A Compression Format and Tools for GNSS Observation Data

Yuki Hatanaka

Abstract

A new version of the Receiver Independent Exchange (RINEX) format (version 3.0) for Global Navigation Satellite System (GNSS) observation data has been proposed by Gurtner and Estey (2006) to accommodate recent progress in the GNSS environment such as modernization of the Global Positioning System (GPS) and the emergence of new GNSS systems. The compact RINEX format version 3.0 has been developed to compress files in this format by adjusting the existing old compression format for RINEX version 2.xx. The compression rate, combined with the additional text compression, is about 38% of that with the simple application of text compression. The compression/decompression of both old and new formats can be performed seamlessly with the same tools and the same usage. The format and tools will contribute to the popularization of RINEX format version 3.00 and, through this, facilitate the exchange and use of GNSS data.

1. Introduction

Standardization of data formats is a key issue for management, analysis, and exchange of data of GNSS observation networks without being restricted by receiver-specific data formats. The RINEX format version 2 (Gurtner and Mader, 1991) has been used widely in the geodetic community, including the International GNSS Service (IGS), as a *de facto* standard for more than 15 years. This format was originally developed for the data of GPS and was later accommodated to the Russian GLONASS system without changing the basic structure of the format. The ongoing modernization of GPS and the emergence of the new GNSS systems, however, require more flexibility of the format. In fact, the RINEX version 2 format is incapable of supporting all of the data types currently available from some L2C-capable receivers (Langley and Leandro, 2007). To support more flexibility to handle the new GNSS signals, a major revision of RINEX format was made and the new version 3.00 of the format was proposed in IGS (Gurtner and Estey, 2006). It is expected that the RINEX version 3.00 format will eventually become the *de facto* IGS data standard.

A drawback of the RINEX format is that the file size of the observation file becomes large compared with receiver-specific binary formats even if ordinary file compression schemes are applied. To mitigate this drawback, the Compact RINEX format version 1.0, a compression format which is compatible with the RINEX version 2 observation file format, was developed (Hatanaka, 1996a,b) and has been used to exchange and archive data. Because the new RINEX version 3.00 format also has the same drawback, a similar compression scheme for this format is desired.

This paper describes the new compression format, Compact RINEX format 3.0, which is compatible with the RINEX version 3.00 observation file format, and compression tools as well. (Note that the Compact RINEX format is a compression format only for the RINEX observation data files, not for navigation message files or meteorological data files).

2. Compression techniques and rules

The technique used for compression of RINEX version 3.00 files is basically the same as that adopted for the previous version (1.0) of the Compact RINEX format (Hatanaka, 1996) except for some details. The explanation below is largely revised from Hatanaka (1996a,b) to clarify the details and the differences from the previous version of the format.

2.1 Definition of data series that are subjects of differential operation

The compression techniques adopted in the Compact RINEX format are kinds of differential operations of data series. Here, a data series is defined as an epoch-to-epoch continuous sequence of data of the same category.

The data series of the four categories listed in Table 1 are subjects of the differential operation. One of two methods of differential operation is applied to the data of each of the four categories according to its type, “numeric” or “text”. Note that RINEX header and event records (including corresponding epoch records) are not subjects of the operation.

The data series of category A and category B are easily identified since their elements are unique within one epoch of data. A series of observation records (category C) is defined for each data type and satellite. The corresponding data of the same satellite in adjacent epochs belong to the same data series even if the order of the satellite in the list is changed from epoch to epoch in a RINEX file. A series of flags of Loss of Lock Indicator (LLI) and signal strength (category D) is defined for each satellite but not for each data type. A bundle of these flags of all data types is handled as one piece of text data and the initialization of differential operation is, hence always done for the data in all types together for each satellite. In order to identify corresponding observation data between adjacent epochs for the differential operation, each of the satellite IDs in the satellite list must be unique for each epoch in the original RINEX file.

The differential operation is initialized and terminated at the first and the last epoch of the series, respectively. Table 2 summarizes the cases to initialize differential operation, i.e. cases to (re)start data series. Epoch intervals may be uneven and interruption of the differential operation epochs is necessary not at missing epochs but at existing epochs where corresponding data are missing. On the other hand, differential operations may be initialized at arbitrary epochs so that the data series can be split into two series even if the data is not missing. A data series is terminated in the following cases: (1) the last piece of data before the re-initialization of the differential operation (Table 2), (2) the end of the file, and (3) the corresponding data field is blank at the next epoch for category B and C data series.

