Guide to the WMO Table Driven Code Form Used for the Representation and Exchange of Regularly Spaced Data In Binary Form:

FM 92 GRIB Edition 2

Layer 1: Basic Aspects of FM 92 GRIB Edition 2 (GRIB2)

Layer 2: Structure and Uses of GRIB2 Messages

Layer 3: Detailed Description of GRIB2

Geneva, 1 January 2003

Preface

This guide has been prepared to assist experts who wish to use the WMO Table Driven Data Representation Form FM 92 GRIB Edition 2 (GRIB2).

This guide is designed in three layers to accommodate users who require different levels of understanding.

Layer 1 is a general description designed for those who need to become familiar with the table driven code form but do not need a detailed understanding.

Layer 2 focuses on the functionality and application of GRIB2, and is intended for those who must use software that encodes and/or decodes GRIB2, but will not actually write the software.

Layer 3 is intended for those who must actually write GRIB2 encoding and/or decoding software, although those wishing to study the code form in depth, will find it equally useful.

The WMO gratefully acknowledges the contributions of the experts who developed this guidance material. The Guide was prepared by Dr. Clifford H. Dey of the U. S. A. National Centre for Environmental Prediction. Contributions were also received in particular from Charles Sanders - Australia, Jean Clochard - Meteo-France, John Hennessy - ECMWF and Simon Elliott - EUMETSAT.

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Layer 1: Basic Aspects of GRIB2

1.1 Overview

The World Meteorological Organization (WMO) Commission for Basic Systems (CBS) Extraordinary Meeting Number VIII (1985) approved a general purpose, bit-oriented data exchange format, designated FM 92-VIII Ext. GRIB (GRIdded Binary). The expanded name of the code form was "Processed data in the form of grid-point values expressed in binary form". It is an efficient vehicle for transmitting large volumes of gridded data to automated centres over high-speed telecommunication lines using modern protocols. By packing information into the GRIB code, messages can be made more compact than character oriented bulletins, which will produce faster computer-to-computer transmissions. GRIB can equally well serve as a data storage format, generating the same efficiencies relative to information storage and retrieval devices.

Changes and extensions to GRIB were approved at the regular meeting of the WMO/CBS in February 1988; additional changes were made in May 1989 and October 1990. The 1990 changes were of such structural magnitude as to require a new edition of GRIB, Edition1 (hereafter referred to as GRIB1). The Subgroup on Data Representation and Codes (SGDRC) made augmentations several more times during the 1990s. These changes involved only additions to some of the tables. Therefore, the version number was incremented each time. However, since the code structure did not change, the Edition Number did not change either, and it therefore remained at 1.

As the end of the 20th century approached, however, it had become apparent that GRIB1 could not satisfy all the requirements for representation of regularly spaced data in binary form that were placed upon it. Most obvious was that the internationally coordinated portion of GRIB1 Code Table 2 (Indicator of Parameter) was completely full. This forced WMO Members to add new parameters to their own local use portion of Table 2. Indeed, some Members found it necessary to define several local versions of Table 2 to accommodate all the needed parameters. More fundamentally, however, GRIB1 was designed with a single overall structure for identifying products. Although this structure had some flexibility, it was not sufficient to represent many of the new products, such as those from ensemble predictions, that were becoming available by the end of the 1990s. WMO Members responded to this situation by creating their own local extensions to GRIB Edition 1. This situation was inhibiting the exchange of numerical products in GRIB1. It was clear that a basic revision of GRIB was now needed to meet the requirements placed upon it.

Consequently, the CBS Implementation Co-ordination Team on Data representation and Codes ICT/DRC began developing a revised GRIB code form that would contain the flexibility needed to meet the requirements that GRIB1 could not. Since this involved a basic restructuring of GRIB, it was assigned Edition 2 (hereafter referred to as GRIB2). A new expanded name was given to the code form: "General Regularly-distributed Information in Binary form". The Extraordinary Meeting of the WMO/CBS in October 1998 (CBS EXT. (98)) approved GRIB2 for experimental use. After a period of further refinement and testing, the ICT/DRC recommended in April 2000 that GRIB2 be approved for operational use. The regular meeting of the WMO/CBS in December 2000 (CBS XII) approved this Recommendation. Because ICAO requested continuation of GRIB1, however, the United Kingdom and United States World Area Forecast System centres agreed to continue production of data sets in GRIB1 as long as required by ICAO. It is expected that both GRIB1 and GRIB2 data sets will be in use for some time.

The purpose of this document is to describe the GRIB Edition 2 Code Form and its accompanying tables. The document is divided into three layers. Layer 1 is a general description designed for those who need to become familiar with the table/template driven code form but do not need a detailed understanding. Layer 2 describes the structure and use of GRIB2, and is intended for those who must use software that encodes and/or decodes GRIB2 but will not actually write the encoding and/or decoding software. Layer 3 is intended for those who must actually write GRIB2 software, although those wishing to study the table/template driven code form in depth, will find it equally useful.

A Caveat: The Official International Documentation for GRIB2 is the WMO Manual on codes (WMO Publication No. 306, Vol. 1, Part B, Secretariat of the WMO, Geneva, Switzerland, 2001). This document is intended to be a guide to the use of GRIB2 and may not include all the features currently found in the Manual. The features described here are intended to be a completely consistent sub-set of the full WMO documentation; if there are any discrepancies the Manual on Codes is the final authority.

1.2 General Description

1.2.1 Code Structure

1.2.1.1 Code Sections

Each GRIB2 message intended for either transmission or storage contains one or more parameters with values located at an array of grid points or represented as a set of spectral coefficients. Logical divisions of the message are designated as sections, each of which provides control information and/or data. There are nine different types of sections, one of which is optional. The nine sections and their general contents are:

Section Number	Section Name	Section Contents
Section 0:	Indicator Section	"GRIB", Discipline, GRIB Edition number, length of message
Section 1:	Identification Section	Length of section, section number, characteristics that apply to all processed data in the GRIB message
Section 2:	Local Use Section (optional)	Length of section, section number, additional items for local use by originating centres
Section 3:	Grid Definition Section	Length of section, section number, definition of grid surface and geometry of data values within the surface
Section 4:	Product Definition Section	Length of Section, section number, description of the nature of the data
Section 5:	Data Representation Section	Length of section, section number, description of how the data values are represented
Section 6:	Bit-Map Section	Length of section, section number, indication of presence or absence of data at each grid point, as applicable
Section 7:	Data Section	Length of section, section number, data values
Section 8:	End Section	"7777"

All but the Local Use Section must appear at least once in every GRIB2 message.

The GRIB2 Indicator, Grid Definition, Bit-Map, Data, and End Sections map directly to their counterparts in GRIB1, although their contents in GRIB2 are somewhat different than in GRIB1. However, the GRIB2 Identification, Product Definition, and Data Representation Sections all map into the GRIB1 Product Definition Section, and the GRIB2 Sections contain substantially more information than in GRIB1. The GRIB2 Local Use Section is not present in GRIB1. This mapping is presented schematically below:

```
GRIB1 Sections                                          GRIB2 Sections

Indicator Section  <---------------------------------->  Indicator Section
No counterpart <------------------------------------->  Local Use Section
                                             ¦-------> Identification Section
Product Definition Section <---------------¦------->  Product Definition Section
                                             ¦-------> Data Representation Section
Grid Description Section <------------------------->  Grid Definition Section
Bit-Map Section <------------------------------------>  Bit-Map Section
Binary Data Section <------------------------------->  Data Section
End Section <---------------------------------------->  End Section
```

The subdivision of the GRIB1 Product Definition Section into the GRIB2 Identification, Product Definition, and Data Representation Sections is one of the fundamental differences between GRIB1 and GRIB2. This, combined with the option for iterating the Sections (described next) and expansion of the concept of templates (described in Item 1.2.2), are what provide GRIB2 with its substantially enhanced flexibility over what is possible in GRIB1.

1.2.1.2 Iterating the Sections

GRIB1 only permits one field to be represented by a single GRIB1 message. However, GRIB2 achieves additional flexibility by allowing more than one field to be represented in a single GRIB2 message. This is allowed by permitting specific groups of sections to be repeated within a GRIB2 message. Consider the sections of a GRIB2 message referred to above:

```
Section 0:  Indicator Section
Section 1:  Identification Section
Section 2:  Local Use Section (optional)                                  |
Section 3:  Grid Definition Section                            |          |
Section 4:  Product Definition Section       |                 |          |
Section 5:  Data Representation Section      | repeated        |repeated  |repeated
Section 6:  Bit-Map Section                  |                 |          |
Section 7:  Data Section                     |                 |          |
Section 8:  End Section
```

The GRIB2 regulations state that (A) Sequences of GRIB2 sections 2 to 7, 3 to 7, or 4 to 7 may be repeated within a single GRIB2 message, (B) All sections within such repeated sequences must be present and shall appear in the numerical order noted above, and (C) Unrepeated sections remain in effect until redefined. This is denoted schematically in the above table by the three groups of vertical bars.

Consider, for example, 500 hPa height field forecasts on a Northern Hemisphere polar stereographic grid produced by a particular numerical model at forecast hours 12, 24, 36, and 48. These four fields could be represented by a single GRIB2 message by repeating the sequence of Sections 4 to 7 four times, making the appropriate forecast time changes in the Product Definition Section in each iteration of the sequence. This GRIB2 message would appear schematically as follows:

```
Section 0:   Indicator Section
Section 1:   Identification Section
Section 2:   Local Use Section (optional)
Section 3:   Grid Definition Section
Section 4:   Product Definition Section   (hour = 12)| repetition 1
Section 5:   Data Representation Section             |
Section 6:   Bit-Map Section                         |
Section 7:   Data Section                            |
Section 4:   Product Definition Section              (hour = 24)| repetition 2
Section 5:   Data Representation Section                        |
Section 6:   Bit-Map Section                                    |
Section 7:   Data Section
Section 4:   Product Definition Section                  (hour = 36)       | repetition 3
Section 5:   Data Representation Section                                   |
Section 6:   Bit-Map Section                                               |
Section 7:   Data Section                                                  |
Section 4:   Product Definition Section                          (hour = 48)          | repetition 4
Section 5:   Data Representation Section                                              |
Section 6:   Bit-Map Section                                                          |
Section 7:   Data Section                                                             |
Section 8:   End Section
```

Note that since the Grid Definition Section is not repeated, it remains in effect for all four forecast hours.

As another example, consider 500 hPa height field forecasts produced at forecast 24 hours on four different grid projections. These could be represented in a single GRIB2 message by repeating the sequence of Sections 3 to 7 four times, making the appropriate changes in the Grid Definition Section in each sequence, but leaving the Product Definition Section, and therefore the forecast hour, unchanged. In this case, the GRIB2 message would appear schematically as:

```
Section 0:   Indicator Section
Section 1:   Identification Section
Section 2:   Local Use Section (optional)
Section 3:   Grid Definition Section    (grid  #1)        | repetition 1
Section 4:   Product Definition Section   (hour = 24)     |
Section 5:   Data Representation Section                  |
Section 6:   Bit-Map Section                              |
Section 7:   Data Section                                 |
Section 3:   Grid Definition Section            (grid  #2)          | repetition 2
Section 4:   Product Definition Section           (hour = 24)       |
Section 5:   Data Representation Section                            |
Section 6:   Bit-Map Section                                        |
Section 7:   Data Section                                           |
Section 3:   Grid Definition Section                     (grid  #3)           | repetition 3
Section 4:   Product Definition Section                  (hour = 24)          |
Section 5:   Data Representation Section                                      |
Section 6:   Bit-Map Section                                                  |
Section 7:   Data Section                                                     |
Section 3:   Grid Definition Section                              (grid  #4)           | repetition 4
Section 4:   Product Definition Section                           (hour = 24)          |
Section 5:   Data Representation Section                                               |
Section 6:   Bit-Map Section                                                           |
Section 7:   Data Section                                                              |
Section 8:   End Section
```

1.2.2 Code Templates

Although not referred to as such, the template concept is used in GRIB1 in the Grid Description Section, where octets 6 – 32 are defined as follows:

Octet 6	Data representation type (see Table 6)
Octets 7 – 32	Grid definition (according to data representation type – octet 6 above)

Thus, the contents of octets 7 – 32 are not explicitly defined. Rather, the value in octet 6 refers to an entry in GRIB1 Table 6, and that entry defines the contents of octets 7 – 32. In the nomenclature of GRIB2, the contents of octet 6 would be referred to as the template number, and the contents of octets 7 – 32 would be referred to as the template. In GRIB2, this powerful concept has been retained in the Grid Definition Section, but expanded to product definition and data representation as well. It has also been made more flexible by leaving variable the number of octets used for the template. The separation of identification, product definition and data representation into separate sections facilitates this application of the template concept in GRIB2.

Thus, there are three categories of GRIB2 templates – Grid Definition Templates, Product Definition Templates, and Data Representation Templates. They are identified by the Grid Definition Template Number, Product Definition Template Number, and Data Representation Template Number, respectively. These template numbers are coded in the appropriate section. Two octets are allocated for each template number, ensuring table space will not become exhausted.

When a new product, new grid, or new type of data representation is needed, one has to simply define the appropriate new template(s) and submit them to the ICT/DRC for approval (the approval process is described in Section 1.3 of this Layer). With ample table space allowed, GRIB2 thus possesses the flexibility to represent virtually any product using virtually any type of data representation on virtually any type of grid projection both now and in the future.

The templates themselves are somewhat complicated. They are described in detail in Layer 2 of this Guide.

1.2.3 Tables

Because of the extensive use of templates, there are two categories of tables in GRIB2 – Template Tables and Code and Flag Tables. The tables in both categories are numerous and, at times, complicated. In fact, the tables form by far the largest part of the documentation of GRIB2 in the Manual on Codes. Both types of tables are described briefly below and in detail in Layer 2 of this Guide.

1.2.3.1Template Tables

All templates are described in the Template Tables. These Tables are categorized by the Section number in which the templates are found. In the tables, the templates themselves are labelled m.n, where m is the number of the section is which the template is found and n is the template number coded in the appropriate section. The name of the template is given by a code table and is also referred to by the template number n. The first quantity in each template is in the octet specified in its respective section. Although the templates have variable lengths, the last octet of the template can always be calculated from values coded in the section.

1.2.3.2 Code and Flag Tables

A code table is a list of choices where only one of the choices can be selected at a given time. The selection is accomplished by coding the number of the desired entry in the appropriate place in the GRIB2 Section. A flag table, on the other hand, is a list of choices where any combination of the choices can be selected at a given time. The combination is accomplished by turning bits of a bit string on or off. Code and Flag tables are also categorised by the Section number in which the code or flag table is referred to. There are far more code and flag tables in GRIB2 that there are in GRIB1. Many of these are used for the representation of the parameters (discussed in the next Section).

1.2.4 Identification of Parameters

As noted in the Overview (Section 1.1), the identification of parameters has been a serious problem with GRIB1 for some time. The problem arose because GRIB1 only allocated one octet for the "Indicator of parameter" (GRIB1 Table 2). With only one octet, GRIB1 Table 2 has only 256 entries: entries 0 – 127 are allocated for international coordination, entries 128 – 254 are allocated for originating centre use, and entry 255 indicates a missing parameter. As early as the mid-1990s, it was clear that allocating only 128 entries for international coordination was going to become a serious problem and that proved to be the case. For this reason, the developers of GRIB2 made a special effort to rectify this problem. Their solution is a different approach to the identification of parameter than in GRIB1, and therefore deserves special mention.

The most straightforward solution would have been to simply allocate 2 octets for the identification of parameters in GRIB2. This would have been a table with 65536 entries, and would have certainly had an ample number of entries. However, it was decided that a single table of such size would prove to be difficult to organise in a way that would allow users to easily find the parameter they desired. Rather, it was decided to use a branching structure based on three parameters – discipline, category, and name. The first of these parameters – discipline – is given in octet 7 of the Indicator Section. That octet refers to Code Table 0.0. The current Code Table 0.0 is the following:

Code Table 0.0 – Discipline of processed data in the GRIB message

Code Figure	Meaning
0	Meteorological products
1	Hydrological products
2	Land surface products
3	Space products
4-9	Reserved
10	Oceanographic products
11-191	Reserved
192-254	Reserved for local use
255	Missing

Code Table 4.1 – Category of parameters by product discipline – provides the next branch. Table 4.1 has a list of parameter categories for each of the product disciplines given in Table 0.0. To give only one example, the sub-table for Discipline 0 – Meteorological products – is currently the following:

Code Table 4.1: Category of parameters by product discipline

Product discipline 1: Meteorological products

Category	Description
0	Temperature
1	Moisture
2	Momentum
3	Mass
4	Short-wave Radiation
5	Long-wave Radiation
6	Cloud
7	Thermodynamic Stability indicies
8	Kinematic Stability indices
9	Temperature Probabilities
10	Moisture Probabilities
11	Momentum Probabilities
12	Mass Probabilities
13	Aerosols
14	Trace gases (e.g., ozone, CO2)
15	Radar
16	Forecast Radar Imagery
17	Electro-dynamics
18	Nuclear/radiology
19	Physical atmospheric properties
29-189	Reserved
190	CCITTIA5 string
191	Miscellaneous
192-254	Reserved for local use
255	Missing

Code Table 4.2 – Parameter number by product discipline and parameter category - provides the third branch. Table 4.2 has a list of parameter numbers and names for each product discipline given in Table 0.0 and each parameter category given in Table 4.1. As an example, the sub-table for Discipline 0 (Meteorological products), Category 0 (Temperature) is currently the following:

Code Table 4.2: Parameter number by product discipline and parameter category

Product discipline 0: Meteorological products, Product category 0: Temperature

Category	Description	Units
0	Temperature	K
1	Virtual temperature	K
2	Potential temperature	K
3	Pseudo-adiabatic potential temperature or equivalent potential temperature	K
4	Maximum temperature	K
5	Minimum temperature	K
6	Dew point temperature	K
7	Dew point depression (or deficit)	K
8	Lapse rate	$K\ m^{-1}$
9	Temperature anomaly	K
10	Latent heat net flux	$W\ m^{-2}$
11	Sensible heat net flux	$W\ m^{-2}$
12	Heat index	K
13	Wind chill factor	K

14	Minimum dew point depression	K
15	Virtual potential temperature	K
16-191	Reserved	
192-254	Reserved for local use	
255	Missing	

As with any branching structure such as this, a possible problem is that one of the sub-categories of either Table 4.1 or Table 4.2 could become saturated even though there are a huge number of unused entries in other parts of the table. It is felt, however, that this is unlikely for a long time to come, and that this approach will therefore provide enough table space for new parameters for the forseeable future. Hopefully, finding desired entries in this branching structure will also prove more user-friendly that finding desired entries in a single table of 65536 entries.

1.3 Updating the Code Form

1.3.1 General Procedures

There are two general categories of changes to table-driven code forms – changes that require corresponding modifications to processing software and changes that that do not. Although both categories of changes must undergo a validation process (described in section 1.3.4) before being approved, the required software modifications must be available for use in the validation process for changes in the former category, while existing software may be used in the latter. Changes requiring software modifications are therefore more complicated to validate than changes that do not require software modification.

Changes to the code structure always require corresponding modifications to processing software and are assigned a new Edition Number. Furthermore, code structure changes are seldom required with urgency. Consequently, changes to the code structure are made very infrequently. As noted above, GRIB1 was approved in October 1990 and GRIB2 in December 2000, 10 years later.

Changes that do not require corresponding modifications to processing software are far less disruptive, are easier to validate, and are often required with greater urgency. Therefore, these changes are made with greater frequency. In the case of BUFR and CREX, changes to the supporting tables do not require corresponding modifications to processing software. Consequently, additions to the BUFR tables have been made 9 times since 1988.

However, this is not necessarily the case with GRIB. Additions to the GRIB2 product discipline, product category, and parameter name tables indeed do not require corresponding software modifications. As with BUFR and CREX table additions, their validation is simpler and can be made more frequently. On the other hand, additions of a new template or grid projection, while seeming at first glance to be only simple table additions, do require software modifications in order to process information using these new features. Nevertheless, such changes would have far greater urgency than most code structure changes. Therefore, although these changes must also undergo the more complicated validation process that is required for code structure changes, they may well have to be implemented on a timelier basis than code structure changes. This is likely to be a challenge the WMO will have to deal with.

All amendments to BUFR and CREX must be proposed in writing to the WMO Secretariat. The proposal must specify the needs, purposes and requirements, target dates for effective use, and include information on a contact point for technical matters. An Expert Team on Data Representation and Codes (ET/DRC) under the Commission for Basic Systems (CBS) Open Programme Area Group on Information Systems and Services (OPAG/ISS), supported by the Secretariat, then validates the stated requirements and develops a draft recommendation to respond to the requirements as appropriate.

What happens next depends on whether the draft recommendation involves changes to the supporting software or not.

1.3.2 Changes Requiring Software Modifications

When the recommended solution developed by the ET/DRC requires corresponding changes to software encoding data into or decoding data out of the code form, both the full CBS and the full WMO Executive Council must approve the recommendation. However, the Chairperson of OPAG/ISS must first endorse it prior to its consideration by CBS. This must be done early enough that the draft recommendation can be published as a CBS pre-session document at least three months prior to the CBS Session. If the full CBS approves the draft recommendation, it is submitted to the full WMO Executive Council (EC) for approval. If the EC approves the recommendation, the recommendation will be implemented on the first Wednesday following the first of November of the year following the CBS Session.

1.3.2.1 Example of a Change to the Code Structure

Let us consider a worst-case timeline for such a change. CBS met in an extraordinary session in December 2002. Suppose a requirement for a new feature is stated in writing to the WMO Secretariat on 1 January 2003. The Secretariat passes the requirement to the ET/DRC, who then must validate the stated requirements and develop a draft recommendation that will meet the stated requirement. For the purpose of this example, we will assume the ET/DRC draft recommendation calls for a change to the GRIB2 code structure. In this case, both the full CBS and the full EC must therefore approve the ET/DRC draft recommendation. The next meeting of the CBS will be in the fall of 2004 and the next meeting of the EC in early 2005. If both approve the draft recommendation, it will take effect on the first Wednesday following the first of November in 2005, nearly three years after the WMO Secretariat originally received the requirement.

