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INTER-PROGRAMME COORDINATION TEAM ON SPACE WEATHER

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FORMATS AND STANDARDS
Update on GRIB2/BUFR coding for space weather

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Summary and Purpose of Document

This document summarises recent progress in the development of data format standards for the representation of space weather data in WMO Table Driven Code Forms (BUFR, GRIB2), and invites discussion on the development of a cohesive plan for the representation of space weather data for exchange over the WMO Information System (WIS), in conjunction with the actions identified in ICTSW/3 (Action 3.15).

ACTION PROPOSED

The Inter-Programme Coordination Team is invited to:

a) Note the information provided in this paper regarding recent developments in the specification of space weather data in WMO Table Driven Code Forms BUFR and GRIB2; and

b) In conjunction with the actions specified in ICTSW/3 (Action 3.15), develop a plan for the representation of space weather observations and forecasts for exchange under the WIS, leveraging recent developments in BUFR and GRIB2.

REFERENCES

1. The WMO Table Driven Codes: The 21st Century Universal Observation Codes http://www.wmo.int/pages/prog/www/WMOCodes/MigrationTDCF/Plan/Introduction_en.pdf
2. Space Weather in GRIB2 - WMO IPET-DRC-III / Doc.2.3 (12) http://www.wmo.int/pages/prog/www/ISS/Meetings/IPET-DRC_Melbourne2011/Documents/IPETDRC-III_Doc2-3_12_SpaceWeather.doc

APPENDIX Draft BUFR template for space weather parameters, ISES “WIS pilot project”

DISCUSSION

1. INTRODUCTION

1.1 Background

ISES WIS pilot project (BUFR)
The "WIS pilot project" commenced under ISES in April 2013 aims to demonstrate, and document requirements for, the exchange of space weather data through the WMO Information System (WIS) by establishing the operational exchange of a small number of simple space weather parameters. Through this process, requirements and procedures will be documented such as data format requirements, required metadata standards, software requirements, certification requirements on Regional Warning Centres (RWCs), and the requirements and process of registering space weather data with WMO (e.g. standard table updates).

The main objectives of the project may be summarised as:
- Research the WIS, familiarise with its current state and how space weather data may fit into the present architecture;
- Identify the space weather parameters for exchange under the pilot project;
- Define relevant data formats for the space weather parameters and formalise these;
- Define discovery metadata for the space weather parameters;
- Investigate and document the formal requirements on agencies to contribute and access data through the WIS;
- Investigate and document the software and hardware requirements on agencies to implement a WIS capability;
- Trial simple data exchange (using local code tables if WMO BUFR table updates for space weather are not formalised);
- Document the above.

The WMO BUFR format (Binary Universal Form for Representation of Data; see Ref. 1) was identified as the most suitable data format for the exchange of non-gridded space weather data under this project. BUFR is a binary Table Driven Code Form (TDCF), and as such is compact and fully self descriptive. It is recommended for all present and future WMO applications (Ref. 1).

ICTSW-4/Doc. 8.4 presents further details on the ISES WIS pilot project.

GRIB2 coding proposal
At the third meeting of Inter-Programme Expert Team on Data Representation and Codes (IPET-DRC, now IPET-DRMM), in Melbourne in 2011, a proposed methodology for reporting space weather in GRIB2 format was tabled by the USA (IPET-DRC-III / Doc.2.3 (12); see Ref. 2). The proposal followed earlier discussion in the IPET-DRC group on representation of space weather data in GRIB2, initiated by a topical paper from the USA. ICTSW was asked in August 2013 to provide feedback on the latest draft GRIB2 table updates for space weather and is currently awaiting a response to that feedback. The GRIB2 update proposal is currently under validation.

Related ICTSW actions
ICTSW-3 Action 3.15: "T. Onsager to coordinate with all ISES RWCs and the space weather service providers within ICTSW to develop a plan for registering relevant space weather products to the WIS (i.e., prioritizing products to be registered, ensuring consistency of information, and defining metadata accordingly)"

1.2 New developments

ISES WIS pilot project (BUFR)
ICTSW-4/Doc. 8.4 updates on the status of the ISES WIS pilot project. Among the developments relevant to the present paper, a draft BUFR template has been compiled by the ISES working group, covering four simple space weather forecast/observation products selected for exchange under this project:

- Solar flare probability (forecast only)
- Solar flaring activity level (forecast and observation)
- Geomagnetic activity level - daily average Ap index (forecast and observation)
- Geomagnetic activity level - maximum 3-hourly Kp index over 24 hours (forecast and observation)

The (draft only) BUFR template is attached as an Appendix.

