amount

Code figure		
0	0	0
1	1 okta or less, but not zero	1/10 or less, but not zero
2	2 oktas	2/10 - 3/10
3	3 oktas	4/10
4	4 oktas	5/10
5	5 oktas	6/10
6	6 oktas	7/10 - 8/10
7	7 oktas or more, but not 8 oktas	9/10 or more, but not 10/10
8	8 oktas	10/10
9	Sky obscured by fog and/or other meteorological phenomena	
10	Sky partially obscured by fog and/or other meteorological phenomena	
11	Scattered	
12	Broken	
13	Few	
14	Reserved	
15	Cloud cover is Indiscernible for reasons other than fog or other meteorological phenomena, or observation is not made	

0 02 002

Type of instrumentation for wind measurement

Bit No	Type of Instrumentation and original units for wind measurement (measured in m s^{-1} unless otherwise indicated)
1	Certified Instruments
2	Originally measured in knots
3	Originally measured in kmh^{-1}
All 4	Missing value

BUFR and CREX Tables

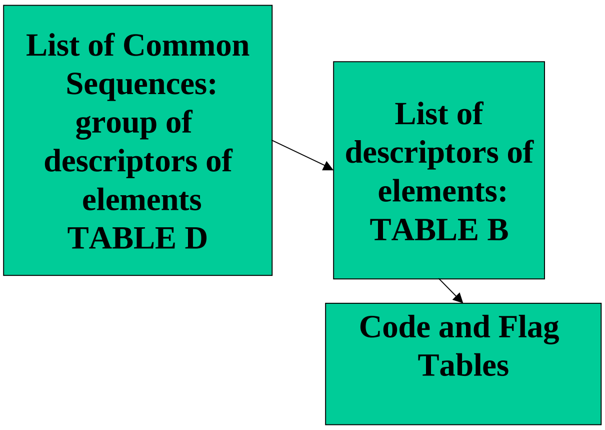

Figure 1

4.3 The self-descriptive feature of BUFR and CREX leads to another advantage over traditional alphanumeric character codes: the relative ease of decoding a BUFR (or a CREX) message. Where a large number of specialized and complex programs are needed to decode the plethora of character codes in current use, only a single "universal BUFR (or CREX) decoder" program is capable of decoding any BUFR (or CREX) 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 does not need to be modified with changes in observational requirements; only the tables need to be augmented, a relatively trivial task. The program needs to keep in memory the BUFR Tables. In figure 1 the decoding process is summarized:

- the decoder identifies the successive descriptors from the Data Description Section. If the descriptor is a common sequence descriptor, the decoder goes to Table D to find the element descriptors listed in the sequence and then go to Table B to find the characteristic of the element descriptors (units, scale, reference value, width). Then the decoder can decode properly the corresponding data values from the Data Section. If the descriptor from the Data Description Section is an element descriptor, the decoder goes directly to Table B.
- If in Table B, the unit column of the element descriptor contains "Code table" or "Flag table", the interpreter of the decoded data will have to examine the corresponding code table or flag table to understand the meaning of the coded value. The interpreter could also be, in some cases, an automatic process, which acts depending on the value of the code or the flags.

5. SPECIFIC FEATURES

5.1 BUFR offers condensation, therefore voluminous data (ex. satellites, ACARS, wind profilers) will require less resources for transmission and stocking. Condensation (packing) is performed by an algorithm defined within the code regulations. BUFR also permits the transmission of associated data (flags, substituted values) with the original observation data. However, the big disadvantage is that human cannot read BUFR data directly. BUFR processing does assume the availability of well designed computer programs (decoder and encoder for the reverse) that are capable of parsing the descriptors, matching them to the bit stream of data and extracting the numbers from the bit stream, 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 which modern means, like TCP/IP protocol (INTERNET) or the already old X.25 protocol, offer. Such protocols have various error detecting schemes built in so there need be little concern about the corruption of information in the transmission process.

5.2 CREX provides human readability. It is easy to understand, to code and to read (to decode) with only several hours of explanation. It requires for the transmission of big or many reports a substantial amount of characters. CREX tables have the same parameters as BUFR tables and are ruled by similar regulations. CREX is somehow the image of BUFR in characters. CREX is simpler than BUFR, but CREX does not offer the packing, nor the facility of coding associated data (quality control information, substituted values), that BUFR permits.