The above rules for the identification of data series and that of initialization of the differential operations are the same as those of the Compact RINEX version 1.0 format. There is, however, one subtle but significant difference concerning the handling of the LLI and signal strength flags (the category D series). In the case of Compact RINEX version 1.0, these data are set for each data type separately and the initialization of the differential operation is triggered by that of the corresponding observation record (the category C series) of the corresponding satellite. The version 1.0 format is, therefore, not capable of handling only–flag data (without an observation field). The version 3.0 format is improved to solve this defect: a category D series is defined not for each data type but for all data types bundled as described previously and the initialization for the category D series is triggered independently of that for the category C series.

Table 1 Categories of data series that are subject of differential operations, and the type of operation.

Category	Contents	Type
A	Epoch information (time tag, event flag, number of satellites, and list of satellites)	text
B	Clock offset	numeric
C	Observation record	numeric
D	LLI and signal strength	text

2.2 Differential operation for text data

Texts of category A and D data series are highly redundant because most of the characters are common between adjacent epochs. The idea of the differential operation for the “text” data is to eliminate redundant

Table 2 Cases to initialize differential operation

Category of series / Case	A-D altogether	Independently		
		B	C	D
First epoch in the file	M	-	-	-
Next epoch to an insertion of event records (event flag >1)	M	-	-	-
An arbitrary epoch	O	O	O	O
When new satellites appear	-	-	M	M
When a corresponding numeric data field in the previous epoch is blank	-	M	M	-

M: mandatory
O: Optional
See Table 1 for the contents of the category A-D.

characters. A character in the text of the current epoch is replaced with a space if it is the same as that of the previous epoch in the original RINEX file. When non-space characters in the text are changed to spaces, or “disappear” in other words, a special character “&” is assigned to distinguish the disappearance of the character from unchanged character. This procedure assumes that the character “&” does not appear in the category A and D data of the original RINEX file. The original sequence of the text data is recoverable from the complete text of the first epoch in the series and the differential texts of succeeding epochs.

In the case of Compact RINEX format version 1.0, the first column of an epoch line (category A series) is replaced by "&" in the case of initialization of differential operation. This is an exceptional rule of the differential operation for “text” data based on the assumption that the first column is always a space, but is necessary to mark the initialized epoch lines and distinguish them from differenced data. This exceptional rule is abolished in the Compact RINEX format version 3.0 since the record identifier ">" is placed at the first column in the RINEX format version 3.00 and it can be the mark of the initialization of differential operation as well. Since the record identifier of the original data is always “>”, the first column of the epoch line is always replaced with a space by the differential operation. The record identifier “>” remains only in the case of the initialization. Note that the character "&" at the first column of the lines where epoch data are expected is reserved for escape lines (as described in the section 3 and Appendix 2).

There is no such mark for the initialization of the differential operation for category D series. To clarify the initialization, a new rule is set in the version 3.0 format: All spaces in the initial data of a category D series are replaced with the character "&".

The differential operation described here does not solely decrease the size of the text data but is effective when combined with elimination of spaces at the end of each line and additional compression by ordinary file-compression programs.

2.3 Differential operation for numeric data

Efficiency of compression of the “numeric” data is crucial to the total performance of the compression since they occupy the greatest part of the data in RINEX observation files. A multiple-order differential operation is applied for the “numeric” data series (categories B and C). This procedure reduces the size of the correlated components of the numeric data series with a cost of increase of the random or un-correlated component as demonstrated by Fig. 1.