1.3 Scope of the document

The present document summarises recent progress in the development of data format standards for the representation of space weather data in WMO Table Driven Code Forms (BUFR and GRIB2), and invites discussion in ICTSW-4 on the development of a plan for the representation of space weather data for exchange over the WIS.

2. ISSUE: FORMAT FOR SPACE WEATHER DATA OVER THE WIS

Noting the benefits of recent developments in BUFR/GRIB2 for the exchange of selected space weather parameters over the WIS, there is still no cohesive plan for how space weather data should be formatted to be exchanged over the WIS.

A plan should identify how to best leverage previous developments such as the GRIB2 coding proposal for space weather, while satisfying additional requirements for space weather data exchange, such as the exchange of non-gridded forecasts and observation

3. PROPOSED SOLUTION

3.1 The meeting should note the work being done on WMO Table Drive Code Form (TDCF) formats for space weather data under the ISES pilot project (BUFR), and the proposal for an update to the GRIB2 tables for gridded space weather data, tabled at IPET-DRMM by the USA and currently under validation.

3.2 The meeting should note the differences between the proposed GRIB2 table updates (for gridded space weather data) and the use of BUFR for simple space weather forecast/observation parameters under the ISES WIS pilot project.

3.3 The meeting is invited to discuss standardised data formats for the exchange of space weather data through the WIS, in particular with a view to identifying how the space weather community might best leverage previous developments such as the GRIB2 proposal, while satisfying additional requirements for data exchange, such as non-gridded observations and forecasts.

3.4 In conjunction with ICTSW-3 (Action 3.15), the meeting is encouraged to consider an action to address the following:

- Identify those space weather data and parameters the community would most benefit from under a standardised data exchange through the WIS
- Identify the most suitable format for representation of the selected parameters, in light of existing coding proposals.
- Formulate a proposal to update the relevant WMO code tables for space weather data not covered by existing proposals.

Draft BUFR template for space weather data

ISES WMO Information System (WIS) space weather data exchange pilot project

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This document proposes a BUFR template for a small subset of key space weather parameters, selected for exchange through the WMO Information System (WIS) under the ISES WIS space weather data exchange pilot project ("WIS pilot project").

A brief overview of BUFR messages and descriptors is given in Sections 2 and 3. Section 4 covers the reference system. Section 5 details the proposed BUFR table updates. The proposed BUFR templates (sample encodings) are shown in Section 6.

1. Space weather parameters

This document proposes BUFR templates for the following subset of space weather parameters, selected for exchange under the WIS pilot project:

Geomagnetic activity 'A' index over a specified time period – defined over either a 3 hour period or over a 24 hour period (which is simply the average of 8 x 3-hourly 'A' indices over the day) and can be either a planetary (global) index or a regional index (region specified by lat/lon range). This can be either a forecast or an observation. A has range 0-400 [integer].

Geomagnetic activity maximum 'K' index over a specified time period – the K index is defined over a 3 hour period, and can be either a planetary (global) index or a regional index (region specified by lat/lon range). The parameter for exchange is the "maximum K index expected (observed) over a specified period", where the period is usually 24 hours. This can be either a forecast or an observation. K has range 0-9 [integer].

Solar flare probability – Forecast probability of occurrence of solar flares in each of three magnitude classes: C, M or X, defined for both the full solar disk (whole of Sun), or any discrete regions on the sun, which are labelled by 5-digit NOAA Active Region codes (eg AR11798). ie three flare probabilities for the full Sun, and three flare probabilities for each Active Region on the visible Sun. Solar flare probability is a forecast only. Probabilities have range 0-100.

Solar flaring activity level – Forecast (or observed) solar flaring activity level (category) based on expected or observed number and magnitude of flares over a 24 hour time period from the reference time. The standard activity categories (Quiet, Eruptive, Active, Major flares, Proton flares) are to be defined in a code table, according to the standard ISES (URSIGRAM) definition. The solar flaring activity level relates to the whole Sun only. The time period is fixed to 24 hours. When referenced as a forecast the selected activity level is expected with a probability of ≥50%.

