Tutorial 1
UNIX environment, Tools and Skills.
GNSS Standard File Formats

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February 20, 2018

Tutorial 0.1. UNIX Environment, Tools and Skills

Objectives

To present a (very limited) set of UNIX instructions in order to manage files and directories, as well as some basic elements of `awk/gawk` programming and the graphical plotting environment `graph.py`. The aim is not to teach UNIX or programming languages, but to provide some basic tools needed to develop the practical sessions.

Note: The following exercises are very elementary and can be omitted if the reader already has some basic knowledge of UNIX and `gawk`.

Files to use
`sxyz.eci`

Programs to use
`graph.py`

Development

This session has been organised as a series of guided exercises to be done in the established order, which introduces the main instructions for use in the following sessions.

1. First instructions

(a) Show the name of the directory where you are located.
Execute: `pwd`

(b) Examine the directory content[1].
Execute: `ls`

(c) Exanine the directory content, sorted by time.
Execute: `ls -lt`

(d) Access the `HTML` directory and view its contents, sorted by time reversed.
Execute:
```
cd HTML
ls -ltr
```

(e) Go back to the `GNSS_TUTBOOK` directory.
Execute: `cd ..`

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[1]If the installation has been done properly according to instructions in the installation guide, the following three directories will be found: `FILES`, `PROG` and `HTML`. These directories, together with the Notepad files, will appear in the `GNSS_TUTBOOK` directory.

(f) Show a text line on the screen:
Execute:
```
echo "Have a nice day"
```

(g) Direct the contents to a file:
Execute:
```
echo "Have a nice day" > test
ls -ltr
echo "you too" >> test
```

(h) Show the contents of the file on the screen:
Execute:
```
cat test
```
Try to execute this too: `echo test`. What happens?

(i) Edit a file
Execute:[2]
```
Notepad test
```

2. Directory management

(a) Check that you are in the GNSS_TUTBOOK directory. Create the directory `working` inside the GNSS_TUTBOOK directory. Access it. Go back to the directory immediately above, in this case the GNSS_TUTBOOK directory, (by executing 'cd ..').
Execute:
```
pwd
mkdir working
cd working
pwd
cd ..
pwd
```

3. File management

(a) Go to the `working` directory (which is inside the GNSS_TUTBOOK directory). Copy the file `test` to your current directory (symbolised by '.').
Execute:
```
cd working
cp ../test .
ls -ltr
```

(b) Copy the file `test` to the file `file1`.[3] Check the contents of `file1`.
Execute:
```
cp test file1
ls -lt
more file1
```

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[2]Any text editor can also be used.

[3]As file `file1` does not exist, a new file will be created with this name and with the same contents as file `test`.

(c) Create a 'link'[4] from file `file2` to file `test`. Check the file contents. Check the contents of `file2`.
Execute:

```
ln -s test file2
ls -lt
more file2
```

(d) Using a text editor (e.g. `Notepad` or similar), edit `file2` and change the word *day* to the word *YEAR*. Save the changes and exit `Notepad`. Next, check the contents of file `test` and its link `file2`. Have the contents of the original file `test` been modified through its link `file2`?
Execute:

```
Notepad file2
more test
more file1
```

(e) Remove file `file1` and its link `file2`. Check if they have been deleted. Create the directory `other`. Remove the directory `other`.
Execute:

```
ls -lt
rm file1 file2
ls -lt
mkdir other
ls -lt
rm -r other
ls -lt
```

(f) Find information on the '`mkdir`' and '`rm`' commands in the help pages (i.e. in the UNIX manual).
Execute:

```
man mkdir
man rm
```

4. **Programming environment `gawk`[5]**

(a) Check that you are in the `working` directory, by executing 'pwd'. From within the working directory, create a link from file `sxyz.eci` (which is placed in the directory `GNSS_TUTBOOK/FILES/TUT1`) to a file with the same name in the working directory.
Execute:

```
pwd
ln -s ../FILES/TUT1/sxyz.eci .
ls -lt
```

The file `sxyz.eci` contains three columns of coordinates, in a geocentric inertial system, of a set of satellites at different epochs. It contains the following fields:

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[4]This differs from the previous case because `file2` is not a new file, just a pointer to file `test`. Thus, the 'link' `file2` represents the minimum space expense, independent of the file `test` size. Execute `man ln` to see the meaning of different types of links.

[5]`gawk` is the GNU implementation of `awk` (from the Free Software Foundation).

```
SATELLITE time(sec) X(km) Y(km) Z(km)
```

(b) Execute the instructions `cat`, `more` and `less` in order to display the file contents `sxyz.eci`. What differences can be seen among these instructions?[6]

Execute:

```
cat sxyz.eci
more sxyz.eci
less sxyz.eci
cat sxyz.eci | less
```

(c) Using the programming language `gawk`, print (on screen) the first and third fields of file `sxyz.eci`.

Execute:

```
gawk '{print $1,$3}' sxyz.eci |more
or
cat sxyz.eci |gawk '{print $1,$3}' |more
```

(d) Now print all the fields at the same time.

Execute:

```
cat sxyz.eci | gawk '{print $0}' | more
```

(e) The following instruction generates the file `prb1` which contains data from a single satellite. Which satellite is selected?

