# BUFR format in a nutshell

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# WMO Binary Codes



ECMWF Data Coverage (All obs DA) - Aircraft
01/Dec/2015; 00 UTC
Total number of obs = 229354

- **BUFR** (**B**inary **U**niversal **F**orm for the **R**epresentation of meteorological data) is

  – a flexible binary format

  – mainly used to encode in situ and satellite observations

  – can also represent forecast data.



Tuesday 1 December 2015 00UTC ©ECMWF Analysis t+000 VT: Tuesday 1 December 2015 00UTC
850 hPa Temperature / 500 hPa Geopotential

- **GRIB** (**G**eneral **R**egularly-distributed **I**nformation in **B**inary form) is

  – designed to encode data produced by numerical weather prediction models.

  – can also represent observations, but on a regularly distributed coverage

# WMO Binary Codes

Manual on Codes
International Codes
VOLUME I.2

PART B – Binary Codes
PART C – Common Features to Binary and Alphanumeric Codes

2011 edition
Updated in 2014

World
Meteorological
Organization

WMO-No. 306

Weather • Climate • Water
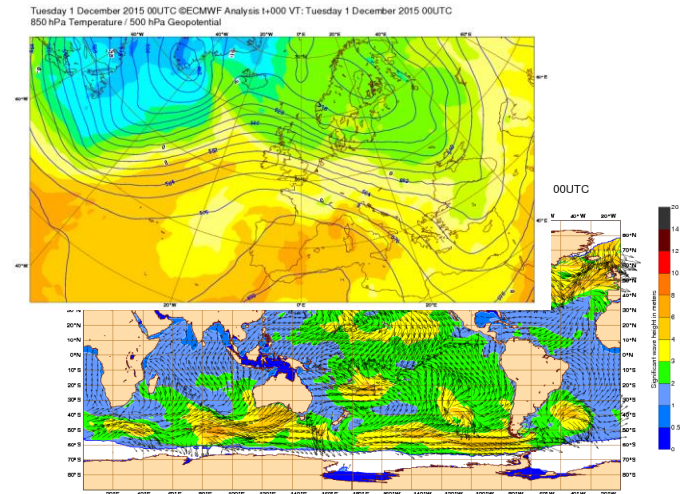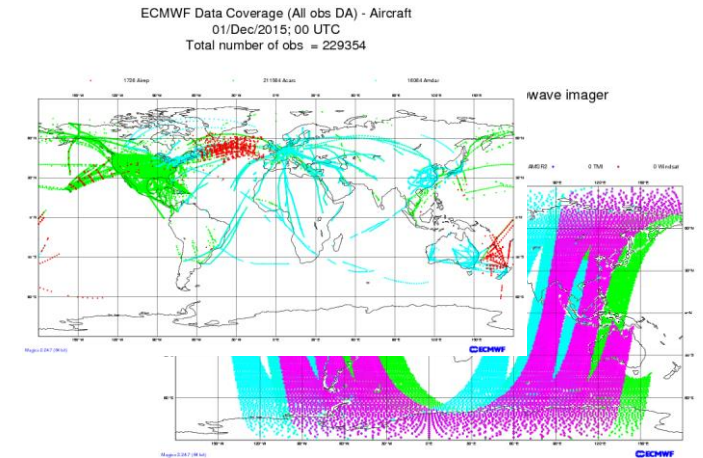
o Fully describes GRIB and BUFR coding standards
o Anyone reading the manual can implement a decoder/encoder
o It is the only authoritative source for the WMO binary codes GRIB and BUFR
o It is publicly accessible on the WMO web site http://www.wmo.int/pages/prog/www/WMOCodes.html
o There are some freely available decoders/encoders
o There isn't any reference decoder/encoder
o A revision of the full manual is published every three/four years
o A new version of the tables which are part of the manual is released externally twice a year.
o Latest version of the tables is accessible in several formats from the WMO web site http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/LatestVERSION.html
o WMO Inter-Program Expert Team on Codes Maintenance is maintaining the manual
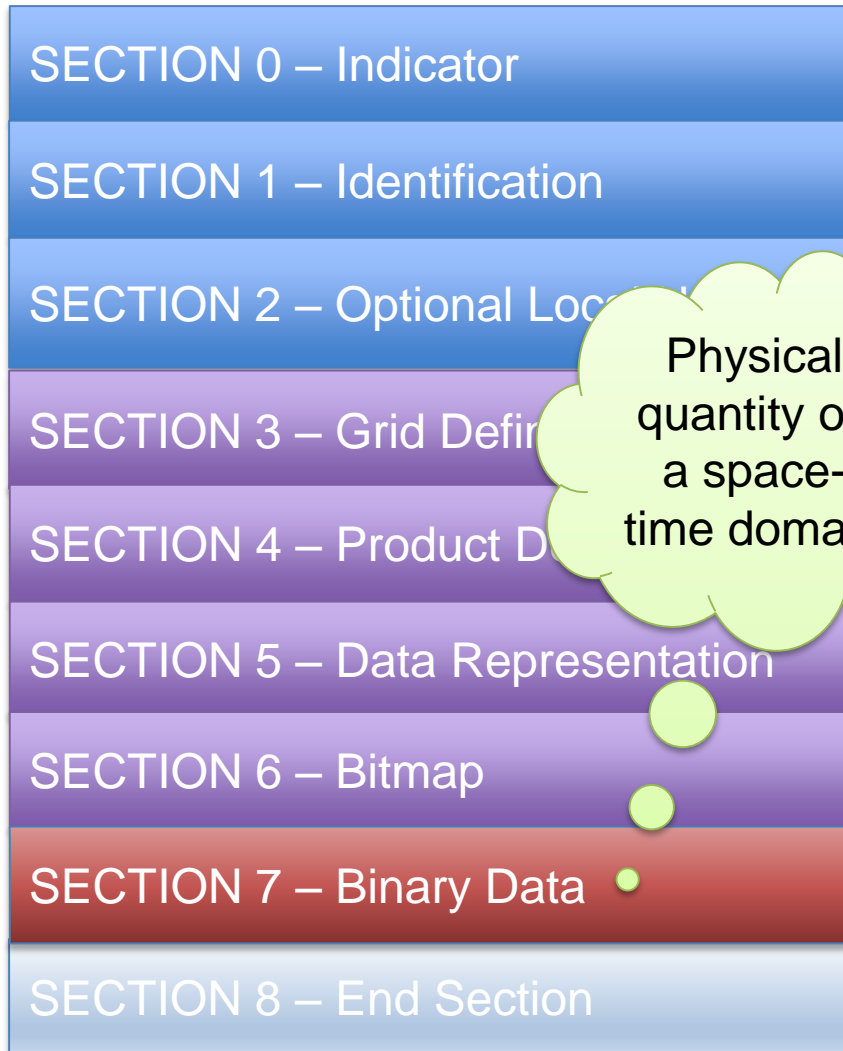
# WMO Binary Codes