Now consider the best-case timeline for such a change. Recall that the draft recommendation must be prepared in time to be published as a CBS pre-session document at least three months prior the full CBS meeting. Allowing three additional months for translation of the draft recommendation into the various WMO languages, it should be given to the Secretariat six month prior to the CBS session, no later than mid-June in this case. Allowing five months for the ET/DRC to validate the requirements and prepare the draft recommendation, the original proposal would need to be received by the Secretariat in January 2004 if it is to be considered by CBS in the fall of 2004, and take effect on the first Wednesday after the first of November 2005. This is still almost 2 years after the Secretariat received the statement of requirement.

The bottom line is that changes to GRIB2 requiring corresponding changes to processing software will usually take from 2 to 3 years (the alert reader may have noted it could take more than 3 years) following their receipt to be implemented. These timelines may seem to some unduly long. However, it must be stressed that the necessity for careful preparation, validation, and approval of such recommendations, along with the realities of the workload faced by national meteorological services that must perform the necessary software modifications, require such long lead times.

1.3.3 Changes Not Requiring Software Modifications

Changes not requiring software modifications can follow the same approval process as changes that do. However, as noted previously, such changes are not only far less disruptive than code structure changes, they are also required more frequently and often with greater urgency. Therefore, a special approval process has been developed by the WMO Secretariat to ensure the necessary flexibility is available to respond to urgent requirements of users during intersessional periods (i.e., between Sessions of CBS). This approval process is referred to as the "Fast Track".

Once requests for changes have been received, justified, and deemed to not require software changes, the “Fast Track” procedure is as follows:

- The requests are dealt with in session or via correspondence by the ET/DRC, which allocates the available table entries.
- The recommendation is submitted for information to the requesting source, focal points on code matters, Chairperson of the OPAG/ISS and President of CBS, through e-mail and posted on the WMO web server.
- Associated documents kept on the WMO web server will include associated pairs: a first document to record the request, the second one for descriptors themselves, target validation date and target operational date.
- Upon successful completion of the validation and approval by the chairs of ET/DRC and OPAG/ISS and the President of CBS, the recommendation is “Approved for Pre-Operational implementation”.
- Upon approval by the Full CBS and the full EC, the recommendation is “Approved for Full Operational Implementation”.
- These table entries are reviewed at least twice a year and will thus be in one of the three stages reflected in three different lists or tables:
    - Awaiting Validation
    - Approved for Pre-Operational Implementation: fully validated and approved by the chairs of ET/DRC and OPAG/ISS and the President of CBS
    - Approved for Full Operational Implementation: approved by the full CS and full EC. These Table Entries will then appear in the Manual on Codes

By making the recommended new table entries available on the WMO web server, centres with urgent needs can use the new entries as soon as they are declared “Available for Pre-Operational Implementation”. This can be substantially earlier than the “Full Implementation” date. As noted in the previous section, the actual date of full operational implementation is the first Wednesday following the first of November of the year following the CBS Session that officially approved the recommended new table entries.

1.3.3.1 Example of Adding a New Parameter

An example of a change not requiring corresponding modifications to processing software is the addition of a new parameter to GRIB2 Table 4.2 (Parameter number by product discipline and parameter category). As in the previous section, let us consider a timeline for such a change. Suppose a requirement for addition of a new parameter to GRIB Table 4.2 is stated in writing to the WMO Secretariat on 1 January 2003. As before, the Secretariat passes the requirement to the ET/DRC, who then must validate the stated requirements and develop a draft recommendation that will meet it. In this example, the ET/DRC recommendation will not call for a change to the GRIB2 code structure, and therefore can be approved via the “Fast Track”.
In this case the request is dealt with in session or via correspondence by the ET/DRC, which allocates the available table entries. The ET/DRC Recommendation is then submitted for information via e-mail to the requesting source, the focal points on code matters, the chair of the OPAG/ISS and the President of CBS and posted on the WMO web server. Then the associated documents are put on the WMO web server. When first put on the web server, the Recommendation will be marked as “Awaiting Validation”. The validation in this case is rather simple, and usually can be accomplished in two months. Once validated, the chairs of ET/DRC and OPAG/ISS and the President of CS must approve the Recommendation. Allowing time for correspondence, perhaps by 1 April 2003 the status of the Recommendation can be changed to “Approved for Pre-Operational Implementation”. This would allow time for operational centres to implement the new table entries into their processing systems on the first Wednesday following the first of November 2003. Although it will not be approved for full operational implementation until the first Wednesday following the first of November 2005, the year following the next CBS Session, the new table entries can be used operationally a full two years before the “Full Operational

Implementation" date. In this light, the significance of the "Full Operational Implementation" date is to mark the publication of the changes in the WMO Manual on Codes.

1.3.4 Validation of Updates

Whether requiring corresponding modifications to processing software or not, all changes must be validated by a procedure required by the CBS. Under this procedure, proposed changes should be tested by the use of two independently developed encoders and two independently developed decoders that incorporate the proposed change. However, where the data originated from a necessarily unique source (e.g., the data stream from an experimental satellite), the successful testing of a single encoder with at least two independent decoders is considered adequate.

For those recommendations that are considered by the full CBS for approval, CBS may either approve or not approve but not alter them. All changes to the WMO table-driven code forms BUFR, CREX, and GRIB are documented in the form of supplements to the WMO Manual on Codes. However, these supplements are issued no more than once a year.

In the above discussion, a distinction was made between the validation process for those changes that require corresponding changes to processing software and those changes that do not. Existing software can be used to validate table additions that do not require software changes. Consequently, they are relatively simple to validate. The first step is to verify the table entries are consistent with the original request, a simple pencil and paper exercise. Then, sample data can be prepared and tested with existing software as indicated above.

The effort needed to validate changes that do require corresponding modifications to processing software, however, can vary widely. A fairly simple example is the addition of a new grid or product definition template. Most computer software is sufficiently modular that such changes can be isolated and tested as required by the CBS rather easily. On the other hand, the validating of GRIB2 is perhaps one of the most complex examples of validation. Although sharing many aspects with GRIB1, the structure of GRIB2 is sufficiently different that virtually new processing software is required. This software had to be written and tested before the validations could be done. The validations that were performed for the GRIB2 Code Form involved not two centres but six. Furthermore, at least two independent encoders and two independent decoders tested each of the 53 templates of GRIB2. Consequently, the GRIB2 validation process took many computer runs by six centres over a period of over two years. Clearly, this testing effort was several orders of magnitude greater that that which will be required for the addition of a single template.

Layer 2: Structure and Use of GRIB2 Messages

2.1 Sections of a GRIB2 Message

Each GRIB2 message intended for either transmission or storage contains one or more parameters with values located at an array of grid points or represented as a set of spectral coefficients. Logical divisions of the message are designated as sections, each of which provides control information and/or data. There are nine different types of sections in a GRIB2 message, one of which is optional. The nine sections and their general contents are:

Section Number	Section Name	Section Contents
Section 0:	Indicator Section	"GRIB", Discipline, GRIB Edition number, length of message
Section 1:	Identification Section	Length of section, section number, characteristics that apply to all processed data in the GRIB message
Section 2:	Local Use Section (optional)	Length of section, section number, additional items for local use by originating centres
Section 3:	Grid Definition Section	Length of section, section number, definition of grid surface and geometry of data values within the surface
Section 4:	Product Definition Section	Length of Section, section number, description of the nature of the data
Section 5:	Data Representation Section	Length of section, section number, description of how the data values are represented
Section 6:	Bit-Map Section	Length of section, section number, indication of presence or absence of data at each grid point, as applicable
Section 7:	Data Section	Length of section, section number, data values
Section 8:	End Section	"7777"

All but the Local Use Section must appear at least once in every GRIB2 message. With the exception of the first four octets of the Indicator Section and the End Section, all octets contain binary values. All sections end on an octet boundary; the sections are padded with bits set to zero as necessary to accomplish this. These extra bits must be accounted for in finding one's way through the sections; their content should be ignored.

2.1.1 Section 0: Indicator Section

The Indicator Section serves to: identify the start of the GRIB2 message in a human readable form, describe the "Discipline" of the information contained in the message, indicate the Edition Number of GRIB (2 in the case of GRIB2) used to encode the message, and the total length of the message. The section is always 16 octets long. The contents of the Indicator Section are:

Octet No.	Contents
1-4	"GRIB" (coded according to the International Alphabet No. 5)
5-6	Reserved

7	Discipline – GRIB Master Table Number (see Code Table 0.0)
8	GRIB Edition Number (currently 2)
9-16	Total length of GRIB message in octets (including Section 0)

It was noted in Layer 1 that the identification of parameters in GRIB 2 uses a branching structure based on three parameters – Discipline, Category, and Name. Octet 7 contains the first of these three branches – Discipline. The contents of octet 7 are defined by Code Table 0.0, which is currently defined as follows:

Code Table 0.0: Discipline of processed data in the GRIB message, number of GRIB Master Table

Code figure	Meaning
0	Meteorological products
1	Hydrological products
2	Land surface products
3	Space products
4-9	Reserved
10	Oceanographic products
11-191	Reserved
192-254	Reserved for local use
255	Missing

For example, Discipline = 0 indicates this GRIB2 message contains Meteorological Products, while Discipline = 10 indicates this message contains Oceanographic Products. Code table 0.0 gives all the currently defined disciplines. It might be useful at this point to note that all GRIB2 Code Tables are referred to as Code Table m.n, where m is the number of the Section that refers to the Code Table and n is the number of the Code Table within that Section. Thus, Code Table 3.4 would be the fourth code table referred to in Section 3.

The GRIB Edition Number, which is always 2 for GRIB2, is in octet 8. Finally, since GRIB2 permits multiple fields in a single message, it was decided to allocate 8 octets for the length of a GRIB2 message. This permits lengths of up to $2^{64} – 1$, which should be more than enough for reasonable GRIB2 messages.

2.1.2 Section 1: Identification Section

The Identification Section contains characteristics that apply to all processed data in the GRIB message. These characteristics identify the originating centre or sub-centre, indicate the GRIB Master Table and Local Table versions used, and give the reference time, the production status, and the type of processed data contained in this GRIB message. The contents of the Section are:

Octet No.	Contents	
1-4	Length of section in octets (21 or nn)	
5	Number of Section (“1”)	
6-7	Identification of originating/generating centre (see Common Code Table C-1)	
8-9	Identification of originating/generating sub-centre (allocated by originating/ generating centre)	
10	GRIB Master Tables Version Number (see Code Table 1.0) (currently 1)	
11	GRIB Local Tables Version Number (see Code Table 1.1)	
12	Significance of Reference Time (see Code Table 1.2)	
13-14	Year (4 digits)	
15	Month	
16	Day	Reference time of data
17	Hour	

18	Minute	|
19	Second	|
20	Production status of processed data in this GRIB message (see Code Table 1.3)	
21	Type of processed data in this GRIB message (see Code Table 1.4)	
22-nn	Reserved: need not be present	

Note that octets beyond 21 of the Identification Section are reserved for future use and need not be present. Users of GRIB messages are strongly urged to always use the length of section given in octets 1 – 4 of sections 1 - 7 to determine where the next section begins. Never assume a fixed octet length of any section other than the Indicator Section (Section 0 – always 16 octets long) and the End Section (Section 8 – always 4 octets long). Also note that the Section number is given in octet 5. This is true for sections 1 – 7. It is an aid to finding one's way through a GRIB message containing multiple data sets.

Octets 6-7 and 8-9 identify the centre that originated the data contained in the GRIB message. Octets 6-7 indicate the originating/generating centre. The value contained in octets 6-7 refers to Common Code Table C-1 – Identification of originating/generating centre – maintained by the WMO Secretariat. A subset of Common Code Table C-1 is reproduced below:

Octets 6-7	Originating/generating centre
	74-99: Centres in Region VI
74	UK Meteorological Office - Bracknell (RSMC)
75	)
76	Moscow (RSMC/RAFC)
77	Reserved
78	Offenbach (RSMC)
79	)
80	Rome (RSMC)
81	)
82	Norrköping
83	)
84	Reserved
85	Toulouse (RSMC)

Thus, if octets 6-7 contain the number 74, Table C-1 indicates the originating/generating centre is the UK Meteorological Office in Bracknell. However, octets 8-9 must be considered as well. They indicate the originating/generating sub-centre. The originating/generating centre indicated by octets 6-7 allocates these values. If octets 8-9 contain the number 0, the centre defined by octets 6-7 – the UK Meteorological Office in Bracknell in this case - did in fact originate the data the GRIB message. However, if octets 8-9 contain a number other than zero, a sub-centre of the UK Meteorological Office actually originated the data in the GRIB message. For example, if octets 8-9 contain the number 1, a sub-centre of the UK Meteorological Office named Egxx, Shanwick Oceanic Area Control Centre actually originated the data contained in the GRIB message. In general, one must contact the originating/generating centre to find the sub-centre referred to in octets 8-9.

It is necessary to access the proper tables in order to correctly decode a GRIB message. These are identified by octets 10 and 11. These octets refer to Code Tables 1.0 and 1.1, respectively, which are currently defined as:

Code Table 1.0: GRIB Master Tables Version Number

Code figure	Meaning
0	Experimental
1	Initial operational version number
2-254	Future operational version numbers
255	Local table used

Code Table 1.1: GRIB Local Tables Version Number

Code figure	Meaning
0	Local tables not used
1-254	Number of local tables version used
255	Missing

The WMO Secretariat maintains all versions of the GRIB Master Table. Octet 10 contains the version number of the Master Table used to generate the data contained in the GRIB message. If octet 10 contains the value 255, however, a local table was used. In this case, the value in octet 11 – Local Table Version Number – is the relevant one. However, to obtain the local table version referred to by octet 11, one must contact the centre that originated the data in the GRIB message as identified by octets 6-7 and 8-9. If local tables were not used, octet 11 will contain the value 0.

The meaning of the Reference Time of the Data in GRIB1 was a source of some confusion because it was not clearly defined. In an attempt to be more precise, the Reference Time of the Data in GRIB2 is given in terms of both a date/time and its significance. The significance of the reference time – contained in octet 12 – refers to Code Table 1.2, currently defined as:

Code Table 1.2: Significance of Reference Time

Code figure	Meaning
0	Analysis
1	Start of forecast
2	Verifying time of forecast
3	Observation time
4-191	Reserved
192-254	Reserved for local use
255	Missing

This parameter identifies, for example, whether the Reference Date/Time refers to the time of an analysis (octet 12 = 0), the start of a forecast (octet 12 = 1), the verifying time of a forecast (octet 12 = 2), etc. The precise time of the data itself is found by combining the Reference Date/Time itself, contained in octets 13 – 19, with additional time information given in the Product Definition Section (Section 4).

Finally, octets 20 and 21 give additional information about the data in the GRIB message via Code Tables 1.3 and 1.4:

Code Table 1.3: Production status of data

Code figure	Meaning
0	Operational products
1	Operational test products
2	Research products
3	Re-analysis products
4-191	Reserved
192-254	Reserved for local use

255	Missing

Code Table 1.4: Type of data

Code figure	Meaning
0	Analysis products
1	Forecast products
2	Analysis and forecast products
3	Control forecast products
4	Perturbed forecast products
5	Control and perturbed forecast products
6	Processed satellite observations
7	Processed radar observations
8-191	Reserved
192-254	Reserved for local use
255	Missing

Note: An initialised analysis is considered a zero hour forecast

The production status (octet 20) refers to whether the data is an operational product, an operational test product, a research product, etc. The Type of data (octet 21) indicates whether the data is an analysis product, a forecast product, a perturbed forecast products, etc.

2.1.3 Section 2: Local Use Section

The purpose of the Local Use Section is just what the Section name implies – information for local use by the originating/generating centre. The originating/generating centre can put anything it desires in this Section. The contents of Section 2 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“2”)
6-nn	Local use

2.1.4 Section 3: Grid Definition Section

The purpose of the Grid Definition Section is to define the grid surface and geometry of the data values within the surface for the data contained in the next occurrence of the Data Section. GRIB2 retains the powerful GRIB1 concept of a template in this Section and extends it to the Product Definition, Data Representation, and Data Sections as well. Use of a template means there are very few values common to all Grid Definition Sections possible in GRIB2. Rather, the number of the Grid Definition Template used is encoded. The values that must follow are those required by that particular Grid Definition Template. The contents of Section 3 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“3”)
6	Source of grid definition (see Code Table 3.0 and Note 1)
7-10	Number of data points
11	Number of octets for optional list of numbers defining number of points (see Note 2)

12	Interpretation of list of numbers defining number of points (see Code Table 3.11)
13-14	Grid Definition Template Number (N) (see Code Table 3.1)
15-xx	Grid Definition Template (see Template 3.N, where N is the Grid Definition Template Number given in octets 13-14)
[xx+1]-nn	Optional list of numbers defining number of points (see Notes 2, 3, and 4)

Notes:

1. If octet 6 is not zero, octets 15-xx (15-nn if octet 11 is zero) may not be supplied. This should be documented with all bits set to 1 (missing value) in the Grid Definition Template Number.

2. An optional list of numbers defining the number of points is used to document a quasi-regular grid, where the number of points may vary from one row to another (row being defined as adjacent points in a coordinate line, so this is dependent on the data layout). In such a case, octet 11 is non-zero, and gives the number of octets on which each number of points is encoded. For all other cases, such as regular grids, octets 11 and 12 are zero and no list is appended to the Grid Definition Template.

3. If a list of numbers defining the number of points is present, it is appended at the end of the Grid Definition Template (or directly after the Grid Definition Template Number if the template is missing), and the length of the list is given by the grid definition. When the Grid Definition Template is present, the length is given according to bit 3 of the scanning mode flag octet (the length is N_j or N_y for flag value 0). List ordering is implied by data scanning.

4. Depending on the code value given in octet 12, the list of numbers defining the number of points corresponds either to the coordinate lines as given in the grid definition, or to a full circle.

The somewhat forbidding appearance of the contents and notes of the Grid Definition Section is due to several special cases defined by octets 6, 11, and 12. Octet 6 refers to Code Table 3.0:

Code Table 3.0: Source of Grid Definition

Code figure	Meaning	Comments
0	Specified in Code table 3.1	
1	Predetermined grid definition Defined by originating centre	
2-191	Reserved	
192-254	Reserved for local use	
255	A grid definition does not apply to this product	

First, when octet 6 is not zero, Note 1 applies. In this case, either a predetermined grid definition defined by the originating/generating centre is used (octet 6 = 1) or a grid definition does not apply to this product (octet 6 = 255). The former case should be avoided if at all possible, for then users must contact the originating/generating centre to determine the meaning of the values in octets 15 - xx: it will not be found in the WMO Code Manual. In the latter case, there is no Grid Definition Template at all. This is documented by setting octets 13 - 14 to missing (all bits set to 1).

Octets 11 and 12 and Notes 2, 3, and 4 account for the possibility of a quasi-regular grid. This is one in which the number of grid points varies from grid row to grid row. As the notes suggest, this can be complicated, so discussion of this case is reserved for Layer 3.

The large majority of GRIB2 messages will not utilize these special cases. Therefore, if one can mentally remove them from the contents of Section 3, the Grid Definition Section becomes simpler: following the standard length and number of section in octets 1 – 5, the number of points is given, then the Grid Definition Template Number, followed by the values required by the Grid Definition Template of that number. The particular Grid Definition template used thus describes the large majority of the values found in Section 3.

As an example, suppose the value in octets 13 - 14 is 20. One then refers to Code Table 3.1:

Code Table 3.1: Grid Definition Template Number

Code figure	Meaning	Comments
0	Latitude/longitude	Also called equidistant cylindrical, or Plate Carree.
1	Rotated latitude/longitude	
2	Stretched latitude/longitude	
3	Stretched and rotated latitude/longitude	
4-9	Reserved	
10	Mercator	
11-19	Reserved	
20	Polar stereographic	can be south or north.
21-29	Reserved	
30	Lambert Conformal	can be secant or tangent, conical or bipolar. (Also called Albers equal-area.)
31-39	Reserved	
40	Gaussian latitude/longitude	
41	Rotated Gaussian latitude/longitude	
42	Stretched Gaussian latitude/longitude	
43	Stretched and rotated Gaussian latitude/longitude	
44-49	Reserved	
50	Spherical harmonic coefficients	
51	Rotated spherical harmonic coefficients	

52	Stretched spherical harmonic coefficients
53	Stretched and rotated spherical harmonic coefficients
54-89	Reserved
90	Space view perspective orthographic.
91-99	Reserved
100	Triangular grid based on an icosahedron
101-109	Reserved
110	Equatorial azimuthal equidistant projection
111-119	Reserved
120	Azimuth-range projection
121- 999	Reserved
1000	Cross-section grid, with points equally spaced on the horizontal
1001-1099	Reserved
1100	Hovmöller diagram grid, with points equally spaced on the horizontal
1101- 1199	Reserved
1200	Time section grid
1201-32767	Reserved
32768-65534	Reserved for local use
65535	Missing

Inspection of Code Table 3.1 reveals that 20 corresponds to a Polar Stereographic grid projection. One then looks up Grid Definition Template 3.20 to find the contents of the remainder of the Grid Description Section. In this case, Template 3.20 requires use of octets 14 – 65, and describes in detail what the contents of octets 15 – 65 are. On the other hand, if the value in octets 13 – 14 were 30, Code Table 3.1 indicates this would correspond to a Lambert Conformal grid projection. Inspection of Grid Definition Template 3.30 reveals that octets 15 – 81 would be needed to define this grid projection. Furthermore, much of the contents of octets 15 – 81 describing a Lambert Conformal grid projection would be different than the contents of octets 15 – 65 describing a Polar Stereographic grid projection.

Use of the template concept allows virtually any grid to be defined in GRIB2 – if an existing template does not define it; one develops a new template and submits it to the WMO for approval through the official channels described in Layer 1. Utilisation of the template concept also defers much of the complexity in this and the Product Definition, Data Representation, and Data Sections to the discussion of the templates themselves – found in Section 2.2 of this Layer. The various Templates themselves refer to a number of Code and Flag Tables. However, although this document attempts to reproduce enough GRIB2 Code and Flag tables to explain the examples given, it does not seek to reproduce them all. The reader must refer to the WMO GRIB2 Code Manual itself for Code and Flag Tables not reproduced here.