Execute:

```
cat sxyz.eci | gawk '{if ($1==5) print $0 }' > prb1
more prb1
```

(f) What is the meaning of the values in the second column of file `prb2` generated by the next instruction?

Execute (in a single line):[7]

```
cat sxyz.eci | gawk '{if ($1==5)
            print $2,sqrt($3**2+$4**2+$5**2)}'> prb2
more prb2
```

(g) Discuss the structure of the following instruction that makes a 'print' with a particular format (where `%i`=integer, `%f`= float, `%s`= string).

Execute:

```
cat sxyz.eci |gawk '{printf
   "%2i %02i %11.3f %i %s \n",$1,$1,$3,$3, $1}'|more
```

(h) Access the manual pages of `gawk`.

Execute:

```
man gawk
```

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[6]The command '|' allows us to connect the output of a process with the input of another. For example, the output of `cat` can be sent to `more`.

[7]The sentence line is a single line, although it may appear as two lines because of typesetting constraints.

5. Graphics environment `graph.py`

(a) Program `graph.py` is in directory `/usr/bin`. Link this program to the current directory `"."` (i.e. directory `working`).
Execute:

```
ln -s /usr/bin/graph.py .
```

(b) For the previously generated file `prb1`, plot the third field (x coordinate) as a function of the second one (time in seconds).
Execute:[8]

```
graph.py -f prb1 -x2 -y3
```

(c) Using file `sxyz.eci`, plot satellites #5 and #9.
Execute:[9]

```
graph.py -f sxyz.eci -x2 -y3 -c '($1 == 5)'
         -f sxyz.eci -x2 -y3 -c '($1 == 9)'
```

(d) Repeat the previous plot for the interval $[20\,000 : 30\,000]$ on the x-axis.
Execute:

```
graph.py -f sxyz.eci -x2 -y3 -c '($1 == 5)'
         -f sxyz.eci -x2 -y3 -c '($1 == 9)'
         --xn 20000 --xx 30000
```

(e) Using file `prb1`, plot on the same graph the x (third field), y (fourth field) and z (fifth field) coordinate as a function of time (second field).
Execute:

```
graph.py -f prb1 -x2 -y3 -f prb1 -x2 -y4 -f prb1 -x2 -y5
```

(f) Using file `prb1`, plot on the same graph the distance of the satellites from Earth's mass centre ($r = \sqrt{x^2 + y^2 + z^2}$) as a function of time.
Execute:

```
graph.py -f prb1 -x2 -y'math.sqrt($3*$3+$4*$4+$5*$5)'
```

(g) For the same file used in the previous cases (`prb1`), write the title `"orbit"`, x label `"sec"` and y label `"m"`.
Execute:

```
graph.py -f prb1 -x2 -y3 -t "orbit" --xl "sec" --yl "m"
```

---

[8]Depending on the `PATH` configuration, it would be necessary to execute '`./graph.py`' instead of '`graph.py`'. Another possibility is to include the current directory '`.`' in the `PATH` variable of the current terminal. This is done in the `bash` environment by executing `export PATH="./:$PATH"`. On the other hand, if we want to make this `PATH` update permanent, then the sentence `export PATH="./:$PATH"` must be included at the end of file '`.bashrc`' in the home directory. When working in `tcsh` instead of `bash`, the equivalent sentences are as follows: execute `set PATH=./:${PATH}` in the current directory (for a non-permanent change), or add the sentence `set path=(./ $path)` to the end of file `/etc/csh.cshrc` to make the `PATH` update permanent. Note that, in this last case, administrator privileges are needed to edit the `/etc/csh.cshrc` file.

[9]Note that, in the Windows OS, instructions like '`($1=="5")`' must be written as `"($1=='5')"`; that is, replacing (`"`) by (`'`).

(h) Visualise the different forms of graphic representations in the following instructions (with points, lines and other symbols or colours).

Execute:

```
graph.py -f prb1 -x2 -y3 -s.
graph.py -f prb1 -x2 -y3 -s-
graph.py -f prb1 -x2 -y3 -s-.
graph.py -f prb1 -x2 -y3 -s--
graph.py -f prb1 -x2 -y3 -so
graph.py -f prb1 -x2 -y3 -s+
graph.py -f prb1 -x2 -y3 -sp
graph.py -f prb1 -x2 -y3 -so --cl r
graph.py -f prb1 -x2 -y3 -s. --cl g
```

(i) Save the plot in a POSTSCRIPT file "orbit.ps" and in a PNG! (PNG!) file "orbit.png".
Execute:

```
graph.py -f prb1 -x2 -y3 --sv orbit.ps
graph.py -f prb1 -x2 -y3 --sv orbit.png
```

(j) Check "help" in graph.py.
Execute:

```
graph.py -help
```

Tutorial 0.2. GNSS Standard File Format

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Objectives

To become familiar with the different format standard(s) involved in the GNSS data sets. To provide the user with a reliable and powerful tool to learn the standard formats in a very easy and friendly way, aided by explanatory tool tips. These tips will be triggered automatically when the mouse is hovered over a field. The explanations include a description of the field, the format in which it is written and, if applicable, its units.