**BUFR** is a **bit stream** of encoded data

```
42 55 46 52 00 00 DC 03 00 00 12 00 00 62 01 80 00 01 0D 01 0C 0A    BUFR    ‹        b Ä
1E 00 00 00 00 00 34 00 01 01 7D CA 78 00 00 7E 95 46 00 4A 59 34        4    } x    ~ïF JY4
00 39 31 33 33 34 20 20 20 20 20 20 20 20 20 20 20 20 00 DC 78 05    91334                ‹x
26 78 03 08 02 00 00 00 46 00 00 00 00 00 1C 00 00 01 80 C7 05 0D    &x        F            Ä«
17 0D 0D 96 00 41 31 1F 1F 01 1F 01 20 41 31 21 07 00 00 00 6E 00      ñ A1      A1!      n
B6 A7 2F B9 4F 00 04 A5 93 43 F4 AA 30 06 4E 76 B9 DB 9F 60 AF 00    ðß/π0   ●ìCÙ™0 Nvπ€ü`Ø
F5 E9 DD 4F F4 B0 00 82 16 40 90 55 81 42 C1 FF FF F8 5F FF FF 0F    ıÈ›0Ù∞ Ç @éUÅB¡˘˘˘_˘˘
FF FF FF FF FF FC 01 FF FF F0 00 00 00 00 00 00 03 10 0C 68 D1 A3    ˘˘˘˘˘˘˘˘  ˳       ●    h−£