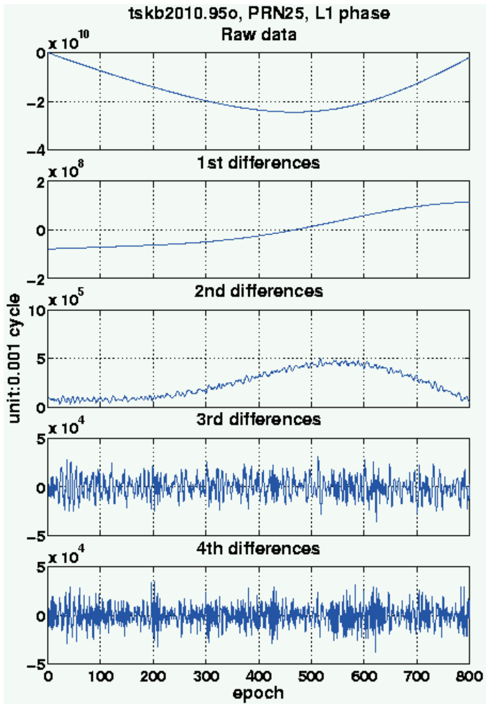

Fig. 1 An example of the original and differenced data series. The sampling interval is 30 seconds. The drift in the original phase data decreases by raising the order of difference, while the random noise remains and slightly increases.

The reason that the “multiple” difference effectively reduces the size of correlated signals is easily understood from the fact that the m-th order difference of a series is, if epoch interval is even, equivalent to the prediction error of the data by the (m-1)-th order polynomial fit to the data of m epochs just before the target epoch.

The detail of the algorithm of the operation and the definition of the differenced data series (processed epoch series) are described in Appendix 1. Table 3 and Table 4 show the mean log-range (~ number of digits) of an example of differential data for a dataset of 30-second sampling and that of 1-Hz sampling, respectively. Data of an IGS site REDU are chosen as the samples since many types of observation, including Doppler data, are recorded with both

Table 3 An example of average digits for data of 30-second sampling (file: redu0010.07o)

	L1	L2	C1	P2	P1	D1	D2	S1	S2	All
Original data	10.1	10	10.4	10.4	10.4	6.2	6.1	4.7	4.6	8.1
1st order difference	7.7	7.6	7.0	7.0	7.0	4.0	3.9	1.2	0.5	5.1
2nd order difference	5.5	5.4	4.8	4.8	4.8	3.0	2.9	1.6	0.9	3.7
3rd order difference	4.1	4.0	3.7	3.6	3.6	3.3	3.2	1.9	1.1	3.2
4th order difference	4.3	4.2	4.0	3.9	3.9	3.5	3.4	2.3	1.4	3.4

Table 4 An example of average digits for a data of high-rate (1 Hz) sampling (file: concatenation of redu001xxx.07o)

	L1	L2	C1	P2	P1	D1	D2	S1	S2	All
Original data	10.1	10.0	10.4	10.4	10.4	6.2	6.1	4.7	4.6	8.1
1st order difference	6.2	6.1	5.5	5.5	5.5	2.7	2.6	0.7	0.1	3.9
2nd order difference	2.5	2.4	2.0	2.6	2.6	2.8	2.7	1.0	0.2	2.1
3rd order difference	2.5	2.4	2.1	2.9	2.9	3.1	3.0	1.2	0.3	2.3
4th order difference	2.7	2.6	2.3	3.1	3.1	3.3	3.2	1.6	0.4	2.5

sampling rates. The values in the tables are calculated by taking averages of $\log_{10}(|y|+1)$, where y is observation data multiplied by 1000 so as to be integer. The order of difference that minimizes the data size depends on the data type, sampling rate, noise level, etc. as shown in the tables. The 1st-order difference minimizes the range of the signal-strength data (SN1 and SN2) because it does not change frequently. The 2nd- and 3rd-order difference is optimum for phase data (L1 and L2) for 1-Hz and 30-second sampling interval, respectively. If we select one common order of difference for all data types, 3rd-order may be a reasonable choice.

The sizes of multiple-difference of the numeric data may become large around the epochs where there is a sudden and big jump in the original data, which may be caused by cycle slips or resets of clock. In such cases, termination and initialization of the differential operation may produce better results in terms of compression performance. The application of the optional initialization of the differential operation at an arbitrary epoch (see Table 2) may be used for this purpose and is recommended when a big jump is detected in a numeric data series.

2.4 Limitation of the compression scheme

Since a differential scheme is used, the data after a corrupted part can not be recovered until the differential operations are initialized. There is not a perfect solution for this problem. It is, however, possible to decrease the loss of information by initializing the differential operation of all data periodically (for example, every 100 epochs). This may increase the chances of salvaging parts of data after corruption of data in the middle while costing reduced compression performance.

