Radford UNIVERSITY

Raspberry Pi-Based Ionospheric Data Extraction Using Global Navigation Satellite Systems

Enikő Szabad, Em Stipes, Rhett Herman

Arctic Geophysics Research Experience, Radford University

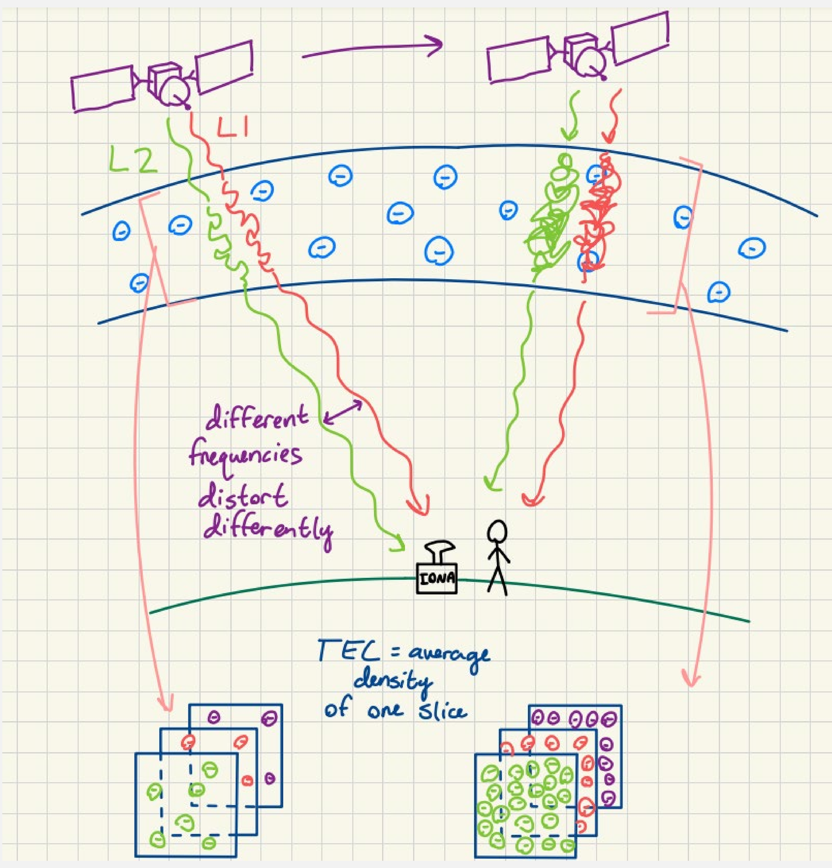
NS13B – 1246

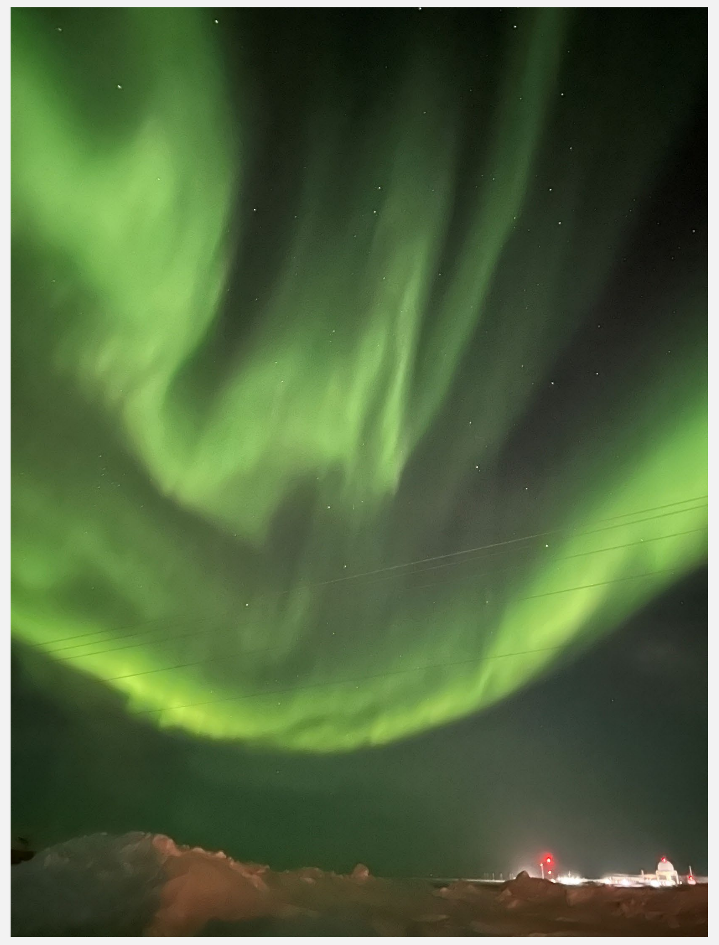
Radford UNIVERSITY
Department of Physics