46 8D 1A 34 68 D2 E5 4A 9B 3E 34 6A 13 63 52 AB 1A 35 58 D5 6A 55    Fç 4h"ÂJõ>4j cR´ 5X'jU
AB 56 34 68 D1 A3 46 8D 1A 34 68 D1 A3 46 8D 1A 34 60 37 37 37 37    ´V4h−£Fç 4h−£Fç 4`7777
```
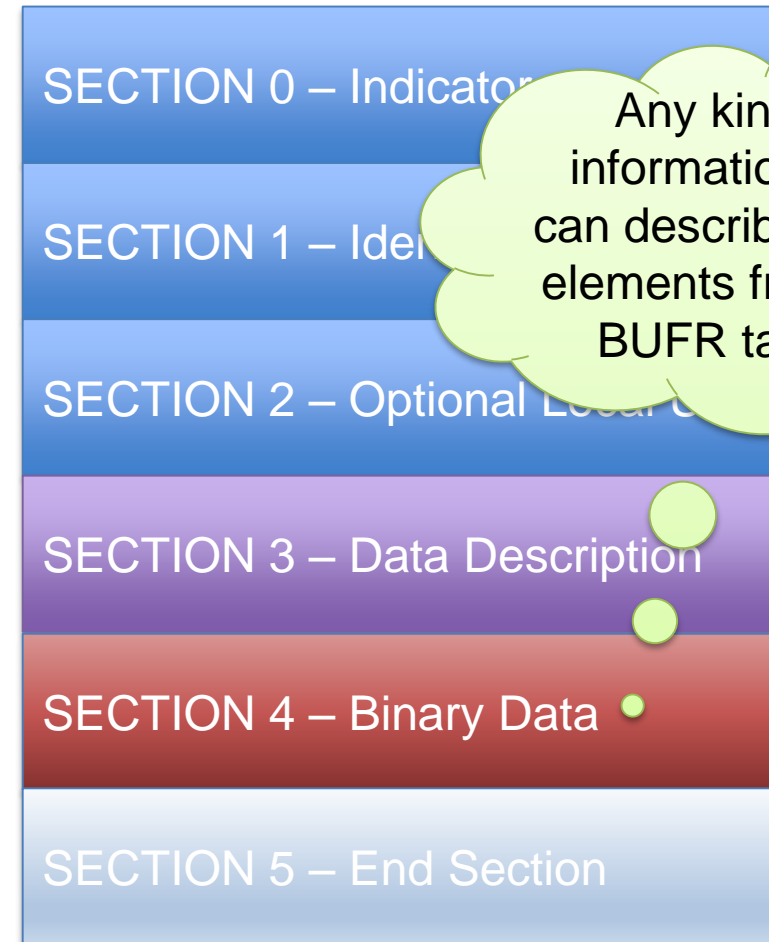
**GRIB** is a **byte stream** of encoded data

```
47 52 49 42 00 00 66 01 00 00 1C 01 62 01 FF 80 33 6D 00 01 06 0C    GRIB  f        b ˘Ä3m
05 0C 00 0C 00 C8 05 00 00 00 15 00 00 00 00 00 32 02 2B 0A 00 F8         »           2 +   ˘
01 90 80 33 C2 00 16 76 88 00 68 1A 00 76 F2 00 64 00 64 40 00 00    éÄ3¬  và h  vÚ d d@
00 00 80 55 F0 80 9C 40 00 00 00 00 43 3E B0 71 00 00 00 00 00 00     ÄU●Äú@      C>∞q
0C 08 80 11 3C 1F 09 7C 00 00 37 37 37 37                            Ä < | 7777
```
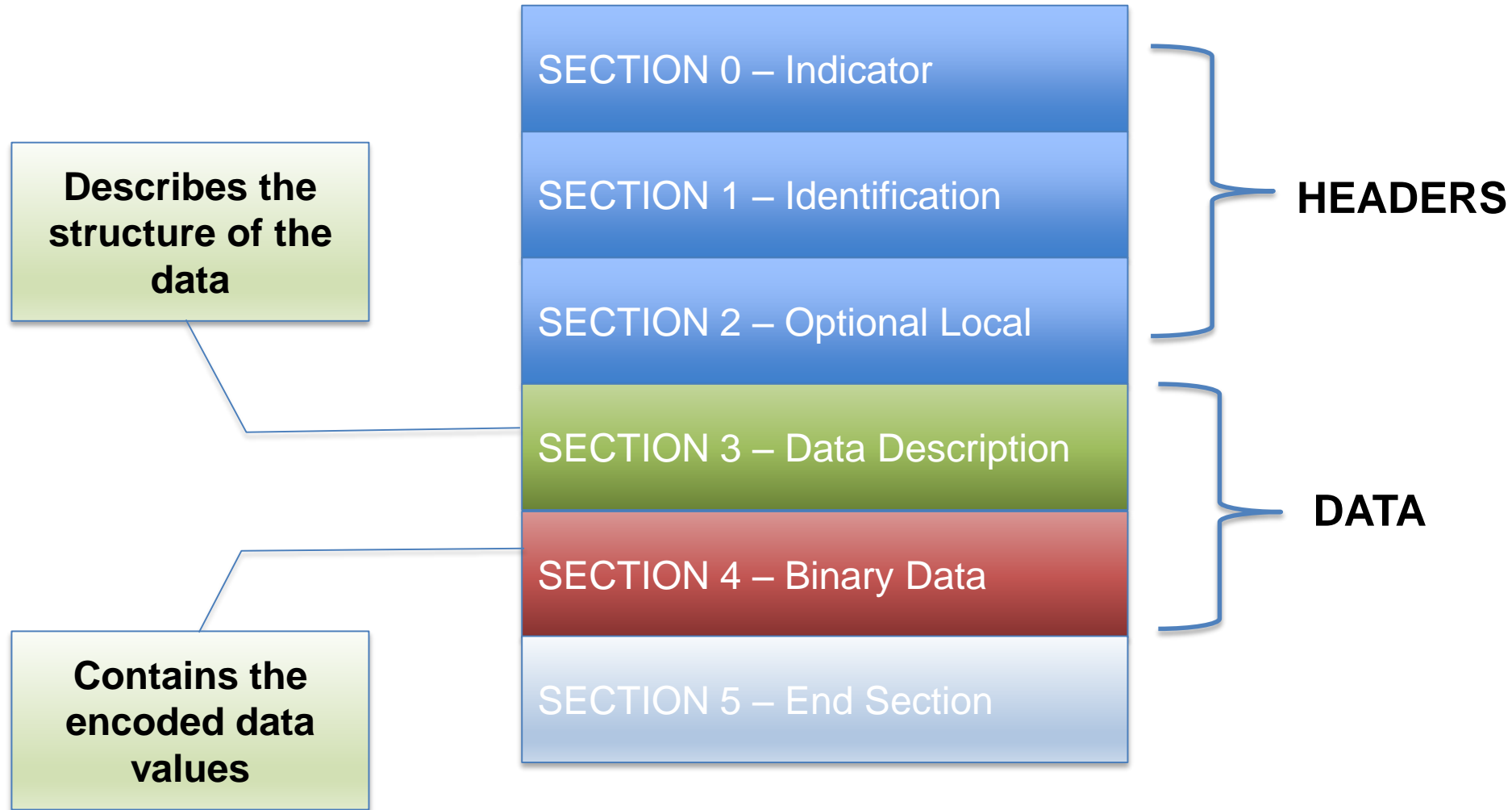
GRIB structure