2. Structure of BUFR messages

A BUFR message is comprised of the following six sections[1]. Elements specific to this project are indicated in the table below using [] (eg "[Fixed at 0]"):

Section	Octet number	Content
Section 0 (Indicator section)		
	1-4	<"BUFR">
	5-7	<total length of BUFR message>
	8	<BUFR edition number>
Section 1 (Identification section)		
	1-3	<Length of section 1>
	4	<BUFR master table [Table 0}>
	5-6	<Identification of originating/generating centre>
	7-8	<Identification of originating/generating sub-centre>
	9	<Update sequence number (zero for original BUFR messages; incremented by one for updates)>
	10	<Optional section present? [No Optional section present]>
	11	<Data Category (Table A) [32: Space weather data]>
	12	<International data sub-category [CCT C-13 0-6]>
	13	<Local sub-category>
	14	<Version number of master table used (currently 12 for WMO FM 94-IX Ext. BUFR tables)>
	15	<Version number of local tables used to augment the master table in use>
	16-17	<Year (4 digits)>
	18	<Month>
	19	<Day>
	20	<Hour>
	21	<Minute [Fixed at 0]>
	22	<Second [Fixed at 0]>
	23-	Reserved for local use by ADP centres
Section 2 (Optional section)		
		[No Optional section required]
Section 3 (Data description section)		
	1-3	<Length of section 3>
	4	<Set to zero (reserved)>
	5-6	<Number of data subsets>
	7	<Bit 1 = 1 Observed data; Bit 1 = 0 Other data; Bit 2 = 1 Compressed data; Bit 2 = 0 Non compressed data; Bits 3-8 set to zero (reserved)>
	8-	<Collection of element/replication/operator/sequence descriptors which define the form and contents of individual data elements comprising one data subset in the data section>
Section 4 (Data section)		
	1-3	<Length of section 4>
	4	Set to zero (reserved)
	5-	<Binary data as defined by sequence descriptors>
Section 5 (End section)		
	1-4	<"7777">

The primary data section is Section 4. Data is included in this section in the binary format described in Section 3. The format of the data is defined using a collection of (one or more) descriptors, called a template. The present document outlines the BUFR template for selected space weather parameters.

[1] BUFR User's Guide, European Centre for Medium-Range Weather Forecasts, August 2008

3. Structure of BUFR descriptors

Each BUFR descriptor is 16-bits wide, and has an F-X-Y structure, according to:

F	X	Y
2 bits (range 0-3)	6 bits (range 0-63)	8 bits (range 0-255)

The F value (range 0 to 3) determines the type of descriptor. The four types of BUFR descriptors are summarised in the table below.

F	**Descriptor Type**	**Descriptions**
0	Element	Convey elemental data and related metadata. Definitions contained in WMO BUFR specification "Table B"
1	Replication	Convey repetition of a selection of descriptors (details of repetition specified by values of X and Y)
2	Operator	Convey special operations on data. Definitions contained in WMO BUFR specification "Table C"
3	Sequence	Alias for a sequence of any other descriptors. Definitions contained in WMO BUFR specification "Table D"

Details of each descriptor are kept in standard BUFR tables maintained by WMO. The four main tables are shown below[2].

BUFR Table	Description
A	Data Category For use in Section 1. Allows for quick, broad categorization of BUFR messages without having to decode them.
B	Classification of Elements Catalogue of Element Descriptors (F=0)
C	Catalogue of Data Description Operators (F=2)
D	Lists of common sequences Catalogue of Sequence Descriptors (F=3)

For more detailed information, refer to the WMO Guide on BUFR, and various BUFR users guides. [2] [3]

[2] A Primer on Writing BUFR templates, National Prediction Operations Division, Meteorological Service of Canada, Version 1.4, July 18, 2008

[3] BUFR User's Guide, European Centre for Medium-Range Weather Forecasts, August 2008

4. Reference System

Geographic reference system
Use standard geographic reference system to which WMO BUFR descriptors 0 05 002 and 0 06 002 refer.

Solar reference system
Location of solar active regions are specified by "Stoneyhurst" latitude and longitude according to the following definition[4]:

> Sun assumed spherical with radius = 695,990,000 m (Allen, C.W., 1976 Astrophysical Quantities (3rd Ed.; London: Athlone)) and Stonyhurst latitude and longitude system with origin at the intersection of the solar central meridian (as seen from Earth) and the solar equator (Thompson, W, Coordinate systems for solar image data, A&A 449, 791–803 (2006)).

This definition was proposed as part of the pending GRIB2 table update for space weather.