6. EXAMPLE FOR SYNOP:

- In alphanumeric code form **FM 12 SYNOP**:

  - AAXX 09091
  - 03075 41480 62413 11073 21105 39962 40001 55019 71562 86800=

  - In code form **FM 95 CREX**:

  - CREX ++ *Indicator Section*
  - T000101 A000 D07999++ *Description Section*
  - 03 075 1 1989 01 09 09 00039 5845 -00308 0030 3000 075 240 0013 -073 -105 09962 10001 05 0019 015 07 02 075 38 20 10++ *Data Section*
  - 7777 *End Section*

    - or with check digit (one figure inserted before each parameter allowing better transmission control):

  - CREX ++
  - T000101 A000 D07999E++
  - 003 1075 21 31989 401 509 609 700039 85845 9-00308 00030 13000 2075 3240 40013 5-073 6-105 709962 810001 905 00019 1015 207 302 4075 538 620 710++
  - 7777

Interpretation of the example:

Encoded in **SYNOP**	Encoded in **CREX**		Name of the element	**Decoded value**	**CREX Data Section**
	CREX		Indicator of a CREX message		
	T000101		CREX Master Table Number 00, Edition 01, Version 01		
	A000		Data type (000 = Surface data – land)		
	D07999		See note below		
II = 03		B 01 001	WMO block number		03
iii = 075		B 01 002	WMO station number		075
i_R = 4			no counterpart needed in CREX		
i_x = 1		B 02 001	Type of station	manned	1
		B 04 001	Year (of observation)		1989
		B 04 002	Month (of observation)		01
		B 04 003	Day (of observation)		09
		B 04 004	Hour (of observation)		09
		B 07 001	Height of station (barometer)	39 m	00039
		B 05 002	Latitude (coarse accuracy)	58.45 deg.	5845
		B 06 002	Longitude (coarse accuracy)	- 3.08 deg.	-00308
h = 4		B 20 013	Height of base of cloud	300 m	0030
VV = 80		B 20 001	Horizontal visibility	30 km	3000
N = 6		B 20 010	Cloud cover (total)	6/8 = 75 %	075
dd = 24		B 11 011	Wind direction at 10 m	240 degrees	240
ff = 13		B 11 012	Wind speed at 10 m	13 m/s	0013
s_nTTT = 1073		B 12 004	Dry-bulb temperature at 2 m	- 7.3 ^oC	-073
$s_nT_dT_dT_d$ = 1105		B 12 006	Dew-point temperature at 2 m	- 10.5 ^oC	-105
$P_0P_0P_0P_0$ = 9962		B 10 004	Pressure	996.2 hPa	09962
PPPP = 0001		B 10 051	Pressure reduced to mean sea level	1000.1 hPa	10001
a = 5		B 10 063	Characteristic of pressure tendency		05
ppp = 019		B 10 061	3-hour pressure change	1.9 hPa	0019
ww = 15		B 20 003	Present weather	precipitation in sight	015
W_1 = 7		B 20 004	Past weather (1)	snow	07
W_2 = 2		B 20 005	Past weather (2)	more then 1/2 of the sky covered	02
N_h = 6		B 20 051	Amount of low clouds	6/8 = 75 %	075
C_L = 8		B 20 012	Cloud type (Type of low clouds)	Cu and Sc	38
C_M = 0		B 20 012	Cloud type (Type of middle clouds)	no C_M clouds	20
C_H = 0		B 20 012	Cloud type (Type of high clouds)	no C_H clouds	10
			End of Data Section		++
			End of the CREX message		7777

Note:

The sequence descriptor 07999 represents a sequence of the element descriptors B01001, B01002, B02001, ..., B20012 as given in the third column. The sequence descriptor D07999 is hypothetical and has been created for the purpose of this example. Apart from the time identification (Year, Month, Day, Hour) and coordinate locations (barometer height, latitude, longitude) the sequence of the elements in the CREX message corresponds to the sequence of the elements in the above presented SYNOP report. The systematic passing of geographical coordinates, easily performed with the table driven codes, would alleviate the famous Volume A problems. The Volume A is updated with too much delay by the secretariat, which sometimes receives late or never the updates that the Countries should send. That solution would solve 98% of the wrong coordinates for a station. The remaining 2% errors are and would remain the station itself which has being incorrectly located. E, if present at the end of the Description Section, indicates the presence of check digit in front of each data value.

7. OPERATION DESCRIPTORS

7.1 Table C corresponds to a set of operations which can be performed within the Data Description Section of the message. It contains operator descriptors which, for instance, can be used to modify the characteristic of the elements in Table B.

7.2 There is also an operator which defines the repetition (or replication) of a set of data descriptors (and therefore the corresponding repetition of the data values in the Data Section). This feature will be used to give the number of levels in a sounding. In CREX, the operators have been simplified.