3. The Compact RINEX format version 3.0

The Compact RINEX format version 3.0 is developed by modifying the previous version 1.0 of the same format. (The major version number 2 is skipped.) The new format is fully compatible with the RINEX format version 3.00 and is expected to keep the compatibility for future minor revisions of the RINEX format as long as the structure of the RINEX format is unchanged.

The specification of the Compact RINEX format is described in Appendix 2, and an excerpt of an example file is shown with comments and memos in Appendix 3. It is an ASCII text format and high compression rate is achieved by combination with ordinary file compressions such as the UNIX commands “compress” or “gzip”. The basic structure and elements of the old and new Compact RINEX formats are mostly the same. The differences could be minimized owing to the similarity of the RINEX format version 3.00 to that of version 2.xx. The similarity of the new and old formats (of both the RINEX and Compact RINEX formats) simplifies the modification of compression and decompression software and makes it easy to implement functions to handle the both formats in one program.

The Compact RINEX format is NOT a lossless file compression format, but the contents are lossless. The following information in the original RINEX texts is lost by conversion to the Compact RINEX format:

(1) spaces at the end of each line,

(2) distinction of subtle differences in the format of numerical data such as the distinction between "-0.123" and "-.123",

(3) the type of newline code.

The recovered RINEX file may be different from the original one in these particulars.

The units of the numeric data are not the same as those in the original RINEX files. In the specification of RINEX format version 3.00 (Gurtner and Estey, 2006), three decimal places are assigned for observation data and twelve decimal places for receiver clock offset. In the Compact RINEX format, all numeric data are dealt with as integer values by moving the figures three or twelve places to the left prior to application of the differential operation. The units of numeric data in Compact RINEX format version 3.0 are, therefore, 1/1000 of those of RINEX format version 3.00 for observation data and 10^{-12} for clock offset data.

The optional record section is newly defined for future extension of the Compact RINEX format. A possible extension is to define a sort of checksum. As mentioned in section 2.4, the differential scheme has a weakness related to the corruption of the file. The detection of corruption of file is, hence, important. At present, corruption of file can be detected only if there is a violation of the format specification. A function of a sort of checksum for the format is, hence, desired to be developed and incorporated in future.

4. Software tools

The software RNXCMP version 4 (Technical Reports of the Geographical Survey Institute H･1-No.6 "The RNXCMP software for compression/restoration of RINEX observation files") was developed by implementing functions to compress/decompress the new formats to the software of the previous version 2.4.3. The software consists of the source codes and the executable binaries of the main tools, the scripts and batch files of the frontend tools, and related documents.

4.1 The main tools

There are two main tools in the software; RNX2CRX for compressing a RINEX observation file into the Compact RINEX format and CRX2RNX for recovering the original RINEX file from the Compact RINEX file.

The main tools deal with not only the conversion between the new formats (RINEX 3.xx and Compact RINEX 3.0) but also that between the old formats (RINEX 2.xx and Compact RINEX 1.0). Users can apply the same commands in the same way for both the new and the old formats, and do not have to care about the format versions (except for version 1 of the RINEX format which is not supported). The conversion from the old format to the new format is, however, out of the scope of the software.

The source codes of the main tools have been compiled on several platforms (UNIX, DOS and MacOSX). On any platform, the tools accept any of two types of the new-line codes of ASCII text in the input files; LF (0x0A) and CR+LF (0x0D+0x0A). Hence users do not have to care about the systems (UNIX or DOS) on which the input RINEX or Compact RINEX files were created. The new-line codes for the output Compact RINEX texts are always LF on UNIX and MacOSX systems and CR+LF on DOS systems. The new-line code CR (0x0D), that was the case of the old Mac OS (up to version 9), is not supported, however. In this case, users have to convert "CR" into "LF" or "CR+LF" before applying the tools.

The main tools can read a specified input file and write an output file if the extension of the input file name follows the naming convention ("*yy*o/*yy*O" for RINEX and "*yy*d/*yy*D" for Compact RINEX, where *yy* is the last two digits of the year; see Table 4 of Gurtner and Estey, 2006). Otherwise, the tools use the standard input and the standard output so that they can be used as filter commands.