Files to use
`LaunchHTML.html`, `GLONASS_Navigation_Rinex_v2.11.html`,
`SP3_Version_C.html`, `Observation_Rinex_v3.01.html`,
`ANTEX_v1.3.html`, `Observation_Rinex_v2.11.html`,
`IONEX_v1.0.html`, `Observation_Rinex_v2.10.html`,
`SP3_Version_C.html`, `RINEX_CLOCKS_v3.00.html`,
`SBAS_Navigation_Rinex_v3.01.html`,
`GPS_Navigation_Rinex_v2.11.html`

Programs to use
Any Web browser (`Firefox` can be used, as well).

Development

1. RINEX measurement files: v2.10

This standard gathers the GNSS observations collected by a receiver. The file is divided clearly into two different sections: the header section and the observables section. While in the header global information is given for the entire file, the observables section contains the code and carrier measurements, among others, stored by epoch.

Open file `Observation_Rinex v2.10.html` with a Web browser and answer the following questions (the answer is provided at the end of each question).

(a) Hover the mouse over the title '`Observation RINEX 2.10 Format`', where some general information is given. Which was the first institution to develop this format?

$\rightarrow$ *The Astronomical Institute of the University of Berne.*

(b) What was the reason for developing such a standard?

$\rightarrow$ *The exchange of GPS data from several different GPS receivers.*

(c) Which type of optimisation has been applied to this standard?

→ *Minimum space requirements, keeping the observation records as short as possible.*

(d) What is the maximum record (i.e. line) length?

→ *Files are kept to 81-character lines.*

(e) The header section contains a set of labels. Where are they located?

→ *The header labels are located between the* `61st` *and the* `80st` *column of each line.*

(f) Where can a collection of currently used formats be found?

→ *On the IGS website: http://igscb.jpl.nasa.gov/components/formats.html.*

(g) The header section of this file is dual coloured in order to distinguish header information from header labels. What is the first and the last header label of the header section?

→ *The first label is '*`RINEX VERSION / TYPE`*' while the last label is '*`END OF HEADER`*'.*

(h) What is the difference between the '`RINEX VERSION / TYPE`' and the '`COMMENT `' labels?

→ *While the first one is a mandatory label, the second is optional and may not appear in some RINEX files.*

(i) Hover over the first field in the '`RINEX VERSION / TYPE`' line; what is the main advance in this RINEX version?

→ *Version 2 has been prepared to contain GLONASS or other satellite system observations apart from GPS satellites.*

(j) Where is the antenna located approximately? In which reference system?

→ *The approximate antenna position is (478 902 8.4701, 176 610.0133, 419 501 7.0310) in the WGS-84 system.*

(k) Hover over the first field in the '`LEAP SECONDS`' line; what is the difference between the various satellite systems, when counting leap seconds?

→ *The Glonass time system is tied to UTC, so leap seconds are needed, for instance, to mix Galileo or GPS with Glonass data.*

(l) How many satellites are present in the current file? To which satellite system do they belong?

→ *There are 14 different satellites:*
14 GNSS satellites = 10 GPS + 3 Glonass + 1 SBAS.

(m) Line 'PRN / # OF OBS ' has to be consistent with the observables listed in line '# / TYPES OF OBSERV'. What are these observations? Do all satellites contain the same observables in this example?

→ *The observables are:* L1, L2, P1, P2, C1, S1, S2.
Glonass and SBAS satellites only have: L1, C1, S1.

(n) How does the standard indicate the end of the header?

→ *The last field of the header is a record of 60 empty characters.*

(o) The data section of this file is again dual coloured in order to distinguish blocks of data. According two the different colours used, how many epochs are included in this file?

→ *There are two different epochs, each with a different colour.*

(p) The first line of an epoch contains information on a whole block of measurements. When is the first epoch of the file?

→ *The first epoch corresponds to* 5/3/2010 *at* 00:00:00.

(q) How many satellites are present in the first epoch? Is there any particular feature occurring due to this number?

→ *The first epoch contains* 14 *different satellites. Because there are more than* 12 *satellites, the list of epoch satellites is divided into two different lines.*

(r) Measurements follow the order stated in line '# / TYPES OF OBSERV' line. The satellite order is given in the first line of the epoch. What are the units for the observables?

→ L1, L2: *cycles of the carrier.*
P1, P2, C1: *metres.*
S1, S2: *receiver dependent.*

(s) Hover over the first L1 measure of satellite G13. The measure is given together with two indicators. What are these indicators? What do they represent?

→ *Loss of Lock Indicator: Depending on its value, it can show a cycle slip, an opposite wavelength factor, or an anti-spoofing measurement. Signal Strength: Projected into the* [1-9] *interval.*

2. RINEX measurement files: v2.11

Open file Observation_Rinex_v2.11.html with a Web browser.

(a) Hover over the 'WAVELENGTH FACT L1/2' line records. The first line states the default values for the wavelength measures for the L1 and L2 frequencies. Which satellite system do the default values apply to? Interpret the second line of the 'WAVELENGTH FACT L1/2' records.

→ *The Default Wavelength Factor applies for GPS only.*
Three satellites (G14, G18, G19) *have a full cycle factor in the first frequency (L1) and half a cycle factor in the second frequency (L2).*

(b) Hover over the first record of line '# / TYPES OF OBSERV'. What observation types are defined in RINEX version 2.11? In what units are these observations measured?