[4] Definition extracted from: Space Weather in GRIB2, IPET-DRC-III / Doc.2.3 (12) (9. IX. 2011)

5. BUFR table updates for space weather

A number of new descriptors and codes must be defined before we can encode space weather data in BUFR. These descriptors must be included in the relevant code tables.

For the purpose of this draft it is assumed that space weather comes under the standard Master Table 0. Most of the space-weather specific descriptors are defined in a specific class table for space weather (here we have defined a new class 41 for the purpose of this template only), with some specialised coordinate descriptors being added to appropriate coordinate classes under Table 0. Also, assume an update to Code Table A and Common Code Table 13 for relevant data sub-categories.

Assume updated tables as follows:

BUFR TABLE RELATIVE TO SECTION 1

BUFR Table A – *Data category*

Code figure	Meaning
32	Space weather data

* Code figure 32 used for example purposes only

COMMON CODE TABLE C–13: *Data sub-categories of categories defined by entries in BUFR Table A*

DATA CATEGORIES		INTERNATIONAL DATA SUB-CATEGORIES	
BUFR Edition 4, Octet 11 in Section 1		BUFR Edition 4, Octet 12 (if = 255, it means other sub-category or undefined)	
Code figure	Name	Code figure	Name
32 *	Space Weather data	0	Solar activity forecast
		1	Solar activity observation
		2	Solar flare probability forecast
		3	Geomagnetic activity A index forecast
		4	Geomagnetic activity A index observation
		5	Geomagnetic activity Kp index forecast
		6	Geomagnetic activity Kp index observation

* Code figure 32 used for example purposes only

WMO BUFR/CREX Table B – *Classification of elements*

F	X*	Class
0	41	Space weather data

* X = 41 used for example purposes only

Class 01 – BUFR/CREX Identification

TABLE REFERENCE	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH

F X Y					(bits)
0 01 131 *	Solar active region of interest [1]	Numeric	0	0	20

Notes:

(1) 5-digit NOAA active region label (eg 11797); missing value=”unknown or un-numbered region”

* 131 used for example purposes only

Class 27 – BUFR/CREX Non-coordinate location (horizontal – 1)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (bits)
0 27 041 *	Heliographic latitude	degree	2	-9000	15

Notes:

* 041 used for example purposes only

Class 28 – BUFR/CREX Non-coordinate location (horizontal – 2)

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (bits)
0 28 041 *	Heliographic longitude (Stonyhurst coordinate)	degree	2	-9000	15

Notes:

* 041 used for example purposes only

Class 41 – Space weather data

TABLE REFERENCE F X Y	ELEMENT NAME	UNIT	SCALE	REFERENCE VALUE	DATA WIDTH (bits)
0 41 001	Geomagnetic activity A index (average over interval) [2]	nT	0	0	9
0 41 002	Geomagnetic activity K index (maximum over interval) [3]	Numeric	0	0	4
0 41 003	Reason for increased geomagnetic activity	Flag table	0	0	3
0 41 004	Solar activity level	Code table	0	0	4
0 41 005	Probability of C class solar flare	%	0	0	7
0 41 006	Probability of M class solar flare	%	0	0	7
0 41 007	Probability of X class solar flare	%	0	0	7

Notes:

(2) A index has valid range 0-400 (integer)

(3) Kp index has valid range 0-9 (integer)

New code tables for space weather

0 41 003 Reason for increased geomagnetic activity	
BIT NUMBER	DEFINITION

1	Coronal Hole high speed solar wind stream
2	Coronal Mass Ejection
3	Other reason

* Note: 0 41 003 set to missing for unknown or no geomagnetic event

0 41 004 Solar flaring activity level over a 24 hour period (ISES scale)	
CODE FIGURE	DEFINITION
0	Quiet (less than C-class X-ray flares)
1	Eruptive (C-class X-ray flares)
2	Active (M-class X-ray flares)
3	Major flares (X-class X-ray flares)
4	Proton flares

* Note: When referenced as a forecast, the implied probability of the relevant activity level being reached is ≥ 50%. E.g. a forecast of Eruptive indicates C-class flares are expected over the next 24 hours with a probability ≥ 50%.

6. BUFR templates for space weather parameters

For the purposes of this document we follow Pelletier (2008)[5] in our definition of a BUFR template as "a sequence of BUFR descriptors that completely expresses the form and content of a BUFR data product and is recognized by the WMO or by a local authority as a canonical form of the product".