SECTION 0 – Indicator
SECTION 1 – Identification
SECTION 2 – Optional Local
SECTION 3 – Grid Defin
SECTION 4 – Product D
SECTION 5 – Data Representation
SECTION 6 – Bitmap
SECTION 7 – Binary Data
SECTION 8 – End Section

Physical quantity on a space-time domain

BUFR structure

SECTION 0 – Indicator
SECTION 1 – Iden
SECTION 2 – Optional Local
SECTION 3 – Data Description
SECTION 4 – Binary Data
SECTION 5 – End Section

Any kind of information you can describe using elements from the BUFR tables

# BUFR structure

**Describes the structure of the data**

**Contains the encoded data values**

| SECTION 0 – Indicator |
|---|
| SECTION 1 – Identification |
| SECTION 2 – Optional Local |
| SECTION 3 – Data Description |
| SECTION 4 – Binary Data |
| SECTION 5 – End Section |

**HEADERS**

**DATA**

# BUFR headers

| | |
|---|---|
| SECTION 0 – Indicator | BUFR<br>Total length of BUFR message<br>BUFR edition number |
| SECTION 1 – Identification | Length of section<br>BUFR master table<br>Version number of master tables<br>Identification of originating/generating centre<br>Version number of local tables<br>Identification of originating/generating sub-centre<br>Data category<br>International data sub-category<br>Local data sub-category<br>Year<br>Month<br>Day<br>Hour<br>Minute<br>Second |
| SECTION 2 – Optional Local | Whatever the originating centre needs for internal purposes (processing, archiving) |

# Which BUFR tables?

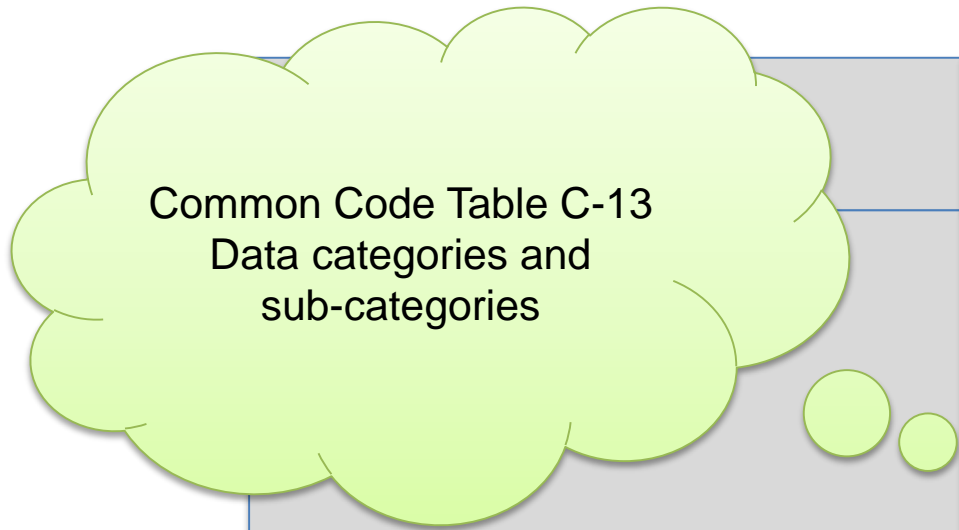| SECTION 0 – Indicator | BUFR<br>Total length of BU...<br>BUFR edition number |
|---|---|
| SECTION 1 – Identification | Length of section<br>**BUFR master table**<br>**Version number of master tables**<br>**Identification of originating/generating centre**<br>**Version number of local tables**<br>Identification of originating/generating sub-centre<br>Data category<br>International data sub-category<br>Local data sub-category<br>Year<br>Month<br>Day<br>Hour<br>Minute<br>Second |
| SECTION 2 – Optional Local | Whatever the originating centre needs for...<br>purposes (processing, archiving) |