The tools have an option '-s' to skip corrupted parts of the input to be read. When this option is specified and corrupted data are detected, RNX2CRX skips them and tries to find the next normal epoch to continue conversion. CRX2RNX has the same option but it can only recover the data after the epoch that the differential operations of all data are initialized. This option assumes that numbers of data types are not changed during the skipped part of the data. RNX2CRX has an option '-e [N]' to initialize the differential operation periodically every N epochs. This option may be used to increase chances to recover parts of data by using an option of CRX2RNX with cost of increase of file size.

As explained in section 2.3, initialization of the differential operation may produce better results when a big jump is detected in a numeric data series. RNX2CRX initializes a differential operation of observation data series (Category C) if a differential value larger than a threshold (10000000.000 in the case of version 4.0.3) is detected.

Although the specification of the Compact RINEX format allows the maximum differential order M for numerical data up to 9, the value of M is fixed to 3 in the current version (4.0.3) of the compression tool RNX2CRX. As shown in Table 3 and 4, this value of M is not optimum for every observation type of every case. An option of switching the value of M is one possible improvement in the future. The decompression tool CRX2RNX may accept the value of M up to 5.

4.2 Supplementary frontend tools

Since the Compact RINEX format is an ASCII text format, the high compression rate is achieved by combining the generation of the Compact RINEX file with an additional standard data compression program. The tools RNX2CRX and CRX2RNX do not handle this additional process, however. For convenience, the frontend tools RNX2CRZ(.bat) and CRZ2CRX(.bat) are also provided to do these two steps by one command. The frontend tools are the c-shell scripts for UNIX systems and the batch files and an executable binary file for MS-DOS/Windows systems. The DOS batch files assume that the file compression tools (compress.exe, compr.bat, decompr.bat) that are compatible with UNIX compress/uncompress commands are installed.

These frontend tools are applicable not only to the RINEX/CRINEX files but also to the (UNIX-)compression or decompression of all RINEX files (i.e., for navigation message files and met files, too).

5. Compression performance and running speed

Table 5 shows a comparison of compression performance for a sample of a RINEX version 3.00 file that was provided by Langley & Leandro (2007) and is available from an IGS data center. The file contains nine data types including modernized GPS signals and the sampling interval is 30 seconds. A compression rate for the conversion to Compact RINEX (from ASCII to ASCII) is 23%, which is nearly the same level as the performance of UNIX compress (“rate-1” in Table 5). By performing additional compression with “UNIX compress”, a compression rate of 9% is achieved. This rate looks better than that of Compact RINEX version 1.0 (Hatanaka, 1996), but it is mainly due to the relatively sparse contents of the file used for the test, and it is not evidence of more efficiency of the new compression format. The values in the column “rate-2” in Table 5 are the comparison of compression rate relative to that of the UNIX “compress” command. The size of “UNIX-compressed” Compact RINEX is 38.3% of that of the “UNIX-compressed” RINEX file. This value is nearly the same as that of Compact RINEX version 1.0 (Hatanaka, 1996).

The running speed of the old and new versions of software are compared in Table 6. The files used for the benchmark test are 24-hour files of 30-second sampling of the 1358 GEONET stations of November 1, 2005. All the files are in the old format (RINEX version 2.10 or Compact

Table 5 Compression performance for an example RINEX version 3.00 file (unb32243.07o).

	Size (kb)	Rate-1	Rate-2
RINEX	3833	**100.0%**	424.5%
Compress	903	23.6	**100.0**
C-RINEX	1010	26.4	111.8
C-RINEX+compress	346	9.0	38.3

Table 6 Comparison of running time between the old and new version of the software (CPU: Intel Xeon 3GHz)

	Ver. 2.4.3	Ver.4.0.3
(1)RINEX→C-RINEX	171s	109s
(2)C-RINEX→RINEX	222s	165s
(3) (1)+UNIX compress	149s	108s
(4) UNIX uncompress+(2)	221s	153s

RINEX version 1.0). The running speeds of the new tools are about 25-36% faster than that of the old one, and hence, not only the users of the RINEX version 3.00 format but also users of the RINEX version 2.xx format can take the benefit from the new compression/decompression tools.

6. Conclusions

The Compact RINEX format version 3.0 and the compression/decompression software tools were developed for compression of files in the RINEX observation file format version 3.00. The compression performance is on the same level as that of the old format for the RINEX format version 2.xx. The tools can handle both the new and the old format.

