Understanding the RINEX Format

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ABSTRACT

The Receiver Independent Exchange (RINEX) format was initially developed by the Astronomical Institute of the University of Bern, Switzerland, in the late 1980s. It has since become the international standard for the storage and exchange of Global Navigation Satellite System (GNSS) data, not only enabling interoperability between receiver brands and processing software packages but also the generation of many valuable products and services to the GNSS user community by the International GNSS Service (IGS). RINEX files are universally used by international organisations, academia, national organisations, all levels of government and private industry. Consequently, users need to understand the contents and format of these files. Focussing on GNSS observation files, this paper provides a brief history of the RINEX format and outlines examples of recent RINEX format versions. It discusses the editing of RINEX observation files and how GNSS data contributes to the datum modernisation efforts in NSW. This also includes the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for the maintenance of the NSW survey control network and the timely update of survey information in the Survey Control Information Management System (SCIMS).

KEYWORDS: *RINEX, GNSS, metadata, AUSPOS, datum modernisation*.

1 INTRODUCTION

The Receiver Independent Exchange (RINEX) format is the international standard for the storage and exchange of Global Navigation Satellite System (GNSS) data, enabling interoperability between receiver brands and post-processing software packages. It allows efficient and unambiguous archiving of GNSS data and associated metadata in one place (in a human-readable form), while also facilitating the easy transfer and distribution of such data, independent of the equipment used to collect it and the engine employed for data processing.

RINEX files are commonly used by international organisations (e.g. the International GNSS Service, IGS), academia, national organisations (e.g. Geoscience Australia), state government, local government and private surveying companies. Online processing services, such as Geoscience Australia's free online Global Positioning System (GPS) processing service, AUSPOS (GA, 2024), and the CSRS-PPP online Precise Point Positioning (PPP) service provided by Natural Resources Canada (NRCan, 2024), require the user to submit data in RINEX format. Consequently, it is important that users understand the contents and format of these files.

DCS Spatial Services, a unit of the NSW Department of Customer Service (DCS), is responsible for the establishment, maintenance and improvement of the state's survey control network, which comprises more than 250,000 survey marks on public record made available to users via the Survey Control Information Management System (SCIMS). The backbone of the NSW survey control network is provided by CORSnet-NSW, Australia's largest state-owned and operated GNSS Continuously Operating Reference Station (CORS) network. CORSnet-NSW currently consists of 209 stations, providing fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications (e.g. Janssen et al., 2016; DCS Spatial Services, 2024a). DCS Spatial Services uses RINEX files in providing services to its customers and the broader surveying profession as well as interacting with federal counterparts to support national initiatives.

This paper provides a brief history of the RINEX format and outlines examples of recent RINEX format versions. It then discusses the editing of RINEX observation files and how GNSS data contributes to datum modernisation in NSW. This also includes the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for the maintenance of the NSW survey control network and the timely update of survey information in SCIMS.

2 A BRIEF HISTORY OF RINEX

All manufacturers store raw GNSS (and most other survey instrument) data in proprietary, binary (non-human readable) data formats that are designed to be compact, optimise specific observations, enhance performance with their own algorithms and software modules (or complete software suites) and that lock users into their brand. As such, swapping raw survey data between brands was never intended. That was until RINEX was invented.

Initially, the RINEX format was developed by the Astronomical Institute of the University of Bern, Switzerland, to facilitate the easy exchange of GPS data to be collected during the first large European GPS campaign, EUREF89, which involved more than 60 GPS receivers of four different manufacturers (Gurtner et al., 1989). It defined three different file types: observation data file, navigation message file and meteorological data file. The reader is encouraged to appreciate the complexity and delicacy of negotiations and confidence that was entrusted to this organisation to initially gain access, and then continued access over the decades, to the proprietary Intellectual Property (IP) of each of the major manufacturers and the very idea of championing interoperability.

Each RINEX file consisted of a header section containing metadata related to the station occupied and the equipment used, followed by a main body with the actual data. The files were designed to have a maximum line length of 80 characters, written in American Standard Code for Information Interchange (ASCII) to enable humans to read (and edit) the data and guarantee an easy exchange between different computer systems. The cost of being human-readable is that RINEX files are always larger in size than the raw format files. The observed GPS data included the carrier-phase measurement on one or two frequencies, the pseudo-range (code) measurement, the Doppler measurement, the signal strength and the observation time.

Through the use of the RINEX format, it was possible to combine data observed by a multitude of receiver brands and models in order to be processed together. Over many years, and under the umbrella of the IGS, the RINEX format has since been modified, expanded and improved to allow multi-GNSS data to be handled, thus becoming the international standard used for the transfer, archival and distribution of GNSS data by the IGS and countless other users in the

GNSS community worldwide (IGS, 2024a). For example, this has resulted in the computation of the ever-improving International Terrestrial Reference Frame (ITRF – for the latest ITRF2020, see Altamimi et al., 2023). Based on the collation and processing of globally collected GNSS data, the IGS provides a wide range of valuable products to the GNSS user community, including precise satellite orbits and clocks, terrestrial reference frame products (e.g. station positions and earth rotation parameters) and global ionospheric maps (IGS, 2024b). Without RINEX, this collaboration and its benefits, along with open, regional CORS networks such as CORSnet-NSW, would have been impossible. The alternative would have been for each manufacturer to build and operate their own closed proprietary system. Understandably, the costs would have been prohibitive.