0 -> meteorology
No other values defined

Master tables are the official WMO tables

WMO tables are updated every six months and the latest tables can be found [here](#)
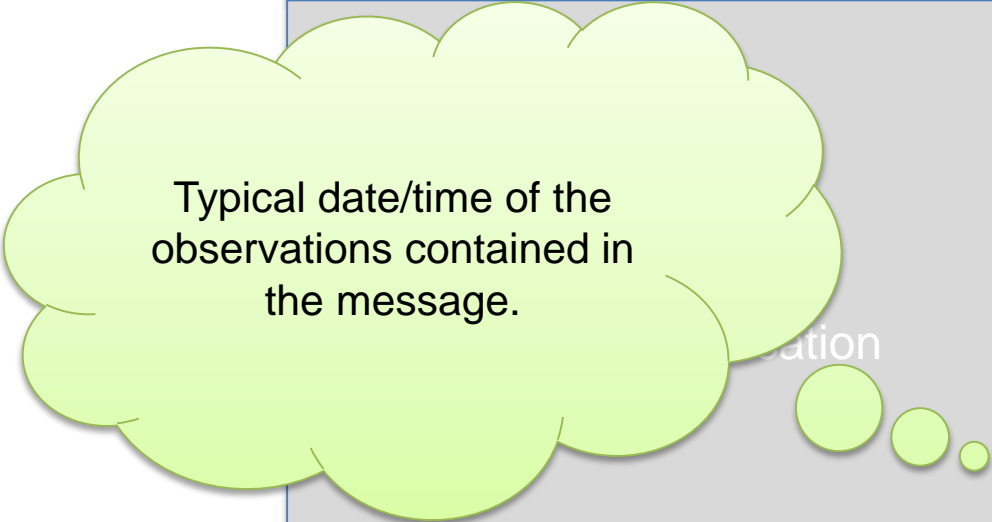
Local tables are defined by the originating Centre and can be used to exchange data by bilateral agreement. Not WMO official. Versions are maintained by the Centre

# BUFR data category

Common Code Table C-13
Data categories and
sub-categories

**SECTION 1 – Identification**

BUFR
Total length of BUFR message
BUFR edition number

Length of section
BUFR master table
Version number of master tables
Identification of originating/generating centre
Version number of local tables
Identification of originating/generating sub-centre
**Data category**
**International data sub-category**
**Local data sub-category**
Year
Month
Day
Hour
Minute
Second

**SECTION 2 – Optional Local**

Whatever the originating centre needs for internal purposes (processing, archiving)

# BUFR data category

| SECTION 0 – Indicator | BUFR<br>Total length of BUFR message<br>BUFR edition number |
| --- | --- |
| ...ation | Length of section<br>BUFR master table<br>Version number of master tables<br>Identification of originating/generating centre<br>Version number of local tables<br>Identification of originating/generating sub-centre<br>Data category<br>International data sub-category<br>Local data sub-category<br>**Year**<br>**Month**<br>**Day**<br>**Hour**<br>**Minute**<br>**Second** |
| SECTION 2 – Optional Local | Whatever the originating centre needs for internal purposes (processing, archiving) |

Typical date/time of the observations contained in the message.

# BUFR data

recipe

### SECTION 3

```
301051 004006 007002 010004
012001 011001 011002 011031
011032 011033 020041
```

- **Contains a list of six digit descriptors in the form F-X-Y → 0-04-006**
- **Descriptors starting with**
  **F=0** are elements listed in **Table B**
  **F=1** denote replication of descriptors
  **F=2** are operators acting on descriptors (**Table C**)
  **F=3** are sequences of descriptors listed in **Table D**

### SECTION 4

```
0100101011101010010101010101010
1010001000101010101010001010100
1010010101001001010010100101010
1010101010111100001010101001001
```

**Contains the encoded values as a bit stream to be decoded.**
**How?**
- Implementing the decoding regulations and notes
- Using the Tables

ingredients

# BUFR Table B (descriptors starting with 0)

**Class 12 – BUFR/CREX Temperature**

encoding parameters

meaning

Elements descriptors

| TABLE REFERENCE F X Y | ELEMENT NAME | BUFR | | | | CREX | | |
|---|---|---|---|---|---|---|---|---|
| | | UNIT | SCALE | REFERENCE VALUE | DATA WIDTH (Bits) | UNIT | SCALE | DATA WIDTH (Characters) |
| 0 12 001 | Temperature/air temperature | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 002 | Wet-bulb temperature | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 003 | Dewpoint temperature | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 004 | Air temperature at 2 m | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 005 | Wet-bulb temperature at 2 m | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 006 | Dewpoint temperature at 2 m | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 007 | Virtual temperature | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 011 | Maximum temperature, at height and over period specified | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 012 | Minimum temperature, at height and over period specified | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 013 | Ground minimum temperature, past 12 hours | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 014 | Maximum temperature at 2 m, past 12 hours | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 015 | Minimum temperature at 2 m, past 12 hours | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 016 | Maximum temperature at 2 m, past 24 hours | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 017 | Minimum temperature at 2 m, past 24 hours | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 021 | Maximum temperature at 2 m | K | 2 | 0 | 16 | °C | 2 | 4 |
| 0 12 022 | Minimum temperature at 2 m | K | 2 | 0 | 16 | °C | 2 | 4 |
| 0 12 023 | Temperature | °C | 0 | –99 | 8 | °C | 0 | 2 |
| 0 12 024 | Dewpoint temperature | °C | 0 | –99 | 8 | °C | 0 | 2 |
| 0 12 030 | Soil temperature | K | 1 | 0 | 12 | °C | 1 | 3 |
| 0 12 049 | Temperature change over specified period | K | 0 | –30 | 6 | °C | 0 | 2 |
| 0 12 051 | Standard deviation temperature | K | 1 | 0 | 10 | °C | 1 | 3 |
| 0 12 052 | Highest daily mean temperature | K | 1 | 0 | 12 | °C | 1 | 3 |