$\rightarrow$ *Pseudorange measures:* C *and* P *code* [m]
Carrier phase: L [cycles of the carrier]
Doppler frequency: D [Hz]
Signal-to-noise ratio: S [receiver-dependent].

(c) What value is set in the 'RCV CLOCK OFFS APPL' record? Where can the Receiver Clock Offset be found later in the RINEX file?

$\rightarrow$ *It has a value of* 1, *which means that an offset is applied in the receiver clock. The value of this offset is reported in the last record of the first line of each epoch.*

3. RINEX Measurement files: v3.01

Open file Observation_Rinex_v3.01.html with a Web browser.

(a) This RINEX version is newer than version 2. At first glance the header section is larger and the observation data records are reorganised to be column readable. Which satellite system does this file belong to? What type of file is it?

$\rightarrow$ *This file contains GPS, Glonass and SBAS observations, so it is a mixed file. It is an observation data file. Note that the possible values may have changed from the previous version.*

(b) The date record in 'PGM / RUN BY / DATE' also has been redesigned. What is the date format now? What has changed in the versions?

$\rightarrow$ *In version 2.11, there was no a strict rule stating date file creation. In version 3.01, the date has to follow the structure* Year/Month/Day - Hour/Minute/Second - Time zone.

(c) A 'MARKER TYPE ' record has been added to the header. What type of marker type would report a station at the North Pole?

$\rightarrow$ *The North Pole is located in the middle of the Arctic Ocean, almost permanently covered with constantly shifting sea ice. It suits the* 'FLOATING_ICE' *marker type.*

(d) An extensive description of the ANTENNA can now be obtained from this new standard. What type of antenna information is available?

$\rightarrow$ *Antenna Number. Antenna Type + Radome Identifier.*
ARP: (Height, East Eccentricity, North Eccentricity).
ARP: (X,Y,Z) when mounted on a vehicle.
Antenna Phase Centre: (North, East, North) w.r.t. the ARP.
Antenna Bore-sight: (North, East, North) or (X,Y,Z).
Antenna Zero Direction: Azimuth or Vector.

(e) A new 'SYS / # / OBS TYPES' record has been added in this file. What observations are present for the SBAS satellites?
Hover over the observation descriptors. How many pseudorange code descriptors are present for the sixth Beidou (Compass) frequency?

$\rightarrow$ *Glonass and SBAS satellites have the same four observation types:* L1C S1C C1C S1C. *RINEX v3.01 defines* C6I, C6Q, C6X *pseudorange code descriptors for Beidou.*

(f) A new 'SIGNAL STRENGTH UNIT ' record has been added to standardise RINEX SSI. What indicator would have a signal-to-noise ratio of 33 dBHz at the output of the correlator?

$\rightarrow$ *From the RINEX table, it would present a* `5 SSI` *value.*

(g) Records '`SYS / DCBS APPLIED`' and '`SYS / PCVS APPLIED`' inform if DCB or PCV has been applied. What programs/files have been used in these files?

$\rightarrow$ *DCBs are corrected using the* `CC2NONCC` *program[10] with the input file* `p1c1bias.hist`*. PCVs are corrected using the* `PAGES` *program with input file* `igs05.atx`*.*

(h) Hover over the '`SYS / SCALE FACTOR`' data records. What is the purpose of implementing such a scale factor?

$\rightarrow$ *The purpose of the scale factor is to increase resolution of the phase observations.*

(i) Find the week number in the '`LEAP SECONDS`' line. What is the reason for the week roll-over? When it did happen first?

$\rightarrow$ *Because it is a 10-bit number.*
It happened on `22/08/1999` *at* `00:00:00` *GPS time.*

(j) Hover over any observation data record. Why are there lines of 80 characters, and lines that are longer?

$\rightarrow$ *While the epoch headers retain a record length of 80 characters, the observation record length limitation of RINEX versions 1 and 2 has been removed.*

4. RINEX navigation files: v2.11 (GPS)

The standard navigation messages broadcast by the GNSS satellites discussed here can vary slightly from one satellite system to another. For example, while the GPS navigation RINEX contains pseudo-Keplerian elements that permit the calculation of the satellite's position, Glonass navigation RINEX contains the satellite's position, velocity and Sun and Moon acceleration in order to integrate the satellite orbits using the Runge–Kutta numerical method.

Open file `GPS_Navigation_Rinex_v2.11.html` with a Web browser.

(a) As usual, this file is divided into a header section and a data record section. The header section is shorter than in the observation RINEX. How short can a GPS navigation message RINEX header be?

$\rightarrow$ *The shortest header contains just three lines:* '`RINEX VERSION / TYPE`'*,* '`PGM / RUN BY / DATE`' *and* '`END OF HEADER`'*.*

(b) What ionospheric corrections are given?
The `alpha0`, `alpha1`, `alpha2`, `alpha3` *and the* `beta0`, `beta1`, `beta2`, `beta3` *coefficients for the Klobuchar model.*

(c) How many leap seconds are used in the file? When is it recommended to state the number of leap seconds?

$\rightarrow$ *Fifteen leap seconds. It is recommended for mixed GPS/Glonass files.*

(d) This file contains the ephemerides for two different satellites, each block of ephemeris having a separate colour. Where is the satellite identifier found? What satellites are present in the file?