In the mid-1990s, the success of the RINEX format spawned a spin-off: the Solution Independent Exchange (SINEX) format, which is used by the geodetic community to store and transfer solutions of various parameters derived in various types of analysis (e.g. AUSPOS solutions containing more detailed information for advanced users). This was followed by a family of other RINEX-like file formats (IGS, 2024a) that are mainly used by the IGS, including exchange formats for satellite and receiver clock offsets determined by processing data of a GNSS network, for Space-Based Augmentation System (SBAS) broadcast data files, for ionosphere models determined by processing data of a GNSS network (IONEX), and for phase centre variations of geodetic GNSS antennas (ANTEX).

To date, the following four versions of RINEX have been developed and published (Gini, 2023):

- The original RINEX version 1 was presented at and accepted by the 5th International Geodetic Symposium on Satellite Positioning in Las Cruces, New Mexico, in 1989.
- RINEX version 2 was presented at and accepted by the 2nd International Symposium of Precise Positioning with the Global Positioning System in Ottawa, Canada, in 1990. It mainly added the possibility to include tracking data from different satellite systems (i.e. GLONASS, SBAS). Over time, it was modified via several sub-versions, culminating in version 2.11.
- RINEX version 3 was developed in the early 2000s and initially released in 2007 to support multi-GNSS and clearly identify the tracking modes of each of the observations by introducing 3-character observation codes for all GNSS constellations. Over time, it was modified via several sub-versions, culminating in version 3.05.
- RINEX version 4 was released in 2021 as a necessary step to support the modern multi-GNSS navigation messages by introducing and defining navigation 'data records' to hold both individual satellite navigation messages, constellation-wide parameters and global parameters as transmitted by the different GNSS constellations. It has since been updated to version 4.01.

3 EXAMPLES OF RECENT RINEX FORMAT VERSIONS

While it is recognised that the RINEX format encompasses observation data, navigation data and meteorological data, along with extensions such as satellite and receiver clock data and SBAS broadcast data files, this paper focuses on RINEX observation files as these are the most important for surveyors in practice (and the most likely to be edited). Apart from using the broadcast ephemeris data collected by their own receiver, surveyors can easily obtain precise orbit files from various sources if required (e.g. via IGS, 2024b), and the other files are generally not used in common surveying applications.

3.1 RINEX 2.11

Following several revisions for improvement and clarification, RINEX 2.11 (Gurtner and Estey, 2012) is the last official RINEX version 2 format. Its major difference compared to the original RINEX version 1 format is that it caters for tracking data from different satellite systems in addition to GPS. This format has been used for archiving AUSPOS datasets by DCS Spatial Services for inclusion into the GDA2020 state adjustment (see section 5.1), partly because AUSPOS remains GPS-only at present (Janssen and McElroy, 2022). However, a move to RINEX 3.05, along with optimising internal workflows, is imminent.

The RINEX file name must not contain any spaces, parentheses or symbols. It is beneficial to use the international RINEX 2.11 file naming convention XXXXDDDS.YYO consisting of 8 characters followed by a 3-character extension, where XXXX is a 4-character site name, DDD is the day of year (i.e. 001 to 365, or 366 during a leap year), S is the session identifier (i.e. 0 to 9, or A to X indicating the first observation epoch's hour of the day with A = 0 hours and X = 23 hours), YY is the 2-digit year (i.e. 24 for the year 2024) and the letter O indicates that this is an observation file.

RINEX file name extensions are sometimes further refined to indicate the type of compression that may be used to reduce the ASCII file size. Hatanaka (2008) developed a compression scheme and related software tools that take advantage of the structure of the RINEX observation data by forming higher-order differences in time between observations of the same type and satellite (indicated by the extension .YYd). This compressed ASCII file is then often compressed again using standard compression programs, e.g. yielding a UNIX-compressed (.YYd.Z) or gzip-compressed (.YYd.gz) Hatanaka RINEX file.

The RINEX file consists of a header section (including mandatory and optional records) followed by a data section and ends with a blank line, each row being a maximum of 80 characters long. A single RINEX file should only include a single occupation on a single mark. The header section contains information for the entire file, including mandatory header labels in columns 61-80 for each line in the header, which must appear exactly as stipulated. The header information must also appear in the correct columns to be valid, e.g. antenna information and antenna height. This is of particular importance when the RINEX header is edited (see section 4).

Figure 1 shows an example of a typical RINEX 2.11 header. It includes the following information:

- Line 1: RINEX version and statement that this is an observation file with mixed GNSS data (e.g. as opposed to GPS-only).
- Line 2: Program used to generate the RINEX file, who ran it (here blank) and when it was run.
- Line 3-4: Comments (can be placed anywhere between the first and last line in the header).
- Line 5: Marker name, in this case the 4-character ID issued to NSW by Geoscience Australia.
- Line 6: Marker number, here the SCIMS number.
- Line 7: Observer and agency, here NSW (i.e. DCS Spatial Services).