# BUFR Table B (descriptors starting with 0)

Element descriptors corresponding to the following classes in Table B shall remain in effect until superseded by redefinition:

**X (class)**

| | |
|---|---|
| **01** | **Identification** |
| **02** | **Instrumentation** |
| **03** | **Reserved** |
| **04** | **Location (time)** |
| **05** | **Location (horizontal – 1)** |
| **06** | **Location (horizontal – 2)** |
| **07** | **Location (vertical)** |
| **08** | **Significance qualifiers** |
| **09** | **Reserved** |

# Significance qualifier Code table

**0-08-021 Time significance**

| Code | Meaning |
|------|---------|
| 0 | Reserved |
| 1 | Time series |
| 2 | Time averaged (see Note 1) |
| 3 | Accumulated |
| 4 | Forecast |
| 5 | Forecast time series |
| 6 | Forecast time averaged |
| 7 | Forecast accumulated |
| 8 | Ensemble mean (see Note 2) |
| 9 | Ensemble mean time series |
| 10 | Ensemble mean time averaged |
| 11 | Ensemble mean accumulated |
| 12 | Ensemble mean forecast |
| 13 | Ensemble mean forecast time series |
| 14 | Ensemble mean forecast time averaged |
| 15 | Ensemble mean forecast accumulated |
| 16 | Analysis |
| 17 | Start of phenomenon |
| 18 | Radiosonde launch time |
| 19 | Start of orbit |
| 20 | End of orbit |
| 21 | Time of ascending node |
| 22 | Time of occurrence of wind shift |
| 23 | Monitoring period |
| 24 | Agreed time limit for report reception |
| 25 | Nominal reporting time |
| 26 | Time of last known position |
| 27 | First guess |
| 28 | Start of scan |
| 29 | End of scan or time of ending |
| 30 | Time of occurrence |
| 31 | Missing value |

# BUFR decoding formula

$$value = (intValue + Reference) \cdot 10^{-scale}$$

**Class 12 – BUFR/CREX Temperature**

| TABLE REFERENCE | ELEMENT NAME | BUFR | | | |
| F X Y | | UNIT | SCALE | REFERENCE VALUE | DATA WIDTH (Bits) |
| --- | --- | --- | --- | --- | --- |
| 0 12 001 | Temperature/air temperature | K | 1 | 0 | 12 |

... ... ... ... 012001 ... ... ... ...

01001010111010100101010101010 1010000000**101101110010**01010100 1010010101001001010010100101001010 1010101010101111000010101001001

( 2930 + 0 ) * 10⁻¹ = 293.0 K

# BUFR missing value

**Class 12 – BUFR/CREX Temperature**

| TABLE REFERENCE F X Y | ELEMENT NAME | BUFR | | | |
|---|---|---|---|---|---|
| | | UNIT | SCALE | REFERENCE VALUE | DATA WIDTH (Bits) |
| 0 12 001 | Temperature/air temperature | K | 1 | 0 | 12 |

… … … … 012001 … … … …

**All bits set to 1 = missing value**

```
0100101011101010010101010101010
101000000111111111111101010100
1010010101001001010010101001010
1010101010101111000010101001001
```

# BUFR decoding formula range and precision

$$value = (intValue + Reference)\, 10^{-scale}$$

$$precision = 10^{-scale}$$

$$valueMax = (intValueMax + Reference)\, 10^{-scale}$$

$$valueMax = \left(2^{width} - 2 + Reference\right) 10^{-scale}$$

$$valueMin = (intValueMin + Reference)\, 10^{-scale}$$

$$valueMin = Reference\, 10^{-scale}$$

**Class 12 – BUFR/CREX Temperature**

| TABLE REFERENCE F X Y | ELEMENT NAME | BUFR | | | |
|---|---|---|---|---|---|
| | | UNIT | SCALE | REFERENCE VALUE | DATA WIDTH (Bits) |
| 0 12 001 | Temperature/air temperature | K | 1 | 0 | 12 |

$$valueMax = 4094 * 10^{-1} = 409.4$$

$$valueMin = 0$$

$$precision = 0.1$$

# BUFR decoding formula practical

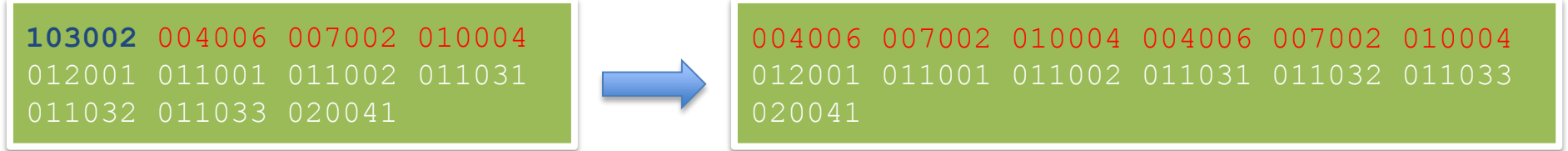Compute min and Max and precision for the following table B elements.