Introduction

The ionosphere is a layer of our atmosphere ~60-300 km Earth's surface which has a relatively large concentration of charged particles. These charged particles interact with EM waves that pass through them. We are particularly interested in the signals emitted by the orbiting constellation of GNSS satellites. This interaction is known as scintillation, and results in a slight frequency change between what we receive and the actual frequency emitted by these satellites. This frequency difference, along with some of the orbital parameters of the emitting satellites, allows us to estimate the total electron content (TEC) of our ionosphere at any point within our view.

Our work was dedicated to understanding a low-cost tool to study ionospheric scintillation remotely, i.e. without having the receiving antenna directly connected to a computer. We also gained a better understanding of how the ionosphere is structured, using the model by Gomez Socola et al., 2022 as a basis. We worked to simplify and clarify the methodology so that it is readily accessible to anyone who wishes to perform these same studies.





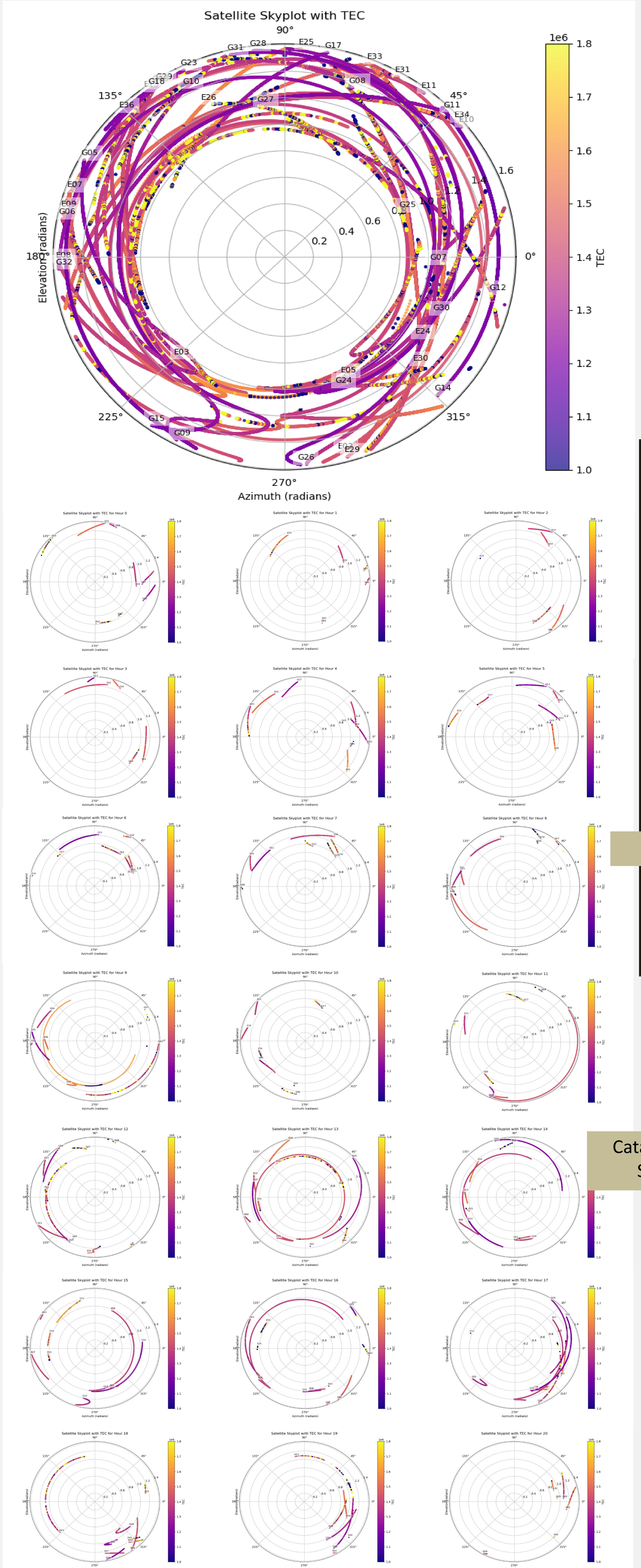
Do it Yourself!