2.1.5 Section 4: Product Definition Section

The purpose of the Product Definition Section is to describe the nature of the data contained in the next occurrence of the Data Section. The contents of Section 4 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("4")
6-7	Number of coordinate values after Template (see Note 1)
8-9	Product Definition Template Number (see Code Table 4.0)
10-xx	Product Definition Template (see Template 4.X, where X is the Product Definition Template Number given in octets 8-9)
[xx+1]-nn	Optional list of coordinate values (see Notes 2 and 3)

Notes:

1. Coordinate values are intended to document the vertical discretisation associated with model data on hybrid vertical coordinate levels. A number of zero in octets 6-7 indicates that no such values are present. Otherwise, the number corresponds to the whole set of values.

2. Hybrid systems, in this context, employ a means of representing vertical coordinates in terms of a mathematical combination of pressure and sigma coordinates. When used in conjunction with a surface pressure field and an appropriate mathematical expression, the vertical coordinate parameters may be used to interpret the hybrid vertical coordinate.

3. Hybrid vertical coordinate values, if present, should be encoded in IEEE 32-bit floating point format. They are intended to be encoded as pairs.

Once again, a special case adds some complexity to the list of contents of Section 4. Here, the special case is the possible use of a hybrid vertical coordinate system. As Note 2 indicates, a hybrid vertical coordinate system is a mathematical combination of pressure and sigma vertical coordinates. In this case, a series of pairs of numbers, indicating the combination of the two vertical coordinate systems for each coordinate level, must be given. Octets 6-7 and the Notes describe adjustments that must be made to the Product Definition Section in this event.

When hybrid vertical coordinates are not used (which is far more common), Section 4 contains simply the length and number of section in octets 1 – 5, the number zero to indicate hybrid coordinates are not used, the Product Definition Template Number, and the values required by the Product Definition Template of that number. For example, suppose the value in octets 8 - 9 is 0. One then refers to Code Table 4.0:

Code Table 4.0: Product Definition Template Number

Number	Description
0	Analysis or forecast at a horizontal level or in a horizontal layer at a point in time
1	Individual ensemble forecast, control and perturbed, at a horizontal level or in a horizontal layer at a point in time
2	Derived forecast based on all ensemble members at a horizontal level or in a horizontal layer at a point in time
3	Derived forecasts based on a cluster of ensemble members over a rectangular area at a horizontal level or in a horizontal layer at a point in time
4	Derived forecasts based on a cluster of ensemble members over a circular area at a horizontal level or in a horizontal layer at a point in time
5	Probability forecasts at a horizontal level or in a horizontal layer at a point in time
6	Percentile forecasts at a horizontal level or in a horizontal layer at a point in time
7	Analysis or forecast error at a horizontal level or in a horizontal layer at a point in time
8	Average, accumulation, extreme values or other statistically processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
9	Probability forecasts at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
10	Percentile forecasts at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
11-19	Reserved
20	Radar product
21-29	Reserved
30	Satellite product
31-253	Reserved
254	CCITT IA5 character string
255-999	Reserved
1000	Cross section of analysis and forecast at a point in time
1001	Gross section of averaged or otherwise statistically processed analysis or forecast over a range of time
1002	Cross section of analysis and forecast, averaged or otherwise statistically processed
1003-1099	Reserved
1100	Hovmöller-type grid with no averaging or other statistical processing
1101	Hovmöller-type grid with averaging or other statistical processing
1102-32767	Reserved
32768-65534	Reserved for local use
65535	Missing

Code Table 4.0 indicates a value of 0 corresponds to an analysis or forecast at a horizontal level or in a horizontal layer at a point in time. Product Definition Template 4.0 then utilises octets 10 - 34 to specify precisely what the product in the next occurrence of the Data Section is.

The subdivision of the GRIB1 Product Definition Section into the GRIB2 Identification, Product Definition, and Data Representation Sections permits each of these sections to focus on a single aspect of data set description. The extension of the template concept to the GRIB2 Product Definition and Data Representation sections adds enormous flexibility to the GRIB2 code form. As with the Grid Definition Section, the complexity of the Product Definition Section is in the values required by the various templates, discussed in Section 2.2 of this guide.

2.1.6 Section 5: Data Representation Section

The purpose of the Data Representation Section is to describe how the data values are represented in the next occurrence of the Data Section. The contents of Section 5 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("5")
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-nn	Data Representation Template (see Template 5.X, where X is the Data Representation Template Number given in octets 10-11)

The pattern taken by the contents of a section that uses a template may be becoming familiar by now. In this Section, the special case noted in the description of the contents of octets 6 - 9 has to do with the use of a bit map. The value in octets 6 - 9 indicates to the user how many data point values are to be found in the Data Section. However, When a bit map is used (this is discussed in Section 2.1.7), those data points whose value is zero do not have that zero value appear in the Data Section. The number of data point values to be found in the data Section (given by octets 6 - 9 of the Data Representation Section) may therefore be fewer than the number of data points themselves (given by octets 7 - 10 of the Grid Definition Section).

As an example of the Data Representation Section, suppose the value in octets 10 - 11 is 0. We now refer to Code Table 5.0:

Code Table 5.0: Data Representation Template Number

Code figure	Meaning
0	Grid point data - simple packing
1	Matrix value - simple packing
2	Grid point data - complex packing
3	Grid point data - complex packing and spatial differencing
4-49	Reserved
50	Spectral data -simple packing
51	Spherical harmonics data - complex packing
52-191	Reserved
192-254	Reserved for local use
255	Missing

The Code Table indicates a value of 0 corresponds to grid point values with simple packing. Data Representation Template 5.0 then indicates that octets 12 – 21 are required to describe this type of data representation, and what the contents of those octets are.

2.1.7 Section 6: Bit-Map Section

The purpose of the Bit-Map Section is to indicate the presence or absence of data at each of the grid points, as applicable, in the next occurrence of the Data Section. The contents of Section 6 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("6")
6	Bit-map indicator (see code Table 6.0 and Note 1)
7-nn	Bit-map

Notes:

1. If octet 6 is not zero, the length of the Section is 6 and octets 7 - nn are not present.

We noted in the discussion of the Data Representation Section the possibility that not every data point will have a corresponding value in the Data Section. Consider, for example, a precipitation field. There will be many data points in a precipitation field with a zero value – no precipitation. In order to conserve space, a bit map can be used to efficiently indicate those data points with a zero precipitation value that does not appear in the Data Section. This is accomplished by generating a bit string with one bit corresponding to each data point. A bit set to one implies the presence of a data value at that data point, while a bit set to zero implies the absence of a data value at that data point. Those data points for which the bit is set to zero will not have a corresponding value in the Data Section.

The Bit-map indicator in octet 6 refers to Code Table 6.0:

Code Table 6.0: Bit Map Indicator

Code figure	Meaning
0	A bit map applies to this product and is specified in this Section
1 - 253	A bit map pre-determined by the originating/generating Centre applies to this product and is not specified in this Section.
254	A bit map defined previously in the same "GRIB" message applies to this product.
255	A bit map does not apply to this product.

The Code Table indicates a value of zero in octet 6 means a Bit-map is specified in octets 7 - nn. However, other choices are available as well. A bit-map that applies to this product may be pre-determined by the originating/generating centre (octet 6 = 1 - 253), a bit-map previously defined in the same GRIB2 message may apply (octet 6 = 254: recall that GRIB2 permits encoding multiple data sets in a single message), or a bit-map may not apply at all (octet 6 = 255). In all these cases, octets 7 – nn are absent and the length of the Section is 6.

2.1.8 Section 7: Data Section

The Data Section contains the data values themselves. The contents of Section 7 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-nn	Data in a format described by Data Template 7.X, where X is the Data Representation Template number given in octets 10-11 of Section 5

The various data compression schemes have not been discussed as yet. They are discussed in Section 2.3 of this Layer, and in more detail in Layer 3. At this point, suffice it to say that there are three basic approaches to data compression used in GRIB2; simple packing, complex packing, and spatial differencing. If only simple packing is used, the data values in octets 6 - nn are in the form of a binary string, filled with bits set to zero to ensure the Section ends on an octet boundary. However, if Complex packing and/or spatial differencing is used, the storage of the data values in the Data Section is more complicated, and is described by the appropriate Data Template, as indicated in the Contents above. Note the implied link between Data Representation Template 5.X and Data Template 7.X, where X in both cases is the Data Representation Template Number given in octets 10 - 11 of the Data Representation Section. Data storage in these cases is discussed more fully with the discussion of the compression schemes.

Recall that GRIB2 permits multiple data sets to be encoded in a single GRIB2 message. This was described briefly in Layer 1, where it was noted that multiple data sets implies multiple occurrences of the Grid Description, Product Definition, Data Representation, and Bit-Map Sections. However, it was also noted that this did not require each of these four sections be repeated for each occurrence of the Data Section. Rather, the contents of the most recent occurrences of the Grid Description, Product Definition, Data Representation, and Bit-Map Sections prior to any individual occurrence of the Data Section are those that describe the contents of that occurrence of that Data Section.

2.1.9 Section 8: End Section

The End Section serves to identify the end of the GRIB2 message in a human readable form. The contents of Section 7 are:

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

The End Section is always 4 octets long. The Indicator (16 octets long) and End Sections are the only fixed-length sections in a GRIB2 message.

2.2 GRIB2 Templates

The use of the GRIB1 concept of templates to describe the GRIB2 grid definition, product definition, and data representation aspects of a data set are one of the most important enhancements of GRIB2 over GRIB1. The developers of GRIB2 anticipated that the added flexibility arising from this more extensive use of the template concept would allow GRIB2 to adapt to new and as yet unforeseen requirements for data representation. This Section of the Guide describes the templates and their use.

2.2.1 Grid Definition Templates

Recall that the purpose of the Grid Definition Section is to define the grid surface and geometry of the data values within the surface for the data contained in the next occurrence of the Data Section. Most of the information necessary to accomplish this is within the Grid Definition Template. As noted in Section 2.1.4 above, the contents of Section 3 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“3”)
6	Source of grid definition (see Code Table 3.0 and Note 1)
7-10	Number of data points
11	Number of octets for optional list of numbers defining number of points (see Note 2)
12	Interpretation of list of numbers defining number of points (see Code Table 3.11)
13-14	Grid Definition Template Number (=N) (see Code Table 3.1)
15-xx	Grid Definition Template (see Template 3.N, where N is the Grid Definition Template Number given in octets 13-14)
[xx+1]-nn	Optional list of numbers defining number of points (see Notes 2, 3, and 4)

Let us assume the values in octets 6, 11, and 12 are all zero, thus eliminating the special cases described in Section 2.1.4, and the value in octets 13 - 14 is 20. Code Table 3.1 reveals that 20 corresponds to a Polar Stereographic grid projection. It is described by Grid Definition template 3.20. We now insert Grid Definition Template 3.20 into octets 15-xx. The contents of the Grid Definition Section then become:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“3”)
6	Source of grid definition (see Code Table 3.0 and Note 1)
7-10	Number of data points
11	Number of octets for optional list of numbers defining number of points (see Note 2)
12	Interpretation of list of numbers defining number of points (see Code Table 3.11)
13-14	Grid Definition Template Number (=N) (see Code Table 3.1)
15	Shape of the earth (see Code Table 3.2)
16	Scale factor of radius of spherical earth
17-20	Scaled value of radius of spherical earth
21	Scale factor of major axis of oblate spheroid earth
22-25	Scaled value of major axis of oblate spheroid earth
26	Scale factor of minor axis of oblate spheroid earth
27-30	Scaled value of minor axis of oblate spheroid earth
31-34	Nx – number of points along X-axis
35-38	Ny – number of points along Y-axis
39-42	La1 – latitude of first grid point
43-46	Lo1 – longitude of first grid point
47	Resolution and component flag (see flag table 3.3 and Note 1)
48-51	LaD – Latitude where Dx and Dy are specified
52-55	LoV – orientation of the grid (see note 2)
56-59	Dx – X direction grid length (see Note 3)
60-63	Dy – Y direction grid length (see Note 3)
64	Projection centre flag (see Flag Table 3.5)
65	Scanning mode (see Flag Table 3.4)

The four notes referred to in Grid Definition Template 3.20 are:

1. The resolution flag (bit 3-4 of Flag Table 3.3) is not applicable.
2. LoV is the longitude value of the meridian that is parallel to the Y-axis (or columns of the grid) along which latitude increases as the Y-coordinate increases (the orientation longitude may or may not appear on a particular grid).
3. Grid length is in units of 10-3 m at the latitude specified by LaD.

4. Bit 2 of the projection flag is not applicable to the polar stereographic projection.

Octets 15 – 30 establish the shape and size of the earth. GRIB1 only allowed two possibilities - a spherical earth with radius 6367.47 km or an oblate spheroid earth with the major axis 6378.160 km, minor axis 6356.775 km and f = 1/297.0. This proved to cause problems, for data producers were using other than these sets of values, and GRIB1 had no procedures for specifying them. Octet 15 permits a wider variety of choices via Code Table 3.2:

Code Table 3.2: Shape of the Earth

Code figure	Meaning
0	Earth assumed spherical with radius = 6367.47 km
1	Earth assumed spherical with radius specified by data producer
2	Earth assumed oblate spheroid with size as determined by IAU in 1965 (major axis = 6378.160 km, minor axis = 6356.775 km, f = 1/297.0)
3	Earth assumed oblate spheroid with major and minor axes specified by data producer
4	Earth assumed oblate spheroid as defined in IAG-GRS80 model (major axis = 6378.1370 km, minor axis = 6356.752314 km, f = 1/298.257222101)
5	Earth assumed represented by WGS84 (as used by ICAO since 1998)
6	Earth assumed spherical with radius of 6371.2290 km
7-191	Reserved
192-254	Reserved for local use
255	Missing

Note:
WGS84 is a geodetic system that uses IAG-GRS80 as basis.

Note that GRIB2 still permits the two GRIB1 choices: the former by setting octet 15 to 0 and the latter by setting octet 15 to 2. When either of these two choices is selected, octets 16 – 30 are set to missing (all bits on). GRIB2 also allows a spherical (octet 15 = 6) and an oblate spheroid (octet 15 = 4) earth with another set of pre-set values. However, far more flexibility is achieved by allowing the data producer to encode into octets 16 – 30 the values for either a spherical earth (octet 15 = 1, octets 16-20 define the radius, and octets 21-30 are set to missing)) or an oblate spheroid earth (octet 15 = 3, octets 16-20 are set to missing, and octets 21-30 define the major and minor axes). Many Grid Definition Templates have the same parameters in octets 15 – 30.

After the shape and size of the earth has been established, octets 31 – 65 describe the grid itself. Several things need to be noted here. First, octet 47 refers to Flag Table 3.3:

Flag Table 3.3: Resolution and Component Flags

Bit Number	Value	Meaning
1-2		Reserved
3	0	i direction increments not given
	1	i direction increments given
4	0	j direction increments not given
	1	j direction increments given
5	0	Resolved u- and v- components of vector quantities relative to easterly and northerly directions
	1	Resolved u- and v- components of vector quantities relative to the defined grid in the direction of increasing x and y (or i and j) coordinates respectively

6-8	Reserved - set to zero

A flag table is a string of bits, where each bit can be turned on (i.e., set to 1) or off (i.e., set to 0). Thus any combination of the possible choices can be selected. This means that the contents of octet 47 should not be interpreted as a value, for that is meaningless in this case. Rather, the individual bits must be inspected.

Second, Code Table 3.4 indicates the order of the "scanning" of the grid points. I.e., which is the first grid encoded, the second, the third, and etc.

Flag Table 3.4: Scanning Mode

Bit Number	Value	Meaning
1	0	Points of first row or column scan in the +i (+x) direction
	1	Points of first row or column scan in the -i (-x) direction
2	0	Points of first row or column scan in the -j (-y) direction
	1	Points of first row or column scan in the +j (+y) direction
3	0	Adjacent points in i (x) direction are consecutive
	1	Adjacent points in j (y) direction is consecutive
4	0	All rows scan in the same direction
	1	Adjacent rows scan in opposite directions
5-8		Reserved

Notes:
(1) i direction: west to east along a parallel or left to right along an X-axis
(2) j direction: south to north along a meridian, or bottom to top along a Y-axis
(3) If bit number 4 is set, the first row scan is as defined by previous flags

---

GRIB2 permits selection of scanning patterns not allowed in GRIB1. In particular, when bit 4 is set to 1, adjacent rows scan in opposite directions. This scanning mode is useful when the complex packing and spatial differencing compression scheme is used. This will be discussed in more detail in Section 2.3.3 of Layer 2.

Third, Flag Table 3.5 is used to indicate whether the polar stereographic projection is a northern hemisphere or southern hemisphere one.

Flag Table 3.5: Projection Centre

Bit Number	Value	Meaning
1	0	North Pole is on the projection plane
	1	South Pole is on the projection plane
2	0	Only one projection centre is used
	1	Projection is bi-polar and symmetric

Fourth, note that all latitudes, longitudes, and angles are given in units of 10^{-6} degrees, except for specific cases explicitly stated in some grid definitions.

2.2.2 Product Definition Templates

The purpose of the Product Definition Section is to describe the nature of the data contained in the next occurrence of the Data Section. Most of the information necessary to accomplish this is within the Product Definition Template. As noted in Section 2.1.5 above, the contents of Section 4 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“4”)
6-7	Number of coordinate values after Template (see Note 1)
8-9	Product Definition Template Number (see Code Table 4.0)
10-xx	Product Definition Template (see Template 4.X, where X is the Product Definition Template Number given in octets 8-9)
[xx+1]-nn	Optional list of coordinate values (see Notes 2 and 3)

We will assume that octets 6 – 7 contain the value zero (meaning hybrid vertical coordinates are not used and octets [xx+1] – nn are therefore absent), and the value in octets 8 - 9 is 0, indicating Product Definition Template 4.0 is to be used. Code Table 4.0 indicates this corresponds to an analysis or forecast at a horizontal level or in a horizontal layer at a point in time. Product Definition Template 4.0 utilises octets 10 - 34 to specify precisely what the product in the next occurrence of the Data Section is. We now insert Product Definition Template 4.0 into octets 10 - xx. The contents of the Product Definition Section then become:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“4”)
6-7	Number of coordinate values after Template (see Note 1)
8-9	Product Definition Template Number (see Code Table 4.0)
10	Parameter Category (see Code Table 4.1)
11	Parameter number (see Code Table 4.2)
12	Type of generating process (see code Table 4.3)
13	Background generating process identifier (defined by originating centre)
14	Analysis or forecast generating process identifier (defined by originating centre)
15-16	Hours of observational data cut-off after reference time (see Note 1)
17	Minutes of observational data cut-off after reference time
18	Indicator of unit of time range (see Code Table 4.4)
19-22	Forecast time in units defined by octet 18
23	Type of first fixed surface (see Code Table 4.5)
24	Scale factor of first fixed surface
25-28	Scaled value of first fixed surface
29	Type of second fixed surface (see Code Table 4.5)
30	Scale factor of second fixed surface
31-34	Scaled value of second fixed surface

There is one note to this product definition template:

Product Definition Template Note:

1. Hours greater than 65534 will be coded as 65534.

Octets 10 and 11 complete identification of the parameter. Recall that the identification of parameters in GRIB 2 uses a branching structure based on three parameters – Discipline, Category, and Name. Octet 7 of the Indicator Section contains the first of these three branches – Discipline via Code Table 0.0. As an example, Discipline = 0 would indicate this GRIB2 message contains Meteorological Products. Octets 10 and 11 contain the other two branches, Category and Name, respectively. Octet 10 refers to Code Table 4.1 – Category of Parameters by Product Discipline:

Code Table 4.1: Category of parameters by product discipline

Product Discipline 0: Meteorological products

Category	Description
0	Temperature
1	Moisture
2	Momentum
3	Mass
4	Short-wave Radiation
5	Long-wave Radiation
6	Cloud
7	Thermodynamic Stability indices
8	Kinematic Stability indices
9	Temperature Probabilities
10	Moisture Probabilities
11	Momentum Probabilities
12	Mass Probabilities
13	Aerosols
14	Trace gases (e.g., ozone, CO2)
15	Radar
16	Forecast Radar Imagery
17	Electro-dynamics
18	Nuclear/radiology
19	Physical atmospheric properties
20-189	Reserved
190	CCITT IA5 string
191	Miscellaneous
192-254	Reserved for local use
255	Missing

Thus, if octet 10 contains a value of 3, Code Table 4.1 indicates that for Product Discipline 0 (Meteorological Products), Category 3 is Mass. Also note that Code Table 4.1 is broken down into sections. Although only the section applicable for Product Discipline 0 – Meteorological Products – is shown above, the full Code Table 4.1 contains sections for Product Disciplines 1 (Hydrological Products), 2 (Land Surface Products), 3 (Space Products), and 10 (Oceanographic Products) as well. As more Product Disciplines are added to Code Table 0.0, appropriate sections will be added to Code Table 4.1.

Octet 11 refers to Code Table 4.2 – Parameter Number by Product Discipline and Parameter Category:

Code Table 4.2 Parameter number by product discipline and parameter category

Product Discipline 0: Meteorological products, Parameter Category 3: Mass

Number	Parameter	Units
0	Pressure	Pa
1	Pressure reduced to MSL	Pa
2	Pressure tendency	Pa s^{-1}
3	ICAO Standard Atmosphere Reference Height	m
4	Geopotential	m^2 s^{-2}
5	Geopotential height	gpm
6	Geometric height	m
7	Standard deviation of height	m
8	Pressure anomaly	Pa
9	Geopotential height anomaly	gpm
10	Density	kg m^{-3}
11	Altimeter setting	Pa
12	Thickness	m
13	Pressure altitude	m
14	Density altitude	m
15-191	Reserved	
192-254	Reserved for local use	
255	Missing	

If octet 11 contains a value of 5, then Code Table 4.2 indicates that for this product discipline and category, the parameter name is geopotential height and the units are geopotential meters. Code Table 4.2 is also broken into sections, one section for each combination of Product Discipline and Parameter Category currently defined. Each such section contains all the parameters currently defined for that particular combination of Product Discipline and Parameter Category. As one can imagine, Code Table 4.2 is already extensive and promises to grow much more over time. Nevertheless the developers of GRIB2 felt that a hierarchical system such as this will prove far easier for the user to use and the WMO to manage than a single code table eventually containing perhaps thousands of entries.

Note also the units given in the right hand column of Code Table 4.2. GRIB1 and GRIB2 both use SI Standard Units. For the convenience of the user, these units are listed in this column for each parameter in the table.