- Line 8: Receiver serial number, receiver type and firmware version.
- Line 9: Antenna serial number (for integrated antennas the same as the receiver serial number) and antenna type (using the IGS naming convention).
- Line 10: Approximate site position in WGS84 Cartesian coordinates (X, Y, Z).
- Line 11: Antenna height (measured vertically between ground mark and Antenna Reference Point, ARP) and any horizontal offset from the mark (i.e. small horizontal eccentricities of the ARP to the marker, which are typically zero for all but some scientific applications).
- Line 12: Wavelength factor for the L1 and L2 frequency, in this case indicating full cycle ambiguities for both frequencies.
- Line 13: Number and types of observations, in this case L1, L2, C1, P2, S1, S2 – i.e. carrier phase measurements, code measurements and signal strengths on the L1 and L2 frequency, respectively.
- Line 14: Sampling interval, in this case 30 seconds.
- Line 15-21: Comments, here including the name of the raw binary data file.
- Line 22: Time of first observation epoch, here 00:37:30 hours (GPS time) on 1 June 2021.
- Line 23: Number of leap seconds between GPS time and UTC, in this case 18. GPS time started at 00:00:00 UTC (midnight) on 6 January 1980 (i.e. Sunday morning). Since then, several leap seconds have been introduced to UTC (but not GPS time), currently resulting in GPS time being 18 seconds ahead of UTC.
- Line 24: End of RINEX header indicator.

```
 1      2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
 2 teqc  2016Nov7                          20210617 05:02:57UTCPGM / RUN BY / DATE
 3 Linux2.6.32-279.el6.x86_64|x86_64|gcc|Win64-MinGW64|=       COMMENT
 4 BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
 5 48DE                                                        MARKER NAME
 6 PM183662                                                    MARKER NUMBER
 7 NSW                 NSW                                     OBSERVER / AGENCY
 8 1516405             LEICA GS15          8.00/7.500          REC # / TYPE / VERS
 9 1516405             LEIGS15.R2      NONE                    ANT # / TYPE
10  -4585969.9235  2736510.8223 -3477269.8581                  APPROX POSITION XYZ
11         1.5190        0.0000        0.0000                  ANTENNA: DELTA H/E/N
12      1     1                                                WAVELENGTH FACT L1/2
13      6    L1    L2    C1    P2    S1    S2                  # / TYPES OF OBSERV
14     30.0000                                                 INTERVAL
15 Source: 6405_0601_103528.m00                                COMMENT
16 Forced Modulo Decimation to 30 seconds                      COMMENT
17 DefaultJobName                                              COMMENT
18 DefaultUserDiscription                                      COMMENT
19 Project creator:                                            COMMENT
20  SNR is mapped to RINEX snr flag value [0-9]                COMMENT
21   L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                  COMMENT
22   2021     6     1     0    37   30.0000000     GPS         TIME OF FIRST OBS
23     18                                                      LEAP SECONDS
24                                                             END OF HEADER
```

Figure 1: Typical RINEX 2.11 header.

Figure 2 shows a typical RINEX 2.11 observation data block. It contains the following information:

- Line 25-26: Date and time of the observation epoch (receiver time of the received signals) in the format year, month, day, hours, minutes, seconds (here 00:37:30 hours on 1 June 2021), epoch flag (0 = OK, 1 = power failure between current and previous epoch, >1 = special event, e.g. 2 = start moving antenna), the number of satellites in the current epoch (here 18), followed by the system identifier (G = GPS, R = GLONASS, E = Galileo, S = SBAS or geostationary) and the 2-digit satellite number (i.e. Pseudo-Random Noise code, PRN, or GLONASS slot number). In this example, 8 GPS, 6 GLONASS and 4 Galileo satellites were observed.

- Line 27-28: Observations recorded for the first satellite listed (G01) – see line 13 in Figure 1 for the corresponding observation types in the RINEX header. In this example, six types of observations were recorded for all but the Galileo satellites (the L2 frequency is not used by Galileo) – L1 carrier phase measurement, L2 carrier phase measurement, L1 code measurement (C1), L2 code measurement (P2), L1 signal strength (S1) and L2 signal strength (S2). Each observation value is defined as a floating-point value of total length 14 with 3 decimals (F14.3). This is followed by two optional single-digit integer records (I1) pertaining to the Loss of Lock Indicator (LLI, range 0-7 or blank, phase observations only) and the Signal Strength Indicator (SSI, range 1-9 for increasing signal strength or blank).
- Line 29-62: Observations recorded for the other satellites in this epoch, with missing observations (or those not observed) indicated as blanks (e.g. no L2 observations to the Galileo satellites).

```
25  21  6  1  0 37 30.0000000  0 18G01G03G04G10G21G22G31G32R02R03R04R13
26                                 R18R19E05E09E11E36
27  110137934.272 8  85821775.74248  20958552.220    20958554.400                    53.300
28         53.550
29  119766659.544 7  93324688.12247  22790840.660    22790843.240                    45.200
30         45.100
31  124156873.931 7  96745619.03746  23626267.600    23626269.980                    43.200
32         40.100
33  130281153.04615 101517801.02255  24791680.380    24791685.800                    35.450
34         34.100
35  107660051.087 8  83890939.09847  20487029.500    20487028.240                    51.400
36         45.600
37  109924937.177 8  85655784.12247  20918020.040    20918017.020                    52.900
38         44.550
39  109426889.942 8  85267704.15548  20823245.920    20823244.660                    53.300
40         53.250
41  122182552.628 7  95207188.87447  23250567.920    23250568.700                    47.650
42         42.200
43  122656371.420 6  95399420.181 6  22985753.460    22985758.360                    38.500
44         39.000
45  109283847.384 8  84998559.602 8  20415141.460    20415142.640                    52.450
46         48.900
47  114565531.929 6  89106523.251 5  21394302.360    21394302.020                    38.150
48         33.950
49  110306911.273 6  85794276.777 7  20656940.920    20656944.020                    39.850
50         42.650
51  114943294.330 8  89400354.336 7  21532750.260    21532755.080                    50.650
52         47.400
53  112735465.036 6  87683135.364 6  21074705.120    21074707.020                    38.950
54         41.550
55  129830473.839 8                  24705917.480                                    48.750
56
57  117250086.174 9                  22311949.220                                    54.400
58
59  133045175.973 7                  25317654.460                                    42.450
60
61  128710168.325 8                  24492734.840                                    52.900
62
63  21  6  1  0 38  0.0000000  0 20G01G03G04G10G21G22G31G32R02R03R04R12
64                                 R13R14R18R19E05E09E11E36
```