1. Gather the equipment – listed above
2. Configure Receiver
    a. Use U-center in configuration view to disable NMEA messages and enable UBX RXM RAW messages.
    b. Change rate at which receiver takes data to 2s
3. Connect receiver to Raspberry Pi via USB
4. Download RTKLIB onto Raspberry Pi
5. Test RTKLIB data collection software
6. Make shell script to take data and save it; it will be a UBX file
7. Edit the /etc/rc.local file and add a command to run shell script at boot
8. Download RTKLIB -> RTKCONV onto a separate windows computer
9. Transfer UBX file to Windows computer and convert using RTKCONV
10. Use Python parse through the data and create data frames
11. Calculate TEC using Eqs. (3) and (4) in Gomez Socola et al., 2022
12. Graph TEC per satellite over the span of a few hours.
13. Celebrate because you did it!!!!

Data and Equipment

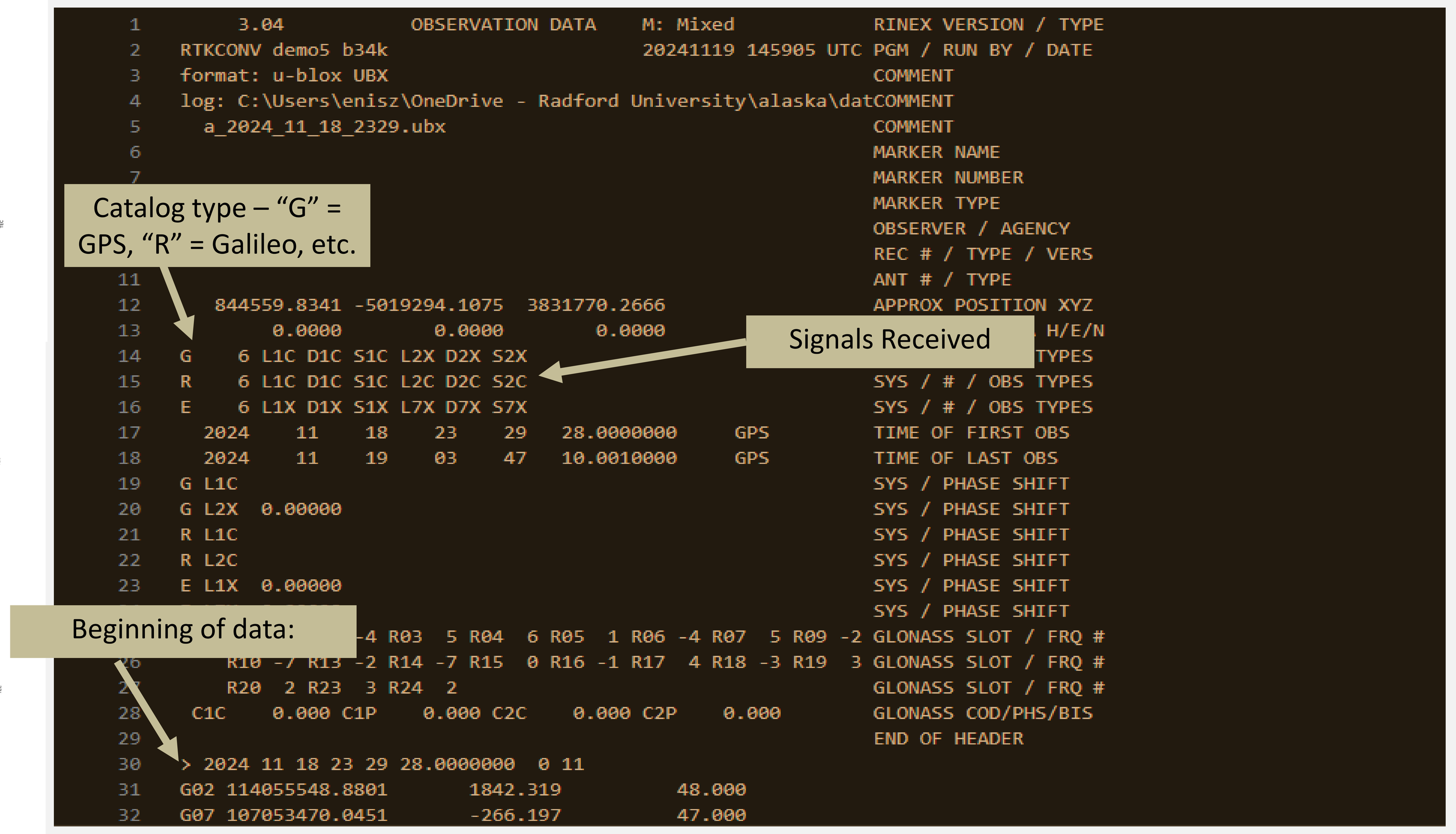
Equipment for remote unit

- GNSS Multi-Band L1/L2/L5 Surveying Antenna
- GPS-RTK-SMA ZED-F9P multi-band receiver
- Raspberry Pi 4 model B
- Raspberry Pi T-cobbler (for simplicity)
- Raspberry Pi portable battery



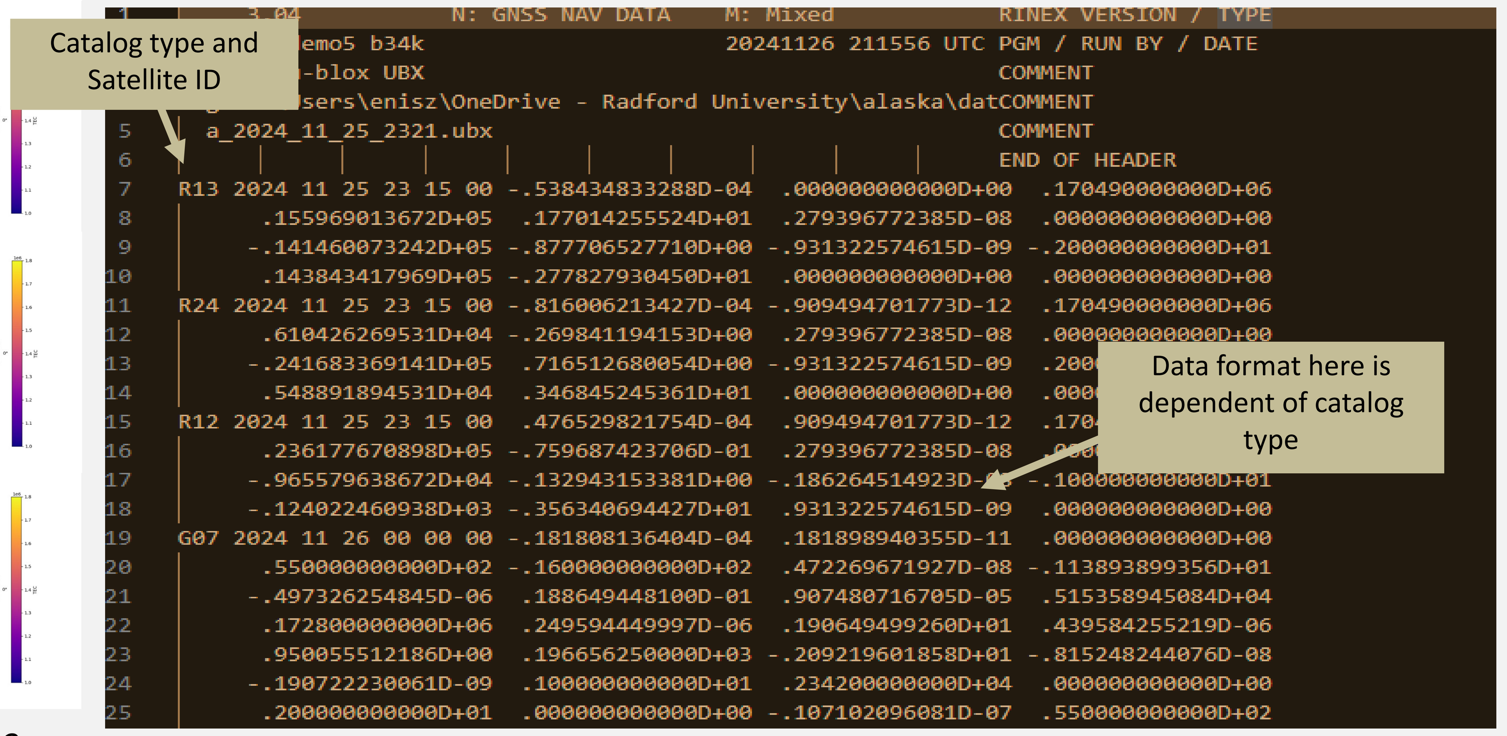
The top graph is a polar graph showing the path of the satellites and the calculated TEC for 21 hours. The smaller squares are the hour by hour parts that make up the larger graph