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[10]Program `CC2NONCC` is available from *https://goby.nrl.navy.mil/IGStime/cc2noncc/*.

$\rightarrow$ *The satellite identifier is found in the first record of the ephemeris block. The PRN identifiers present in the file are* PRN 6 *and* PRN 13.

(e) The first line of each ephemeris block contains three records to compute the satellite clock offset to the GPS time. What are these three coefficients?

$\rightarrow$ *They are the polynomial coefficients to compute the satellite clock offset from the GPS system time. These coefficients are: bias, drift and drift rate from the GPS time.*

(f) GPS orbits are nearly circular. In the third line can be found the broadcast orbit eccentricity. What are the orbit eccentricities for the file satellites?

$\rightarrow$ PRN 6 *has an eccentricity of* $0.006\,267\,404\,183\,75$.
PRN 13 *has an eccentricity of* $0.002\,002\,393\,477\,60$.

(g) The last non-blank field (second record in the eighth row) states the validity period for each ephemeris block. What is the value if it is not known? In this case, what is the fitting interval?

$\rightarrow$ *The value is zero when the fitting interval is unknown. In this case, the fitting interval is* $[t_0 - 2\,h, t_0 + 2\,h]$.

5. RINEX navigation files: v2.11 (Glonass)

Open file GLONASS_Navigation_RINEX_v2.11.html with a Web browser.

(a) How do you identify this file as a Glonass navigation message?

$\rightarrow$ *The RINEX file type value is a '*G*'.*

(b) Does this file include any ionospheric information?

$\rightarrow$ *The Glonass navigation message does not broadcast ionospheric corrections.*

(c) What correction has to be applied to correct Glonass system time to UTC for the SU time zone?

$\rightarrow$ Tutc = Tsv + TauN - GammaN*(Tsv-Tb) + TauC.

(d) Each of the other lines of Glonass navigation files contain three records with satellite position, velocity and Sun–Moon acceleration. In which units are they given? What information gives the fourth record of each line?

$\rightarrow$ *Units are: km, km/s and km/s^2.*
Message Frame Time, Satellite Health, Frequency Number, Information Age.

(e) Frequency information is found in the third row of each ephemeris block. What are the channel numbers of the two satellites present in the file? Which are the associated frequencies?

$\rightarrow$ R3 *used the* `21st frequency slot`, *so*
$$1602 + 0.5625 * 21 = 1613.8125 \ MHz.$$
R11 *used the* `4th frequency slot`, *so*
$$1602 + 0.5625 * 4 = 1604.2500 \ MHz.$$

6. RINEX navigation files: v3.01 (SBAS)

Open file `SBAS_Navigation_RINEX_v3.01.html` with a Web browser.

(a) The SBAS broadcast navigation message is given in a new version (v3.01). The first change is observed in the first header line, where the file type and the satellite system are now clearly divided. What is the difference between the older version 2.11 in representing the navigation messages?

$\rightarrow$ *In the older navigation message version, the satellite system record was unused. In version 2.11, file type* `N` *or* `G` *would directly represent a GPS or Glonass navigation message.*
In version 3.01, file type `N` *represents a navigation message, where the satellite system record specifies which of the* `G`, `R`, `S`, `E`, `M` *satellite system(s) is involved.*

(b) The '`TIME SYSTEM CORR`' line allows the satellite system time to be transformed to UTC time through a correction. What are the coefficients of the formula? Which is the augmentation system of this navigation message?

$\rightarrow$ *The formula is:* `CORR(t) = a0 + a1*DELTAT`
Particularised:
`CORR(t)= 0.1331791282E-06 + 0.107469589E-12*(t-552960)`
The augmentation system is EGNOS.

(c) This file contains ephemerides for a geostationary satellite. What is the difference in time between the two records? Where can it be found?

$\rightarrow$ *The epoch time is located in the first line of each data epoch.*
The first epoch corresponds to `18/12/2010` *at* `00:01:04`.
The second epoch corresponds to `18/12/2010` *at* `00:05:20`.
So, between them, the elapsed time is 4 minutes and 16 seconds.

(d) SBAS navigation files are similar to Glonass ones, in that both contain records of satellite position, velocity and accelerations. What is the flag for a healthy satellite? Which IODN corresponds to the ephemeris present in the file?

$\rightarrow$ *A healthy satellite contains a* `0.0 Health flag`.
The first ephemeris block has `IODN: 23`.
The second ephemeris block has `IODN: 24`.

7. Global Ionospheric Map files: IONEX v1.0

Using a GNSS tracking network it is possible to extract information about the TEC of the ionosphere on a global scale. The IONEX format is a well-defined standard used to exchange ionospheric maps. It follows the same philosophy as the RINEX format, even when the files are organised into a header and a data section where the maps are allocated.

Open file `IONEX_v1.0.html` with a Web browser.

(a) Hover over the third record of the first line. How many sources can contribute to produce an IONEX map? And how many models?