Figure 2: Typical RINEX 2.11 observation block.

The interested reader is referred to Gurtner and Estey (2012) for more detailed information on the RINEX 2.11 format.

3.2 RINEX 3.04 & 3.05

Following several revisions for improvement and clarification, RINEX 3.05 (Romero, 2020) is the last official RINEX version 3 format. Its major difference compared to RINEX 2.11 is that it fully supports multi-GNSS (G = GPS, R = GLONASS, E = Galileo, C = Beidou, J = QZSS, I = NavIC/IRNSS, S = SBAS) and clearly identifies the tracking modes of each of the observations by utilising 3-character observation codes for all GNSS constellations. In particular, the possibility to track frequencies on different channels required a more flexible and more detailed definition of the observation codes.

Some software currently supports formats up to RINEX 3.04 only, which has minor differences to the latest version (apart from missing signals and tracking codes to fully support the 2nd and 3rd generation of Beidou). RINEX 3.04 is also the format currently being used by DCS Spatial Services for archiving CORSnet-NSW datasets and providing them to Geoscience Australia (e.g. to be used by the AUSPOS service).

The RINEX 3.04/3.05 file naming convention (Figure 3) stipulates a much longer file name than RINEX 2.11, providing more detailed information about the dataset collected by being more descriptive, flexible and extendable (this was introduced with RINEX 3.02). In particular, this facilitates the efficient storage and exchange of RINEX data in large communities like the IGS. For practical surveying applications, this naming convention may appear to be too detailed to be adopted. However, it is important that users of IGS products or CORS data understand the new RINEX file naming in order to obtain the desired data for their purposes.

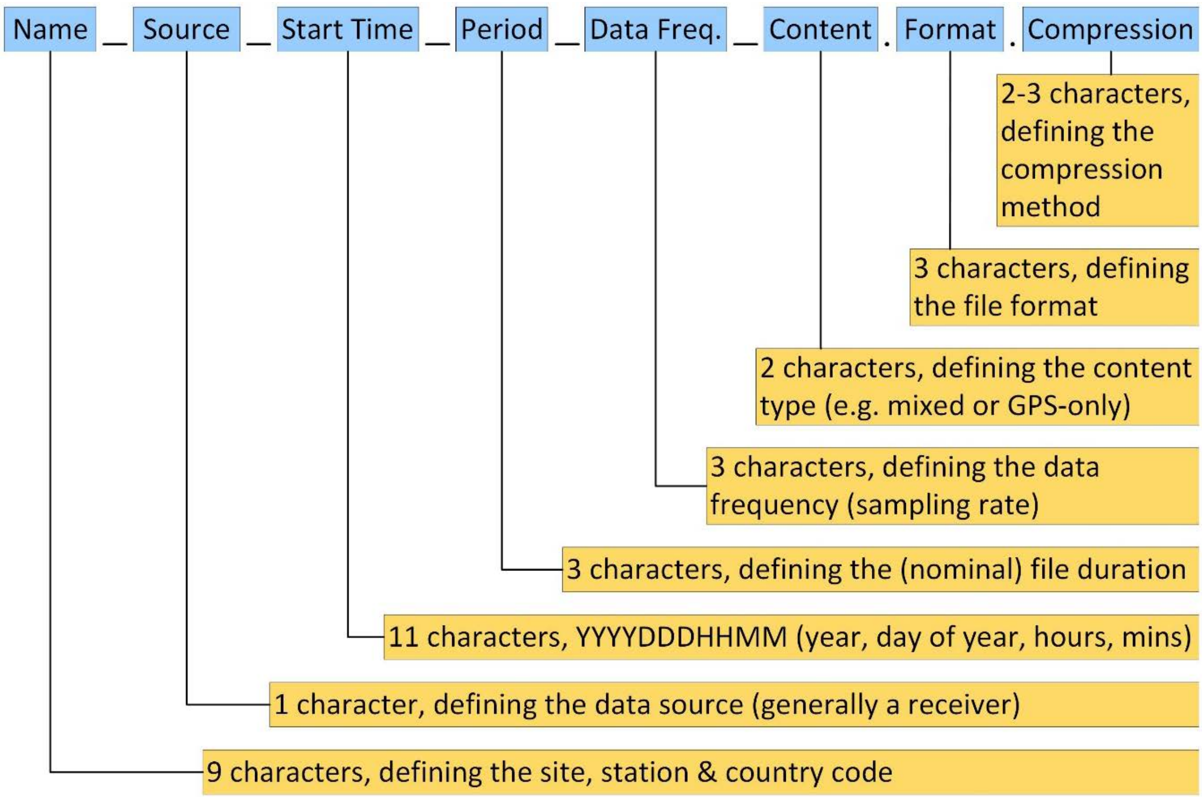

Figure 3: Philosophy of RINEX long file names introduced with version 3.02 (adapted from Gini, 2023).