Octets 12 – 14 describe the type of process that generated the data field of geopotential height values. Code Table 4.3, referred to by octet 12, is fairly general:

Code table 4.3: Type of generating process

Code figure	Meaning
0	Analysis
1	Initialization
2	Forecast
3	Bias corrected forecast
4	Ensemble forecast
5	Probability forecast
6	Forecast error
7	Analysis error
8	Observation
9-191	Reserved
192-254	Reserved for local use
255	Missing

For example, a value of 2 in octet 12 would indicate only that a forecast generated this particular geopotential height field. However, this general description can be refined by information in octets 13 and 14 if the generating centre chooses to do so. For example, octet 14 could state what kind of forecast model generated the geopotential height forecast. Note that to understand the meaning of values in octets 13 and 14, a user of a GRIB message must to contact the originating/generating centre.

Octets 15 – 17 describe the data cut-off for the analysis or forecast used to generate this particular forecast field. This information was added to GRIB2 because it was found to be useful information that GRIB1 was not capable of describing. The Production Definition Template Note 1 indicates the largest value possible in octets 15 – 16 is 65534. Thus, the largest data cut-off value possible is 65534 hours (or 2730 days, or almost 7.5 years) after analysis time, surely adequate for almost all applications.

Octets 18 – 22 describe the time of the forecast field in a rather general way via Code Table 4.4:

Code Table 4.4: Indicator of unit of time range

Code figure	Meaning
0	Minute
1	Hour
2	Day
3	Month
4	Year
5	Decade (10 years)
6	Normal (30 years)
7	Century (100 years)
8-9	Reserved
10	3 hours
11	6 hours
12	12 hours
13	Second
14-191	Reserved
192-254	Reserved for local use
255	Missing

A forecast time of almost any length can be defined by combining the wide variety of time units with the 2 octets allowed for the value itself. For example, a forecast time of 65534 centuries, or 6,553,400 years can currently be described.

Octets 23 – 34 describe the level or layer applicable for this particular forecast field. Code Table 4.5 defines the type of fixed surface used:

Code table 4.5: Fixed surface types and units

Code Figure	Meaning	Units
0	Reserved	
1	Ground or water surface	-
2	Cloud base level	-
3	Level of cloud tops	-
4	Level of 0^{o} C isotherm	-
5	Level of adiabatic condensation lifted from the surface	-
6	Maximum wind level	-
7	Tropopause	-
8	Nominal top of the atmosphere	-
9	Sea bottom	-
10-19	Reserved	
20	Isothermal level	K
21-99	Reserved	
100	Isobaric surface	Pa
101	Mean sea level	
102	Specific altitude above mean sea level	m
103	Specified height level above ground	m
104	Sigma level	“sigma” value
105	Hybrid level	-
106	Depth below land surface	m
107	Isentropic (theta) level	K
108	Level at specified pressure difference from ground to level	Pa
109	Potential vorticity surface	$K\ m^{2}\ kg^{-1}\ s^{-1}$
110	Reserved	
111	Eta* level	-
112-116	Reserved	
117	Mixed layer depth	m
118-159	Reserved	
160	Depth below sea level	m
161-191	Reserved	
192-254	Reserved for local use	
255	Missing	

Code Table 4.5 is used to define both a level and a layer. To define a level, octets 23-28 have values and octets 29-34 are set to missing. To define a layer, octets 23-34 are all used.

2.2.3 Data Representation Templates

The purpose of the Data Representation Section is to describe how the data values contained in the next occurrence of the Data Section are represented. As with the Grid Definition and Product Definition sections, most of the information necessary to accomplish this is contained in the Data Representation Definition Template. As noted in Section 2.1.6 above, the contents of Section 5 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-nn	Data Representation Template (see Template 5.X, where X is the Data Representation Template Number given in octets 10-11)

We will assume the value in octets 10 - 11 is 0, indicating Data Representation Template 5.0 is to be used. Code Table 5.0 indicates this corresponds to grid point data - simple packing. Data Representation Template 5.0 uses octets 12 – 21 to describe this type of data representation, and what the contents of those octets are. We now insert Data Representation Template 4.0 into octets 12 - xx. The contents of the Data Representation Section then become:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)

The use of R, E, and D in grid point data - simple packing and the IEEE representation of R, as well as the organization of the Data Representation Section for other compression schemes allowed in GRIB2, are discussed in Section 2.3 of this Layer. The type of original field values is given by octet 21 and defined by Code Table 5.1:

Code Table 5.1: Type of original field values

Code figure	Meaning
0	Floating point
1	Integer
2-191	Reserved
192-254	Reserved for local use
255	Missing

Thus, it is currently possible to define only floating point or integer original field values. There is, however, ample space for other options to be added in the future.

2.2.4 Data Templates

The Data Section contains the data values themselves. As noted in Section 2.1.8 above, the contents of Section 7 are:

Octet No.	Contents
1-4	Length of section in octets (nn)

5	Number of Section ("7")
6-nn	Data in a format described by Data Template 7.X, where X is the Data Representation Template Number given in octets 10-11 of Section 5

Note the X part of the Data Template Number used in Section 7 is the same as the X part of the Data Representation Template Number given in Section 5. This is because the organization of the data values in the Data Section depends on the Data Representation Template used in Section 5. In the example given in Section 2.2.3, Data Representation Template 5.0 was used. To continue this example, Data Template 7.0 must therefore be used in Section 7, and both refer to Grid point data – simple packing. Inserting Data Template 7.0 into octets 6-nn, the contents of the Data Section become:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-nn	Binary data values – binary string, with each (scaled) value data value.

Data Template 7.0 is particularly simple. However, if Data Representation Template 5.2 had been used in the Data Representation Section, the more complicated Data Template 7.2 would have had to be used in the Data Section, and both would have referred to Grid point data – complex packing. Examples of the organization of the data section for some of the data compression schemes allowed in GRIB2 are discussed in Section 2.3 of this Layer.

2.3 GRIB2 Compression Schemes

As with GRIB1, GRIB2 represents numeric data as a series of binary digits, or bits. Such data representation is independent of any particular machine representation; by convention, data lengths are measured in octets, where an octet is a string of 8 bits. Data are coded as binary integers using the minimum number of bits required for the desired precision. Numeric values, in SI Standard Units as shown in the right hand column of Code Table 4.2, may first be scaled by a power of ten to achieve an appropriate decimal precision. A reference value may be then subtracted from them to reduce redundancy and eliminate negative numbers. They may be then be further scaled by a power of two to pack them into a pre-selected word length. The two scaling operations are independent; which, or both, are used in any given case depends upon choices made as to the method of packing. This is described in some detail later in this section.

An original data value Y (in SI Standard Units as shown in Code Table 4.2) can be recovered with the formula:

$$Y * 10^D = R + (X1 + X2) * 2^E ,$$

For simple packing

D	=	Decimal scale factor
E	=	Binary scale factor
R	=	Reference value of the whole field
X1	=	0
X2	=	Scaled (encoded) value

For complex grid point packing schemes, D, E, and R are as above, but

X1	=	Reference value (scaled integer) of the group the data value belongs to,
X2	=	Scaled (encoded) value with the group reference value (X1) removed.

The reference value R is placed in the data section as an IEEE 32-bit floating-point value, and hence occupies 4 octets. The IEEE representation of the reference value R used in GRIB2 is a departure from GRIB1, which used the standard IBM representation for a 32-bit real floating-point number. The IEEE single precision floating-point representation is specified in the standard ISO/IEC 559-1985 and ANSI/IEEE 754-1985 (R1991), which should be consulted for more details. The representation occupies four octets and is

seeeeeee emmmmmmm mmmmmmmm mmmmmmmm

where

s is the sign bit; 0 means positive, 1 negative
e…e is an 8 bit biased exponent
m…m is the mantissa, with the first bit deleted.

The following table gives the value of R:

e…e	m…m	Value of R
0	Any	$(-1)^s(m\ldots m)2^{-23}2^{-126} = (-1)^s(m\ldots m)2^{-149}$
1…254	Any	$(-1)^s(1.0 + (m\ldots m)2^{-23})2^{((e\ldots e)-127)}$
255	0	positive (s = 0) or negative (s = 1) infinity
255	>0	NaN (Not A valid Number, result of illegal operations)

Normally, only biased exponent values from 1 to 254 inclusive are used, except for positive or negative zero that are represented by setting both the biased exponent and the mantissa to 0. The numbers are stored with the high order octet first. The sign bit will be the first bit of the first octet. The low order bit of the mantissa will be the last (eighth) bit of the fourth octet.

This floating-point representation has been chosen because it is in common use in modern computer hardware. Some computers use this representation with the order of the octets reversed. They will have to convert the representation, either by reversing the octets or by computing the floating-point value directly using the above formulae.

The uses of D, E, R, X1, and X2 in the various compression schemes allowed in GRIB2 are discussed in the remainder of this section.

2.3.1 Grid Point Data - Simple Packing

As we found in Section 2.2.3, when the Grid Point Data - Simple Packing compression scheme is used, the Data Representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)

The contents of the Data Section are correspondingly:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“7”)
6-nn	Binary data values - binary string, with each (scaled) data value (X2).

Step 1: The first step, if necessary, is to convert the original field into the SI Standard Units given in the right hand column of Code Table 4.2. Some of these units may seem a little peculiar (for example, kg m^{-2} is equivalent to a water depth of 1 mm) and others may seem inappropriate (Pa for pressure, for example, implies substantially greater precision than is typical in meteorological usage, but inverse seconds are not nearly precise enough for divergence and vorticity), but they are all self-consistent. Furthermore, the precision of the parameters, as actually packed in a GRIB2 message, can be set to any desired degree through the appropriate use of the power-of-ten (“D”) scaling and the power-of-two (“E”) scaling to be described momentarily. Code Table 5.1 defines the type of original field values (Y):

Code Table 5.1: Type of original field values

Code figure	Meaning
0	Floating point
1	Integer
2-191	Reserved
192-254	Reserved for local use
255	Missing

The appropriate entry from Code Table 5.1 is stored in octet 21 of the Data Representation Section

Step 2: At this point there is a choice to be made. If it is desired to use a pre-selected number of bits (the “word” bit-length) for each of the packed variables, then just proceed on to the next step. However, if a variable number of bits are used, where the “word” bit-length is calculated to accommodate the data values, then it is necessary to undertake the power of ten, or “D”, scaling. In this case, the D value should be selected such that when the original data, in the Standard SI Units of Code Table 4.2, is multiplied by 10^D, the integer part of the result will have enough precision to contain all the appropriate information of the variable. Anticipating things a little bit, the (scaled) value will be rounded to an integer as a part of the packing process; thus the “significant part” of the value of the variable has to be moved to the left of the decimal point prior to the rounding. For example, temperature might be scaled with D = 1, thus changing the units from degrees Kelvin to tenths of degrees Kelvin. Pressure, on the other hand, might be scaled with D = -2, actually reducing the precision from Pascals to hundreds of Pascals, or HectoPascals, a more reasonable precision for meteorological use. Vorticity would be scaled up by using D = 8, and etc. The value of D selected is stored in octets 18-19 of the Data Representation Section.

Step 3: The third step in the packing operation is to scan through the field, which may or may not have been D scaled at this point, to find the minimum value of the parameter, create largest IEEE 32 bit representation value which is smaller or equal than minimum value and subtract that minimum – the reference value R – from all the data points, leaving a residual of non-negative numbers. To overcome some precision limitations of the reference value, decimal scaling should be applied if the range of the values is not significantly greater than the epsilon of the reference value (minimum difference between two values in the precision of the reference value). This step has two benefits. The first of these is convenience – making all the data points non-negative bypasses problems with different computer hardware that represent negatives in various ways. The GRIB message is rendered just that more machine independent by being non-negative throughout. The second benefit is more consequential: It can result in a substantial compression of the bulletin size without any loss of information content. If a field has an appreciable bias away from zero, the residuals formed by the minimum removal operation will all be much smaller numbers than otherwise. Thus they will need fewer bits to contain them when they are, eventually, packed as integers. The value of R is stored in octets 12-15 of the Data Representation Section.

Step 4: The fourth step begins with a simple scan through the field of non-negative residuals to find the maximum value.

At this point another choice must be made, similar to the one made previously. This time, if a calculated “word” bit-length is to be used, it is necessary to calculate how many bits are going to be needed to contain the largest data value when the latter has been rounded to an integer. Recall that at the previous decision point, the variables were D scaled such that a rounding operation will preserve all the significant part of the information. Discovering how many bits are needed is a simple scan through a table of powers of two. This number of bits - the calculated “word” bit-length - is stored in octet 20 of the Data Representation Section. Since the power of two scaling is not employed in this case, E is set equal to 0 and stored in octets 16-17 of the Data Representation Section.

If, alternatively, it is desired to use a pre-selected “word” bit-length, the data must now be scaled by a power of two (the “E” scaling) sufficient to either reduce the maximum value down to just fit into the available number of bits or enlarge the value to just fit. The latter possibility takes care of the problem of small numbers where the precision is all in the fractional part of the number. How much precision is retained for the eventual rounding is a function of the pre-selected “word” bit-length and the typical range, or maximum value with the minimum removed, of the particular variable. The choice of the pre-selected “word” bit-length (which is, of course, made ahead of time) must be made with full knowledge of the characteristics of the particular variable that is to be packed and a prior assumption of how much precision needs to be retained for the largest likely value. The pre-selected “word” bit-length is stored in octet 20 of the Data Representation Section, and the value of E is stored in octets 16-17 of the Data Representation Section.

Step 5: The fifth steps is to round all the values to integers, now that they have all been scaled to appropriate units, and pack each of them into the specified “word” bit-length. In the terminology introduced at the beginning of this section, these are the X2 values (when using simple packing, the X1 values are always zero and hence are not stored in this case), and are stored in octets 6-nn of the Data Section. If when this is completed the binary string does not end on an octet boundary, sufficient bits set to zero must be appended to the end of the binary string so that it does end on an octet boundary.

Advantages And Disadvantages of the Two Methods: We have described two alternate approaches to constructing GRIB messages: a pre-selected “word” bit-length and a calculated “word” bit-length method. The choice of which to use depends of the relative advantages and disadvantages of each method with regards to message length and precision.

Message length: the pre-selected “word” bit-length messages are always the same length for a given parameter, while the calculated “word” bit-length messages are variable. The variation is driven by the range of the value of the parameter over the field (or the maximum value), which can change from day to day. Whether variations in message length is a problem or not depends of the computer systems used to work with the GRIB messages.

Precision: The calculated “word” bit-length bulletins have affixed and unchanging precision, determined by the D scaling. This assures that the same information content is available day after day. It is straightforward to change the precision in a familiar manner, that is, simply by orders of magnitude, just by altering the D value. This comes at a cost, of course, for increasing the precision by a power of 10 adds about 3.3 bits (on average) to each data point in the message.

The pre-selected “word” bit-length messages show a variable precision which is case by case data driven and is determined by the E scaling that was used to fit the values into the available space. This can happen even with the same data, on the same date, but at adjacent grid areas. If one area shows a low variability and the neighbouring one a high variability such that a power-or-two scaling is needed in the two areas, then, unfortunately, the values on a common boundary will not be exactly equal after they are unpacked. This can be disconcerting and a cause for confusion. Note that this will not happen if only D scaling is employed. On the other hand, the variable precision can be viewed as a strength: a data field with a low variability will be encoded at a higher precision, thus preserving the character of the field; a high variability field will be represented with less precision, but that is not a problem as the small, and possibly lost, variations will not matter in the presence of the large ones. The precision of the encoded field can be increased by adding bits to the fixed “word” bit length, but the degree of change (a power of two for each bit) may not be as easy to deal with (or explain to people) as the simple order of magnitude change afforded by the D scaling method.

No matter which compression method was employed, a proper GRIB2 decoding program, one that takes account of the transmitted values of both D and E, would return the correct unpacked numbers, regardless of which packing method was employed. It would be transparent to the user except for the questions of precision outlined above.

2.3.2 Grid Point Data - Complex Packing

When the Grid Point Data - Complex Packing compression scheme is used, the relevant Data Representation Template is 5.2. It is the same as Data Representation Template 5.0 (Grid Point Data – Simple Packing) for octets 12 – 21, but contains additional information in octets 22 – 47. Upon insertion of Template 5.2, the Data Representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)

22	Group splitting method used (see Code Table 5.4)
23	Missing value management used (see Code Table 5.5)
24-27	Primary missing value substitute
28-31	Secondary missing value substitute
32-35	NG - Number of groups of data values into which field is split
36	Reference for group widths (see Note 12)
37	Number of bits used for the group widths (after the reference value in octet 36 has been removed)
38-41	Reference for group lengths (see Note 13)
42	Length increment for the group lengths (see Note 14)
43-46	True length of last group
47	Number of bits used for the scaled group lengths (after subtraction of the reference value given in octets 38-41 and division by the length increment given in octet 42)

The corresponding Data Template is 7.2. Upon insertion of Template 7.2, the Data Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-xx	NG group reference values (XI in the decoding formula), each of which is encoded using the number of bits specified in octet 20 of Data Representation Template 5.0. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[xx+1]-yy	NG group widths, each of which is encoded using the number of bits specified in octet 37 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[yy+1]-zz	NG scaled group lengths, each of which is encoded using the number of bits specified in octet 47 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary. (see Note 14 of Data Representation Template 5.2)
[zz+1]-nn	Packed values (X2 in the decoding formula), where each value is a deviation from its respective group reference value.

Before laying out where the various second order values, sub-parameters, counters, and what have you, go, it is appropriate to describe the complex packing scheme for grid point values in an algorithmic manner.

In comparison with the description of the simple packing scheme for grid point values in the previous section, the encoding method for complex packing is the same up to part way through the fifth step, after the scaled values have been rounded to scaled integers but before the scaled integers are actually packed into either pre-selected bit-length "words" or calculated bit-length "words". The basic outline of complex packing is to scan through the array of scaled integers (one per grid point, or, possibly less than that if the Bit Map Section has been employed to discard some of the null value points) and seek out sub-sections exhibiting relatively low variability. One then finds the (local) minimum value in that sub-section and subtracts it from the ("first order") integers in that sub-section, which leave a set of "second-order" integers. These numbers are than scanned to find the maximum value, which in turn is used to calculate the minimum number of bits necessary for a "word" to contain the sub-section set of second order numbers.

The term "first order" in this context refers to the integer variables that result from subtracting the overall (*global) minimum from the original variables (in Step 3) and then doing all scaling and rounding; "second order" refers to the variables that result from subtracting the local minimum from the sub-set of first order variables. No further scaling is necessary or appropriate.

The sub-section set of numbers is then packed into “words” of the just determined bit-length. The overall savings in space comes about because the second order values are, usually, smaller than their firs order counterparts. The have, after all, had two minima subtracted from the original values, the overall minimum and the local minimum, where the first order values have had only the overall minimum subtracted out. There is no guarantee, however, that the second order packing will compress a given field to a greater degree than the first order packing. If the first order field of integers is highly variable, or generally close to zero, then there will be no gain in compression. But if the field shows long runs of small variation, particularly if some of the runs are constant (zero variability), then the second order packing will contribute to the compression.

The process then repeats and a whole collection of sub-sections is found, their local minima are subtracted out, etc. One of the tricky parts of this process is defining just what is meant by a “sub-section of low variability”. The WMO Manual is silent on this as it only describes how the sub-sections and their ancillary data are to be packed in the message. A number of Meteorological Services have designed selection criteria and built them into their GRIB encoder. It is beyond the scope of this document to attempt to describe the selection criteria in any detail. However, several of these groups have expressed their willingness to share their GRIB encoders with any who ask for them. This is discussed in Section 2.6 of this Layer.

Before laying out where the second order values are placed in a message, we had best review just what information has to be saved. We need to include the following information:

1) How many sub-sections there are;
2) The treatment of missing values;
3) Where does each sub-section begin;
4) Where does each sub-section end; or, how many data points are in each sub-section;
5) What is the local minimum value (a first order value) that was found for each sub-section;
6) What is the bit width of the collection of first order values (the local minima) found for each sub-section;
7) What are the second order values for each sub-section;
8) What are the bit widths of the second order values appropriate for all the sub-sections; and finally,
9) Sufficient information to specify where the above information is located.

A moment’s consideration (OK, maybe a long moment) will satisfy the reader that the information given will be sufficient to reconstruct the original data field. Now we consider where the information needed for these points is stored in GRIB2 to satisfy Point 9.

<u>Point 1:</u> The number of sub-sections is referred to in the WMO Manual as the number of groups (NG). This value is stored in octets 32-35 of the Data Representation Section. The selection criteria used to determine the groups is documented by entering a code figure from Code Table 5.4 into octet 22 of the Data Representation Section. Currently, this code table contains only two very general categories:

Code Table 5.4: Group Splitting Method

Code figure	Meaning
0	Row by row splitting
1	General group splitting
2-191	Reserved
192-254	Reserved for local use
255	Missing

Row by row splitting is where each row of grid points is chosen to be a group. All group splitting strategies fall into the General group splitting category.

Point 2: In addition to specifying a bit map in the Bit Map Section, missing data can be managed explicitly in the Data Representation and Data Sections. This alternative permits added flexibility in the description of missing data by distinguishing between a primary missing value and a secondary missing value via reference to Code Table 5.5:

Code Table 5.5 Missing Value Management for Complex Packing

Code figure	Meaning
0	No explicit missing values included within data values
1	Primary missing values included within data values
2	Primary and secondary missing values included within data values
3-191	Reserved
192-254	Reserved for local use
255	Missing

This concept may be useful, for example, to distinguish a missing value due to a land/sea mask from a missing value for some other reason. If this approach is used, the appropriate code figure from Code Table 5.5 is entered into octet 23 of the Data Representation Section, and the primary and secondary missing value substitutes into octets 24-27 and 28-31, respectively. One way to implement the use of a primary and secondary missing value would be to define the global maximum field value +2 as the primary missing value, the global maximum field value +1 as the secondary missing value, and make appropriate adjustments.

Points 5 and 6: Once the groups have been determined as noted under Point 1) above, the smallest value in every group – the group reference value - are determined. The largest of the group reference values is then found and the number of bits required to represent it is determined. This number of bits is stored in octet 20 of the Data Representation Section. The group reference values themselves - the X1 values in the GRIB2 compression formula - are stored in octets 6 – xx of the Data Section.