The format and tools developed in this study facilitate the exchange and use of observation data of GNSS, and would contribute toward the standardization of the GNSS data exchange format by supporting popularization of the new RINEX format version 3.00.

The latest version of the software is available from following URL:
ftp://terras.gsi.go.jp/software/RNXCMP/

Acknowledgements

I would thank Dr. W. Gurtner of Bern University for discussions on the revision of the compression format. The development and checking of the software were aided by many people; those who provided sample files of the RINEX version 3.00 files, those who gave me feedback comments of trying testing version of the software and those who claimed me about bugs of the released versions. I would like to thank them.

References

Gurtner, W., G. Mader (1990): Receiver Independent Exchange Format Version 2, GPS Bulletin, Vol.3, No.3, 1-8.

Gurtner, W., L. Estey (2006): RINEX The Receiver Independent Exchange Format Version 3.00., available from ftp://igscb.jpl.nasa.gov/igscb/data/format/rinex300.pdf

Hatanaka, Y. (1996a): Compact RINEX Format and Tools (beta-test version), proceeding of 1996 Analysis Center Workshop of IGS, March 19-21, 1996, 121-129.

Hatanaka, Y. (1996b): A RINEX Compression Format and Tools, Proceedings of ION GPS-96, September 17-20, 1996, 177-183.

Langley & Leandro (2007): RINEX 3.00 Initiative, IGS mail #5632.

Appendix 1 Algorithm of Differential and Recovering Operations of Numeric Data Series

Let $Y_i^0 (i = 1,2,\dots,n)$ be an epoch series of numeric data of a specific type. The superscript represents the order of difference. The multiple-order differences are calculated from the original epoch series.

$$\left.\begin{aligned} Y_i^1 &= Y_i^0 - Y_{i-1}^0, \\ &\vdots \\ Y_i^m &= Y_i^{m-1} - Y_{i-1}^m; \quad i = 2,\cdots,n, \end{aligned}\right\} \qquad (1)$$

where $m = \min(i-1, M)$ and M is the maximum order of difference and is defined for each data series. This process is schematically indicated by the red arrows in Fig. A-1. This scheme can be viewed as an updating process of the state vector $[Y_i^0, Y_i^1, \cdots, Y_i^m]$ of the i-th epoch. Because the state vector of the current (i-th) epoch can be derived from only the given data Y_i^0 of the current epoch and the state vector of the previous (i-1)-th epoch, the calculation scheme can be implemented as a filtering process.

The output of the operation (1) is the "processed epoch series", that is defined by the following data series:

$$\left.\begin{aligned} Y_i^{m-1} &= Y_{i-1}^{m-1} + Y_i^m, \\ &\vdots \\ Y_i^1 &= Y_{i-1}^1 + Y_i^2, \\ Y_i^0 &= Y_{i-1}^0 + Y_i^1; \quad i = 2,\cdots,n. \end{aligned}\right\} \qquad (2)$$

The data series (2) and M are the necessary and sufficient data to recover the original epoch series.

The operation to recover the original data from the processed epoch series (2) is as follows:

$$\left.\begin{aligned} &Y_i^{m-1} = Y_{i-1}^{m-1} + Y_i^m, \\ &\vdots \\ &Y_i^1 = Y_{i-1}^1 + Y_i^2, \\ &Y_i^0 = Y_{i-1}^0 + Y_i^1; \qquad i = 2,\cdots,n. \end{aligned}\right\} \tag{3}$$

This process is schematically indicated by the blue arrows in Fig. A-1. As in the case of the differential process (1), process (3) can also be implemented as a filtering process because the state vector of i-th epoch can be derived from just the given differential data Y_i^m of i-th epoch and the state vector of (i-1)-th epoch.