7.3 The CREX operator descriptors are: **R** for repetitions and **C** for change of characteristic.

– **R**: repetitions, Rxxyyy

- xx: number of following descriptors to be repeated
- yyy: number of repetitions (if yyy= 0, it means delayed, that means the number of repetitions will be known only when the report is transmitted - for example, for a sounding, the number of characteristic levels will be put into the data section)

– **TABLE C:** Operator descriptors, Cxxyyy, where yyy = new value and xx =

- 01: CHANGE OF ELEMENT SIZE
- 02: CHANGE OF SCALE
- 07: CHANGE OF UNITS
- 05: INSERTION OF CHARACTERS CCITT5
- 60: NATIONAL LETTERS INSERTION

8. EXAMPLE OF AN OZONE SOUNDING

EXAMPLE OF AN OZONE SOUNDING IN CREX

CREX++			
T000101			
A008			
D01001	:	WMO station and block number	71
			917
B01015	:	station or site name	Eureka^^^^^^^^^^^^^^^^
D01024	:	latitude	7598
		longitude	-08593
		elevation	00010
B08021	:	18 = launch time follows	18
D01011	:	year	1998
		month	04
		day	29
D01012	:	hours	23
		minutes	18
B02011	:	radiosonde type	061
B02143	:	ozone instrument type	019
B02142	:	ozone sonde serial number	////

D15004	:	ozone sounding correction factor	////
D15005	:	ozone p	375
R04000	:	delayed replication factor = number of levels	0082
		The next four descriptors are repeated 82 times	
B04015	:	time increment since launch time (minutes)	see below
B08006	:	ozone VSS	see below
B07004	:	pressure	see below
B15003	:	measured ozone partial pressure	see below
++			
7777		end of message	

ACTUAL CREX MESSAGE:

```
KULA01 CWAO 051800
CREX++
T000101 A008 D09040++
71 917 EUREKA              7598 -08593 00010 18 1998 04 29 23 18
 061 019 //// //// 375 0082
 0000 400 10137 030 0000 200 10000 030 0001 002 09687 037
 0002 002 09366 033 0004 002 08831 037 0005 200 08500 036
 0007 002 08013 043 0007 002 07881 047 0008 002 07646 037
 0009 002 07442 042 0011 200 07000 031 0012 002 06849 027
 0013 002 06710 036 0015 002 06291 029 0022 200 05000 028
 0025 002 04557 027 0029 002 04065 024 0029 200 04000 020
 0032 002 03626 025 0038 002 03000 020 0040 002 02890 021
 0040 002 02829 065 0041 002 02726 105 0043 002 02576 118
 0044 200 02500 135 0048 002 02218 165 0049 002 02147 161
 0050 002 02104 171 0051 002 02031 153 0051 002 02010 159
 0051 200 02000 171 0052 002 01941 188 0054 002 01854 198
 0056 002 01744 187 0056 002 01717 194 0057 002 01683 191
 0058 002 01640 161 0058 002 01623 159 0059 002 01585 168
 0059 002 01576 185 0060 002 01545 197 0061 002 01500 202
 0063 002 01414 221 0064 002 01370 220 0065 002 01335 230
 0066 002 01269 219 0067 002 01232 227 0067 002 01226 235
 0068 002 01208 241 0072 002 01055 242 0074 200 01000 236
 0075 002 00960 228 0076 002 00936 192 0077 002 00912 180
 0078 002 00897 187 0078 002 00883 210 0079 002 00868 221
 0079 002 00850 202 0080 002 00841 199 0081 002 00815 208
 0081 002 00807 189 0081 002 00803 171 0082 002 00790 152
 0082 002 00777 157 0083 002 00764 172 0084 002 00741 156
 0084 002 00722 156 0085 002 00715 162 0085 200 00700 188
 0085 200 00700 193 0086 002 00682 203 0088 002 00639 212
 0090 002 00608 206 0091 002 00588 190 0091 002 00582 192
 0092 002 00570 209 0092 002 00557 215 0096 200 00500 197
 0099 002 00437 171 0108 002 00316 139 0110 200 00300 128
 0115 002 00242 108++
7777
```

9. IN SUMMARY: WHAT IS IN THE DATA DESCRIPTION SECTION OF BUFR OR CREX?

A set of descriptors: symbol = FXXYYY, 3 parts: F, XX, YYY

DESCRIPTORS	F		XX = number		YYY = number		Example	
	CREX 1 letter	BUFR 2 bits	CREX 2 bytes	BUFR 6 bits	CREX 3 bytes	BUFR 8 bits	CREX	BUFR
Table B (element)	"B"	"0"	CLASS		ELEMENT		B12006	012006
Repetition operator	"R"	"1"	Number of descriptors to be repeated		Number of repetitions (if = 0, transmitted in Data Section)		R04002 R04000	104002 104000
Table C (Operation)	"C"	"2"	Operation		Operand		C01004 *(change of data width)*	201136
Table D (Common sequence)	"D"	"3"	Category		Reference number of sequence		D05002	305002

10. IN SUMMARY:

Table driven codes, like BUFR and CREX offers:

- o self description
- o flexibility
- o expandability
- o *condensation (packing), quality flags, associated values for BUFR*
- o *simple readability for CREX*

These codes are universal. They are the ideal codes for coding observations and the most adapted to the fast scientific and technological evolution of the 21st Century. They are the last observation codes that WMO had to design. BUFR and CREX can be easily expanded to satisfy all observational requirements, without deviating from WMO recommendations, even to answer national needs for specific domestic data exchange, as it is presently the case in many Countries.