The following examples illustrate the benefit of the long file naming convention, with data source, start time, duration, sampling rate and data type now easily visible as part of the file name:

- BATH00AUS_R_20240501200_03H_10S_MO.rnx indicates a RINEX observation file for Bathurst CORS (being the first monument [0] and the first receiver [0, unless additional receivers are connected to the antenna] located at this site in Australia), sourced from a receiver (via vendor or other software), observed in 2024 on day of year 050 and starting at 12:00 hours, that contains 3 hours of data at a 10-second sampling rate and mixed GNSS observation data (i.e. from at least two satellite constellations).
- BATH00AUS_R_20240501715_15M_01S_GO.rnx also indicates a RINEX observation file for Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 050 but starting at 17:15 hours, containing 15 minutes of data at a 1-second sampling rate and GPS-only observation data.
- BATH00AUS_R_20240620000_01D_30S_MO.rnx indicates a RINEX observation file for Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 062, starting at 00:00 hours, containing 1 day of data at a 30-second sampling rate and mixed GNSS observation data.
- Accordingly, BATH00AUS_R_20240620000_01D_MN.rnx.gz indicates a compressed (the gz extension indicates compression using the standard GNU zip, or gzip, algorithm) RINEX navigation file collected at Bathurst CORS, being the first monument and receiver at this site, sourced from a receiver, observed in 2024 on day of year 062, starting at 00:00 hours and containing 1 day of mixed GNSS navigation data.

As in the older versions, the RINEX observation file consists of a header section followed by a data section and ends with a blank line. While each row in the header continues to have a maximum length of 80 characters, this limitation has been removed for the data section (as explained below).

Figure 4 shows an example of a typical RINEX 3.04 header. It includes the following information:

- Line 1: RINEX version and statement that this is an observation file with mixed GNSS data (e.g. as opposed to GPS-only).
- Line 2: Program used to generate the RINEX file, who ran it (here blank) and when it was run.
- Line 3: Marker name, in this case the 4-character ID issued to NSW by Geoscience Australia.
- Line 4: Marker number, here the SCIMS number.
- Line 5: Marker type, here geodetic (i.e. an earth-fixed, high-precision monument). Selecting an attribute other than GEODETIC or NON_GEODETIC (i.e. a low-precision monument) indicates that the data was collected by a moving receiver (e.g. on a person, car, ship, aircraft, space vehicle, glacier, floating ice or even an animal).
- Line 6: Observer and agency, in this case indicating an organisation external to DCS Spatial Services.
- Line 7: Receiver serial number, receiver type and firmware version.
- Line 8: Antenna serial number (for integrated antennas the same as the receiver serial number) and antenna type (using the IGS naming convention).
- Line 9: Approximate site position in Cartesian coordinates (X, Y, Z) – ITRF (not WGS84) recommended.

- Line 10: Antenna height (measured vertically between ground mark and ARP) and any horizontal offset from the mark (if applicable).
- Line 11-14: For each satellite system, the number and types of observations, here specifying 8 observation types for GPS, 4 observation types for GLONASS, 6 observation types for QZSS and 4 observation types for Galileo. The 3-character observation codes include observation type (C = pseudo-range, L = carrier phase, D = Doppler, S = signal strength, X = receiver channel number), band/frequency (range 1-9) and attribute (tracking mode or channel, e.g. C, P, W, I, Q). For instance, for GPS, L1C and C1C are the L1 carrier phase and pseudo-range derived from the C/A code, while L2W and C2W are the L2 carrier phase and pseudo-range derived from Z-tracking (an effective method to acquire the encrypted P(Y) code under Anti-Spoofing conditions). This example only contains code and carrier phase measurements in order to keep the file width manageable.
- Line 15: Signal strength unit (DBHZ = signal-to-noise ratio given in dbHz).
- Line 16: Sampling interval, in this case 30 seconds.
- Line 17: Comment, here the name of the raw binary data file (can be placed anywhere between the first and last line in the header).
- Line 18-19: Time of first and last observation epoch, in this case 01:46:00 hours and 05:15:30 (GPS time) on 29 June 2023, respectively.
- Line 20: Receiver clock offset applied (0 = no, 1 = yes).
- Line 21-22: GLONASS slot and frequency numbers, indicating the number of satellites in the list followed by each satellite number and its frequency number (range -7 to +6).
- Line 23-25: Phase shift correction used to generate phases consistent with respect to cycle shifts, stated for each affected satellite system and carrier phase observation code. In this case, three observation codes include a correction of -0.25 or +0.25 cycles (blank = none).
- Line 26: Number of leap seconds between GPS time and UTC, here 18.
- Line 27: End of RINEX header indicator.

```
1      3.04           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
2 cnvtToRINEX 3.14.0                      20230901 041049 UTC PGM / RUN BY / DATE
3 35CC                                                        MARKER NAME
4 PM85387                                                     MARKER NUMBER
5 GEODETIC                                                    MARKER TYPE
6 EXTERNAL            EXTERNAL                                OBSERVER / AGENCY
7 5729470244          TRIMBLE R10         5.50                REC # / TYPE / VERS
8 5729470244          TRMR10          NONE                    ANT # / TYPE
9  -4436326.0200  2842136.4690 -3583184.7181                  APPROX POSITION XYZ
10        1.7780        0.0000        0.0000                  ANTENNA: DELTA H/E/N
11 G    8 C1C C2W C2X C5X L1C L2W L2X L5X                     SYS / # / OBS TYPES
12 R    4 C1C C2C L1C L2C                                     SYS / # / OBS TYPES
13 J    6 C1C C2X C5X L1C L2X L5X                             SYS / # / OBS TYPES
14 E    4 C1X C8X L1X L8X                                     SYS / # / OBS TYPES
15 DBHZ                                                       SIGNAL STRENGTH UNIT
16     30.000                                                 INTERVAL
17 Source: 02441800.T04                                       COMMENT
18   2023     6    29     1    46    0.0000000     GPS        TIME OF FIRST OBS
19   2023     6    29     5    15   30.0000000     GPS        TIME OF LAST OBS
20      0                                                     RCV CLOCK OFFS APPL
21  12 R05  1 R06 -4 R07  5 R08  6 R09 -2 R10 -7 R15  0 R16 -1 GLONASS SLOT / FRQ #
22     R17  4 R18 -3 R19  3 R20  2                            GLONASS SLOT / FRQ #
23 G L2X -0.25000                                             SYS / PHASE SHIFT
24 R L2C -0.25000                                             SYS / PHASE SHIFT
25 J L2X +0.25000                                             SYS / PHASE SHIFT
26     18                                                     LEAP SECONDS
27                                                            END OF HEADER
```