Point 7 and 8: For each group, the group reference value calculated to provide the information needed to satisfy Points 5) and 6) is subtracted from the Scaled Integers calculated under Step 5 of the Simple Packing method. These are the scaled values with the reference value removed - the X2 values in the GRIB2 compression formula. They are stored in octets [zz + 1] – nn of the Data Section using the appropriate group width calculated under Point 3 below.

Points 3 and 4: Group width is defined as the number of bits used for every second-order value in a group. For each group, this is the number of bits required to represent the largest of the X2 values in that group. Group widths are calculated for all the groups in a field of grid point values. The smallest of these group widths is stored in octet 36 of the Data Representation Section. This minimum group width is then subtracted from every group width leaving an array of group width increments. The number of bits required to represent the largest of these group width (increments) is stored in octet 37 of the Data Representation Section. The group width (increments) themselves are then stored in octets [xx+1] – yy of the Data Section using the number of bits given in octet 37 of the Data Representation Section for each value.

Group length is defined as the number of values in a group. Group lengths (Ln) .can be calculated from the formula Ln = ref + Kn*len_inc, where n = 1,NG. Thus, Kn = (Ln – ref) / len_inc. The group lengths themselves (Ln) are calculated for every group in the field of grid point values. The smallest of these group lengths (ref) is then found and stored in octets 38-41 of the Data Representation Section, and len_inc is stored in octet 42 of the Data Representation Section. The Kn values - the scaled group lengths - are stored in octets [yy+1] – zz of the Data Section. Using the values of ref and len_inc from the Data Representation Section and the scaled group lengths Kn from the Data Section, the true group lengths (the Ln values) can be calculated from the formula.

Combining the group widths and the group lengths enables a computer program to calculate the beginning point and ending point of each group.

2.3.3 Grid Point Data - Complex Packing and Spatial Differencing

When the Grid Point Data - Complex Packing and Spatial Differencing compression scheme is used, the relevant Data Representation Template is 5.3. It is the same as Data Representation Template 5.2 (Grid Point Data – Complex Packing), but contains additional information in octets 48 and 49. Upon insertion of Template 5.3, the Data Representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)
22	Group splitting method used (see Code Table 5.4)
23	Missing value management used (see Code Table 5.5)
24-27	Primary missing value substitute
28-31	Secondary missing value substitute
32-35	NG - Number of groups of data values into which field is split
36	Reference for group widths (see Note 12)
37	Number of bits used for the group widths (after the reference value in octet 36 has been removed)
38-41	Reference for group lengths (see Note 13)
42	Length increment for the group lengths (see Note 14)
43-46	True length of last group
47	Number of bits used for the scaled group lengths (after subtraction of the reference value given in octets 38-41 and division by the length increment given in octet 42)
48	Order of Spatial Differencing (see Code Table 5.6)
49	Number of octets required in the Data Section to specify the extra descriptors needed for spatial differencing (octets 6-ww in Data template 7.3)

In this case, the relevant template is Data Template 7.3, which is the same as Data Template 7.2, except octets 6-xx are replaced with new information. Upon insertion of Template 7.3, the Data Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-ww	First value(s) of original (undifferenced) scaled data values, followed by the overall minimum of the differences. The number of values stored is 1 greater than the order of differentiation, and the field width is described in octet 49 of Data Representation Template 5.3
[ww+1]-xx	NG group reference values (X1 in the decoding formula), each of which is encoded using the number of bits specified in octet 20 of Data Representation Template 5.0. Bits set to zero shall be appended where necessary to ensure this sequence of numbers ends on an octet boundary.
[xx+1]-yy	NG group widths, each of which is encoded using the number of bits specified in octet 37 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[yy+1]-zz	NG scaled group lengths, each of which is encoded using the number of bits specified in octet 47 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary. (see Note 14 of Data Representation Template 5.2)
[zz+1]-nn	Packed values (X2 in the decoding formula), where each value is a deviation from its respective group reference value.

Spatial differencing is a pre-processing before group splitting at encoding time. It is intended to reduce the size of sufficiently smooth fields, when combined with a splitting scheme as described in Data Representation Template 5.2. The order of the spatial differencing is documented in octet 48 by reference to Code Table 5.6:

Code Table 5.6: Order of Spatial Differencing

Code Figure	Meaning
0	Reserved
1	First-order spatial differencing
2	Second-order spatial differencing
3-191	Reserved
192-254	Reserved for local use
255	Missing

For first order spatial differencing, an initial field of values f is replaced by a new field of values g, where $g_1 = f_1$, $g_2 = f_2 – f_1$, …, $g_n = f_n – f_{n-1}$. For second order spatial differencing, the field of values g is itself replaced by a new field of values h, where $h_1 = f_1$, $h_2 = f_2$, $h_3 = g_3 – g_2$, …, $h_n = g_n – g_{n-1}$.

Spatial differencing is a useful addition to data compression when the field is smoothly varying. However, even though a field may be smoothly varying, the scanning mode used can disrupt the efficiency of the spatial differencing scheme. For example, when using row-by-row scanning, one usually thinks of scanning row 1 from points 1 to n, then row 2 from points 1 to n, and etc. However, on a typical rectangular grid, point n of row 1 and point 1 of row 2 often have quite different values because they are physically far apart. The consequence would be a large difference at the end of each row, and this would decrease the efficiency of the compression scheme. However, recall now Code Table 3.4 discussed earlier:

Flag Table 3.4: Scanning Mode

Bit Number	Value	Meaning
1	0	Points of first row or column scan in the +i (+x) direction
	1	Points of first row or column scan in the -i (-x) direction
2	0	Points of first row or column scan in the -j (-y) direction
	1	Points of first row or column scan in the +j (+y) direction
3	0	Adjacent points in i (x) direction are consecutive
	1	Adjacent points in j (y) direction is consecutive
4	0	All rows scan in the same direction
	1	Adjacent rows scan in opposite directions
5-8		Reserved

Notes:
(1) i direction: west to east along a parallel or left to right along an X-axis
(2) j direction: south to north along a meridian, or bottom to top along a Y-axis
(3) If bit number 4 is set, the first row scan is as defined by previous flags

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The scanning mode described above would have bit 1 set to 0, bit 3 set to 0, and bit 4 set to 0. However, GRIB2 allows alternate rows to scan in opposite directions. This useful alternative, referred to as boustrophedonic scanning, is invoked by setting bit 4 to 1. As a consequence, point n in row 1 would be followed by point n in row 2, point 1 in row 2 would be followed by point 1 in row 3, and etc. The boustrophedonic scanning pattern is not permitted in GRIB1.

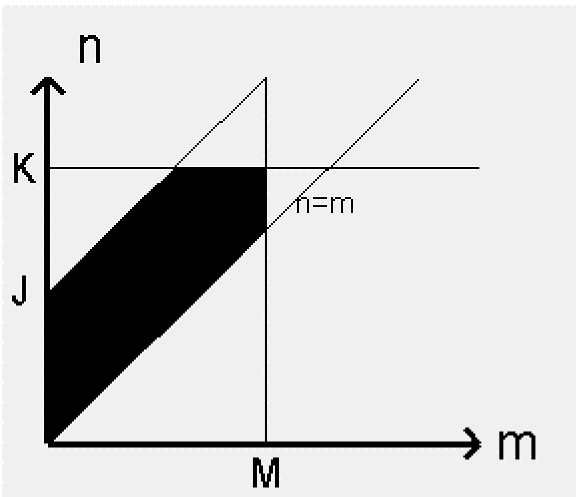
2.3.4 Spectral Truncation

Using the associated Legendre Polynomials of the First Kind, P_n^m, as expansion functions, a field $F(\lambda,\mu)$,can be represented by

$$F(\lambda,\mu) = \sum_{m=-m}^{M} \sum_{n=|m|}^{N(m)} F_n^m P_n^m(\mu) e^{im\lambda} \ ,$$

where λ is the longitude, μ is the sine of latitude, and F_n^{-m} is the complex conjugate of F_n^m.

In the summations, M is the maximum zonal wave number that is to be included, and K and J together define the maximum meridional total wave number N(m) (note that N is a function of m). A sketch shows the relationships:



In this figure, the ordinate (n) is the total meridional wave number, the abscissa (m) is the zonal wave number, the vertical line at m = M is the zonal truncation, and the diagonal passing through (0,0) is the line n = m. The Legendre Polynomials are defined only on or above this line, that is for n greater than or equal to m. On the n axis, the horizontal line at n = K indicates the upper limit to n values, and the diagonal that intersects the n-axis at n = J indicates the upper limit of the area in which the Polynomials are defined. The shaded irregular pentagon defined by the n-axis, the diagonal from n = J, the horizontal n = K, the vertical m = M, and the other diagonal n = m surrounds the region of the (n x m) plane containing the Legendre Polynomials used in the expansion.

This general pentagonal truncation reduces to some more familiar common truncations as special cases:

Triangular:	K = J = M and N(m) = J
Rhomboidal:	K = J + M and N(m) = J + m
Trapezoidal:	K = J, K > M and N(m) = J

In all of the above, m can take on negative values to represent the imaginary part of the spectral coefficients.

IN the following two sections, simple and complex packing schemes are described for spectral data, i.e., for the coefficients of the Legendre Polynomials, the complex numbers F_n^m.

2.3.5 Spectral Data – Simple Packing

The relevant Data Representation Template number for the Spectral Data – Simple Packing compression scheme is 5.50. In this case, the Data Representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value R (IEEE 32-bit floating-point value)
16-17	Binary scale factor (E)
18-19	Decimal scale factor (D)
20	Number of bits used for each packed value (field width)
21-24	Real part of the (0,0) coefficient (IEEE 32-bit floating point value)

The corresponding Data Section Template is 7.50. Using this template, the Data Section is:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“7”)
6-nn	Binary data values - binary string, with each (scaled) value data value

The real part of the F_n^m coefficient for n = m = 0 is usually much lager than all other coefficients, and is stored in the Data Representation Section as a floating-point number in the same way as the global reference value. This is intended to reduce the variability of the coefficients stored in the Data Section and consequently improve that Section’s packing efficiency. The imaginary part of the F_n^m coefficient for n = m = 0 is always zero and therefore not stored. The remaining complex numbers F_n^m are stored in the Data Section as pairs of real numbers Re (F_n^m), Im(F_n^m) ordered with n increasing from m to N(m) for m = 1, 2, …, M.

2.3.6 Spectral Data – Complex Packing

The relevant Data Representation Template number for the Spectral Data – Complex Packing compression scheme is 5.51. Template 5.51 is the same as Template 5.50 for octets 12-20, but contains different information in octets 21-24 and additional information in octets 25-35. In this case, the Data Representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("5")
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value R (IEEE 32-bit floating-point value)
16-17	Binary scale factor (E)
18-19	Decimal scale factor (D)
20	Number of bits used for each packed value (field width)
21-24	P – Laplacian scaling factor (expressed in 10^{-6} units)
25-26	J_s – pentagonal resolution parameter of the unpacked subset (see Note 1)
26-28	K_s – pentagonal resolution parameter of the unpacked subset (see Note 1)
29-30	M_s – pentagonal resolution parameter of the unpacked subset (see Note 1)
31-34	T_s - total number of values in the unpacked subset
35	Precision of the unpacked subset (see Code Table 5.7)

Notes:

(1) The unpacked subset is a set of values defined in the same way as the full set of values (on a spectrum limited to J_s, K_s, and M_s), but on which scaling and packing are not applied. Associated values are stored in octets 6 onwards of Section 7.

(2) The remaining coefficients are multiplied by $(n*(n+1))^p$, scaled and packed. The operator associated with this multiplication is derived from the Laplacian operator on the sphere

(3) The retrieval formula for a coefficient of wave number n is then:

$$Y = (R+X2*2^E)*10^{-D}*(n*(n+1))^{-P}$$

where X2 is the packed scaled value associated with the coefficient.

The corresponding Data Section Template is 7.51. Using this template, the Data Section is:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-(5+I*T_s)	Data values from the unpacked subset (IEEE floating-point values on I octets)
(6-+I*T_s)-nn	Binary data values - binary string, with each (scaled) value data value out of the unpacked subset

Notes:

(1) Values ordering within the unpacked subset is defined according the source of the grid definition associated with the data

(2) The number of octets associated with each value of the unpacked subset (I) is defined in Code Table 5.7, according to the actual value in octet 35 of Data Representation Template 5.1

(3) Values ordering within the packed data is done according to the source of grid definition, skipping the values processed in the unpacked subset

When complex packing is used, a subset of values is stored in the data section unpacked (the unpacked subset), i.e., stored as floating-point numbers. GRIB2 allows these floating- point numbers to be stored at several levels of precision determined by a value from Code Table 5.7 and stored in octet 35 of the Data Representation Section:

Code Table 5.7: Precision of floating-point numbers

Code figure	Meaning
0	Reserved
1	IEEE 32-bit (I=4 in Section 7)
2	IEEE 64-bit (I=8 in Section 7)
3	IEEE 128-bit (I=16 in Section 7)
4-254	Reserved
255	Missing

The remaining coefficients are multiplied by $(n*(n+1))^p$, scaled and packed. The operator associated with this multiplication is derived from the Laplacian operator on the sphere. These coefficients must be retrieved using the special retrieval formula given in Note 3 to Data Representation Template 5.51. The order of storing the scaled and packed values is the same as the storing under simple packing, but with the values from the unpacked subset skipped.

2.4 The Structure of GRIB2 Messages

To get better picture of what a GRIB2 message actually looks like we now provide two examples. Both contain a 500 hPa geopotential height forecast on a 5 X 5 Northern Hemisphere polar stereographic grid with a 100 KM grid increment in both the X and Y directions. The 25 geopotential height values range from a minimum of 5340 geopotential meters (gpm) to a maximum of 5460 gpm for all forecast(s) included. While perhaps not very realistic, the examples are chosen to illustrate a real GRIB2 message in a minimum number of octets.

2.4.1 Structure of A GRIB2 Message with One Data Set

The first sample GRIB2 message contains a hypothetical 12-hour 500 hPa geopotential height forecast. The example incorporates many of the features described previously in the discussions of the sections, templates, and compression schemes.

Before presenting the example, however, a brief description of packing the hypothetical values will be useful. The grid point data – simple packing scheme is used in this example. The logic of the packing process is as follows:

Step 1: The values are in geopotential meters (gpm). This is an SI unit, so no unit conversion is needed.

Step 2: The calculated “word” bit-length method will be chosen. Since the grid point values in this hypothetical forecast range from a minimum of 5340 gpm to a maximum of 5460 gpm and since decimal scaling with a D value of 1 is chosen, the scaled values range from 53400 to 54600.

Step 3: The global reference value is therefore 53400. Subtracting this reference value from all the individual values, the residuals range from 0 to 1200.

Step 4: Since the calculated “word” bit-length method is used, we refer to a table of 2’s and find that the maximum residual of 1200 can be described by a “word” with a length of 11 bits. This number of bits - the calculated “word” bit-length - is stored in octet 20 of the Data Representation Section.

Step 5: All residuals are pack into “words” 11 bits long. Since there are 25 values to be encoded in the Data Section, this will require a bit string 275 bits long, equivalent to 34 octets plus 3 more bits. However, this would mean the Data Section would be 5 bits short of ending on an octet boundary. Therefore, 5 additional bits set to zero are appended to the bit- string, bringing it to an even 35 octets in length.

The full GRIB2 message is presented below. Blank lines have been inserted between each section to improve readability. These blank lines would not, of course, appear in the actual GRIB2 message.

Section Octet No.	Message Octet No.	Value	Meaning
1-4	1-4	GRIB	"GRIB" (coded according to the International Alphabet No. 5)
5-7	5-7	All 1's	Reserved
7	7	0	This GRIB2 message contains meteorological products (the product discipline)
8	8	2	The GRIB Edition Number is 2
9-16	9-16	207	The total length of this GRIB message is 207 octets
1-4	17-20	21	This Section is 21 octets long
5	21	1	This is Section 1
6-7	22-23	74	The originating/generating centre is the U.K. Meteorological Office
8-9	24-25	0	There is no originating/generating sub-centre
10	26	1	GRIB Master Tables Version Number 1 is used
11	27	0	No GRIB Local Tables are used
12	28	1	The Reference Time is the start of the forecast
13-14	29-30	2003	Year = 2003 |
15	31	5	Month = April |
16	32	1	Day = 1 | Reference time of data
17	33	0	Hour = 0 |
18	34	0	Minute = 0 |
19	35	0	Second = 0 |
20	36	0	This GRIB2 message contains operational products
21	37	1	This GRIB2 message contains forecast products
1-4	38-41	65	This Section is 65 octets long
5	42	3	This is Section 3
6	43	0	This grid is specified in Code Table 3.1
7-10	44-47	25	There are 25 data points in this grid
11	48	0	There is no optional list of numbers defining number of points
12	49	0	Since there is no optional list of numbers, no interpretation is needed
13-14	50-51	20	The Grid Definition Template Number is 3.20 – a polar stereographic projection
15	52	1	The earth is assumed to be spherical with radius specified by the data producer
16	53	3	The scale factor for the radius of the spherical earth is 3
17-20	54-57	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	68	all 1's	There is no scale factor for the major axis of an oblate spheroid earth

22-25	59-62	all 1’s	There is no scaled value for the major axis of an oblate spheroid earth
26	63	all 1’s	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	64-67	all 1’s	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	68-71	5	There are 5 points along the X-axis (Nx)
35-38	72-75	5	There are 5 points along the Y-axis (Ny)
39-42	76-79	40000001	The latitude of the first grid point is 40.000001 ^{0} north (La1)
43-46	80-83	349999999	The longitude of the first grid point is 349.999999 ^{0} east (or 10.000001 ^{0} west) (Lo1)
47	84	00000000	No resolution and component flag are turned on(see flag table 3.3 and Note 1)
48-51	85-88	40000001	Dx and Dy are specified at 40.000001 0 north ((LaD)
52-55	89-92	0	The 0 degree meridian is parallel to the Y-axis (LoV)
56-59	93-96	100000000	The X direction grid length is 100.000 km (Dx)
60-63	97-100	100000000	The Y direction grid length is 100.000 km (Dy)
64	101	00	The north pole is on the projection plane and only one projection centre is used
65	102	01000000	Points scan in the +i (+x) direction, rows in the +j (+Y) direction, adjacent points in the (x) direction are consecutive, and all rows scan in the same direction
1-4	103-106	34	This Section is 34 octets long
5	107	4	This is Section 4
6-7	108-109	0	There are no coordinate values after the Product Definition Template
8-9	110-111	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	112	3	The parameter category is 3 – mass products
11	113	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	114	2	A forecast generated this product (the generating process)
13	115	All 1’s	No information on the background generating process is provided
14	116	All 1’s	No further information on the forecast generating process is provided
15-16	117-118	3	The observational data cut-off was 3 hours after the reference time
17	119	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	120	1	The time is given in hours
19-22	121-124	12	The forecast time is 12 hours after the reference time
23	125	100	The first fixed surface is a pressure surface
24	126	0	The scale factor of first fixed surface is 0
25-28	127-130	500	The scaled value of first fixed surface is 500 (500 hPa)
29	131	All 1’s	There is no second fixed surface
30	132	All 1’s	The scale factor of the second fixed surface is missing since it is not needed
31-34	133-136	All 1’s	The scaled value of the second fixed surface is missing since it is not needed

1-4	137-140	21	This Section is 21 octets long
5	141	5	This is Section 5
6-9	142-145	25	There are 25 data points for which values are specified in Section
10-11	146-147	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	148-151	53400	The reference value (R) is 53400.0 (IEEE 32-bit floating-point value)
16-17	152-153	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	154-155	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	156	11	11 bits are used for each packed value in the Data Section
21	157	0	The original field values were floating point numbers
1-4	158-161	6	This Section is 6 octets long
5	162	6	This is Section 6
6	163	0	There is no bit-map
1-4	164-167	40	This Section is 40 octets long
5	168	7	This is Section 7
6-40	169-203	25 scaled integers, last 5 bits set to 0	25 binary data values, each using 11 bits. The binary values thus occupy 275 bits 5 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	204-207	7777	“7777” coded according to the International Alphabet No. 5

2.4.2 Structure of A GRIB2 Message with Multiple Data Sets

The second sample GRIB2 message contains 4 hypothetical 500 hPa geopotential height forecasts, for forecast hours 12, 24, 36, and 48, as might be contained on a typical four-panel graphic product. All other features from the first example are unchanged, including the maximum and minimum geopotential values for each forecast hour (although the other 23 values would, of course, be different). These four fields are represented by a single GRIB2 message by repeating the sequence of Sections 4 to 7 four times, making the appropriate forecast time changes in the Product Definition Section in each iteration of the sequence.

The full GRIB2 message is presented below. As before, blank lines have been inserted between each section to improve readability. These blank lines would not, of course, appear in the actual GRIB2 message. Also, the modified lines of the Product Definition Section (to change the forecast hour) and Data Section (to insert the new data field) are typed in bold letters to increase readability.