- We received the raw data from the receiver in .ubx file format and then converted this .ubx file to RINEX (Receiver Independent Exchange format) in order to extract data needed for TEC calculation.
- RINEX file conversion was done using the RTKLIB processing suite ver. 2.4.3, specifically the RTKCONV tool.
- RTKCONV allows for the conversion of many different RINEX formats, but the only ones we used were the .obs and .nav file formats.
    - .nav files (Navigation files) include the latitude, longitude, and altitude of the satellite when the data was taken.
    - .obs files (Observation files) contain satellite information such as satellite number, pseudo range, carrier phase, doppler shift, and signal-to-noise ratio (S/N.)
- We processed and visualized the data using data frames in Python.
- The data frame was written using Pandas and the Regular Expression libraries.
- Note that the results for total electron content are in TECU ("TEC Units") where 1 TECU=10^{16} e/cm^2. This is a "column density" of the number of electrons an EM wave is constantly traversing.




```
     3.04           OBSERVATION DATA    M: Mixed            RINEX VERSION / TYPE
RTKCONV demo5 b34k                      20241119 145905 UTC PGM / RUN BY / DATE
format: u-blox UBX                                          COMMENT
log: C:\Users\enisz\OneDrive - Radford University\alaska\datCOMMENT
  a_2024_11_18_2329.ubx                                     COMMENT
                                                            MARKER NAME
                                                            MARKER NUMBER
                                                            MARKER TYPE
                                                            OBSERVER / AGENCY
                                                            REC # / TYPE / VERS
                                                            ANT # / TYPE
   844559.8341 -5019294.1075  3831770.2666                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  H/E/N
G    6 L1C D1C S1C L2X D2X S2X                              TYPES
R    6 L1C D1C S1C L2C D2C S2C                              SYS / # / OBS TYPES
E    6 L1X D1X S1X L7X D7X S7X                              SYS / # / OBS TYPES
  2024    11    18    23    29   28.0000000     GPS         TIME OF FIRST OBS
  2024    11    19    03    47   10.0010000     GPS         TIME OF LAST OBS
G L1C                                                       SYS / PHASE SHIFT
G L2X  0.00000                                              SYS / PHASE SHIFT
R L1C                                                       SYS / PHASE SHIFT
R L2C                                                       SYS / PHASE SHIFT
E L1X  0.00000                                              SYS / PHASE SHIFT
                                                            SYS / PHASE SHIFT
      -4 R03  5 R04  6 R05  1 R06 -4 R07  5 R09 -2 GLONASS SLOT / FRQ #
    R10 -7 R13 -2 R14 -7 R15  0 R16 -1 R17  4 R18 -3 R19  3 GLONASS SLOT / FRQ #
    R20  2 R23  3 R24  2                                    GLONASS SLOT / FRQ #
 C1C    0.000 C1P    0.000 C2C    0.000 C2P    0.000        GLONASS COD/PHS/BIS
                                                            END OF HEADER
> 2024 11 18 23 29 28.0000000  0 11
G02 114055548.8801      1842.319          48.000
G07 107053470.0451      -266.197          47.000
```