Figure 4: Typical RINEX 3.04 header.

Figure 5 shows a typical RINEX 3.04 observation data block. It contains the following information:

- Line 28: Date and time of the observation epoch (receiver time of the received signals) in the format year, month, day, hours, minutes, seconds (here 01:46:00 hours on 29 June 2023), epoch flag (0 = OK, 1 = power failure between current and previous epoch, >1 = special event, e.g. 2 = start moving antenna), and the number of satellites in the current epoch (here 15). The special character '>' preceding the epoch information was introduced as an epoch record identifier to enable reading programs to easier detect the next epoch in case of a corrupted data file or when streaming observation data in a RINEX-like format.
- Each following line contains the observations from a single satellite, starting with the system identifier and satellite identifier (PRN). In this example, 2 Galileo, 7 GPS, 1 QZSS and 5 GLONASS satellites were observed. There is no data record length limitation as this depends on the constellation observation list declared in the RINEX header and the available observables per satellite per epoch, i.e. the previous length limitation to 80 characters per row does no longer apply.
- Line 29: Observations recorded for the first satellite (E02, i.e. Galileo satellite 02) – see line 14 in Figure 4 for the corresponding Galileo observation types in the RINEX header. Each observation value continues to be defined as a float value of total length 14 with 3 decimals (F14.3), followed by two optional single-digit integer records (I1 or blank) representing the Loss of Lock Indicator (LLI) and the Signal Strength Indicator (SSI).
- Line 30-43: Observations recorded for the other satellites in this epoch, with missing observations (or those not observed) indicated as blanks.

```
28 > 2023 06 29 01 46  0.0000000  0 15
29 E02  25294920.883 7  25294925.691 7 132925708.305 7 100557451.525 7
30 E25  23447480.428 8  23447484.362 8 123217340.681 8  93213132.913 8
31 G04  21494822.352 6                  21494825.080 5  21494829.933 7 112956049.291 6                                  88017624.905 5  84350336.386 7
32 G07  20337145.830 7                  20337148.174 7                 106872422.420 7                                  83277222.319 7
33 G09  20367487.010 8                  20367490.340 7  20367494.468 8 107031866.687 8                                  83401469.315 7  79926420.520 8
34 G14  23881998.475 6                  23882004.464 7  23882010.066 7 125500746.909 6                                  97792815.156 7  93718137.735 7
35 G20  23898920.072 6  23898925.616 3                                 125589663.277 6  97862096.929 3
36 G27  23825218.979 5                  23825219.068 4  23825223.775 6 125202379.199 5                                  97560279.945 4  93495301.251 6
37 G30  22227137.499 7                  22227142.425 6  22227146.437 8 116804390.872 7                                  91016432.610 6  87224096.414 8
38 J07  37434047.147 6  37434051.555 7  37434054.257 7 196717240.891 6 153286182.977 7 146899267.577 7
39 R05  19811646.971 7  19811650.783 6 105904612.687 7  82370142.314 6
40 R06  20261919.814 6                 108121477.98516
41 R09  22436373.073 7  22436380.500 7 119808978.418 7  93184773.342 7
42 R15  21016941.129 7  21016946.524 7 112308166.088 7  87350586.238 7
43 R16  19461669.657 8  19461674.685 7 103960753.501 8  80858379.014 7
44 > 2023 06 29 01 46 30.0000000  0 16
```

Figure 5: Typical RINEX 3.04 observation block.

The interested reader is referred to Romero (2020) for more detailed information on the RINEX 3.05 format.