Section Octet No.	Message Octet No.	Value	Meaning	
1-4	1-4	GRIB	“GRIB” (coded according to the International Alphabet No. 5)	
5-7	5-7	All 1’s	Reserved	
7	7	0	This GRIB2 message contains meteorological products (the product discipline)	
8	8	2	The GRIB Edition Number is 2	
9-16	9-16	511	The total length of this GRIB message is 511 octets	
1-4	17-20	21	This Section is 21 octets long	
5	21	1	This is Section 1	
6-7	22-23	74	The originating/generating centre is the U.K. Meteorological Office	
8-9	24-25	0	There is no originating/generating sub-centre	
10	26	1	GRIB Master Tables Version Number 1 is used	
11	27	0	No GRIB Local Tables are used	
12	28	1	The Reference Time is the start of the forecast	
13-14	29-30	2003	Year = 2003	
15	31	5	Month = April	
16	32	1	Day = 1	Reference time of data
17	33	0	Hour = 0	
18	34	0	Minute = 0	
19	35	0	Second = 0	
20	36	0	This GRIB2 message contains operational products	
21	37	1	This GRIB2 message contains forecast products	
1-4	38-41	65	This Section is 65 octets long	
5	42	3	This is Section 3	
6	43	0	This grid is specified in Code Table 3.1	
7-10	44-47	25	There are 25 data points in this grid	
11	48	0	There is no optional list of numbers defining number of points	
12	49	0	Since there is no optional list of numbers, no interpretation is needed	
13-14	50-51	20	The Grid Definition Template Number is 3.20 – a polar stereographic projection	
15	52	1	The earth is assumed to be spherical with radius specified by the data producer	
16	53	3	The scale factor for the radius of the spherical earth is 3	
17-20	54-57	6350000	The scaled value of the radius of the spherical earth is 6350000 km	
21	58	all 1’s	There is no scale factor for the major axis of an oblate spheroid earth	

22-25	59-62	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	63	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	64-67	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	68-71	5	There are 5 points along the X-axis (Nx)
35-38	72-75	5	There are 5 points along the Y-axis (Ny)
39-42	76-79	40000001	The latitude of the first grid point is 40.000001 ^{0} north (La1)
43-46	80-83	349999999	The longitude of the first grid point is 349.999999 ^{0} east (or 10.000001 ^{0} west) (Lo1)
47	84	00000000	No resolution and component flag are turned on(see flag table 3.3 and Note 1)
48-51	85-88	40000001	Dx and Dy are specified at 40.000001 0 north ((LaD)
52-55	89-92	0	The 0 degree meridian is parallel to the Y-axis (LoV)
56-59	93-96	100000000	The X direction grid length is 100.000 km (Dx)
60-63	97-100	100000000	The Y direction grid length is 100.000 km (Dy)
64	101	00	The north pole is on the projection plane and only one projection centre is used
65	102	01000000	Points scan in the +i (+x) direction, rows in the +j (+Y) direction, adjacent points in the (x) direction are consecutive, and all rows scan in the same direction
1-4	104-107	34	This Section is 34 octets long
5	108	4	This is Section 4
6-7	109-110	0	There are no coordinate values after the Product Definition Template
8-9	111-112	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	113	3	The parameter category is 3 – mass products
11	114	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	115	2	A forecast generated this product (the generating process)
13	116	All 1's	No information on the background generating process is provided
14	117	All 1's	No further information on the forecast generating process is provided
15-16	118-119	3	The observational data cut-off was 3 hours after the reference time
17	120	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	121	1	The time is given in hours
19-22	122-125	12	The forecast time is 12 hours after the reference time
23	126	100	The first fixed surface is a pressure surface
24	127	0	The scale factor of first fixed surface is 0
25-28	128-131	500	The scaled value of first fixed surface is 500 (500 hPa)
29	132	All 1's	There is no second fixed surface
30	133	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	134-136	All 1's	The scaled value of the second fixed surface is missing since it is not needed

1-4	137-140	21	This Section is 21 octets long
5	141	5	This is Section 5
6-9	142-145	25	There are 25 data points for which values are specified in Section
10-11	146-147	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	148-151	5340	The reference value (R) is 5240.0 (IEEE 32-bit floating-point value)
16-17	152-153	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	154-155	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	156	11	11 bits are used for each packed value in the Data Section
21	157	0	The original field values were floating point numbers
1-4	158-161	6	This Section is 6 octets long
5	162	6	This is Section 6
6	163	0	There is no bit-map
1-4	164-167	40	This Section is 40 octets long
5	168	7	This is Section 7
6-40	169-203	25 scaled integers, last 5 bits set to 0	25 binary data values, each using 11 bits. The values thus occupy 275 bits . 4 additional bits set to zero are necessary for the section to end on an octet boundary.
1-4	204-207	34	This Section is 34 octets long
5	208	4	This is Section 4
6-7	209-210	0	There are no coordinate values after the Product Definition Template
8-9	211-212	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	213	3	The parameter category is 3 – mass products
11	214	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	215	2	A forecast generated this product (the generating process)
13	216	All 1's	No information on the background generating process is provided
14	217	All 1's	No further information on the forecast generating process is provided
15-16	218-219	3	The observational data cut-off was 3 hours after the reference time
17	220	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	221	1	The time is given in hours
19-22	**222-225**	**24**	**The forecast time is 24 hours after the reference time**
23	226	100	The first fixed surface is a pressure surface

24	227	0	The scale factor of first fixed surface is 0
25-28	228-231	500	The scaled value of first fixed surface is 500 (500 hPa)
29	232	All 1's	There is no second fixed surface
30	233	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	234-237	All 1's	The scaled value of the second fixed surface is missing since it is not needed
1-4	238-241	21	This Section is 21 octets long
5	242	5	This is Section 5
6-9	243-246	25	There are 25 data points for which values are specified in Section
10-11	247-248	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	249-252	5340	The reference value (R) is 5240.0 (IEEE 32-bit floating-point value)
16-17	253-254	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	255-2456	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	257	11	11 bits are used for each packed value in the Data Section
21	258	0	The original field values were floating point numbers
1-4	259-262	6	This Section is 6 octets long
5	263	6	This is Section 6
6	264	0	There is no bit-map
1-4	265-268	40	This Section is 40 octets long
5	269	7	This is Section 7
6-40	**270-304**	**25 scaled integers, 25 binary data values, each using 11 bits. The values thus occupy 275 bits .**	
		last 5 bits set to 0	5 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	305-308	34	This Section is 34 octets long
5	309	4	This is Section 4
6-7	310-311	0	There are no coordinate values after the Product Definition Template
8-9	312-313	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	314	3	The parameter category is 3 – mass products
11	315	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	316	2	A forecast generated this product (the generating process)
13	317	All 1's	No information on the background generating process is provided
14	318	All 1's	No further information on the forecast generating process is provided
15-16	319-320	3	The observational data cut-off was 3 hours after the reference time

17	321	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	322	1	The time is given in hours
19-22	**323-326**	**36**	**The forecast time is 36 hours after the reference time**
23	327	100	The first fixed surface is a pressure surface
24	328	0	The scale factor of first fixed surface is 0
25-28	329-332	500	The scaled value of first fixed surface is 500 (500 hPa)
29	333	All 1's	There is no second fixed surface
30	334	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	335-338	All 1's	The scaled value of the second fixed surface is missing since it is not needed
1-4	339-342	21	This Section is 21 octets long
5	343	5	This is Section 5
6-9	344-347	25	There are 25 data points for which values are specified in Section
10-11	348-349	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	350-353	5340	The reference value (R) is 5240.0 (IEEE 32-bit floating-point value)
16-17	354-355	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	356-357	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	358	11	11 bits are used for each packed value in the Data Section
21	359	0	The original field values were floating point numbers
1-4	361-364	6	This Section is 6 octets long
5	365	6	This is Section 6
6	366	0	There is no bit-map
1-4	367-370	40	This Section is 40 octets long
5	371	7	This is Section 7
6-40	**372-406**	**25 scaled integers, 25 binary data values, each using 11 bits. The values thus occupy 275 bits .**	
		last 5 bits set to 0	5 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	407-410	34	This Section is 34 octets long
5	411	4	This is Section 4
6-7	412-413	0	There are no coordinate values after the Product Definition Template
8-9	414-415	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	416	3	The parameter category is 3 – mass products

11	417	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	418	2	A forecast generated this product (the generating process)
13	419	All 1's	No information on the background generating process is provided
14	420	All 1's	No further information on the forecast generating process is provided
15-16	421-422	3	The observational data cut-off was 3 hours after the reference time
17	423	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	424	1	The time is given in hours
19-22	**425-428**	**48**	**The forecast time is 48 hours after the reference time**
23	429	100	The first fixed surface is a pressure surface
24	430	0	The scale factor of first fixed surface is 0
25-28	431-434	500	The scaled value of first fixed surface is 500 (500 hPa)
29	435	All 1's	There is no second fixed surface
30	436	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	437-440	All 1's	The scaled value of the second fixed surface is missing since it is not needed
1-4	441-444	21	This Section is 21 octets long
5	445	5	This is Section 5
6-9	446-449	25	There are 25 data points for which values are specified in Section
10-11	450-451	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	452-455	5340	The reference value (R) is 5240.0 (encoded as an IEEE 32-bit floating-point value)
16-17	456-457	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	458-459	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	460	11	11 bits are used for each packed value in the Data Section
21	461	0	The original field values were floating point numbers
1-4	462-465	6	This Section is 6 octets long
5	466	6	This is Section 6
6	467	0	There is no bit-map
1-4	468-471	40	This Section is 40 octets long
5	472	7	This is Section 7
6-40	**472-507**	**25 scaled integers, 25 binary data values, each using 11 bits. The values thus occupy 275 bits .**	
		last 5 bits set to 0	5 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	508-511	7777	"7777" coded according to the International Alphabet No. 5

2.5 Uses of GRIB2 Messages

Perhaps the best way to assess the potential uses for GRIB2 is to review the current contents of the relevant code tables. We begin by extracting from Code Table 4.0 – Product Definition Template Number – all currently defined Product Definition Templates. There are a total of 19:

Currently Defined Product Definition Templates

No.	Name
0	Analysis or forecast at a horizontal level or in a horizontal layer at a point in time
1	Individual ensemble forecast, control and perturbed, at a horizontal level or in a horizontal layer at a point in time
2	Derived forecast based on all ensemble members at a horizontal level or in a horizontal layer at a point in time
3	Derived forecasts based on a cluster of ensemble members over a rectangular area at a horizontal level or in a horizontal layer at a point in time
4	Derived forecasts based on a cluster of ensemble members over a circular area at a horizontal level or in a horizontal layer at a point in time
5	Probability forecasts at a horizontal level or in a horizontal layer at a point in time
6	Percentile forecasts at a horizontal level or in a horizontal layer at a point in time
7	Analysis or forecast error at a horizontal level or in a horizontal layer at a point in time
8	Average, accumulation, extreme values or other statistically processed values at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
9	Probability forecasts at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
10	Percentile forecasts at a horizontal level or in a horizontal layer in a continuous or non-continuous time interval
20	Radar product
30	Satellite product
254	CCITT IA5 character string
1000	Cross section of analysis and forecast at a point in time
1001	Gross section of averaged or otherwise statistically processed analysis or forecast over a range of time
1002	Cross section of analysis and forecast, averaged or otherwise statistically processed
1100	Hovmöller-type grid with no averaging or other statistical processing
1101	Hovmöller-type grid with averaging or other statistical processing

Most of these templates describe a wide variety of individual products. For example, Product Definition Template 4.0 - Analysis or forecast at a horizontal level or in a horizontal layer at a point in time – permits description of a wide variety of individual products via the currently defined combinations of Product Discipline (from Code Table 0.0), Product Category (from Code Table 4.1), and Product Name (from Code Table 4.2). Code Table 4.2 is rather long for reproduction in its entirety here. Nevertheless, a feeling for the types of individual products can be obtained by extracting the currently defined Product Disciplines and Categories from Code Tables 0.0 and 4.1, respectively:

Currently Defined Product Disciplines

No.	Name
0	Meteorological products
1	Hydrological products
2	Land surface products
3	Space products
10	Oceanographic products

Currently Defined Product Categories

Product Discipline 0: Meteorological products

No.	Category
0	Temperature
1	Moisture
2	Momentum
3	Mass
4	Short-wave Radiation
5	Long-wave Radiation
6	Cloud
7	Thermodynamic Stability indices
8	Kinematic Stability indices
9	Temperature Probabilities
10	Moisture Probabilities
11	Momentum Probabilities
12	Mass Probabilities
13	Aerosols
14	Trace gases (e.g., ozone, CO2)
15	Radar
16	Forecast Radar Imagery
17	Electro-dynamics
18	Nuclear/radiology
19	Physical atmospheric properties
190	CCITT IA5 string
191	Miscellaneous

Product Discipline 1: Hydrological products

No.	Category
0	Hydrology basic products
1	Hydrology probabilities

Product Discipline 2: Land surface products

No.	Category

0 Vegetation/Biomass
1 Agri-aquacultural Special Products
2 Transportation-related Products
3 Soil Products

Product Discipline 3: Space Products

No.	Category
0	Image format products (see Note 1)
1	Quantitative products (see Note 2)

Product Discipline 10: Oceanographic products

No.	Category
0	Waves
1	Currents
2	Ice
3	Surface Properties
4	Sub-surface Properties

For each of the above Product Categories, there is a Table for Product Names permitting up to 255 entries, of which entries 0-191 are internationally coordinated and entries 192-254 are reserved for local use.

Finally, a wide variety of grid projections are available for use with these individual products. The grid projections currently defined in Code Table 3.1 are:

Currently Defined Grid Definition Templates

No.	Name
0	Latitude/longitude
1	Rotated latitude/longitude
2	Stretched latitude/longitude
3	Stretched and rotated latitude/longitude
10	Mercator
20	Polar stereographic
30	Lambert Conformal
40	Gaussian latitude/longitude
41	Rotated Gaussian latitude/longitude
42	Stretched Gaussian latitude/longitude
43	Stretched and rotated Gaussian latitude/longitude
50	Spherical harmonic coefficients
51	Rotated spherical harmonic coefficients
52	Stretched spherical harmonic coefficients
53	Stretched and rotated spherical harmonic coefficients
90	Space view perspective orthographic.
100	Triangular grid based on an icosahedron
110	Equatorial azimuthal equidistant projection
120	Azimuth-range projection
1000	Cross-section grid, with points equally spaced on the horizontal
1100	Hovmöller diagram grid, with points equally spaced on the horizontal
1200	Time section grid

Recall that if some product, grid, or data representation scheme you might need is not yet defined, GRIB2 can probably accommodate your requirements. You need only to follow the procedures outlined in Section 1.3 - Updating the Code Form. It is hopefully clear by now that the developers of GRIB2 have made every effort to allow generous table space for such future expansion.

2.6 Available GRIB2 Software *(updated February 2003)*

NCEP (USA) has both a Fortran 90 and C version of an encoder/decoder. An experimental project (called National Digital Forecast Database) managed by NWS/TDL makes use of GRIB2, with a participation from NCEP.

ECMWF should start migration to GRIB2 and provide EPS probabilities on the GTS in 2003. A decoder will be available to decode these products.

JMA has separate encoder for specific generated products and decoder for limited products, and an extra package will be developed for domestic use of products of very short range forecast on precipitation. Provision of 3 and 6 months ensemble forecast products should start next autumn for national and international users. New products in field form would be considered in GRIB edition 2.

EUMETSAT is generating Cloud mask products in GRIB2. Satellite images will also be available in GRIB 2. A decoder for this type of data is available to user at request. It is still to be included in the PUMA work-station.

Layer 3: Detailed Description of GRIB2

3.1 Quasi-regular Grids

Use of quasi-regular grids is one of the special cases alluded to in the discussion of the Grid Definition Section in Section 2.1.4 of Layer 2. Now this special case will be described in some detail. Let us begin by recalling that the contents of Section 3 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("3")
6	Source of grid definition (see Code Table 3.0 and Note 1)
7-10	Number of data points
11	Number of octets for optional list of numbers defining number of points (see Note 2)
12	Interpretation of list of numbers defining number of points (see Code Table 3.11)
13-14	Grid Definition Template Number (N) (see Code Table 3.1)
15-xx	Grid Definition Template (see Template 3.N, where N is the Grid Definition Template Number given in octets 13-14)
[xx+1]-nn	Optional list of numbers defining number of points (see Notes 2, 3, and 4)

Notes:

1. If octet 6 is not zero, octets 15-xx (15-nn if octet 11 is zero) may not be supplied. This should be documented with all bits set to 1 (missing value) in the Grid Definition Template Number.

2. An optional list of numbers defining the number of points is used to document a quasi-regular grid, where the number of points may vary from one row to another (row being defined as adjacent points in a coordinate line, so this is dependent on the data layout). In such a case, octet 11 is non-zero, and gives the number of octets on which each number of points is encoded. For all other cases, such as regular grids, octets 11 and 12 are zero and no list is appended to the Grid Definition Template.

3. If a list of numbers defining the number of points is present, it is appended at the end of the Grid Definition Template (or directly after the Grid Definition Template Number if the template is missing), and the length of the list is given by the grid definition. When the Grid Definition Template is present, the length is given according to bit 3 of the scanning mode flag octet (the length is N_j or N_y for flag value 0). List ordering is implied by data scanning.

4. Depending on the code value given in octet 12, the list of numbers defining the number of points corresponds either to the coordinate lines as given in the grid definition, or to a full circle.

The quasi-regular grid option is used with latitude-longitude grids. To facilitate this discussion, let us first consider a 10^o X 10^o latitude-longitude grid (Grid Definition Template 3.0) without using the quasi-regular grid option. The contents of the Grid Definition Section in this case would be:

Section Octet No.	Message Octet No.	Value	Meaning
1-4	38-41	72	This Section is 72 octets long
5	42	3	This is Section 3
6	43	0	This grid is specified in Code Table 3.1
7-10	44-47	25	There are 25 data points in this grid
11	48	0	There is no optional list of numbers defining the number of points
12	49	0	Since there is no optional list of numbers, no interpretation is needed
13-14	50-51	1	The Grid Definition Template Number is 3.1 a latitude-longitude grid
15	52	1	The earth is assumed to be spherical with radius specified by the data producer
16	53	3	The scale factor for the radius of the spherical earth is 3
17-20	54-57	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	58	all 1's	There is no scale factor for the major axis of an oblate spheroid earth
22-25	59-62	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	63	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	64-67	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	68-71	36	There are 36 points along a parallel (Ni)
35-38	72-75	19	There are 19 points along a meridian (Nj)
39-42	76-79	0	The basic angle of all latitudes and longitudes is 1 degree
43-46	80-83	all 1's	The unit of the basic angle of all latitudes and longitudes is 10^{-6} degrees
47-50	84-87	90000000	The latitude of the first grid point (La1) is –90.000000$^{o.}$ Bit 1 is set to 1 to indicate negative (south) latitude.
51-54	88-91	0000000	The longitude of the first grid point (Lo1) is 0.000000^{o}
55	92	00111000	I and j direction increments are given. Resolved u- and v- components of vector quantities are relative to the defined grid in the direction of increasing x and y coordinates respectively.
56-59	93-96	90000000	The latitude of the last grid point is +90.000000^{o}
60-63	97-100	350000000	The longitude of the last grid point is +350.000000^{o}
64-67	101-104	10000000	The i direction increment is 10.000000^{o}
68-71	105-108	10000000	The j direction increment is 10.000000^{o}
72	109	01000000	Points in the first row scan in the +I (+x) direction. Points in the first column scan in the +j (+y) direction. Resolved u- and v- components of vector quantities are relative to easterly and northerly directions.

Now, let us consider the changes that would be needed to the above Grid Definition Section to indicate that there are 36 points along the equator, but that the number of points in each grid row away from the equator is reduced by 1. I.e., the rows of grid points along 10^o north and south would have 35 points, the rows of grid points along 20^o north and south would have 34 points, and etc.

This change will require an optional list of numbers defining the number of points in each grid row. In this case, octet 11 is not zero, but gives the number of octets on which each number of points is encoded. Since the largest number of points is 36, one octet will be sufficient, so octets 11 will contain the value 1.

Code Table 3.11 gives the interpretation of the numbers in the list:

Code table 3.11 Interpretation of list of numbers defining number of points

<u>Code figure</u>	<u>Meaning</u>
0	There is no appended list
1	Numbers define number of points corresponding to full coordinate circles (i.e. parallels), coordinate values on each circle are multiple of the circle mesh, and extreme coordinate values given in grid definition (i.e. extreme longitudes) may not be reached in all rows
2	Numbers define number of points corresponding to coordinate lines delimited by extreme coordinate values given in grid definition (i.e. extreme longitudes) which are present in each row
3-254	Reserved
255	Missing

In this case, the numbers correspond to full coordinate circles (i.e., parallels) coordinate values on each circle are multiple of the circle mesh, and extreme coordinate values given in grid definition may not be reached in all rows. Therefore, the number 1 is encoded in octet 12.

Finally, the list of numbers itself is encoded following Grid Definition Template 3.1. The length of the list of numbers is either Ni (contained in octets 31-34) if bit 3 of octet 72 (Scanning mode) is 1 or Nj (contained in octets 35-38) is bit 3 of octet 72 is 0. In this example, bit 3 of octet 72 is zero, indicating the adjacent points in the i (x) direction are consecutive. Thus, the number of values is given by octets 35-38 (Nj – the number of rows of grid points), or 19 in this case. Since there are 19 numbers and each number occupies 1 octet, there will be 19 additional octets in the Grid Definition Section.

With these changes, the Grid Definition Section becomes (modified lines are typed in **bold**):

Section Octet No.	Message Octet No.	Value	Meaning
1-4	38-41	91	This Section is 91 octets long
5	42	3	This is Section 3
6	43	0	This grid is specified in Code Table 3.1
7-10	44-47	684	There are 684 data points in this grid
11	**48**	**1**	**There is an optional list of numbers defining the number of points. Each of the numbers occupies 1 octet.**
12	**49**	**1**	**Numbers define number of points corresponding to full coordinate circles (i.e. parallels), coordinate values on each circle are multiple of the circle mesh, and extreme coordinate values given in the grid definition (i.e. extreme longitudes) may not be reached in all rows.**
13-14	50-51	1	The Grid Definition Template Number is 3.1 a latitude-longitude grid
15	52	1	The earth is assumed to be spherical with radius specified by the data producer
16	53	3	The scale factor for the radius of the spherical earth is 3
17-20	54-57	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	58	all 1's	There is no scale factor for the major axis of an oblate spheroid earth
22-25	59-62	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	63	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	64-67	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	68-71	36	There are 36 points along a parallel (Ni)
35-38	72-75	19	There are 19 points along a meridian (Nj)
39-42	76-79	0	The basic angle of all latitudes and longitudes is 1 degree
43-46	80-83	all 1's	The unit of the basic angle of all latitudes and longitudes is 10^{-6} degrees
47-50	84-87	90000000	The latitude of the first grid point (La1) is –90.000000^{o}. Bit 1 is set to 1 to indicate negative (south) latitude.
51-54	88-91	0000000	The longitude of the first grid point (Lo1) is +0.000000^{o}
55	92	00111000	I and j direction increments are given. Resolved u- and v- components of vector quantities are relative to the defined grid in the direction of increasing x and y coordinates respectively.
56-59	93-96	90000000	The latitude of the last grid point is +90.000000^{o}
60-63	97-100	35000000	The longitude of the last grid point is +350.000000^{o}
64-67	101-104	10000000	The i direction increment is 10.000000^{o}

68-71	105-108	10000000	The j direction increment is 10.000000^{o}
72	109	01000000	Points in the first row scan in the +I (+x) direction. Points in the first column scan in the +j (+y) direction. Resolved u- and v- components of vector quantities are relative to easterly and northerly directions.
73-91	**110-128**	**27, 28, 29, 30 31, 32, 33, 34 35, 36, 35, 34 33, 32, 31, 30 29, 28, 27**	**Number of points in each grid row. Each number is encoded in one octet.**

3.2 Hybrid Vertical Coordinates

Use of hybrid vertical coordinates is one of the special cases alluded to in the discussion of the Product Definition Section in Section 2.1.5 of Layer 2. Now this special case will be described in some detail. Let us begin by recalling that the contents of Section 4 are:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("4")
6-7	Number of coordinate values after Template (see Note 1)
8-9	Product Definition Template Number (see Code Table 4.0)
10-xx	Product Definition Template (see Template 4.X, where X is the Product Definition Template Number given in octets 8-9)
[xx+1]-nn	Optional list of coordinate values (see Notes 2 and 3)

Notes:

1. Coordinate values are intended to document the vertical discretisation associated with model data on hybrid vertical coordinate levels. A number of zero in octets 6-7 indicates that no such values are present. Otherwise, the number corresponds to the whole set of values.