$\rightarrow$ *Several satellite sources can be used:* `Envisat`, `Geostationary`, `Glonass`, `GPS`, `TOPEX/POSEIDON`, `Navy Navigation Satellite` `(NNS)` *or IRI. Two different models are possible: BENt or ERS.*

(b) This file contain two types of information lines: COMMENT lines and DESCRIPTION lines. What is the difference between the two records? Which model is used in this IONEX map? When is this map valid?

$\rightarrow$ *Description lines give a brief description of the technique and model used, while comment lines can contain any kind of information. The IONEX map model of this file is based on spherical harmonics. The ionospheric map is for* `Day of Year (DoY) 288 of 1995`.

(c) What information would you expect to appear in the '`OBSERVABLES` `USED`' line when using a theoretical model?

$\rightarrow$ *A blank line is given when a theoretical model is used.*

(d) After COMMENT line(s) the IONEX Map Grid is described. Give details about: the number and dimension of the maps present in the current file with its mapping function; the number of stations and satellites used for the TEC computations; the grid size and the satellite elevation cut-off.

$\rightarrow$ *The IONEX file contains five 3D* `TEC/RMS/HGT` *maps with a* $1/\cos(z)$ *mapping function.*
80 stations and 24 satellites have been used to produce this map.
The grid extends from 200 *to* $800\,km$ *in height with an equidistant increment of* $50\,km$.
The grid extends from $85°$ *to* $-85°$ *in latitude and from* $0°$ *to* $355°$ *in longitude in increments of* $5°$.

(e) There are some auxiliary data in this file. What type of information is given, and in which units?

$\rightarrow$ *The IONEX map gives the DCBs and their RMS for the satellites used in the map.*
The DCBs are given between the GPS P1 and P2 codes in units of nanoseconds (of L1$-$L2 delay).

(f) Once the header section ends, the ionospheric maps are detailed. How many ionospheric maps are presented in the current file?

$\rightarrow$ *There are three different maps: a TEC; an RMS error map of the associated TEC map; and a final map containing the heights at which the TEC values are obtained.*

(g) Hover over the first TEC values. What is the time for this map?

$\rightarrow$ *The first map corresponds to* `15/10/1995` *at* `00:00:00`*.*

(h) How can the exponent values be interpreted?

$\rightarrow$ *The exponent values indicate the* 10 *exponent to apply to the TEC values:*
Exponent: `-3` *TEC field;* `1000` *TEC value:* $1000 \cdot 10^{-3} = 1$ *TECU. TECU is the given unit for TEC, where 1 TECU corresponds to* $10^{16} e^-/m^2$*.*

(i) How would an non-available TEC value be seen?

$\rightarrow$ *Non-available TEC values are given as* `99999` *values.*

(j) How many TEC values fit in a single line and in which units are these values given?

$\rightarrow$ *TEC rows are given in 16 fields per line, up to the grid limits.*

(k) Hover over any of the RMS values. What is the default exponent for stating the RMS values of the TEC maps?

$\rightarrow$ *The default exponent is* `-1`*:* $10^{-1} = 0.1$ *TECU, where 1 TECU corresponds to* $10^{16} e^-/m^2$*.*

8. **RINEX clock files: v3.00**

The standard files provide station and satellite clock data. Four types of information are given in this format: data analysis results for receiver and satellite clocks derived from a set of network receivers and satellites with respect to a reference clock; broadcast satellite clock monitoring;, discontinuity measurements; and calibration(s) of single GNSS receivers.

Open file `RINEX_CLOCKS_v3.00.html` with a Web browser.

(a) This clock data file starts with a header section as usual. Hover over the first and second comment records. What is the difference between the comments? What kind of information does the second comment give?

$\rightarrow$ *The first comment is generic, while the second is a Timescale Re-Alignment comment. This comment is required if '*`Ax`*' data are given (*`AR`* or* `AS`*). In case clock values have been time-scale shifted, the method applied to all receiver and satellite clocks should be noted.*

(b) Hover over the '`SYS / # / OBS TYPES`' records. Which observation descriptors are present in this RINEX clock file?

$\rightarrow$ *This file contains four different descriptors from the GPS system:* `C1W`*,* `L1W`*,* `C2W`*,* `L2W`*.*

(c) Records '`SYS / DCBS APPLIED`' and '`SYS / PCVS APPLIED`' describe the DCB and PCV. What programs are used to apply different corrections?

$\rightarrow$ *DCB corrections are applied using the* `CC2NONCC` *program, while PCV corrections are applied using the* `PAGES` *program.*

(d) Records '`STATION NAME / NUM`' and '`STATION CLK REF`' give information about the station. Which receiver identifier is present in the file? What external clock of this station is used for calibration?

$\rightarrow$ *The station name is the USNO with a receiver identifier* `40451S003`*. The external clock is the USNO, connected via a continuous cable.*

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(e) What is the analysis centre of this file?

→ *The analysis centre is the USNO, using the GIPSY/OASIS software.*

(f) This file uses two different groups of '`# OF CLK REF`' and '`ANALYSIS CLK REF`'. When does each clock reference apply?

→ *The data set is for the date* `14/07/1994`*. USNO clock reference applies from* `00:00:00` *to* `20:59:59`*. Afterwards, the clock reference used is TIDB from* `21:00:00` *to* `23:59:59`*.*

(g) How many receivers are included in the data file? Which reference frame is used to give station coordinates?