This is an image of part of a .obs file, which is the observational data from the RINEX files. These show the different signal types per catalog. The information includes satellite ID, signal to noise ratio, Doppler shift, pseudorange, and carrier phrase for each of the frequencies sent.




```
     3.04           N: GNSS NAV DATA    M: Mixed            RINEX VERSION / TYPE
    demo5 b34k                          20241126 211556 UTC PGM / RUN BY / DATE
    -blox UBX                                               COMMENT
    sers\enisz\OneDrive - Radford University\alaska\datCOMMENT
  a_2024_11_25_2321.ubx                                     COMMENT
                                                            END OF HEADER
R13 2024 11 25 23 15 00 -.538434833288D-04  .000000000000D+00  .170490000000D+06
     .155969013672D+05  .177014255524D+01  .279396772385D-08  .000000000000D+00
    -.141460073242D+05 -.877706527710D+00 -.931322574615D-09 -.200000000000D+01
     .143843417969D+05 -.277827930450D+01  .000000000000D+00  .000000000000D+00
R24 2024 11 25 23 15 00 -.816006213427D-04 -.909494701773D-12  .170490000000D+06
     .610426269531D+04 -.269841194153D+00  .279396772385D-08  .000000000000D+00
    -.241683369141D+05  .716512680054D+00 -.931322574615D-09  .200
     .548891894531D+04  .346845245361D+01  .000000000000D+00  .000
R12 2024 11 25 23 15 00  .476529821754D-04  .909494701773D-12  .170
     .236177670898D+05 -.759687423706D-01  .279396772385D-08
    -.965579638672D+04 -.132943153381D+00 -.186264514923D-   -.100000000000D+01
    -.124022460938D+03 -.356340694427D+01  .931322574615D-09  .000000000000D+00
G07 2024 11 26 00 00 00 -.181808136404D-04  .181898940355D-11  .000000000000D+00
     .550000000000D+02 -.160000000000D+02  .472269671927D-08 -.113893899356D+01
    -.497326254845D-06  .188649448100D-01  .907480716705D-05  .515358945084D+04
     .172800000000D+06  .249594449997D-06  .190649499260D+01  .439584255219D-06
     .950055512186D+00  .196656250000D+03 -.209219601858D+01 -.815248244076D-08
    -.190722230061D-09  .100000000000D+01  .234200000000D+04  .000000000000D+00
     .200000000000D+01  .000000000000D+00 -.107102096081D-07  .550000000000D+02
```

This shows part of a .nav file which show the satellite's positions. Each catalog stores this information in different ways. The GPS satellites store everything in emphemeris data format which is an Earth centric orbital set of measurements such as eccentricity of orbit and acceleration.

"Iona" hard at work collecting data on Radford University's campus

References, Acknowledgements

Gomez Socola, J.; Rodrigues, F. S. ScintPi 2.0 and 3.0: Low-Cost GNSS-Based Monitors of Ionospheric Scintillation and Total Electron Content. *Earth, Planets and Space* **2022**, *74* (1). DOI:10.1186/s40623-022-01743-x.

Rodrigues, F. S.; Moraes, A. O. ScintPi: A Low-cost, Easy-to-build GPS Ionospheric Scintillation Monitor for Dasi Studies of Space Weather, Education, and Citizen Science Initiatives. *Earth and Space Science* **2019**, *6* (8), 1547–1560. DOI:10.1029/2019ea000588.

The authors would like to acknowledge Kaleb Martin for his work on the preliminary version of this project.

Support for this research provided by the Radford University Physics Department, RU Physics Alumni, the Office of Undergraduate Research and Scholarship (OURS), the Citizen Leader Program, and the McGlothlin Center for Global Education and Engagement