3.3 RINEX 4.00 & 4.01

As the necessary next step for maintaining the suitability of the RINEX format to store GNSS data and measurements into the future, RINEX 4.00 (Romero, 2021) was adopted by the IGS at the 59th Governing Board Meeting on 7 December 2021. This new version is necessary to accommodate the modernised navigation messages from all the different GNSS constellations. Once fully implemented, RINEX version 4 future-proofs the format of the navigation messages, enabling RINEX to properly store GNSS observations, navigation messages and station meteorological data files for the long-term future.

The RINEX 4.00 *observation* files are backward compatible with RINEX 3.0X and therefore there is no issue in the storage and usage of RINEX 4.00 observation files. It provides a few minor extensions in observation types and extended header lines but no major format change, i.e. adapting to RINEX 4.00 for observation files is a minor evolution.

However, RINEX 4.00 *navigation* files are not backward compatible with RINEX 3.0X files. This is the reason why the RINEX version number was increased rather than utilising another RINEX 3.0X sub-version. On the other hand, no change is necessary in regard to file naming and file storage since navigation files of all types can be stored together in different RINEX versions without any issue. All RINEX files state the version number in the first line and most reader programs will skip over unknown navigation file versions until they are ready to process them.

The development has since continued to add some necessary clarifications and new observation codes for upcoming GPS satellites and for L1 NavIC signals, resulting in RINEX 4.01 (Gini, 2023) being released in July 2023. The RINEX format development has been conducted in collaboration with equipment manufacturers and software generators, ensuring that equipment and software tools that can produce and process RINEX 4.00 & 4.01 files will be available to the GNSS community in due course to enable implementation and broader adoption. More details about the RINEX version 4 format can be found in Gini (2023).

4 EDITING RINEX OBSERVATION FILES

Regardless of the RINEX version used, it is important to note that the RINEX header often contains incorrect or incomplete information when initially generated (e.g. the manufacturer's receiver and antenna names not following the IGS naming convention, a default antenna type or a zero antenna height), so thorough editing is very important in order to avoid confusion further down the track. This particularly applies for data archival, data sharing or submission to third parties (especially where machine-to-machine processes are likely to be employed). Ensuring the correctness of the information in the RINEX header is not only good practice but also very valuable when mining data for purposes that were not envisaged when the data was originally collected.

The RINEX format stipulates the antenna type as a 20-character name (see columns 21-40 of line 9 in Figure 1 and line 8 in Figure 4), including several spaces and ending with a 4-character indication of the radome used (NONE meaning that no radome is present). The authoritative source for resolving antenna queries are the frequently updated IGS files *rcvr_ant.tab* and *antenna.gra* (IGS, 2024c). The file *rcvr_ant.tab* details the international naming conventions for GNSS receivers, antennas and radomes (antenna covers), which are also used by AUSPOS. The file *antenna.gra* provides graphs with physical dimensions of GNSS antennas, including the position of the ARP (generally the bottom of the antenna) and vertical offsets to other features such as the centre of bumper or bottom of choke ring. As an aside, the file *igs20.atx*, containing the IGS antenna models recommended for baseline processing, can be found at the same location (it is frequently updated to include new antennas). If still in doubt, users should contact their equipment provider for the required antenna information.

If the antenna height was not measured directly and vertically to the ARP in the field, e.g. when using a vertical height hook measurement or a slant measurement to the bumper or the Slant Height Measurement Mark (SHMM) on the instrument, then it must be converted to the vertical distance between the ground mark and the ARP using the offsets and method (generally applying Pythagoras in conjunction with a vertical offset) specified in the GNSS equipment manual or provided by the manufacturer – see Janssen and McElroy (2022) for examples. The correctness of antenna height and antenna type is crucial to allow the correct antenna model to be applied correctly in processing. An incorrect antenna type can introduce significant bias (more than 10 cm in the vertical component) and noise into the computed coordinates. An error in the antenna height will directly translate into an error in the resulting GNSS-derived ellipsoidal height and thus the derived Australian Height Datum (AHD) height.

If session length is critical to contractual arrangements and/or data acceptance by a third party, it is recommended to always extend session lengths by a few minutes. The start and end of the GNSS observation section in the RINEX file should be visually inspected, particularly to ensure that the first and last few epochs contain reasonably complete data blocks. If epochs at the start/end of the observation are deleted, the time of the first/last observation in the RINEX header should be modified accordingly. Frequent dropouts of satellite signals from epoch to epoch in the RINEX file may indicate bad data quality due to poor sky view conditions (e.g. tree cover or other obstructions). Note that the raw observation files in their native (binary) proprietary format collected by the GNSS receiver are compact and should always be permanently archived – they can be re-converted to RINEX and edited again if required.

5 CONTRIBUTING GNSS DATA FOR NSW DATUM MODERNISATION

5.1 The GDA2020 State Adjustment

The Geocentric Datum of Australia 2020 (GDA2020) is Australia's national datum, which is defined in the ITRF2014 (Altamimi et al., 2016) at epoch 2020.0 and based on a single, nationwide least squares network adjustment that rigorously propagates uncertainty (ICSM, 2021b; Harrison et al., 2023).

In NSW, as of November 2023, the growing GDA2020 state adjustment consists of approximately 1,250,000 measurements between 177,000 stations, translating into about 150,000 SCIMS marks and making it the largest Jurisdictional Data Archive (JDA) in Australia. It was computed with DynAdjust (version 1.2.7) using a phased-adjustment least squares methodology that provides rigorous uncertainty across the entire network (Fraser et al., 2023, 2024). The GDA2020 state adjustment includes about 120,000 GNSS baselines, 22,000 baselines originating from 14,000 AUSPOS sessions, 325,000 directions and 340,000 distances.