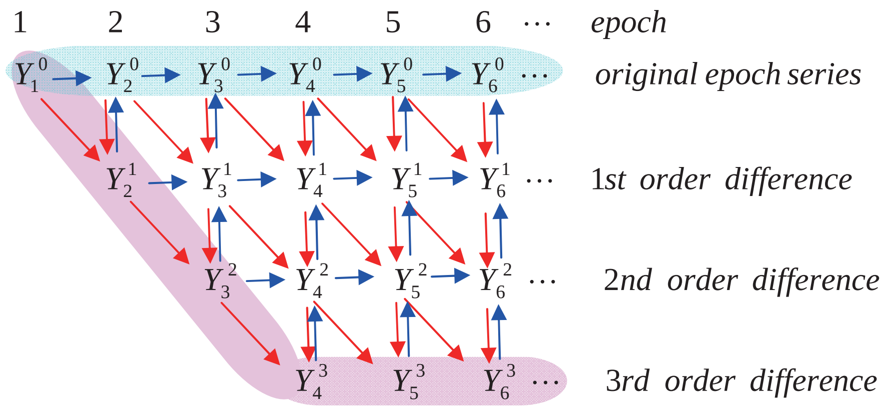

Fig. A-1 Schematic diagram of differential process (red arrows) and recovering process (blue arrows) for the case of M=3. The original epoch series and the processed one are hatched with light blue and magenta, respectively. The columns of the data elements in the diagram are regarded as “state vectors”.

Appendix 2 Specification of Compact RINEX Format Version 3.0

The basic structure of the Compact RINEX format version 3.0 is analogous to that of the RINEX observation format version 3.00. It basically consists of two sections; the header and the data record section. The header section (Table A-1) is placed only once at the top of the file and is followed by the data record sections (Table A-2) repeated for each observation epoch. The optional record section is newly defined (Table A-3) for possible future extension of the format. This section is not usable at current but, if the definition is given in future, it may be inserted between the sections. Throughout a Compact RINEX file, spaces at the end of each line should be removed. (This is not mandatory but highly recommended.)

Table A-1

COMPACT RINEX FILE - HEADER SECTION DESCRIPTION		
HEADER LABEL (Columns 61-80)	**DESCRIPTION**	**FORMAT**
CRINEX VERS / TYPE	- **Format version (“3.0”)** - **File type (“COMPACT RINEX FORMAT”)**	**A20, A20, 20X**
PGM / RUN BY / DATE	- **Name of program creating current file** - **Date of file creation (dd-mmm-yy hh:mm)**	**A40, A20**
(the same as specification of RINEX version 3.xx)	- **Header lines of the original RINEX version 3.xx file**	**A80**

Table A-2

<table>
<tr><th colspan="2">COMPACT RINEX FILE - DATA RECORD SECTION DESCRIPTION</th></tr>
<tr><th>DESCRIPTION</th><th>FORMAT</th></tr>
<tr><td>- First 41 characters of EPOCH record
- List of satellite numbers (in the order of corresponding record lines in the original RINEX file.)

These records are dealt with as "text strings" and manipulated by the differential operation after formatting and before outputting.</td><td>A41
n(A1,A2),
n: number of satellites</td></tr>
<tr><td>- receiver clock offset;
case 1: the maximum differential order and original data if the differential operation is initialized
case 2: differenced data
case 3: no data if the data field in the original RINEX is a blank

This record must be omitted if Epoch flag >1.</td><td>Case 1: I1,"&",I
Case 2: I
Case 3: Null (just a new line)</td></tr>
<tr><td>For cases EPOCH flag = 0 or 1 in original RINEX file:
- observation data;
case 1: the maximum differential order and original data if the differential operation is initialized
case 2: differenced data
case 3: no data if the data field in the original RINEX is a blank

- LLI and Signal strength for all data types; original text but with replacing all spaces with “&” if the differential operation is initialized, otherwise the differenced text.

This record is repeated for each satellite having been observed in the current epoch. The order of the records (satellites) has to be the same as that in the original RINEX file.</td><td>Case 1: I1,"&",I,1X,
Case 2: I,1X,
Case 3: 1X,
This item is repeated for each data type of the corresponding GNSS system defined in the header or the special records.

m(A1,A1)
m: number of data types</td></tr>
<tr><td>For cases EPOCH flag >1 in original RINEX file:
- Special record or cycle slip data in original RINEX file

This record is repeated for each line of special record or cycle slip data. No change is made from the original RINEX file except for elimination of trailing blanks.</td><td>A</td></tr>
</table>

Note 1: The reserved fields of the epoch records in RINEX version 3.00 format are also subject of the “text” differential operation. It is assumed that character “&” will not be used in these fields.