→ Five different stations are used in the file: `GOLD` (USA), `AREQ` (Peru), `TIDB` (Australia), `HARK` (South Africa), `USNO` (USA).

(h) The data record section of this file comes right after the '`END OF HEADER`' record. Each clock data record starts with a data type identifier. Which ones are present?

→ *The following clock data records are present:* `AR` *(Receiver Analysis),* `AS` *(Satellite Analysis),* `CR` *(Receiver Calibration),* `DR` *(Receiver Discontinuities). The only missing record is the* `MS` *(Satellite Monitor) record.*

(i) What data records are present for all clock data types? Which data records are sometimes present?

→ *Records '*`Clock Bias`*' and '*`Clock Bias Sigma`*' are always present. The '*`Clock Rate`*', '*`Clock Rate Sigma`*', '*`Clock Acceleration`*' and '*`Clock Acceleration Sigma`*' are only present for the* `AR` *clock data type.*

9. APC files: ANTEX v1.3

These standard files in ANTEX contain satellite and receiver antenna corrections. Satellite data include satellite and block-specific PCO. Receiver data include elevation and azimuth-dependent corrections for combinations of antennas and radomes.

Open file `ANTEX_v1.3.html` with a Web browser.

(a) As usual, this file contains a header section. Hover over the record present in line '`PCV TYPE / REFANT`'. Which PCV is used in this file? Which antenna is used as a reference?

→ *PCVs are relative (i.e. not absolute, see section 5.6.1, Volume I). This ANTEX file uses the* `AOAD/M_T` *antenna as a reference.*

(b) The different blocks of information are clearly identified using colours. What are the opening and closing records of each block? Which antennas are described in the file?

→ *The antenna blocks start with record '*`START OF ANTENNA`*' and end with '*`END OF ANTENNA`*'. This ANTEX file contains three different antenna descriptions. The first one is from the* `GLONASS R08` *satellite, the second from the GPS satellite* `G12` *(modernised block 2) and the third corresponds to the* `AOAD/M_B` *antenna.*

(c) Analyse Glonass antenna record '`TYPE / SERIAL NO`'. How is the satellite code (CNNN) interpreted? When was the satellite launched? How many satellites were launched that year before this one? Repeat the exercise with the GPS satellite.

→ *The Glonass antenna corresponds to a* `GLONASS (R)` *satellite, numbered* `729`*. It was launched during the year 2008. According to the ANTEX record, it is the 67th launched satellite. The GPS antenna is onboard the* `58th GPS SV`*. It is the* `52nd` *satellite launched during 2006.*

(d) Line '`DAZI`' shows the azimuth increment used to characterise the antenna's azimuth phase pattern. For satellite R08, is the PCV azimuth dependent? What about the GPS one?

→ *Because a* `DAZI` *value of* 0.0 *is given, the PCVs of* `R08` *and* `G12` *are not azimuth dependent.*

(e) '`ZEN1 / ZEN2 / DZEN`' gives information on both `AZI` and `NOAZI` phase patterns. What satellite grids are used to study the antennas? Is there any difference between receiver and satellite antennas?

→ *Both satellite grids start at* 0.0° *and end at* 14.0° *in* 1° *steps. Receiver antennas use zenith degrees, satellite ones use nadir degrees.*

(f) '`# OF FREQUENCIES`' determines the number of frequencies for each antenna block. What frequencies are described in the block for each satellite phase pattern?

→ *Two different frequencies are described. The Glonass satellite describes* `G1` *and* `G2` *frequencies, while the GPS satellites describe* `L1` *and* `L2`*.*

(g) The frequency section extends from '`START OF FREQUENCY`' to '`END OF FREQUENCY`' records. What information is given? Give the eccentricity vector for both satellites. What is the origin of this vector?

→ *The eccentricities of the APC and the phase pattern values are* `R08=(-545.00,0.00,2300.00)` *and* `G12=(-10.16,5.87,-93.55)`*. The vector points from the satellite centre of mass to the satellite APC.*

(h) How many non-azimuth-dependent (NOAZI) phase pattern values are specified? Why?

→ *Fourteen different* `NOAZI` *values are specified, due to the '`ZEN1 / ZEN2 / DZEN`' definition. Because* `DAZI` *is set to* `0`*, NOAZI-dependent phase patterns are specified.*

(i) The third antenna corresponds to a receiver antenna. What is the calibration method? Which agency has created such corrections?

→ *Calibrations have been converted from file* `igs_01.pcv`*. TUM is the creator of the file.*

(j) This antenna has a non-zero DAZI record for the PCVs. What is the value of this increment? Where else can we see this `DAZI`?

$\rightarrow$ *This antenna block has a 30° azimuth increment for the PCVs. So, this value will be given from 0 to 360 in increments of 30°.*
Apart from giving the `NOAZI` *values, this data set includes the* `DAZI` *values, both of them using a 0.0 to 90 grid with a 5° step.*

10. Precise orbit and clock files: SP3 version C

Precise orbital data (satellite position and velocity), the associated satellite clock corrections, orbit accuracy exponents, correlation information between satellite coordinates and satellite clock are available in this format.

Open file `SP3_Version_C.html` with a Web browser.