To achieve this, DCS Spatial Services has developed and implemented several innovative, highly automated tools and workflows to prepare, process and ingest existing and new GNSS baseline data, AUSPOS datasets and street-corner traversing data. Over several years, efforts have been undertaken to source, harvest, clean and utilise legacy geodetic measurements (Haasdyk and Watson, 2013), build state-of-the-art GNSS CORS network infrastructure (Janssen et al., 2016), observe new high-quality GNSS measurements to connect the existing survey network to CORS (Gowans and Grinter, 2013), include static Network Real-Time Kinematic (NRTK) observations and their uncertainties (Bernstein and Janssen, 2022), and systematically rationalise, maintain, upgrade and collect AUSPOS datasets at key sites across the NSW survey control network, including trigonometrical (trig) stations and AHD spirit-levelled marks (Gowans et al., 2015; Janssen and McElroy, 2021). The desired end state is that a network of fundamental AUSPOS-observed survey marks is established at a 10 km density across the eastern and central divisions of the state, ensuring users are always within 5 km (as the crow flies), and often much less, of a fundamental AUSPOS point. Current efforts also focus on densifying the NSW survey control network via secondary adjustments based on connections between survey marks sourced from Deposited Plans through the LandXML to SCIMS (LX2S) pilot project (Hine et al., 2024).

AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW (via inclusion in the National GNSS Campaign Archive, NGCA, hosted by Geoscience Australia), while AUSPOS data of less than 6 hours duration strengthens the datum (via inclusion in the state's Jurisdictional Data Archive, JDA). To date, more than 15,000 AUSPOS solutions have been used to help maintain and improve the NSW survey control network.

Key components of these datum modernisation efforts have been the preservation and upgrade of survey infrastructure, including physical maintenance of permanent survey marks (including but not limited to TS, PM and SS), and the update of metadata such as survey mark information in SCIMS and survey mark photographs. This will enable future users to achieve DCS Spatial Services' vision of a Positional Uncertainty (PU) of 20 mm in the horizontal and 50 mm in the vertical (ellipsoidal height) component anywhere in the state. It will also allow for the future realisation and propagation of the Australian Vertical Working Surface (AVWS – see ICSM, 2021a) at a later date and to easily apply transformation tools to move between current, future and various historical datums and local working surfaces.

5.2 Contributing Industry-Observed GNSS Data

The profession is encouraged to contribute to the maintenance of the NSW survey control network and the timely update of survey information in SCIMS by submitting suitable industry-observed AUSPOS datasets of at least 2 hours duration and related metadata via the DCS Spatial Services Customer Hub on our website (DCS Spatial Services, 2024b). The Customer Hub is a new, user-friendly online platform providing a central contact point to interact with DCS Spatial Services. It is now the primary way for customers to make enquiries, submit data requests and provide feedback. Survey Operations can be contacted through the Customer Hub to submit AUSPOS datasets, Locality Sketch Plans (LSPs), survey mark status reports, Preservation of Survey Infrastructure (POSI) applications, trig station approvals, exemption applications and regulation approvals. Access to the Customer Hub is free and simple, after creating a one-time username and password. Through a ticketed system, customers can track the status of their requests at any point in time, which enables DCS Spatial Services to manage these more efficiently and effectively.

A practical guide to AUSPOS, including the requirements for successful AUSPOS datasets to be submitted to DCS Spatial Services, can be found in Janssen and McElroy (2022). In summary, AUSPOS data submissions to DCS Spatial Services must include the following:

- RINEX observation file of at least 2 hours duration. Also including the raw binary file in the manufacturer's native (proprietary) format is optional but strongly recommended.
- Completed log sheet or field notes, clearly indicating observation date/time, mark observed, receiver and antenna type and serial number used, and antenna height measured vertically to the ARP.
- AUSPOS processing report (using rapid or final IGS orbits).
- Locality Sketch Plan for any new mark placed (submitted separately to the AUSPOS data).
- Photographs of the mark, indicating mark type and sky view conditions (optional but recommended).

6 CONCLUDING REMARKS

The widely used RINEX format is the international standard for the storage and exchange of GNSS data. It allows efficient and unambiguous archiving of GNSS data and associated metadata in one place, while also facilitating the easy transfer and distribution of such data, independent of the equipment used and the data processing software employed. Over the years, and through several versions and sub-versions, the RINEX format has continually been improved and expanded to cater for modern satellite positioning data collected by a growing number of satellite constellations and their signals.

This paper has presented a brief history of the RINEX format and explained recent RINEX format versions using examples relevant to the surveying profession. This included outlining the short and long RINEX file naming conventions and the editing of RINEX observation files to ensure correctness of the header information. It has then given an update on the growing GDA2020 state adjustment and encouraged the profession to contribute to further improvement of the NSW survey control network and the information provided in SCIMS by submitting suitable industry-observed AUSPOS datasets and related metadata to DCS Spatial Services. It is hoped that this contribution has helped the surveying profession to better understand the RINEX format, the philosophy behind it, and its benefits to users. In the words of the legendary Australian band AC/DC: “For those about to R.O.C.K. (i.e. RINEX Observation Contributor Kindness), we salute you!” (Janssen, 2019).

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