Note 2: The length of format 'I' is variable and may not contain a space. Plus signs (+) must be removed.

Note 3: The first N spaces in an observation data line are used as record separators unless eliminated as trailing blanks. Here, N is the number of the data types specified in the header and must be updated if it is changed by event records.

Table A-3

COMPACT RINEX FILE – OPTIONAL RECORD SECTION DESCRIPTION	
DESCRIPTION	**FORMAT**
- (Reserved) **One or more optional lines can be inserted between the header section and the first data record sections or between data record sections. Insertion of the optional lines does NOT trigger the initialization of differential operations.** **This section is defined for future extension of the format and should not be used before the contents and the detailed format specification have been determined.** **Meanwhile, decompression programs should be coded to skip the optional records to preserve backward compatibility for future definition of the optional records.**	**("&",A)**

Appendix 3 A Sample of Compact RINEX Format Version 3.0

The following text is a compressed version of the sample data in Gurtner and Estey (2006) in Compact RINEX Format version 3.0. Memos and remarks are written in red.

```
3.0                   COMPACT RINEX FORMAT                    CRINEX VERS   / TYPE
RNX2CRX ver.4.0.3                         14-Dec-07 00:48     CRINEX PROG / DATE
     3.00             OBSERVATION DATA    M                   RINEX VERSION / TYPE
G = GPS  R = GLONASS  E = GALILEO  S = GEO  M = MIXED         COMMENT
XXRINEXO V9.9         AIUB                20060324 144333 UTC PGM / RUN BY / DATE
EXAMPLE OF A MIXED RINEX FILE VERSIOIN 3.00                   COMMENT
(middle part omitted)
     0                                                        RCV CLOCK OFFS APPL
G    5 C1C L1W L2W C1W S2W                                    SYS / # / OBS TYPES
R    2 C1C L1C                                                SYS / # / OBS TYPES
E    2 L1B L5I                                                SYS / # / OBS TYPES
S    2 C1C L1C                                                SYS / # / OBS TYPES
    18.000                                                    INTERVAL
GC1C GC1P  -0.123 1 CODE P1-C1 082-2006 CC2NONCC              SYS / DCBS APPLIED
DBHZ                                                          SIGNAL STRENGTH UNIT
  2006    03    24    13    10    36.0000000     GPS          TIME OF FIRST OBS
                                                              END OF HEADER
> 2006 03 24 13 10 36.0000000  0  5      G06G09G12E11S20
3&-123456789012
3&23629347915 3&300 3&-353 3&23629347158 3&24158 &&&8&4&&&&
3&20891534648 3&-120 3&-358 3&20891545292 3&38123 &&&9&6&&&&
3&20607600189 3&-430 3&394 3&20607600848 3&35234 &&&9&5&&&&
3&324 3&178 &8&7
3&38137559506 3&335849135 &&&9
                  54             7                R2 R 2E11S20
-198
-10252465 -53875932 -41981022 -10252150 1076
-5458981 -28687907 -22354177 -5469191 4108        7
3472500 18248219 14219376 3471562 1531      6
3&21345678576 3&12345567 &&&5
3&22123456789 3&23456789 &&&5
65431799 48861408  5
0 0
> 2006 03 24 13 11 12.0000000  2  2
      *** FROM NOW ON KINEMATIC DATA! ***                     COMMENT
      TWO COMMENT LINES FOLLOW DIRECTLY THE EVENT RECORD      COMMENT
> 2006  3 24 13 11 12.0000000  0  4      G06G09G12G16
3&-123456789876
3&21110991756 3&16119980 3&12560510 3&21110991441 3&25543 &&&7&4&&&&
3&23588424398 3&-215050557 3&-167571734 3&23588424570 3&41824 &&&6&6&&&&
3&20869878790 3&-113803187 3&-88677926 3&20869878938 3&36961 &&&8&6&&&&
3&20621643727 3&73797462 3&57505177 3&20621644276 3&15368 &&&7&2&&&&
(omitted)
```

The original RINEX header

epoch information (initialized)

Clock offset (initialized)

Observation data and flags (initialized)

A differenced text of epoch info.

Clock offset (differenced)

Differenced data and flags except for two new satellites whose data are initialized for differential operation

Special records inserted (event flag >1)

All data initialized after insertion of the special record