| F X Y | Name | Units | Scale | Reference | Width | min | F Max | Prec |
|-------|------|-------|-------|-----------|-------|-----|-------|------|
| 0 04 001 | Year | a | 0 | 0 | 12 | | | |
| 0 04 006 | Second | s | 0 | 0 | 6 | | | |
| 0 04 007 | Seconds within a minute (microsecond accuracy) | s | 6 | 0 | 26 | | | |
| 0 05 001 | Latitude (high accuracy) | deg | 5 | -9000000 | 25 | | | |
| 0 06 001 | Longitude (high accuracy) | deg | 5 | -18000000 | 26 | | | |
| 0 07 004 | Pressure | Pa | -1 | 0 | 14 | | | |
| 0 08 021 | Time significance | Code | 0 | 0 | 5 | | | |

# BUFR decoding formula practical

Compute min and Max and precision for the following table B elements.

| F X Y | Name | Units | Scale | Reference | Width | min | F Max | Prec |
|-------|------|-------|-------|-----------|-------|-----|-------|------|
| 0 04 001 | Year | a | 0 | 0 | 12 | 0 | 4094 | 1 |
| 0 04 006 | Second | s | 0 | 0 | 6 | 0 | 62 | 1 |
| 0 04 007 | Seconds within a minute (microsecond accuracy) | s | 6 | 0 | 26 | 0 | 67.108862 | 0.000001 |
| 0 05 001 | Latitude (high accuracy) | deg | 5 | -9000000 | 25 | -90.00000 | 245.54430 | 0.00001 |
| 0 06 001 | Longitude (high accuracy) | deg | 5 | -18000000 | 26 | -180.00000 | 491.08862 | 0.00001 |
| 0 07 004 | Pressure | Pa | -1 | 0 | 14 | 0 | 163820 | 10 |
| 0 08 021 | Time significance | Code | 0 | 0 | 5 | 0 | 30 | 1 |

# BUFR replication (descriptors starting with 1)

**103002** 004006 007002 010004
012001 011001 011002 011031
011032 011033 020041

→

004006 007002 010004 004006 007002 010004
012001 011001 011002 011031 011032 011033
020041

*unexpanded*

**106002** 008002 **104003** 005002 006002 010002 012001

*Expansion*

008002 **104003** 005002 006002 010002 012001
008002 **104003** 005002 006002 010002 012001

*expanded*

008002 005002 006002 010002 012001 005002 006002 010002 012001 005002 006002 010002 012001
008002 005002 006002 010002 012001 005002 006002 010002 012001 005002 006002 010002 012001

# BUFR delayed replication (descriptors starting with 1)

103000 031001 004006 007002
010004 012001 011001 011002
011031 011032 011033 020041

→

004006 007002 010004 004006 007002 010004
012001 011001 011002 011031 011032 011033
020041