2. Hybrid systems, in this context, employ a means of representing vertical coordinates in terms of a mathematical combination of pressure and sigma coordinates. When used in conjunction with a surface pressure field and an appropriate mathematical expression, the vertical coordinate parameters may be used to interpret the hybrid vertical coordinate.

3. Hybrid vertical coordinate values, if present, should be encoded in IEEE 32-bit floating point format. They are intended to be encoded as pairs.

As Note 2 indicates, a hybrid vertical coordinate system is a mathematical combination of pressure and sigma vertical coordinates. Therefore, we begin the discussion with a review of the sigma coordinate system.

The general formula for the sigma (σ) coordinate is:

$$\sigma = \frac{P_u - P_\sigma}{P_u - P_l},$$

where P_u is the pressure of the upper boundary of the sigma domain, P_l is the pressure of the lower boundary of the sigma domain, and P_σ is the pressure of an individual sigma surface. The simplest, and perhaps the most common, application of this general formulation is to let the upper boundary of the sigma domain be the top of the atmosphere ($P_u = 0$) and the lower boundary of the sigma domain be the surface of the earth ($P_l = P_{sfc}$). With these assumptions, the expression for σ becomes:

$$\sigma = \frac{P_\sigma}{P_{sfc}},$$

Which can be rewritten as

$$P_\sigma = \sigma \bullet P_{sfc}$$

The hybrid coordinate system has been introduced in numerical models to have both sigma-type levels near the earth and pressure levels at the top of the atmosphere. The above formula is generalized as follows:

$$P_h = a_h \bullet P_{sfc} + b_h$$

Hybrid vertical coordinate values, when present, are encoded as the pair of numbers a_h and b_h in IEEE 32-bit floating point format. Each pair represents a hybrid vertical coordinate level. With the surface pressure field P_{sfc}, the values of P_h can be calculated from the above formula. Note that this implies the surface pressure field accompanies data on hybrid vertical coordinates. The capability of GRIB2 to encode multiple data sets in a single message makes this straightforward to accomplish.

Since each value in the pair of numbers is in IEEE 32-bit floating point format, each such hybrid level encoded would require 8 octets. If a hybrid vertical coordinate system with 10 individual levels were used instead of pressure, the Product Definition Section from the example in Section 2.4.1 of Layer 2 would become (modified lines are typed in bold):

1-4	**104-107**	**111**	**This Section is 111 octets long**
5	108	4	This is Section 4
6-7	109-110	20	There are 20 (10 pairs) of coordinate values after the Product Definition Template
8-9	111-112	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	113	3	The parameter category is 3 – mass products
11	114	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	115	2	A forecast generated this product (the generating process)
13	116	All 1's	No information on the background generating process is provided
14	117	All 1's	No further information on the forecast generating process is provided
15-16	118-119	3	The observational data cut-off was 3 hours after the reference time
17	120	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	121	1	The time is given in hours
19-22	122-125	12	The forecast time is 12 hours after the reference time
23	**126**	**105**	**The first fixed surface is a hybrid coordinate surface**
24	127	0	The scale factor of first fixed surface is 0
25-28	**128-131**	**n (1 – 10)**	**The scaled value of first fixed surface is n. This represents the n^{th} hybrid level.**
29	132	All 1's	There is no second fixed surface
30	133	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	134-137	All 1's	The scaled value of the second fixed surface is missing since it is not needed
35-111	**138-214**	$(a_1, b_1)_{level\ 1}$, $(a_2, b_2)_{level\ 2}$, $(a_3, b_3)_{level\ 3}$, $(a_4, b_4)_{level\ 4}$, $(a_5, b_5)_{level\ 5}$, $(a_6, b_6)_{level\ 6}$, $(a_7, b_7)_{level\ 7}$, $(a_8, b_8)_{level\ 8}$, $(a_9, b_9)_{level\ 9}$, $(a_{10}, b_{10})_{level\ 10}$	**Pairs of numbers describing the hybrid vertical coordinate system. Each individual number is encoded in IEEE 32-bit floating point format and occupies 4 octets**

3.3 Data Compression

3.3.1 Complex Packing Schemes

3.3.1.1 Example of using Complex Packing in a GRIB2 Message with One Data Set

Recall that the Grid Point Data – Simple Packing compression method was used in the sample GRIB2 message in Section 2.4.1 of Layer 2. The Data Representation, Bit Map, Data, and End Sections from that sample GRIB2 message were:

Section Octet No.	Message Octet No.	Value	Meaning
1-4	138-141	21	This Section is 21 octets long
5	142	5	This is Section 5
6-9	143-146	25	There are 25 data points for which values are specified in Section
10-11	147-148	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	149-152	5340	The reference value (R) is 5240.0 (IEEE 32-bit floating-point value)
16-17	153-154	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	155-156	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	157	11	11 bits are used for each packed value in the Data Section
21	158	0	The original field values were floating point numbers
1-4	159-162	6	This Section is 6 octets long
5	163	6	This is Section 6
6	164	0	There is no bit-map
1-4	165-168	40	This Section is 40 octets long
5	169	7	This is Section 7
6-40	170-204	25 scaled integers, last 5 bits set to 0	25 binary data values, each using 11 bits. The binary values thus occupy 275 bits 5 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	205-208	7777	“7777” coded according to the International Alphabet No. 5

The Grid Point Data - Complex Packing method was discussed in general terms in Section 2.3.2 of Layer 2. We will now consider the modifications needed to this sample GRIB2 message when this packing method is used.

The 25 hypothetical grid point values of 500 hPa geopotential height in that example ranged from 3400 gpm to 4600 gpm. In order to illustrate the Grid Point Data – Complex Packing compression method in more detail, we now will assume the full set of 25 hypothetical geopotential height values, after scaling by a D factor of 1, is:

54560	54570	54580	54590	54600
54000	54100	54200	54300	54400
53800	53900	54000	54100	54200
53600	53700	53800	53900	54000
53400	53500	53600	53700	53800

Subtracting the overall global minimum of 53400 results in

01160	01170	01180	01190	01200
00600	00700	00800	00900	01000
00400	00500	00600	00700	00800
00200	00300	00400	00500	00600
00000	00100	00200	00300	00400

Octet 65 of Grid Definition Template 3.20 (Polar Stereographic Projection) determines the scanning mode by reference to Code Table 3.4 (presented in Section 2.3.3 of Layer 2). For row by row scanning (the +j(+y) direction), where each row is itself scanned in the +i (+x) direction, octet 65 would contain the bit string 01000000. This scanning mode produces the following string of values:

00000 00100 00200 00300 00400 00200 00300 00400 00500 00600 00400 00500
00600 00700 00800 00600 00700 00800 00900 01000 01160 01170 01180 01190
01200

Up to now, nothing has changed from the original example. As we saw before, all these values could be packed into a "word" with a length of 11 bits. 25 such "words" would therefore take a bit string 275 bits long. However, when we decide to use the complex packing method for this grid point data instead of the simple packing method, this is where things become different. For convenience, the appropriate Data Representation and Data sections presented in Section 2.3.2 of Layer 2 are repeated here:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("5")
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)
22	Group splitting method used (see Code Table 5.4)
23	Missing value management used (see Code Table 5.5)
24-27	Primary missing value substitute
28-31	Secondary missing value substitute
32-35	NG - Number of groups of data values into which field is split
36	Reference for group widths (see Note 12)
37	Number of bits used for the group widths (after the reference value in octet 36 has been removed)
38-41	Reference for group lengths (see Note 13)
42	Length increment for the group lengths (see Note 14)
43-46	True length of last group
47	Number of bits used for the scaled group lengths (after subtraction of the reference value given in octets 38-41 and division by the length increment given in octet 42)

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section ("7")
6-xx	NG group reference values (XI in the decoding formula), each of which is encoded using the number of bits specified in octet 20 of Data Representation Template 5.0. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[xx+1]-yy	NG group widths, each of which is encoded using the number of bits specified in octet 37 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[yy+1]-zz	NG scaled group lengths, each of which is encoded using the number of bits specified in octet 47 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary. (see Note 14 of Data Representation Template 5.2)
[zz+1]-nn	Packed values (X2 in the decoding formula), where each value is a deviation from its respective group reference value.

We shall consider the first 20 values and the last 5 values as groups. Referring to Code Table 5.4 (it was reproduced in Section 2.3.2 of Layer 2), this falls under the category of General group splitting, identified by code figure 1. The number 1 is therefore stored in octet 22 of Section 5. Furthermore, there are only two groups to treated. This number is referred to as NG and is stored in octets 32-35 of Section 5.

This data has no missing values, so the missing value management option is not needed. Code Table 5.5 (it was also reproduced in Section 2.3.2 of Layer 2) indicates a value of 0 (zero) needs to be encoded in octet 23 of Section 5 to indicate this. Since the missing value management option is not used, octets 24-27 and octets 28-31 will be set to all 1's (missing value).

The 20 values in the first group have a minimum (group reference) of 0 and the 5 values second group have a minimum of 1160. The largest of these two group references – 1160 - packs in a "word" 10 bits long, so 10 will be stored in octet 20 of the Data Representation Section (note the meaning of the contents of octet 20 is different when complex packing is used than it was when simple packing was used). The group reference values themselves – 0 and 1160, the X1 values in the GRIB2 compression formula - are stored in octets 6 – xx of the Data Section. Since 10 bits are required for each value, this will occupy octets 6 –25 of the Data Section.

Next, each group reference value is subtracted from each of the scaled integers in its respective group. The resulting residuals in each group are:

Group 1:	00000 00100 00200 00300 00400 00200 00300 00400 00500 00600
	00400 00500 00600 00700 00800 00600 00700 00800 00900 01000
Group 2:	00000 00010 00020 00030 00040

These residuals are the scaled values with the reference removed – the second-order (X2) values in the GRIB2 compression formula. They are stored in octets [zz+1]-nn of Section 7. The values of zz and nn will be determined presently.

Group width is defined as the number of bits used for every X2 value in a group. For each group, this is the number of bits required to represent the largest of the X2 values in that group. In this example, the two group widths are 9 (to represent 1000 for Group 1) and 6 (to represent 40 for Group 2). The smallest of these group widths (6) is stored in octet 36 of the Data Representation Section. This minimum group width is then subtracted from every group width leaving an array of group width increments. In this case, the group width increments are 3 (9 – 6) and 0 (6 – 6). The number of bits required to represent the largest of these group width increments (2 bits to store 3) is stored in octet 37 of the Data Representation Section. The group width (increments) themselves (3 and 0) are then stored in octets [xx+1] – yy of the Data Section (octets 26 – 29) using the number of bits (2) stored in octet 37 of the Data Representation Section for each value.

Group length (Ln) is defined as the number of values in a group. In this case, Ln is 20 for Group 1 and 5 for Group 2. The smallest of these group lengths (ref) is 5. This value (5) is stored in octets 38-41 of the Data Representation Section.

As pointed out in the GRIB2 Manual, complex packing for grid-point is intended to reduce data section size as compared to simple packing. This is achieved at the expense of extra descriptors per group. In order to keep the volume of these descriptors as low as possible, group widths and lengths have their minimum value subtracted. As a complement, lengths may be scaled using the length increment feature.

This may be used in conjunction with splitting algorithm to determine groups of data. Efficient algorithms with a good quality/price ratio are based on the determination of groups starting from a basic length, say B, and possible extensions of either B or a shorter (incremental) length I. For example, B and I could be 15 and 3, respectively.

In such a case, all groups (but the last one) will have a minimum length of B and length increments multiple of I (assuming B is a multiple of I, which is easy to choose). So B would be stored in octets 38-41, I in octet 42, and the effective length of last groups (reference for group lengths not removed) in octets 43-46.

Finally, the number of bits N_L necessary to store the scaled group lengths (the Kn values in Note 14 of the Manual) will be stored in octet 47. Note that as soon as I is bigger than 1, N_L is reduced relative to using an increment of 1, leading to save space in Data Section.

The Kn values are stored in Data Section for all NG groups. The encoded value of Kn for n= NG is not relevant for decoding, and a zero value may be used.

3.3.2 Complex Packing and Spatial Differencing Schemes

3.3.2.1 Example of using Complex Packing and Spatial Differencing in a GRIB2 Message in a GRIB2 Message with One Data Set

Spatial differencing is performed after rounding the scaled values to scaled integers but before splitting the scaled integers into groups. It is intended to reduce the size of sufficiently smooth fields. When spatial differencing is used, the relevant Data Representation Template is 5.3. Template 5.3 is the same as Data Representation Template 5.2 (Grid Point Data – Complex Packing), but contains additional information in octets 48 and 49 (typed in **bold** below). When Template 5.3 is used, the Data representation Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“5”)
6-9	Number of data points where one or more values are specified in Section 7 when a bit map is present, total number of data points when a bit map is absent
10-11	Data Representation Template Number (see code Table 5.0)
12-15	Reference value (R) (IEEE 32-bit floating-point value)
16-17	Binary Scale Factor (E)
18-19	Decimal Scale Factor (D)
20	Number of bits used for each packed value for simple packing, or for each group reference value for complex packing or spatial differencing
21	Type of original field values (see Code Table 5.1)
22	Group splitting method used (see Code Table 5.4)
23	Missing value management used (see Code Table 5.5)
24-27	Primary missing value substitute
28-31	Secondary missing value substitute
32-35	NG - Number of groups of data values into which field is split
36	Reference for group widths (see Note 12)
37	Number of bits used for the group widths (after the reference value in octet 36 has been removed)
38-41	Reference for group lengths (see Note 13)
42	Length increment for the group lengths (see Note 14)
43-46	True length of last group
47	Number of bits used for the scaled group lengths (after subtraction of the reference value given in octets 38-41 and division by the length increment given in octet 42)
48	**Order of Spatial Differencing (see Code Table 5.6)**
49	**Number of octets required in the Data Section to specify the extra descriptors needed for spatial differencing (octets 6-ww in Data template 7.3)**

In this case, the relevant template is Data Template 7.3, which is the same as Data Template 7.2, except octets 6-xx are replaced with new information (typed in **bold** below). When Template 7.3 is used, the Data Section becomes:

Octet No.	Contents
1-4	Length of section in octets (nn)
5	Number of Section (“7”)
6-ww	**First value(s) of original (undifferenced) scaled data values, followed by the overall minimum of the differences. The number of values stored is 1 greater than the order of differentiation, and the field width is described in octet 49 of Data Representation Template 5.3**
[ww+1]-xx	NG group reference values (X1 in the decoding formula), each of which is encoded using the number of bits specified in octet 20 of Data Representation Template 5.0. Bits set to zero shall be appended where necessary to ensure this sequence of numbers ends on an octet boundary.
[xx+1]-yy	NG group widths, each of which is encoded using the number of bits specified in octet 37 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on an octet boundary.
[yy+1]-zz	NG scaled group lengths, each of which is encoded using the number of bits specified in octet 47 of Data Representation Template 5.2. Bits set to zero shall be appended as necessary to ensure this sequence of numbers ends on

	an octet boundary. (see Note 14 of Data Representation Template 5.2)
[zz+1]-nn	Packed values (X2 in the decoding formula), where each value is a deviation from its respective group reference value.

We begin this illustration by recalling, after scaling by a D factor of 1, the 25 hypothetical grid point values of 500 hPa geopotential height we used to illustrate the complex packing method:

54560	54570	54580	54590	54600
54000	54100	54200	54300	54400
53800	53900	54000	54100	54200
53600	53700	53800	53900	54000
53400	53500	53600	53700	53800

The scanning procedure used is determined by referring to Flag Table 3.4:

Flag Table 3.4: **Scanning Mode**

Bit Number	Value	Meaning
1	0	Points of first row or column scan in the +i (+x) direction
	1	Points of first row or column scan in the -i (-x) direction
2	0	Points of first row or column scan in the -j (-y) direction
	1	Points of first row or column scan in the +j (+y) direction
3	0	Adjacent points in i (x) direction are consecutive
	1	Adjacent points in j (y) direction is consecutive
4	0	All rows scan in the same direction
	1	Adjacent rows scan in opposite directions
5-8		Reserved

Notes:
(1) i direction: west to east along a parallel or left to right along an X-axis
(2) j direction: south to north along a meridian, or bottom to top along a Y-axis
(3) If bit number 4 is set, the first row scan is as defined by previous flags

When spatial differencing is used, the boustrophedonic scanning procedure is often used. Although not particularly beneficial in this simple example, it will be applied here to illustrate its use. This would be documented by setting octet 65 of Grid Definition Template 3.20 (Polar Stereographic Projection) to 01010000. In this event, the string of values would be:

53400 53500 53600 53700 53800 54000 53900 53800 53700 53600 53800 53900
54000 54100 54200 54400 54300 54200 54100 54000 54560 54570 54580 54590

54600

The order of the spatial differencing is determined by the value encoded in octet 48 of Data Representation Template 5.3 via reference to Code Table 5.6:

Code Table 5.6: Order of Spatial Differencing

Code Figure	Meaning
0	Reserved
1	First-order spatial differencing
2	Second-order spatial differencing
3-191	Reserved
192-254	Reserved for local use
255	Missing

For first order spatial differencing, a field of scaled values f (integers) is replaced by a new field of values g, where $g_1 = f_1$, $g_2 = f_2 – f_1$, …, $g_n = f_n – f_{n-1}$. For second order spatial differencing, the field of values g is itself replaced by a new field of values h, where $h_1 = f_1$, $h_2 = f_2$, $h_3 = g_3 – g_2$, …, $h_n = g_n – g_{n-1}$. In this illustration, we will use first order spatial differencing. The result is:

53400 00100 00100 00100 00100 00200 -00100 -00100 -00100 -00100 00200 00100
00100 00100 00100 00200 -00100 -00100 -00100 -00100 00560 00010 00010 00010
00010

Since we are using first order differencing, there will be 2 values (one greater than the order of differencing) stored in octets 6-ww of Template 7.3, g_1 and the overall minimum of the difference values. The value of g_1 (53400) requires 15 bits to store. The overall minimum of the difference values will usually be negative therefore the Note (4) of Data Template 7.3 about the sign bit applies. The number of bits required to store these two values is therefore 47 (15 + 32). This number of bits is encoded in octet 49 of Data Representation Template 5.3. The two values themselves (53400 and –00100) are then stored in octets 6-52 of the Data Section (note that ww is 52 – this will be used later).

Subtracting the overall minimum of –00100 from each of the difference values (but not from the first value g_1), the string of numbers becomes:

53400 00200 00200 00200 00200 00300 00000 00000 00000 00000 00300 00200
00200 00200 00200 00300 00000 00000 00000 00000 00660 00110 00110 00110
00110

We shall consider the first 19 and the last 5 difference values as groups. As in the previous Section, this falls under the category of General group splitting, identified by code figure 1, and the number 1 is therefore stored in octet 22 of Section 5. Also as before, there are only two groups to treated, so the value of NG is 2 and this value is stored in octets 32-35 of Section 5.

This data also has no missing values, so the missing value management option is not needed. A value of 0 (zero) is encoded in octet 23 of Section 5 to indicate this. Since the missing value management option is not used, octets 24-27 and octets 28-31 will be set to all 1's (missing value).

The 19 values in the first group have a minimum (group reference) of 00000 and the 5 values second group have a minimum of 110. The larger of these two group references – 110 - packs in a "word" 6 bits long, so 6 will be stored in octet 20 of the Data Representation Section. The group reference values themselves – 00000 and 00110, the X1 values in the GRIB2 compression formula - are stored in the Data Section. Since 6 bits are required for each value, they will occupy octets 53 – 64 of the Data Section (octets [ww+1]-xx, where ww is 52 and xx is 64: xx will be used later).

Next, each group reference value is subtracted from each of the scaled integers in its respective group. The resulting residuals in each group are:

Group 1:	00200 00200 00200 00200 00300 00000 00000 00000 00000 00300 00200 00200 00200 00200 00300 00000 00000 00000 00000
Group 2:	00550 00000 00000 00000 00000

These residuals are the scaled values with the reference removed – the second-order (X2) values in the GRIB2 compression formula. They are stored in octets [zz+1]-nn of Section 7. The values of zz and nn will be determined presently.

Group width is defined as the number of bits used for every X2 value in a group. For each group, this is the number of bits required to represent the largest of the X2 values in that group. In this example, the two group widths are 8 (to represent 300 for Group 1) and 9 (to represent 550 for Group 2). The smallest of these group widths (8) is stored in octet 36 of the Data Representation Section. This minimum, or reference, group width is then subtracted from every group width leaving an array of group width increments. In this case, the group width increments are 0 (8 - 8) and 1 (9 - 8). The number of bits required to represent the largest of these group width increments (1 bit to store 1) is stored in octet 37 of the Data Representation Section. The group width (increments) themselves (0 and 1) are then stored in octets 65 – 66 of the Data Section (octets [xx+1] – yy, where xx is 64 and yy is 66: yy will be used later) using the number of bits (1) stored in octet 37 of the Data Representation Section for each value.

Group length (Ln) is defined as the number of values in a group. In this case, Ln is 19 for Group 1 and 5 for Group 2. The smallest of these group lengths (ref) is 5. This value (5) is stored in octets 38-41 of the Data Representation Section.

As pointed out in the GRIB2 Manual, complex packing for grid-point is intended to reduce data section size as compared to simple packing. This is achieved at the expense of extra descriptors per group. In order to keep the volume of these descriptors as low as possible, group widths and lengths have their minimum value subtracted. As a complement, lengths may be scaled using the length increment feature.