This section presents templates for encoding the following space weather data:

- Solar activity forecast / observation
- Solar flare probability forecast
- Geomagnetic activity A index forecast / observation
- Geomagnetic activity Kp index forecast / observation

1. Solar flaring activity level (forecast and observation)

The solar activity message consists solely of full disk solar activity level according to the ISES (URSIGRAM) scale, either forecast or observed, and referenced to a 24 hour time period from the reference time. The solar flaring activity level references a pre-defined code table (0 41 004).

Sample encoding of solar activity level (observation or forecast)		
SEQUENCE F X Y	VALUE (eg)	MEANING
3 01 011		Reference date (Table D sequence specifying YMD)
3 01 012		Reference time (Table D sequence specifying HM)
0 41 004	2	Solar flaring activity level over 24 hour period (reference code table)

2. C/M/X solar flare probability (forecast)

The solar flare probability is a forecast only and contains full disk C/M/X flare probability as well as (optional) C/M/X flare probabilities from discrete active regions (ie discrete geographic regions). The probabilities are specified using three explicitly defined compound classes: probability of C-class flares, probability of M-class flares and probability of X-class flares.

The first set of probabilities in the message corresponds to the full solar disk and subsequent sets to each of 'n' active regions, where the number 'n' is specified within the sequence, and can take any value from zero to 254.

Delayed replication is used to replicate the structure of that portion of the message related to the discrete region probabilities. The number of replicates 'n' is specified dynamically (ie within the sequence). The number of replicates 'n' may take the value 0 when there are no discrete active regions to report on, in which case the sequence ends at the number of replicates=0.

Sample encoding of C/M/X solar flare probability (forecast), with three active regions on the solar disk		
SEQUENCE F X Y	VALUE (eg)	MEANING
3 01 011		Reference date (Table D sequence specifying YMD)
3 01 012		Reference time (Table D sequence specifying HM)

5 A Primer on Writing BUFR templates, National Prediction Operations Division, Meteorological Service of Canada, Version 1.4, July 18, 2008

0 04 024	24	Time period in hours (relates to all subsequent observations)
0 41 005	80	Probability of C class solar flare (full disk)
0 41 006	60	Probability of M class solar flare (full disk)
0 41 007	40	Probability of X class solar flare (full disk)
1 06 000		Specify delayed replication (F=1 indicates this is replication; X=6 indicates it is replication of 6 descriptors; Y=0 indicates it is delayed replication)
0 31 001	3	Delayed replication factor (specify number of replicates to follow, in this case the number of active regions with data)
0 01 131	<value>	Region of interest (5-digit NOAA solar active region number, eg 11797)
0 27 041	<value>	AR central latitude in heliographic coordinates
0 28 041	<value>	AR central longitude in heliographic (Stoneyhurst) coordinates
0 41 005	<value>	Probability of C class solar flare
0 41 006	<value>	Probability of M class solar flare
0 41 007	<value>	Probability of X class solar flare

3. Geomagnetic activity indices (forecast and observation)

Geomagnetic activity is forecast using one, or both, of the A index or the K index. Since these parameters are often forecast or reported on independently, they have been encoded into individual BUFR messages. This is a less efficient but more flexible approach; in particular it allows greater flexibility in reporting these parameters over different timescales and geographic regions.

Sample encoding for geomagnetic activity forecast (average A-index over period)

SEQUENCE F X Y	VALUE (eg)	MEANING
3 01 011		Reference date (Table D sequence specifying YMD)
3 01 012		Reference time (Table D sequence specifying HM)
0 04 024	24	Time period in hours
3 01 023		Location (coarse accuracy) (Table D sequence specifying lat/lon) *
3 01 023		Location (coarse accuracy) (Table D sequence specifying lat/lon) *
0 41 001	40	Geomagnetic activity A index (average over time period)
0 41 003	1	Reason for increased geomagnetic activity (bitwise code table)

* Sequential location descriptors are used to specify a region.

Sample encoding for geomagnetic activity forecast (max K-index over period)

SEQUENCE F X Y	VALUE (eg)	MEANING
3 01 011		Reference date (Table D sequence specifying YMD)
3 01 012		Reference time (Table D sequence specifying HM)
0 04 024	24	Time period in hours
3 01 023		Location (coarse accuracy) (Table D sequence specifying lat/lon) *
3 01 023		Location (coarse accuracy) (Table D sequence specifying lat/lon) *
0 41 002	5	Geomagnetic activity K index (maximum over time period)
0 41 003	1	Reason for increased geomagnetic activity (bitwise code table)

* Sequential location descriptors are used to specify a region.