(a) The structure of this file is different from the RINEX ones seen up to now. Hover the mouse over the '`Extended Standard Product 3 Orbit Format`' title, where some general information is given. What additional information is included regarding to the `SP3-c` version?

$\rightarrow$ *Satellite clock corrections, orbit accuracy exponents, comment lines, the GPS week and the first epoch seconds of a week.*

(b) What was the main advance in the SP3-b version? Did this change some previous characteristics?

$\rightarrow$ *Version* `B` *of the* `SP3` *files accommodated Glonass orbits.* `SP3-b` *modifications were backwards compatible with* `SP3-a`*, with the exception of the satellite identification records, from an* `I3` *field to an* `A1,I2` *one.*

(c) What is the main advance in the `SP3-c` version? How is this achieved?

$\rightarrow$ *Files now include not only clock accuracy information, but also information on the accuracy of (X, Y, Z) satellite coordinates, which is added using columns 61 to 80 in each position and clock record.*

(d) How is this format organised? Is there any optional record?

$\rightarrow$ *The format of an SP3 file is a header, followed by a series of epoch times, each with a set of position and clock records listed for each satellite. Optional records are: satellite velocities, clock correction rate of change, position and clock correlation record (`EP` record) and velocity and clock rate-of-change correlation record (`EV` record).*

(e) The first line of the SP3 file contains information about the entire file. What is the version of the current file? What might be the next SP3 version? Which flag mode is set in this file? What time is the first epoch? How many epochs are included in this file? What type of orbit is used in the file? Which agency has created the file?

$\rightarrow$ *The version of the file is* `C-version`*. SP3 versions follow the alphabet, so next one might be the* `SP3-D` *version. The velocity mode flag is set. This means the records will follow the order* `P,V, P,V, ...` *in case there are additional records, (`EP` or `EV`), which would be in the middle.*
The first epoch dates from `08/08/2001` *at* `00:00:00`*.*
There are 192 epochs up to a maximum of 10 million.

The orbit type is HLM, which means it has been fitted by applying a Helmert transformation.
IGS is the agency that created the file.

(f) What is the symbol identifying the start of the second line? Which GPS week number corresponds to this file? Which interval is used in this file?

→ *The ## symbols.*
This file corresponds to the GPS week 1126.
A 900 s interval is used.

(g) The next block (lines 3–7) states the satellites used in the file. How many have contributed? What does a zero value mean? How many different satellites from different satellite systems are identified?

→ *There are 31 different satellites.*
The 0 value indicates that all identifiers have been listed.
Each identifier consists of the satellite system indicator followed by a two-digit integer.

(h) From lines 8 to 12, orbit accuracy of the satellites is listed following the previous block order (lines 3–7). How is this accuracy exponent interpreted?

→ *For example, if the accuracy exponent is $13 \to 2^{13}\,\mathrm{mm} \simeq 8\,\mathrm{m}$. This accuracy represents one standard deviation of the entire file (per satellite).*

(i) The next block comprises lines 13 and 14. Although it is mainly unused, what information is given in the file?

→ *This block states the file type and the system time used in the file.*

(j) The next block comprises lines 15 and 16. What information is given in the file? What is the reason for using such base numbers?

→ *This block contains the floating-point base number used for computing the standard deviations of satellite position, velocity, clock correction and rate of change of the clock correction. Better resolution can be obtained using a floating-point number different from 2.*

(k) After the 'comment' section, the data records start with the previously seen time of first epoch. What symbols mark the start of comments and the new epoch?

→ *Comments start with symbols '/*', while the new epoch starts with symbol '*'.*

(l) The second epoch line contains the position and clock data record. What parameters are given? Which units are used? Explain the different flags applied to the first satellite.

→ *Satellite (X,Y,Z) positions, the clock correction with its corresponding standard deviation exponents. There are four final flags.*
Satellite positions are given in kilometres, clock correction in milliseconds. The exponents generate corrections in millimetres and picoseconds.
The first satellite has set: a discontinuity flag between the previous epoch and the current epoch; an orbit position and clock prediction flag; and a manoeuvre flag.

(m) The third epoch line contains the extended position and clock correlation record. What information is given in the first four records? What is the difference with the previous line? Which correlation coefficients are given next?

→ *The standard deviations of the satellite position and clock correction are given with greater resolution than the approximate values given in the position and clock record.*
The correlations between the X/Y, X/Z, Y/Z *satellite coordinates, and the correlations between the* X/C, Y/C, Z/C *satellite coordinates and clock.*

(n) The fourth epoch line contains the velocity and clock rate-of-change record. In which units are satellite velocities, clock rate of change and their deviations expressed? What happens if the deviations are unknown or too big to represent?

→ *Velocities are given in decimetres/second and clock rate of change in microseconds/second. Velocity deviation is in millimetres/second and clock rate-of-change deviation in picoseconds/second.*
A value of 99 means the standard deviation was too large to represent, while a blank means it is unknown.

(o) The fourth epoch line contains the extended velocity and clock rate-of-change record. What correlation coefficients are given? Why are the values given greater than one?

→ *The correlations between the* Vx/Vy, Vx/Vz, Vy/Vz *satellite velocities, and correlations between the* Vx/Clock, Vy/Clock, Vz/Clock *satellite velocities and clock.*
Because they have to be divided by 10^7.