This may be used in conjunction with splitting algorithm to determine groups of data. Efficient algorithms with a good quality/price ratio are based on the determination of groups starting from a basic length, say B, and possible extensions of either B or a shorter (incremental) length I. For example, B and I could be 15 and 3, respectively.

In such a case, all groups (but the last one) will have a minimum length of B and length increments multiple of I (assuming B is a multiple of I, which is easy to choose). So B would be stored in octets 38-41, I in octet 42, and the effective length of last groups (reference for group lengths not removed) in octets 43-46.

Finally, the number of bits N_L necessary to store the scaled group lengths (the Kn values in Note 14 of the Manual) will be stored in octet 47. Note that as soon as I is bigger than 1, N_L is reduced relative to using an increment of 1, leading to save space in Data Section.

The Kn values are stored in Data Section for all NG groups. The encoded value of Kn for n= NG is not relevant for decoding, and a zero value may be used.

3.4 Structure of a GRIB2 Message with Multiple Data Sets

3.4.1 Iterating the Sections

As was discussed in Layer 1, the GRIB2 regulations state that (A) Sequences of GRIB2 Sections 2 to 7, 3 to 7, or 4 to 7 may be repeated within a single GRIB2 message, (B) All Sections within such repeated sequences must be present and shall appear in the numerical order noted above, and (C) Unrepeated Sections remain in effect until redefined. This is denoted schematically in the table below by the three groups of vertical bars:

```
Section 0:  Indicator Section
Section 1:  Identification Section
Section 2:  Local Use Section (optional)                                  |
Section 3:  Grid Definition Section                             |         |
Section 4:  Product Definition Section  |      |                |
Section 5:  Data Representation Section        |repeated        |repeated |repeated
Section 6:  Bit-Map Section                    |                |         |
Section 7:  Data Section                       |                |         |
Section 8:  End Section
```

An example of a GRIB 2 message with multiple Product Definition, Data Representation, Bit-map, and Data Sections was presented in Section 2.4.3 of Layer 2. That example contained 4 hypothetical 500 hPa geopotential height forecasts - for forecast hours 12, 24, 36, and 48 - as might be contained on a typical four-panel graphic product. In this section, we present examples of GRIB2 messages with the same hypothetical 500 hPa geopotential height forecast, first with multiple Grid Definition Sections and second with multiple Local Use Sections

3.4.2 Example of a GRIB2 Message with Multiple Grid Definition, Product Definition and Data Representation Sections

This sample GRIB2 message contains the same hypothetical 500 hPa geopotential height forecast on two grid projections – a 100 km 5 X 5 grid on a polar stereographic projection and a 10 degree latitude/longitude grid. The Grid Point Data – Simple Packing compression method is used in both cases. The minimum and maximum values on the 5 X 5 grid are the same as before – 5340 gpm and 5460 gpm, respectively. We will assume the forecast values on the latitude/longitude grid have a minimum of 4980 gpm and a maximum of 5840 gpm. The full GRIB2 message is presented below. As before, blank lines have been inserted between each section to improve readability.

Section Octet No.	Message Octet No.	Value	Meaning
1-4	1-4	GRIB	"GRIB" (coded according to the International Alphabet No. 5)
5-7	5-7	All 1's	Reserved
7	7	0	This GRIB2 message contains meteorological products (the product discipline)
8	8	2	The GRIB Edition Number is 2
9-16	9-16	1457	The total length of this GRIB message is 1457 octets
1-4	17-20	21	This Section is 21 octets long
5	21	1	This is Section 1
6-7	22-23	74	The originating/generating centre is the U.K. Meteorological Office
8-9	24-25	0	There is no originating/generating sub-centre
10	26	1	GRIB Master Tables Version Number 1 is used
11	27	0	No GRIB Local Tables are used
12	28	1	The Reference Time is the start of the forecast
13-14	29-30	2003	Year = 2003 |
15	31	5	Month = April |
16	32	1	Day = 1 | Reference time of data
17	33	0	Hour = 0 |
18	34	0	Minute = 0 |
19	35	0	Second = 0 |
20	36	0	This GRIB2 message contains operational products
21	37	1	This GRIB2 message contains forecast products
1-4	38-41	65	This Section is 65 octets long
5	42	3	This is Section 3
6	43	0	This grid is specified in Code Table 3.1
7-10	44-47	25	There are 25 data points in this grid
11	48	0	There is no optional list of numbers defining number of points
12	49	0	Since there is no optional list of numbers, no interpretation is needed
13-14	50-51	2	The Grid Definition Template Number is 3.20 – a polar stereographic projection
15	52	1	The earth is assumed to be spherical with radius specified by the data producer
16	53	3	The scale factor for the radius of the spherical earth is 3
17-20	54-57	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	58	all 1's	There is no scale factor for the major axis of an oblate spheroid earth

22-25	59-62	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	63	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	64-67	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	68-71	5	There are 5 points along the X-axis (Nx)
35-38	72-75	5	There are 5 points along the Y-axis (Ny)
39-42	76-79	40000001	The latitude of the first grid point is 40.000001 ^{0} north (La1)
43-46	80-83	349999999	The longitude of the first grid point is 349.999999 ^{0} east (or 10.000001 ^{0} west) (Lo1)
47	84	00000000	No resolution and component flag are turned on (see flag table 3.3 and Note 1)
48-51	85-88	40000001	Dx and Dy are specified at 40.000001 0 north ((LaD)
52-55	89-92	0	The 0 degree meridian is parallel to the Y-axis (LoV)
56-59	93-96	100000000	The X direction grid length is 100.000 km (Dx)
60-63	97-100	100000000	The Y direction grid length is 100.000 km (Dy)
64	101	00	The north pole is on the projection plane and only one projection centre is used
65	102	01000000	Points scan in the +i (+x) direction, rows in the +j (+Y) direction, adjacent points in the (x) direction are consecutive, and all rows scan in the same direction
1-4	104-107	34	This Section is 34 octets long
5	108	4	This is Section 4
6-7	109-110	0	There are no coordinate values after the Product Definition Template
8-9	111-112	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	113	3	The parameter category is 3 – mass products
11	114	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	115	2	A forecast generated this product (the generating process)
13	116	All 1's	No information on the background generating process is provided
14	117	All 1's	No further information on the forecast generating process is provided
15-16	118-119	3	The observational data cut-off was 3 hours after the reference time
17	120	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	121	1	The time is given in hours
19-22	122-125	12	The forecast time is 12 hours after the reference time
23	126	100	The first fixed surface is a pressure surface
24	127	0	The scale factor of first fixed surface is 0
25-28	128-131	500	The scaled value of first fixed surface is 500 (500 hPa)
29	132	All 1's	There is no second fixed surface
30	133	All 1's	The scale factor of the second fixed surface is missing since it is not needed
31-34	134-136	All 1's	The scaled value of the second fixed surface is missing since it is not needed

1-4	137-140	21	This Section is 21 octets long
5	141	5	This is Section 5
6-9	142-145	25	There are 25 data points for which values are specified in Section
10-11	146-147	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	148-151	53400	The reference value (R) is 53400.0 (IEEE 32-bit floating-point value)
16-17	152-153	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	154-155	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	156	11	11 bits are used for each packed value in the Data Section
21	157	0	The original field values were floating point numbers
1-4	158-161	6	This Section is 6 octets long
5	162	6	This is Section 6
6	163	0	There is no bit-map
1-4	164-167	40	This Section is 40 octets long
5	168	7	This is Section 7
6-40	169-203	25 scaled integers, last 5 bits set to 0	25 binary data values, each using 11 bits. The values thus occupy 275 bits . 4 additional bits set to zero are necessary for the section to end on an octet boundary.
1-4	204-207	72	This Section is 72 octets long
5	208	3	This is Section 3
6	209	0	This grid is specified in Code Table 3.1
7-10	210-213	684	There are 684 data points in this grid
11	214	0	There is no optional list of numbers defining the number of points
12	215	0	Since there is no optional list of numbers, no interpretation is needed
13-14	216-217	1	The Grid Definition Template Number is 3.1 a latitude-longitude grid
15	218	1	The earth is assumed to be spherical with radius specified by the data producer
16	219	3	The scale factor for the radius of the spherical earth is 3
17-20	220-223	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	224	all 1’s	There is no scale factor for the major axis of an oblate spheroid earth
22-25	225-228	all 1’s	There is no scaled value for the major axis of an oblate spheroid earth
26	229	all 1’s	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	230-233	all 1’s	There is no scaled value for the minor axis of an oblate spheroid earth

31-34	234-237	36	There are 36 points along a parallel (Ni)
35-38	238-241	19	There are 19 points along a meridian (Nj)
39-42	242-245	0	The basic angle of all latitudes and longitudes is 1 degree
43-46	246-249	all 1's	The unit of the basic angle of all latitudes and longitudes is 10^{-6} degrees
47-50	250-253	90000000	The latitude of the first grid point (La1) is –90.000000$^{o.}$ Bit 1 is set to 1 to indicate negative (south) latitude.
51-54	254-257	0000000	The longitude of the first grid point (Lo1) is 0.000000^{o}
55	258	00111000	I and j direction increments are given. Resolved u- and v- components of vector quantities are relative to the defined grid in the direction of increasing x and y coordinates respectively.
56-59	259-262	90000000	The latitude of the last grid point is +90.000000^{o}
60-63	263-266	350000000	The longitude of the last grid point is +350.000000^{o}
64-67	267-270	10000000	The i direction increment is 10.000000^{o}
68-71	271-274	10000000	The j direction increment is 10.000000^{o}
72	275	01000000	Points in the first row scan in the +I (+x) direction. Points in the first column scan in the +j (+y) direction. Resolved u- and v- components of vector quantities are relative to easterly and northerly directions.
1-4	276-279	34	This Section is 34 octets long
5	280	4	This is Section 4
6-7	281-282	0	There are no coordinate values after the Product Definition Template
8-9	283-284	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	285	3	The parameter category is 3 – mass products
11	286	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	287	2	A forecast generated this product (the generating process)
13	288	All 1's	No information on the background generating process is provided
14	289	All 1's	No further information on the forecast generating process is provided
15-16	290-291	3	The observational data cut-off was 3 hours after the reference time
17	292	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	293	1	The time is given in hours
19-22	294-297	12	The forecast time is 12 hours after the reference time
23	298	100	The first fixed surface is a pressure surface
24	299	0	The scale factor of first fixed surface is 0
25-28	300-303	500	The scaled value of first fixed surface is 500 (500 hPa)
29	304	All 1's	There is no second fixed surface

30	305	All 1’s	The scale factor of the second fixed surface is missing since it is not needed
31-34	306-309	All 1’s	The scaled value of the second fixed surface is missing since it is not needed
1-4	310-313	21	This Section is 21 octets long
5	314	5	This is Section 5
6-9	315-318	25	There are 25 data points for which values are specified in Section
10-11	319-320	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	321-324	49800	The reference value (R) is 49800.0 (IEEE 32-bit floating-point value)
16-17	325-326	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	327-328	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	329	13	13 bits are used for each packed value in the Data Section
21	330	0	The original field values were floating point numbers
1-4	331-334	6	This Section is 6 octets long
5	335	6	This is Section 6
6	336	0	There is no bit-map
1-4	337-340	1000	This Section is 1000 octets long
5	341	7	This is Section 7
6-1117	270-1453	684 scaled integers, last 4 bits set to 0	684 binary data values (36 X 19), each using 13 bits. The values thus occupy 8892 bits, or 1111 octets plus 4 more bits. 4 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	1454-11457	7777	“7777” coded according to the International Alphabet No. 5

3.4.3 Example of a GRIB2 Message with Multiple Grid Definition, Product Definition, Data Representation and Local Use Sections

The last sample GRIB2 message contains two operational test 48-hour forecasts of 500 hPa geopotential height on the same 10 degree latitude/longitude grid made by the same forecast model. It incorporates the Local Use Section to add information that allows the user to distinguish between the two forecasts. As in the previous example, simple packing is used, and the forecast values have a minimum of 4980 gpm and a maximum of 5840 gpm. The full GRIB2 message is presented below. As before, blank lines have been inserted between each section to improve readability.

Section Octet No.	Message Octet No.	Value	Meaning	
1-4	1-4	GRIB	“GRIB” (coded according to the International Alphabet No. 5)	
5-7	5-7	All 1’s	Reserved	
7	7	0	This GRIB2 message contains meteorological products (the product discipline)	
8	8	2	The GRIB Edition Number is 2	
9-16	9-16	2694	The total length of this GRIB message is 2694 octets	
1-4	17-20	21	This Section is 21 octets long	
5	21	1	This is Section 1	
6-7	22-23	74	The originating/generating centre is the U.K. Meteorological Office	
8-9	24-25	0	There is no originating/generating sub-centre	
10	26	1	GRIB Master Tables Version Number 1 is used	
11	27	0	No GRIB Local Tables are used	
12	28	1	The Reference Time is the start of the forecast	
13-14	29-30	2003	Year = 2003	
15	31	5	Month = April	
16	32	1	Day = 1	Reference time of data
17	33	0	Hour = 0	
18	34	0	Minute = 0	
19	35	0	Second = 0	
20	36	1	This GRIB2 message contains operational test products	
21	37	1	This GRIB2 message contains forecast products	
1-4	38-41	79	This Section is 79 octets long	
5	42	2	This is Section 2	
6-79	43-116	TEXT MESSAGE	“THIS FORECAST WAS MADE WITH THE OPERATIONAL FINITE DIFFERENCE FORMULATION” (Coded according to the International Alphabet No. 5)	
1-4	117-120	72	This Section is 72 octets long	
5	121	3	This is Section 3	
6	122	0	This grid is specified in Code Table 3.1	
7-10	123-126	684	There are 684 data points in this grid	
11	127	0	There is no optional list of numbers defining the number of points	

12	128	0	Since there is no optional list of numbers, no interpretation is needed
13-14	129-130	1	The Grid Definition Template Number is 3.1 a latitude-longitude grid
15	131	1	The earth is assumed to be spherical with radius specified by the data producer
16	132	3	The scale factor for the radius of the spherical earth is 3
17-20	133-136	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	137	all 1's	There is no scale factor for the major axis of an oblate spheroid earth
22-25	138-141	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	142	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	143-146	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	147-150	36	There are 36 points along a parallel (Ni)
35-38	151-154	19	There are 19 points along a meridian (Nj)
39-42	155-158	0	The basic angle of all latitudes and longitudes is 1 degree
43-46	159-162	all 1's	The unit of the basic angle of all latitudes and longitudes is 10^{-6} degrees
47-50	163-166	90000000	The latitude of the first grid point (La1) is -90.000000^{o}. Bit 1 is set to 1 to indicate negative (south) latitude.
51-54	167-170	0000000	The longitude of the first grid point (Lo1) is 0.000000^{o}
55	171	00111000	I and j direction increments are given. Resolved u- and v- components of vector quantities are relative to the defined grid in the direction of increasing x and y coordinates respectively.
56-59	172-175	90000000	The latitude of the last grid point is $+90.000000^{o}$
60-63	176-179	350000000	The longitude of the last grid point is $+350.000000^{o}$
64-67	180-183	10000000	The i direction increment is 10.000000^{o}
68-71	184-187	10000000	The j direction increment is 10.000000^{o}
72	188	01000000	Points in the first row scan in the +I (+x) direction. Points in the first column scan in the +j (+y) direction. Resolved u- and v- components of vector quantities are relative to easterly and northerly directions.

1-4	189-192	34	This Section is 34 octets long
5	193	4	This is Section 4
6-7	194-195	0	There are no coordinate values after the Product Definition Template
8-9	196-197	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	198	3	The parameter category is 3 – mass products
11	199	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	200	2	A forecast generated this product (the generating process)
13	201	All 1's	No information on the background generating process is provided

14	202	All 1’s	No further information on the forecast generating process is provided
15-16	203-204	3	The observational data cut-off was 3 hours after the reference time
17	205	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	206	1	The time is given in hours
19-22	207-210	48	The forecast time is 48 hours after the reference time
23	211	100	The first fixed surface is a pressure surface
24	212	0	The scale factor of first fixed surface is 0
25-28	213-216	500	The scaled value of first fixed surface is 500 (500 hPa)
29	217	All 1’s	There is no second fixed surface
30	218	All 1’s	The scale factor of the second fixed surface is missing since it is not needed
31-34	219-222	All 1’s	The scaled value of the second fixed surface is missing since it is not needed
1-4	223-226	21	This Section is 21 octets long
5	227	5	This is Section 5
6-9	228-231	25	There are 25 data points for which values are specified in Section
10-11	232-233	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	234-237	49800	The reference value (R) is 49800.0 (IEEE 32-bit floating-point value)
16-17	238-239	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	240-241	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	242	13	13 bits are used for each packed value in the Data Section
21	243	0	The original field values were floating point numbers
1-4	244-247	6	This Section is 6 octets long
5	248	6	This is Section 6
6	249	0	There is no bit-map
1-4	250-253	1000	This Section is 1000 octets long
5	254	7	This is Section 7
6-1117	255-1366	684 scaled integers, last 4 bits set to 0	684 binary data values (36 X 19), each using 13 bits. The values thus occupy 8892 bits, or 1111 octets plus 4 more bits. 4 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	1367-1370	74	This Section is 74 octets long
5	1371	2	This is Section 2
6-74	1372-1440	TEXT MESSAGE	“THIS FORECAST WAS MADE WITH THE REVISED FINITE

			DIFFERENCE FORMULATION" (Coded according to the International Alphabet No. 5)
1-4	1441-1444	72	This Section is 72 octets long
5	1445	3	This is Section 3
6	1446	0	This grid is specified in Code Table 3.1
7-10	1447-1450	684	There are 684 data points in this grid
11	1451	0	There is no optional list of numbers defining the number of points
12	1452	0	Since there is no optional list of numbers, no interpretation is needed
13-14	1453-1454	1	The Grid Definition Template Number is 3.1 a latitude-longitude grid
15	1455	1	The earth is assumed to be spherical with radius specified by the data producer
16	1456	3	The scale factor for the radius of the spherical earth is 3
17-20	1457-1460	6350000	The scaled value of the radius of the spherical earth is 6350000 km
21	1461	all 1's	There is no scale factor for the major axis of an oblate spheroid earth
22-25	1462-1465	all 1's	There is no scaled value for the major axis of an oblate spheroid earth
26	1466	all 1's	There is no scale factor for the minor axis of an oblate spheroid earth
27-30	1467-1470	all 1's	There is no scaled value for the minor axis of an oblate spheroid earth
31-34	1471-1474	36	There are 36 points along a parallel (Ni)
35-38	1475-1478	19	There are 19 points along a meridian (Nj)
39-42	1479-1482	0	The basic angle of all latitudes and longitudes is 1 degree
43-46	1483-1486	all 1's	The unit of the basic angle of all latitudes and longitudes is 10^{-6} degrees
47-50	1487-1490	90000000	The latitude of the first grid point (La1) is -90.000000^{o}. Bit 1 is set to 1 to indicate negative (south) latitude.
51-54	1491-1494	0000000	The longitude of the first grid point (Lo1) is 0.000000^{o}
55	1495	00111000	I and j direction increments are given. Resolved u- and v- components of vector quantities are relative to the defined grid in the direction of increasing x and y coordinates respectively.
56-59	1496-1499	90000000	The latitude of the last grid point is $+90.000000^{o}$
60-63	1500-1503	350000000	The longitude of the last grid point is $+350.000000^{o}$
64-67	1504-1507	10000000	The i direction increment is 10.000000^{o}
68-71	1508-1511	10000000	The j direction increment is 10.000000^{o}
72	1512	01000000	Points in the first row scan in the +I (+x) direction. Points in the first column scan in the +j (+y) direction. Resolved u- and v- components of vector quantities are relative to easterly and northerly directions.

1-4	1513-1516	34	This Section is 34 octets long
5	1517	4	This is Section 4
6-7	1518-1519	0	There are no coordinate values after the Product Definition Template
8-9	1520-1521	0	The Product Definition Template Number is 4.0 – an analysis or forecast at a horizontal level or in a horizontal layer at a point in time
10	1522	3	The parameter category is 3 – mass products
11	1523	5	The parameter number is 5 – geopotential height (in geopotential meters)
12	1524	2	A forecast generated this product (the generating process)
13	1525	All 1’s	No information on the background generating process is provided
14	1526	All 1’s	No further information on the forecast generating process is provided
15-16	1527-1528	3	The observational data cut-off was 3 hours after the reference time
17	1529	30	The observational data cut-off was 30 minutes after the observational cut-off hour
18	1530	1	The time is given in hours
19-22	1531-1534	48	The forecast time is 48 hours after the reference time
23	1535	100	The first fixed surface is a pressure surface
24	1536	0	The scale factor of first fixed surface is 0
25-28	1537-1540	500	The scaled value of first fixed surface is 500 (500 hPa)
29	1541	All 1’s	There is no second fixed surface
30	1542	All 1’s	The scale factor of the second fixed surface is missing since it is not needed
31-34	1543-1546	All 1’s	The scaled value of the second fixed surface is missing since it is not needed

1-4	1547-1550	21	This Section is 21 octets long
5	1551	5	This is Section 5
6-9	1552-1555	25	There are 25 data points for which values are specified in Section
10-11	1556-1557	0	The Data Representation Template Number is 5.0 - Grid point data – simple packing
12-15	1558-1561	49800	The reference value (R) is 49800.0 (IEEE 32-bit floating-point value)
16-17	1562-1563	0	The binary scale factor (E) is 0: binary scaling is not used
18-19	1564-1565	1	The decimal scale factor (D) is 1: precision is 0.1 geopotential meters
20	1566	13	13 bits are used for each packed value in the Data Section
21	1567	0	The original field values were floating point numbers

1-4	1568-1571	6	This Section is 6 octets long
5	1572	6	This is Section 6
6	1573	0	There is no bit-map

1-4	1574-1577	1000	This Section is 1000 octets long
5	1578	7	This is Section 7
6-1117	1579-2690	684 scaled integers, last 4 bits set to 0	684 binary data values (36 X 17), each using 13 bits. The values thus occupy 8892 bits, or 1111 octets plus 4 more bits. 4 additional bits set to zero are therefore necessary to end on an octet boundary.
1-4	2691-2694	7777	“7777” coded according to the International Alphabet No. 5