2

0100101011101010100101010101010
101000000010101010100010101000
1010010101001001010010101001010
10101010101111000010101001001
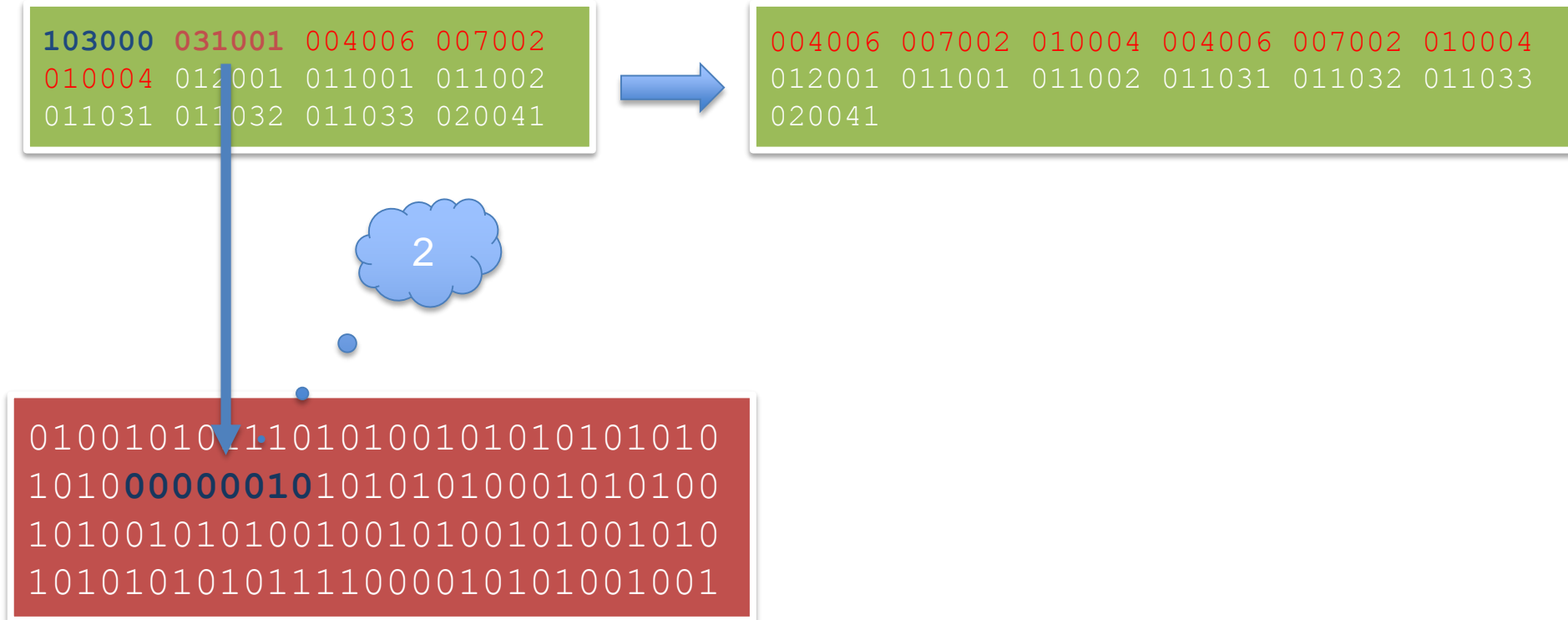
# BUFR operators (descriptors starting with 2)

# BUFR bitmap and quality information

**Percent confidence of wind speed**

**Wind speed** (7th element in referred by the bitmap, corresponds to the zero → present )

```
012001 011001 011002 011031 011032 011033
020041 012001 011001 011002 011002 011032
011033 020041 222000 236000 101010 031031
033007
```

Bitmap

```
010010101110101001010101010101010
101010101000111111101110010101
00100101001010010101010101010101010
1111000010101001001
```

10 bits

**031031**
**Data present indicator**
**0 → present**
**1 → not present**

# BUFR Table D (descriptors starting with 3)

Sequence descriptor

Sequence description

In section 3 is equivalent to the list of descriptors

List of descriptors. It can contain sequence descriptors

Names of the descriptors in the sequence

| TABLE REFERENCE F X Y | TABLE REFERENCES | ELEMENT NAME |
|---|---|---|
| 3 09 052 | | (Sequence for representation of TEMP, TEMP SHIP and TEMP MOBIL observation type data) |
| | 3 01 111 | Identification of launch site and instrumentation for P, T, U and wind measurements |
| | 3 01 113 | Date/time of launch |
| | 3 01 114 | Horizontal and vertical coordinates of launch site |
| | 3 02 049 | Cloud information reported with vertical soundings |
| | 0 22 043 | Sea/water temperature |
| | 1 01 000 | Delayed replication of 1 descriptor |
| | 0 31 002 | Extended delayed descriptor replication factor |
| | 3 03 054 | Temperature, dewpoint and wind data at a pressure level with radiosonde position |
| | 1 01 000 | Delayed replication of 1 descriptor |
| | 0 31 001 | Delayed descriptor replication factor |
| | 3 03 051 | Wind shear data at a pressure level with radiosonde position |

# BUFR uncompressed data and subsets

**SECTION 3**

- **Number of data subsets**
- **Flag observed data/other data**
- **Flag compressed/uncompressed**

```
301051  004006  007002  010004
012001  011001  011002  011031
011032  011033  020041
```

Number of subsets = 2

**SECTION 4**

```
01001010111010100101010101010101010001000101
01010100010101001010010101010010010100101001
01010101010101111000010101010010010100011010
01010100010101010100101010101010010101011010
10101010101010101010101001010101010101010101
01010101010101010101010101010101010101010101
00101000101001001101010110101010101010010101
0101010101000101000101001
```

Subset 1

Subset 2

# BUFR compressed data and subsets

## SECTION 3

- **Number of data subsets**
- **Flag observed data/other data**
- **Flag compressed/uncompressed**

```
301051 004006 007002 010004
012001 011001 011002 011031
011032 011033 020041
```

Number of subsets = 2

Subset 1 and 2

## SECTION 4

```
0100101011101010010101010101010101000100101
0101010001010100101001010100100101001010010
0101010101010111100001010100100101000011010
0101010001010101010010101010100010101011010
1010101010101010101010010101010101010101010
0101010101010101010101010101010101010101010
0010100010100100110101011010101010100010101
01010101010001010010100101
```

**ECMWF**

**EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS**