ESSE 4350: GPS Tracking Program Documentation

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Introduction

This document is used to accompany the TrackingProgram- python based program created during the fall semester of 2020 for ESSE4350: Space Hardware.This documentation should be situated in the same directory as the Program, but if this is not the case, the program can be found on GitHub at https://github.com/mstewart2525/ENG4350-Tracking . Note that each branch of the Github contains a different version of the Laboratories conducted during the semester. The Lab06+ (latest version) of the program will be referenced extensively in this document. This program was created to calculate Look Angles for Tracking GPS Satellites using TLE data

GPS Satellite TLE data can be obtained from
https://celestrak.com/NORAD/elements/gps-ops.txt

Reasoning

The purpose of this program was to perform calculations on a set of given Satellite Two Line Elements Data lines,Station Inputs, Tracking Schedule and Link Data Inputs, to output required signal parameters in a user and computer friendly environment.

- Calculations performed:
    - Calculate Acquisition of Signal and Loss of Signal
        - Outputted as AOS_LOS.csv and AOS_LOS.txt
    - Calculate Azimuth and Elevation Angles (Look Angles)
        - Outputted as AZ_EL.csv
            - Outputs all available Satellite's Look Angles
        - Outputted as AZ_EL.txt
            - Outputs Chosen Satellite's Available Look Angles
    - Calculate Link Budgets
        - Outputted in AZ_EL.txt
    - Calculate Tracking Data (Fazel Data) for a given Satellite
        - Outputted as ControlFile.ascii
    - Lower level variables are available for viewing in the Master.csv file

Structure

The High-level Structure follows the Suggested Program Structure provided in the Software Specifications. Structure is further elaborated on in the "Code Breakdown Section"

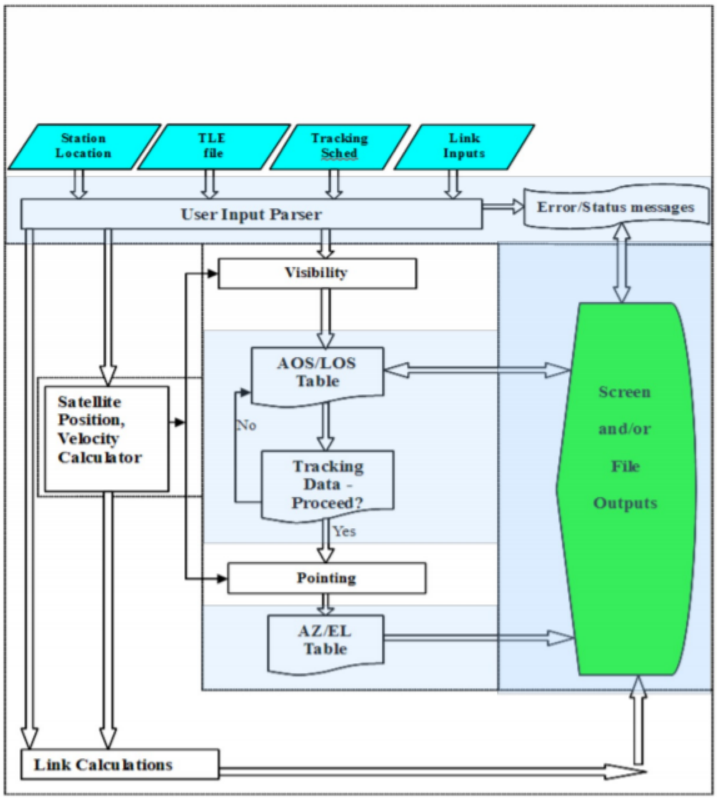


Figure 1.1: High Level Breakdown Structure of the Program.

Operation of Program

To run the code properly it is important to make sure the Input files are formatted properly. Software Specifications defines the formatting requirements. Here they are repeated:

Input Files

Station File

Station File Format

The example file provided in the .zip file is labeled “INPUT_Station.txt”

Suggested file name: station.dat
File type: ASCII
Suggested Format description:

Station name (any string)
Latitude (float, degrees)
Longitude (float, degrees. Negative west of Greenwich)
Altitude (meters)
Local time zone shift with daylight saving hour and proper sign, Eastern time -5 or -4.

Number of points N in AZ/EL horizon table (integer).

MinAZ[0]	Min_EL[0]	Max_EL[0]
AZ[1]	Min_EL[1]	Max_EL[1]
…		
AZ[i]	Min_EL[i]	Max_EL[i]
….		
MaxAZ[N-1]	Min_EL[N-1]	Max_EL[N-1]

Max_AZ_Speed
Max_EL_Speed

Where AZ[i] is a float value in range 0.0 –360.0 deg and EL[i] is an float value in range 0.0 – 90.0. Note more than 2 AZ/EL points can be used to define exclusions from nearby landscape (hills, trees, etc)
Max_AZ_Speed and Max_EL_Speed are float values in deg/sec.

Figure _: Screenshot taken from the Software Specifications document which describes the Station file characteristics

Tracking File

Tracking File Format

Tracking start date/time: YYYY-DOY-hh:mm:ss (or YYYY-MM-DD-hh:mm:ss)
Tracking stop date/time: YYYY-DOY-hh:mm:ss (or YYYY-MM-DD-hh:mm:ss)
Output time step (sec): xx.xx
(Optional) Elevation increment (deg): xx.xx
(Optional) Azimuth increment (deg): xx.xx

Figure _: Screenshot taken from Software Specifications document

Note: No current implemented Code to control Azimuth and Elevation increment.

Running Tracking Program

Once the Input Files are ensured to be in proper format, the next step to run the program is to change the directories of the inputs and outputs of the files. The program should be opened in a python IDE such as Spyder. Scroll down to the bottom of the code and change the directory addresses in the section labeled “Calling Functions ”.

```
##                  Calling Functions

# These functions controls the inputs and outputs of the program.
    #Edit Directories for control over the proper inputs and outputs of the program


[StationInstance,SatList,Tracking,LinkData]=User_Input_parser_Call\
    (r'D:\School\5th Year Fall Semester\ESSE 4350\Tracking\P6+\Input Files\Station.txt'\
     ,r'D:\School\5th Year Fall Semester\ESSE 4350\Tracking\P6+\Input Files\gps-ops.txt'\
         ,r'D:\School\5th Year Fall Semester\ESSE 4350\Tracking\P6+\Input Files\TrackingData.txt'\
             ,r'D:\School\5th Year Fall Semester\ESSE 4350\Tracking\P6+\Input Files\LinkInputs.txt')
# This call function creates instances of each file that can be easily manipulated in Python.
```

Figure 2.1: Author mstew’s Directory Location that needed to be changed for each user. IDE used is Spyder. The newest version of the program uses files in the same folder as the Program

Now we can finally run the code in the IDE but hiting the green arrow on the top left corner of the screen (in Spyder IDE).

After started a list of Satellites will be displayed with their Array indexes. In the Console Window

```
SatList has been created with GPS BIIR-2  (PRN 13)
 Being the First Satellite
GPS BIIR-4  (PRN 20)
 Satellite has been registered as Satellite: 2 Array index: [ 1 ]
GPS BIIR-5  (PRN 28)
 Satellite has been registered as Satellite: 3 Array index: [ 2 ]
GPS BIIR-8  (PRN 16)
 Satellite has been registered as Satellite: 4 Array index: [ 3 ]
GPS BIIR-9  (PRN 21)
 Satellite has been registered as Satellite: 5 Array index: [ 4 ]
GPS BIIR-10 (PRN 22)
 Satellite has been registered as Satellite: 6 Array index: [ 5 ]
GPS BIIR-11 (PRN 19)
 Satellite has been registered as Satellite: 7 Array index: [ 6 ]
GPS BIIR-13 (PRN 02)
 Satellite has been registered as Satellite: 8 Array index: [ 7 ]
GPS BIIRM-1 (PRN 17)
 Satellite has been registered as Satellite: 9 Array index: [ 8 ]
GPS BIIRM-2 (PRN 31)
 Satellite has been registered as Satellite: 10 Array index: [ 9 ]
GPS BIIRM-3 (PRN 12)
 Satellite has been registered as Satellite: 11 Array index: [ 10 ]
```

Figure 2.2: Example of the Satellite Register created

The program will now calculate all Range and Look Angles for the listed Satellites (this may take some time). If calculations take too long, try increasing the time step or reducing the time between start and stop of observation in your Tracking Input file.

It is understood that calculating all Range and Look Angles is not optimal for dealing with large sets of time data.

The Program will output a list of Satellites that are available for viewing in the Command Prompt.

```
SatAvailable GPS BIIR-8  (PRN 16)

SatAvailable GPS BIIRM-2 (PRN 31)

SatAvailable GPS BIIRM-5 (PRN 29)

SatAvailable GPS BIIF-4  (PRN 27)

SatAvailable GPS BIIF-7  (PRN 09)

SatAvailable GPS BIIF-8  (PRN 03)

SatAvailable GPS BIIF-9  (PRN 26)

SatAvailable GPS BIII-1  (PRN 04)
```

Figure2.3: Example of available satellites

A prompt will soon appear asking the user to pick a satellite:

```
Enter the Satellite Index to Output in .sp and .e file:
```

The user can choose a satellite from this list to export a Pointing file,Ephemeris file and Tracking Control file. Note that index 0 would pick the first Satellite listed (in our example BIIR-2). Selecting a satellite will output Azimuth, Elevation, their rates, Satellite Range (from Station), Doppler Shift and Required Receiver level into teh command prompt. Note that only inview data is displayed, meaning that the Station must have a view of the Satellite.

```
Enter the Satellite Index to Output in .sp and .e file:0
GPS BIIR-2  (PRN 13)
 Has been chosen
Availability of Satellite:

 UTC     AZ (Deg) EL Deg AZ-Vel (deg/sec) El-Vel (deg/sec) Range (km) Doppler KHz Level dBm

2021-012-10:30:00  68.15  56.52  -0.01  -0.00  20658  -1.408 -93

2021-012-10:35:00  65.15  54.91  -0.01  -0.00  20743  -1.596 -93

2021-012-10:40:00  62.53  53.18  -0.01  -0.01  20838  -1.777 -93

2021-012-10:45:00  60.27  51.36  -0.01  -0.01  20943  -1.951 -93

2021-012-10:50:00  58.34  49.47  -0.01  -0.01  21058  -2.118 -93

2021-012-10:55:00  56.69  47.51  -0.01  -0.01  21181  -2.276 -93

2021-012-11:00:00  55.31  45.51  -0.00  -0.01  21314  -2.426 -93

2021-012-11:05:00  54.16  43.47  -0.00  -0.01  21455  -2.567 -93
```

Figure 2.4: Command Window output after selecting an index for a Satellite.

The Program will then ask the user if this data is acceptable. Answering with “Y” will output a Tracking Control file in .ascii format, The Azimuth and Elvation Data from the Command Window will be sent into an outputted Azimuth and Elevation test file, and Ephimeris and Pointing files for the corresponding Satellite will be exported.

Output Formats

AOS and LOS

Sat No.	Name	AOS	LOS	Min. Expected Level (dBm)
1	PRNxx	YY-MM-DD hh:mm:ss	YY-MM-DD hh:mm:ss	xx
2	PRNyy	YY-MM-DD hh:mm:ss	YY-MM-DD hh:mm:ss	yy
…				
3	PRNzz	YY-MM-DD hh:mm:ss	YY-MM-DD hh:mm:ss	zz

Where
AOS – Acquisition Of the Satellite
LOS – Loss Of the Satellite
xx, yy, zz – expected minimum level at AOS or LOS in dBm

Figure 2.5: Taken from the Software Specifications document. This standard dictates how the AOS and LOs data is to be outputted.

AZ EL

UTC	AZ Deg	EL deg	AZ-vel deg/sec	EL-vel deg/sec	Range km	Range Rate km/sec	Doppler kHz	Level dBm
YY-DOY-hh:mm:ss	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXXXX	XXX	XXX.XXX	XX

Figure 2.6: Taken from the Software Specifications document. This standard describes how the Azimuth and Elevation Text file is outputted.

Code Breakdown

At first glance, the program is daunting as it requires many moving parts to operate, but in this section we will walk through each part of the code. Note that reading the code from top to bottom doesn't represent the order of which things are called. The code will be broken down from higher level to lower level. Level 0 represents the highest level of code.

- **Bolded Lines Represent Functions**
- *Italicized Lines Represent Classes*
- <u>Underlined Lines Represent Important Variables which the User can change</u>

Level 0 - Calling Functions

Located at the end of the program our calling functions define the inputs locations and output locations. When running the code on a different system, the file locations will be different so these directories must be changed. One could however save all the input documents (TLE file, Station Location, Tracking Schedule and Link Inputs) in the same file folder as the MainCall.py program and directory addresses could be simplified to only the document name.

- **User_Input_parser_call**
  - Purpose: Acts as a bridge from directory t
  - Inputs: Takes in Directory strings
  - Contains:
    - **StationInstance**
    - **SatListPropagate**
    - **linkinput**
  - Outputs: Creates Satellite List (SatList), Link Data, Tracking file instance and a Station file instance.
- **Sat_pos_velCall**
  - Purpose: Acts as the Position and Velocity Calculator (refer to Software Structure above Figure 1)
  - Inputs: Takes in Station Instance, Satellite List and Tracking file Instance
  - Contains:
    - **time_lister**
    - **mean_anomay_motion**
    - **sat_ECI**
    - **sat_ECF**
    - **range_ECF2topo**
    - **range_topo2look_angle**
  - Outputs: Azimuth and Elevation (also called Look Angles)(AZ,EL), Rate of Azimuth and Elevation(Rate_of_AZ,Rate_of_EL), Topocentric Range and Velocity(R_ti,v_rel_ti), Time array (time), Satellite Number Array (used for Satellite referencing)(Satum)
- **SignalCalc**

- Purpose: Calculate Signal loss, Minimum Power Received and Doppler shift for a given Topocentric Range (r_ti)
    - Inputs: Link frequency(LinkData.frequency), Antenna efficiency(LinkData.antennaeff), Antenna Diameter(LinkData.AntennaDia), SAtellite Range (R_ti)
    - Contains:
        - Calculations for Doppler Shift and Signal Loss
        - Required EbNo
            - EbNo is based on Modulation Type and Controls Transmitted Power Requirement thus affecting Minimum Power Received.
    - Outputs: Minimum Received Power, Free Space Signal Loss, Doppler Shift (of each satellite at each time step),
- **Pointing**
    - Purpose: the function isolates available Azimuth and Elevations and Acquisition and Loss of Signal by comparing the previous realized Azimuth and Elevation angles to the created Station instance
        - Remember that the Station instance includes limits on Azimuth and Elevation
    - Inputs: Station instance,Azimuth, Elevation,Time List, Satellite Number (for referencing correct Satellite), and Signal Loss
    - Contains:
        - Conditional statements which determines whether a Satellite is available or not.
    - Outputs: List of Available Azimuths, Available Elevations, Satellite Number

- **Visibility**
    - o Purpose: To Find the Acquisition of and Loss of a Signal and pair them together.
    - Inputs:
        - Station Instance
        - Azimuth
        - Elevation
        - Minimum Level of Power Required
    - Contains: code which pairs
        - the AOS and LOS found in the pointing function
        - Creates a unique pair listing for AOS and Satellite number since Satellite pairing code does not create unique pairings for AOS and LOS pairing
            - In simpler terms the AOS and LOS pairings found above would have multiple LOS times for a singular AOS
        - Utilizes:
            - Pointing Function
        - Outputs:
            - AOS and LOS List
                - This list contains

            - Satellite number (Satnum), AOS Time, LOS Time, Minimum Power Level Requirement (in dBm)
    - Notes:
        - Although Visibility Function is listed as a Level 0 Highest level function here, it is more accurately described as a 0.5 level function since it utilizes components of other Level 0 functions but its output is required for other Level 0
        - This part of the code is difficult to understand but essential the LOS and AOS data gathered from the Pointing() function has intrinsic time dependence, so we can create an accurate list by first looping through each list (AOS and LOS) and creating a pairing every time we see the same Satellite number index and when the Loss of Signal is greater than the Acquisition of Signal. Through this logic we will have multiple LOS times for a singular AOS time which is not wanted. So we then create a unique list which is dependent on a string joining the Satellite number and AOS time.

Level 1- Medium Level Functions/Classes

These Functions largely involve calculations being done to inputted values to output to the higher levels. The majority of them lie within the Satellite Position Velocity Calculator

- *Station*
    - Purpose: create a Station instance from the inputted string.
    - Location:
        - Inside **User_Input_parser_Call**
    - Inputs: Station Location Str
    - Contains:
        - File parser
        - Assignments
    - Outputs: Station Instance with its characteristics

- **SatListPropagate**
    - Purpose: Propagates a List of Satellites using the TLE file
    - Location:
        - Inside **User_Input_paser_Call**
    - Inputs: TLE file
    - Contains:
        - Creates a Listing of Satellites with their properties defined by class Satellite
        - *Satellite*
    - Outputs:
        - SatList (list)
            - Contains all Satellites Data
- *tracking*

- Purpose: Reads data in the Tracking Data file and assigns it to a variable called Tracking
    - Location:
        - **User_Input_parser_Call**
    - Inputs:
        - Tracking file location (string)
    - Contains:
        - Parsing and Assignment code
    - Outputs:
        - Tracking instance
            - Contains all properties read in from file
- *Linkinput*
    - Purpose: creates an object with attributes read in from the Link Input file
    - Location:
        - **User_Input_parser_Call**
    - Inputs:
        - LinkInput string
    - Contains:
        - Readlines and assignment code pieces
    - Outputs:
        - Link Data (object)
            - Contains attributes of read in data
- **Time_lister**
    - Purpose: Creates time list of the observation window
    - Location:
        - **Sat_pos_velCall**
            - Before loops
    - Inputs:
        - Tracking Instance
    - Contains:
        - Iterative code which creates date time list
    - Outputs:
        - Times (List of times to be calculated)
- **THETAN**
    - Purpose:Calculates the GMST values
    - Location
        - **Sat_pos_velCal**l
            - Before Time, Satellite Array
    - Inputs:
        - Times (datetime, time list)
    - Outputs:
        - GMST value at each timestep

- **Mean_anomaly_motion**
    - Purpose: calculates Mean Anomaly Motion and Mean Anomaly at time t, where t is epoch seconds from Satellite's reference Epoch
    - Location:
        - **Sat_pos_velCall**

            - Within Time-Satellite Loop
    - Inputs:
        - Time_dt
            - Datetime object of the current iterated time
        - Satellite Reference Epoch
        - Satellite's Mean Anomaly at reference epoch
        - Satellite mean motion at reference epoch
        - Satellite "ndot"- derivative of mean motion
        - Satellite "n2dot"- 2^{nd} derivative of mean motion
    - Contains:
        - **Refepoch_to_dt**
            - Transforms reference epoch time to datetime object
        - Code which calculates Epoch seconds
        - Code which calculates Mean Anomaly at time t
        - Code which calculates Mean Anomaly Motion at time t
    - Outputs
        - Mt_mean_anomaly
            - In degrees
        - Nt_mean_anomaly
            - In revolutions/day
    - Notes:
        - "ndot" variable is actually ndot/2
        - "n2dot" variable is actually n2dot/6
- **KeplerEqn**
    - Purpose: Calculates the Eccentric Anomaly using the Mt_mean anomaly at time t and eccentricity of the Satellite's orbit. Calculation is done using the Kepler Equation
    - Location:
        - **Sat_pos_velCall**
            - Within Time-Satellite Loop
    - Inputs
        - Mean Anomaly at Time t
        - Eccentricity of Satellite's Orbit
    - Contains
        - <u>permitted_error</u>
            - This is an important variable which improve accuracy of calculation
        - Eccentric Anomaly calculations
    - Outputs
        - Eccentric Anomaly (ecc_anomaly)
- **Sat_ECI**
    - Purpose: Calculates the Satellite's Position and Velocity using the Orbital Parameters gather from TLE file
    - Location: Inside **Sat_pos_VelCall** within Time - Satellite loop
    - Inputs

        - Eccentricity,
        - Eccentric Anomaly,
        - Semi Major Axis
        - Right Ascension of the Ascending Node
        - Argument of Perigee, Inclination
        - Mean Motion
    - Contains:
        - **Perifocal**
    - Outputs
        - ECI Position
        - ECI Velocity
- **GMST**
    - Purpose: Creates a GMST angle for the Time
    - Location: before **Sat ECF** and after **Sat_ECI** inside **Sat_pos_VelCall**
    - Inputs:
        - Date Time from Start time to End Time of Observation period with Step Size defending in Tracking File.
    - Outputs: GMST angle
- **Sat_ECF**
    - Purpose: Calculates Satellite's ECF Coordinates with Relative Velocity
    - Location: directly after **Sat_ECI** inside **Sat_pos_VelCall** Time Satellite Loop
    - Inputs:
        - GMST angle at time step
        - ECI position
        - ECI velocity
    - Outputs: Satellite ECF Coordinates with Relative Velocity
- **Station ECF**
    - Purpose: Calculates Station's ECF Coordinates
    - Location: Directly under **Sat_ECF** in **Sat_pos_VelCall**
    - Inputs: Station instance Longitude, Latitude and Altitude
    - Contains: Calculations
    - Outputs: Station ECF position coordinates
- **Range_ECF2topo**
    - Purpose: Calculates Topocentric Position and Velocity
    - Location: Directly under **Station_ECF** in **Sat_pos_VelCall**
    - Inputs: Station ECF Position, Satellite ECF Position, Satellite ECF Relative Velocity, Station Latitude and Longitude
    - Contains: Coordinate Transformations
    - Outputs: Topocentric Range, Topocentric Relative Velocity
- **Range_topo2lookangle**
    - Purpose: Calculates Look Angles from Topocentric Frame Position
    - Location: Directly under **Range_ECF2Topo** in **Sat_pos_VelCall**
    - Inputs: Topocentric Range, Topocentric Velocity
    - Contains: Look angle calculations
    - Outputs:Azimuth(rads), Elevation(rads) , Azimuth rate(rads/s) and Elevation Rate(rad/s)

Level 2- Lower Level Calculations

These pieces of code are functions or classes which perform a very particular set of tasks but do not contain any more functions or classes underneath them. They have been implemented this low due to their iterative needs of the Level-1 functions calling them

- *Satellite*
    - Purpose: create a Satellite object with Orbit Parameter attributes
    - Location:
        - Located inside **Satlist**
    - inputs :
        - Read in line0- The name of the Satellite
        - Read in line1- first line of TLE data
        - Read in line2- second line of TLE data
    - Contains
        - Line Parsing code
        - Object assignment
    - Outputs:
        - A satellite object which has been appended to a Satellite List
- **Refepoch_top_dt**
    - Purpose: Takes in a Reference Epoch in TLE format and converts it to a Datetime time
    - Location: within **mean_anomaly_motion** function
    - Inputs:
        - TLE reference time
    - Contains:
        - Simple datetime creation code from string
    - Outputs:
        - Datetime object of TLE reference epoch time
    - Notes: I’m not entirely sure why this was needed to be its own function.
- **Perifocal**
    - Purpose: Creates Position and Velocity Data for the Satellite Perifocal Coordinate System from Orbital Element inputs
    - Inputs:
        - Eccentricity, eccentric anomaly, semi major axis, Right ascension of the ascending node, argument of perigee, inclination, mean motion at time time
    - Contains:
        - Code to create perifocal range and velocity
    - Outputs:
        - Perifocal Range and Velocity

Program Testing

Although Testing of the Program could not be done at the Algonquin Radio observatory (due to bugs), the creators have tested the Program by comparing it to STK simulations which use the same Two Line Element (TLE) data. The Tracking Control File was also tested using a verified LabView Virtual instrument. The Following Testing examples build upon each other and show important values along the way. This Program Testing also acts as an intermediate level tutorial, it is recommended to go over the Software Specifications document, Python and STK tutorials before beginning.

STK Comparison Testing

Various testing was done throughout the programming pipeline to assist with debugging. While this test may contain a set of values, previous testing, such as the one found in the Debugging section, use different values.

Testing Setup

For this Testing Scenario we used:

- Observation Test Time: 2021-01-12 19:30:00
- Observation End Time: 2021-01-13 20:00:00
- Step Size: 60 seconds**
    - **Step Size can be increased to decrease computation time, but will reduce accuracy

This Observation Time is the same from the Program and the STK scenario

Setting up Scenario

Note: The Scenario Testing Time has been altered to reflect that of the desired values

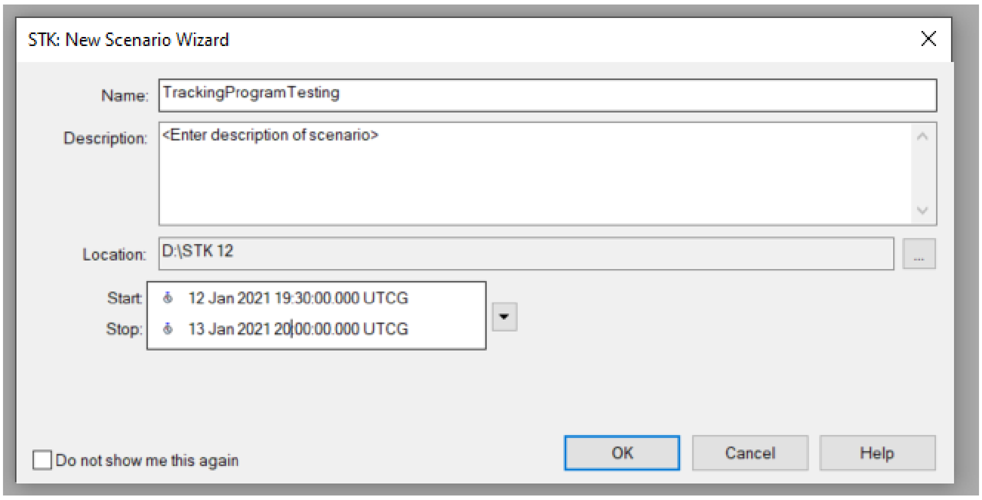


Figure4.1 New Scenario in STK with Start and Stop Time

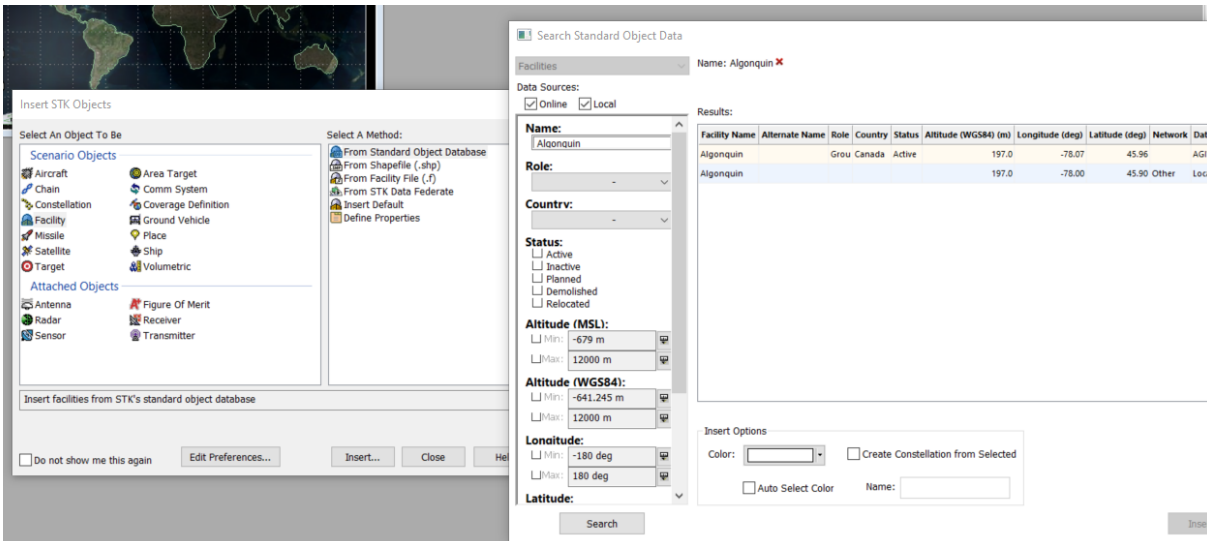


Figure 4.2 :Adding Algonquin Radio Observatory as a facility from the Standard Object Database.

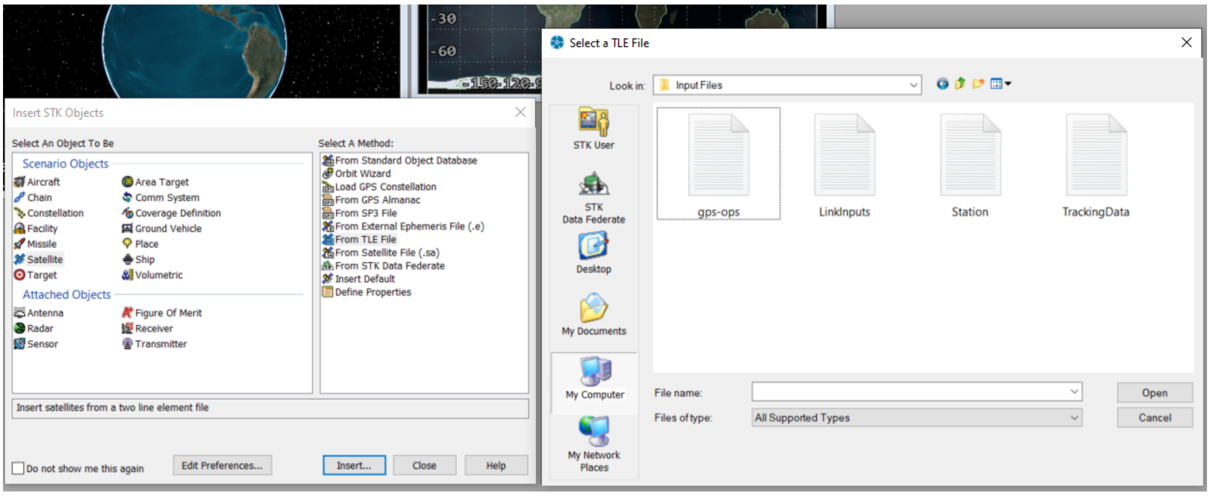


Figure 4.3: Adding Satellites from “gps-ops.txt” TLE file.

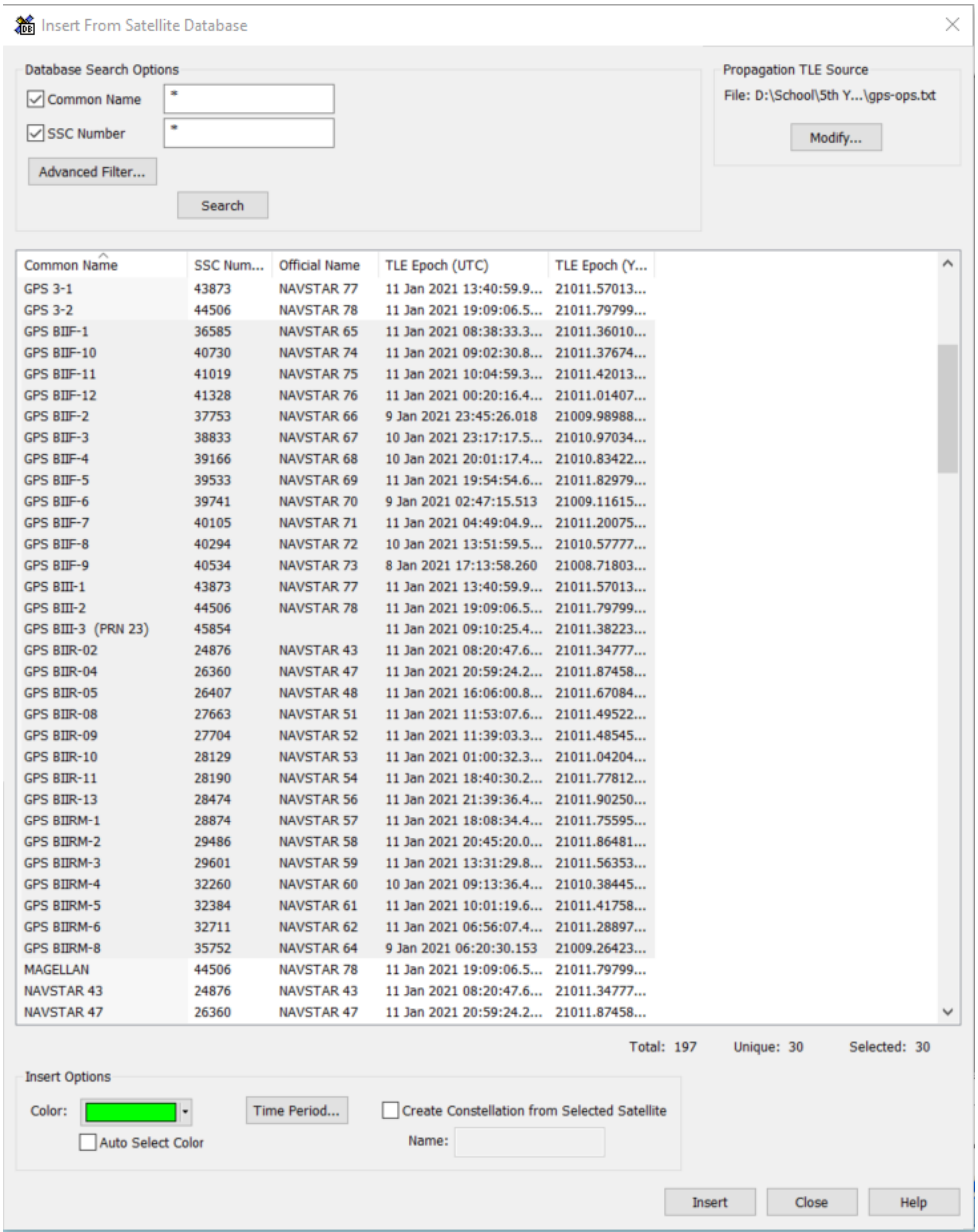


Figure 4.4 Selecting Corresponding Satellites that are known to be our TLE file.

Now that the set of satellites have been imported into STK, one can be chosen to investigate accuracies in values.

Eccentric and Mean Anomalies

This example shows how to investigate lower level values of a Satellite using the useful Master.csv file. It also shows a minor flaw in the program- this error will be investigated in the Debugging Section of this document.

STK Values

Setting Up STK Report

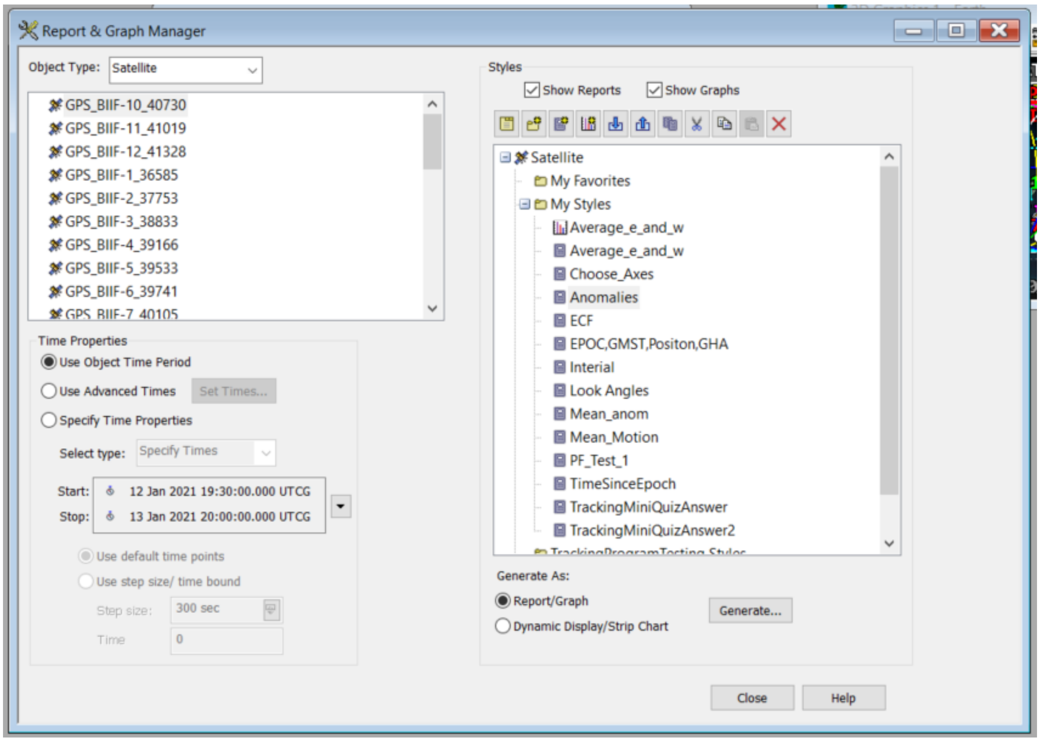


Figure 4.5: Using the Report and Graph Manager A New Report Named “Anomalies ” was created

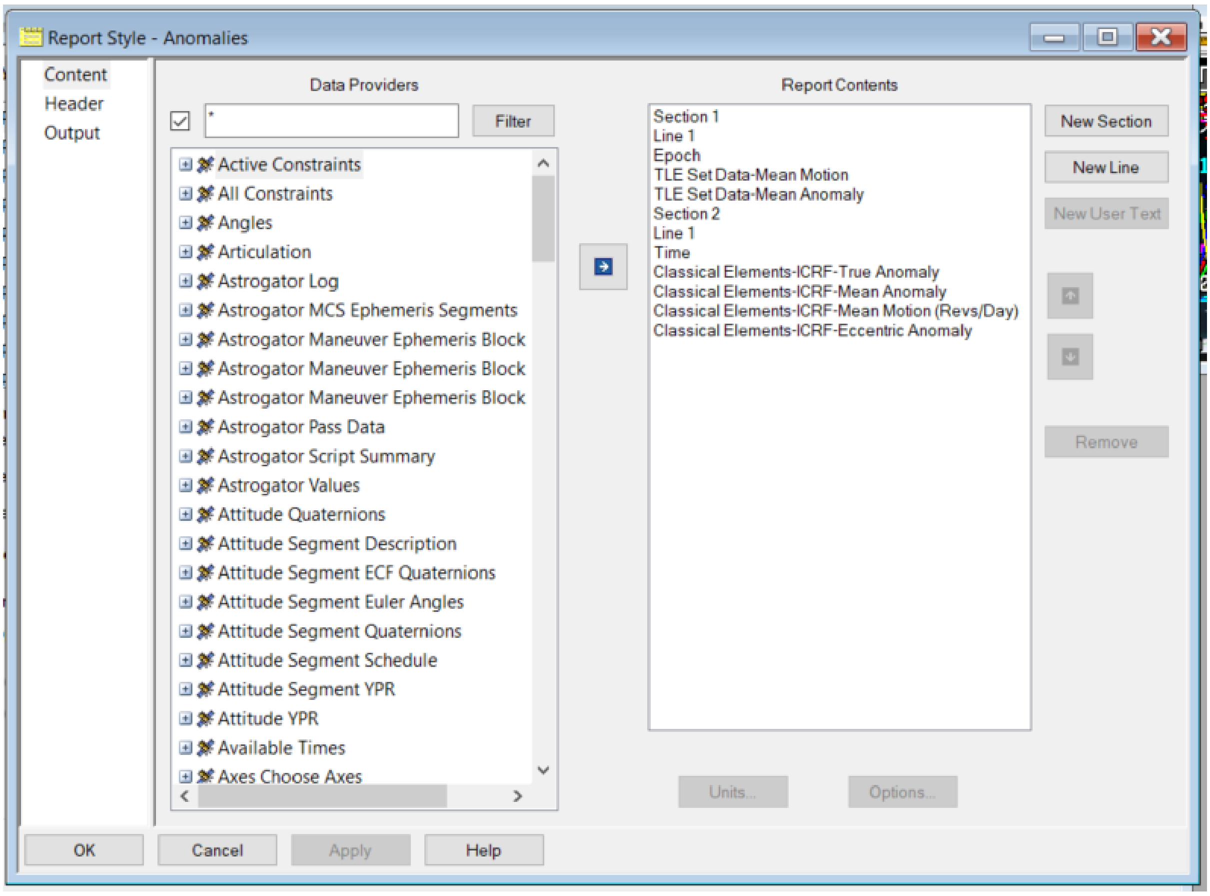


Figure 4.6: “Anomalies ” Report Contents

Resultant Values

Choosing the Satellite labeled: BIIF-10, values were generated for the time frame.

17 Jan 2021 22:29:07

FOR UNFUNDED EDUCATIONAL USE ONLY
Satellite-GPS_BIIF-10_40730

Epoch (UTCG)	Mean Motion (revs/day)	Mean Anomaly (deg)
11 Jan 2021 09:02:30.873	2.005517	4.603

Time (UTCG)	True Anomaly (deg)	Mean Anomaly (deg)	Mean Motion (Revs/Day)	Eccentric Anomaly (deg)
12 Jan 2021 19:30:00.000	318.885	319.339	2.005510	319.112
12 Jan 2021 19:31:00.000	319.397	319.847	2.005507	319.622
12 Jan 2021 19:32:00.000	319.910	320.355	2.005503	320.133
12 Jan 2021 19:33:00.000	320.422	320.862	2.005500	320.643
12 Jan 2021 19:34:00.000	320.934	321.370	2.005496	321.152
12 Jan 2021 19:35:00.000	321.447	321.877	2.005493	321.662
12 Jan 2021 19:36:00.000	321.958	322.384	2.005490	322.172
12 Jan 2021 19:37:00.000	322.470	322.891	2.005486	322.681
12 Jan 2021 19:38:00.000	322.982	323.398	2.005483	323.190
12 Jan 2021 19:39:00.000	323.493	323.904	2.005480	323.699
12 Jan 2021 19:40:00.000	324.004	324.411	2.005476	324.208
12 Jan 2021 19:41:00.000	324.515	324.917	2.005473	324.716
12 Jan 2021 19:42:00.000	325.026	325.423	2.005470	325.225
12 Jan 2021 19:43:00.000	325.537	325.928	2.005466	325.733
12 Jan 2021 19:44:00.000	326.047	326.434	2.005463	326.241
12 Jan 2021 19:45:00.000	326.557	326.939	2.005460	326.748
12 Jan 2021 19:46:00.000	327.067	327.444	2.005457	327.256
12 Jan 2021 19:47:00.000	327.577	327.948	2.005453	327.763
12 Jan 2021 19:48:00.000	328.087	328.453	2.005450	328.270
12 Jan 2021 19:49:00.000	328.596	328.957	2.005447	328.777
12 Jan 2021 19:50:00.000	329.105	329.461	2.005444	329.283
12 Jan 2021 19:51:00.000	329.614	329.965	2.005441	329.790
12 Jan 2021 19:52:00.000	330.123	330.468	2.005437	330.296
12 Jan 2021 19:53:00.000	330.632	330.972	2.005434	330.802
12 Jan 2021 19:54:00.000	331.140	331.475	2.005431	331.308
12 Jan 2021 19:55:00.000	331.648	331.977	2.005428	331.813
12 Jan 2021 19:56:00.000	332.156	332.480	2.005425	332.318

Figure 4.7: Snapshot of STK Generated Anomaly Values .

Program Calculated Values

Ensure Input Files describe ARO and Same observation windows as STK

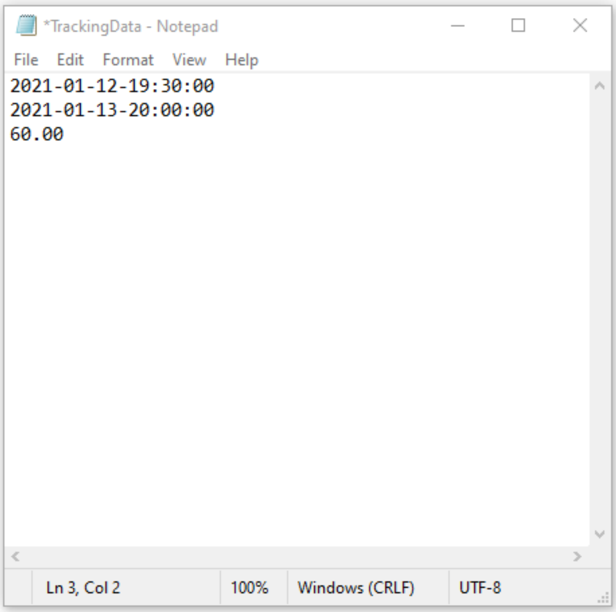


Figure 4.8:Tracking Data file altered to match that of STK

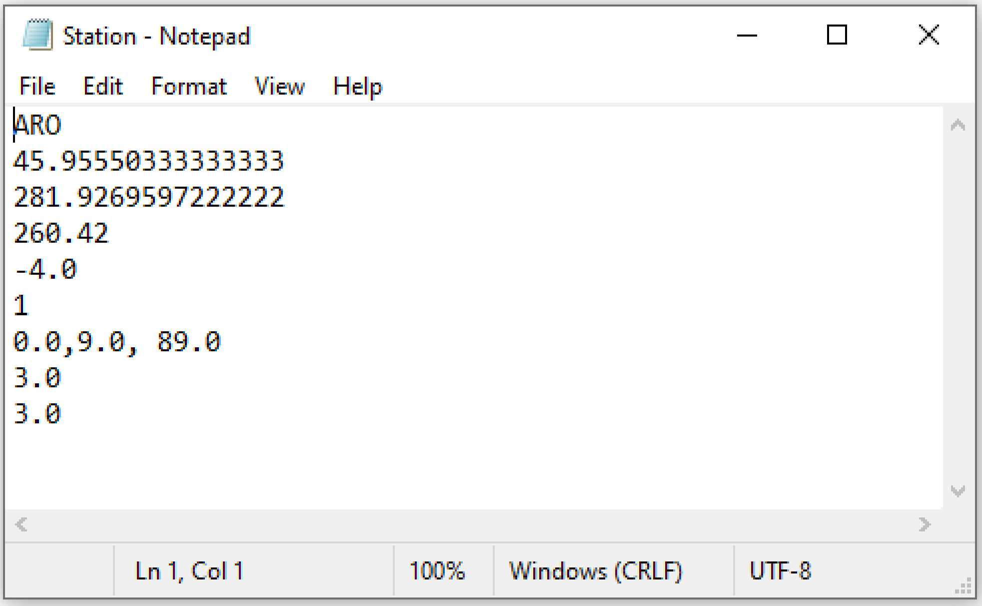


Figure 4.9: Station File Describes ARO

Run Python Program

Open up the IDE and hit the run button. For Spyder this is on the top left.

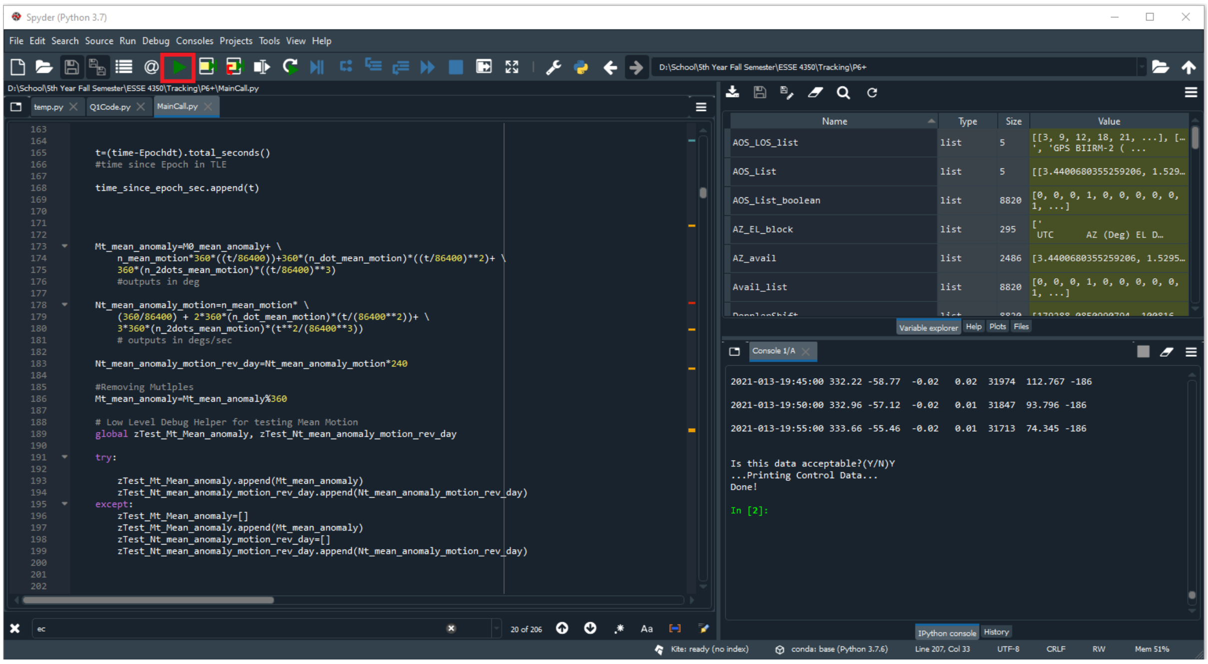


Figure 4.10: Hit Run button to run program

```
GPS BIIF-9  (PRN 26)
 Satellite has been registered as Satellite: 24 Array index: [ 23 ]
GPS BIIF-10 (PRN 08)
 Satellite has been registered as Satellite: 25 Array index: [ 24 ]
GPS BIIF-11 (PRN 10)
 Satellite has been registered as Satellite: 26 Array index: [ 25 ]
GPS BIIF-12 (PRN 32)
 Satellite has been registered as Satellite: 27 Array index: [ 26 ]
GPS BIII-1  (PRN 04)
 Satellite has been registered as Satellite: 28 Array index: [ 27 ]
GPS BIII-2  (PRN 18)
 Satellite has been registered as Satellite: 29 Array index: [ 28 ]
GPS BIII-3  (PRN 23)
 Satellite has been registered as Satellite: 30 Array index: [ 29 ]

Enter the Satellite Index to Output in .sp and .e file:
```

Figure 4.11: User will be prompted in the console window which Satellite to choose. This value controls the output of Satellite Azimuth and Elevation file, Ephemeris Files and Pointing File. Thus it isn't really needed for Mean Anomaly Testing, but we will type in the Tested Satellite (BIIF-10) as an example. Tested Inputted "25"

```
2021-013-19:48:00 128.91 -41.20   0.09   0.16  30423  43.137 -186

2021-013-19:49:00 128.48 -41.23   0.09   0.16  30428  44.261 -186

2021-013-19:50:00 128.05 -41.27   0.09   0.16  30433  45.359 -186

2021-013-19:51:00 127.62 -41.30   0.09   0.16  30438  46.432 -186

2021-013-19:52:00 127.19 -41.32   0.09   0.15  30442  47.479 -186

2021-013-19:53:00 126.76 -41.34   0.09   0.15  30446  48.500 -186

2021-013-19:54:00 126.33 -41.36   0.09   0.15  30449  49.496 -186

2021-013-19:55:00 125.90 -41.38   0.09   0.15  30452  50.465 -186

2021-013-19:56:00 125.46 -41.39   0.09   0.15  30455  51.408 -186

2021-013-19:57:00 125.03 -41.39   0.09   0.15  30458  52.325 -186

2021-013-19:58:00 124.59 -41.40   0.09   0.15  30460  53.215 -186

2021-013-19:59:00 124.16 -41.40   0.09   0.15  30462  54.080 -186


Is this data acceptable?(Y/N)
```

Figure 4.12:Console will output Azimuth and Elevation and ask the user if this value is acceptable. Answer Y will output the Track Control File and Azimuth and Elevation file. Testing User Answer Y.

Resultant Values

By using the Master.csv File, a satellite's characteristics can be easily identified.

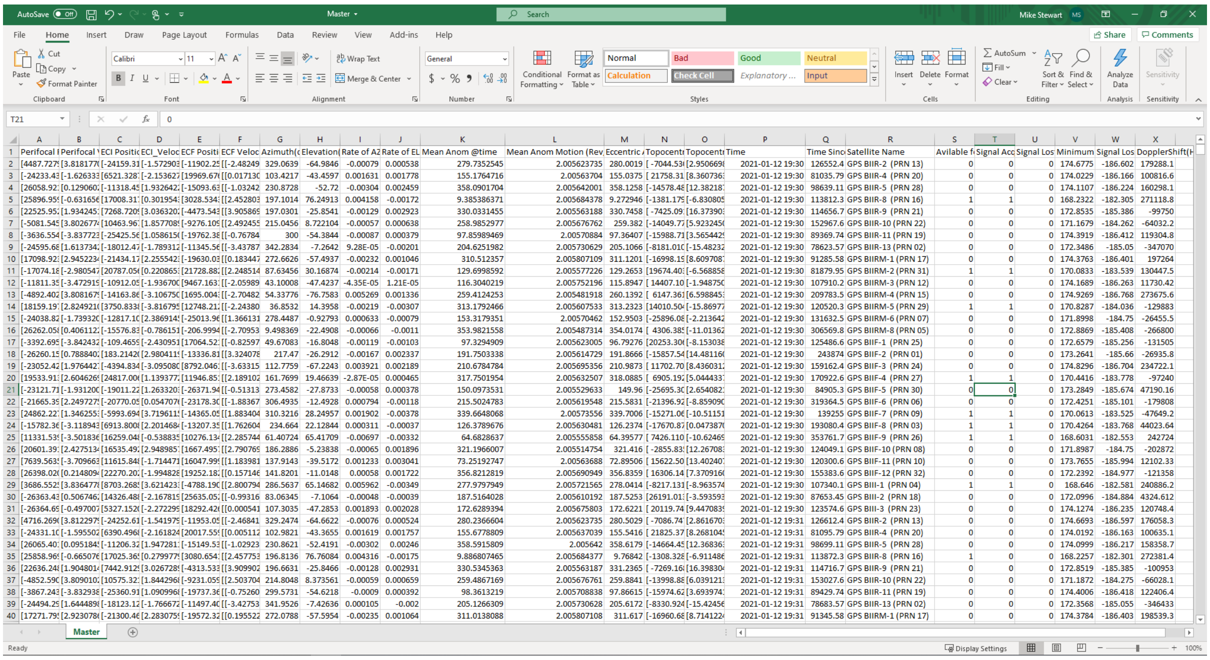


Figure 4.13: Opening the Master.csv file will show a myriad of information. To investigate Mean Anomaly, Mean Anomaly Motion and Eccentric Anomaly for a given satellite we will look at columns K,L,M, P(time) and R(Satellite Name).

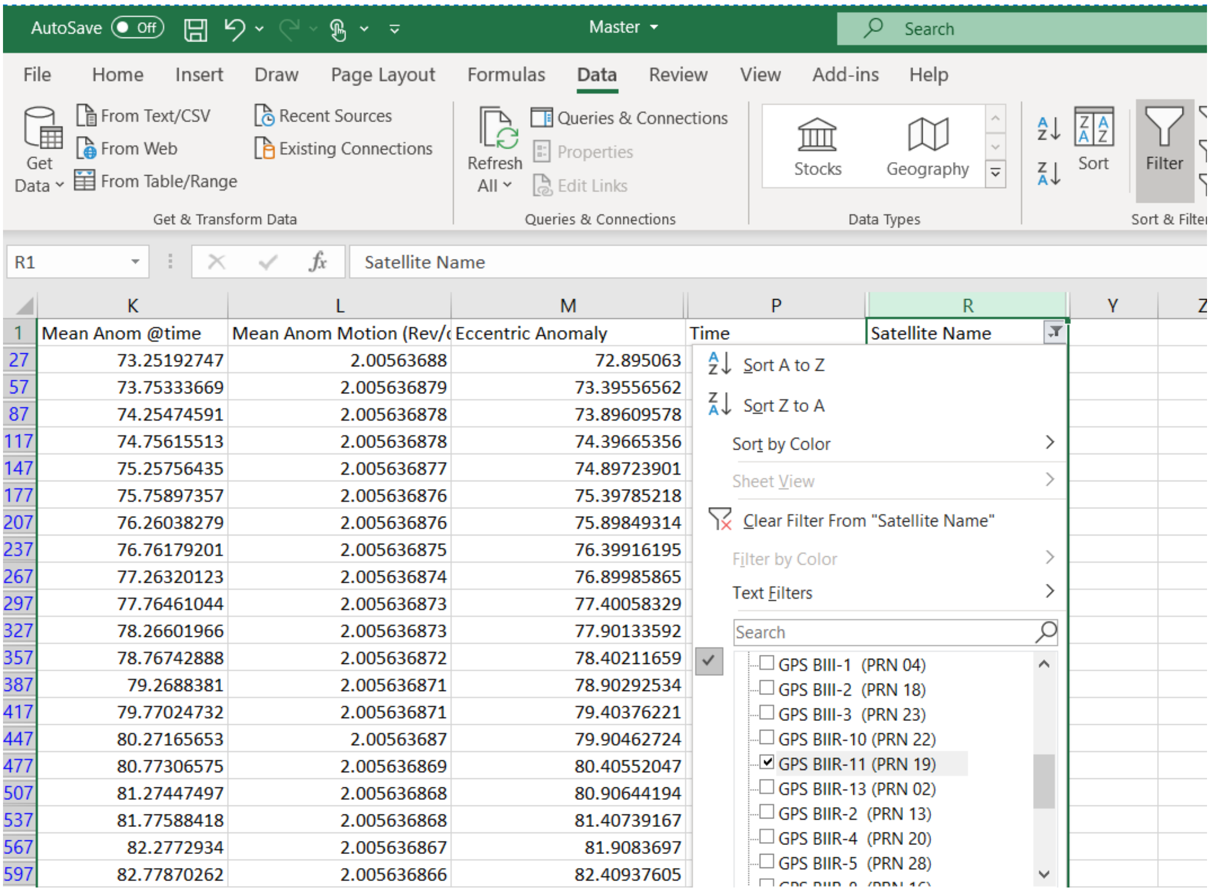


Figure 4.14: Using Excel's Data Filter Tool, the User can sort Column R (Satellite Name) to the Test Satellite used.

Mean Anom @time	Mean Anom Motion (Rev/c	Eccentric Anomaly	Time	Satellite Name
321.1966007	2.005514754	321.4159749	2021-01-12 19:30	GPS BIIF-10 (PRN 08)
321.6979793	2.005514753	321.9149652	2021-01-12 19:31	GPS BIIF-10 (PRN 08)
322.199358	2.005514752	322.4139386	2021-01-12 19:32	GPS BIIF-10 (PRN 08)
322.7007367	2.005514751	322.9128953	2021-01-12 19:33	GPS BIIF-10 (PRN 08)
323.2021154	2.005514749	323.4118355	2021-01-12 19:34	GPS BIIF-10 (PRN 08)
323.7034941	2.005514748	323.9107594	2021-01-12 19:35	GPS BIIF-10 (PRN 08)
324.2048728	2.005514747	324.4096673	2021-01-12 19:36	GPS BIIF-10 (PRN 08)
324.7062515	2.005514746	324.9085592	2021-01-12 19:37	GPS BIIF-10 (PRN 08)
325.2076302	2.005514744	325.4074354	2021-01-12 19:38	GPS BIIF-10 (PRN 08)
325.7090088	2.005514743	325.9062961	2021-01-12 19:39	GPS BIIF-10 (PRN 08)
326.2103875	2.005514742	326.4051414	2021-01-12 19:40	GPS BIIF-10 (PRN 08)
326.7117662	2.005514741	326.9039716	2021-01-12 19:41	GPS BIIF-10 (PRN 08)
327.2131449	2.00551474	327.4027868	2021-01-12 19:42	GPS BIIF-10 (PRN 08)
327.7145236	2.005514738	327.9015873	2021-01-12 19:43	GPS BIIF-10 (PRN 08)
328.2159023	2.005514737	328.4003733	2021-01-12 19:44	GPS BIIF-10 (PRN 08)
328.717281	2.005514736	328.8991449	2021-01-12 19:45	GPS BIIF-10 (PRN 08)
329.2186596	2.005514735	329.3979023	2021-01-12 19:46	GPS BIIF-10 (PRN 08)
329.7200383	2.005514733	329.8966458	2021-01-12 19:47	GPS BIIF-10 (PRN 08)
330.221417	2.005514732	330.3953756	2021-01-12 19:48	GPS BIIF-10 (PRN 08)
330.7227957	2.005514731	330.8940919	2021-01-12 19:49	GPS BIIF-10 (PRN 08)
331.2241744	2.00551473	331.3927948	2021-01-12 19:50	GPS BIIF-10 (PRN 08)
331.7255531	2.005514728	331.8914846	2021-01-12 19:51	GPS BIIF-10 (PRN 08)
332.2269317	2.005514727	332.3901615	2021-01-12 19:52	GPS BIIF-10 (PRN 08)
332.7283104	2.005514726	332.8888257	2021-01-12 19:53	GPS BIIF-10 (PRN 08)
333.2296891	2.005514725	333.3874774	2021-01-12 19:54	GPS BIIF-10 (PRN 08)
333.7310678	2.005514723	333.8861168	2021-01-12 19:55	GPS BIIF-10 (PRN 08)
334.2324465	2.005514722	334.3847441	2021-01-12 19:56	GPS BIIF-10 (PRN 08)

Figure 4.15: Resultant Anomaly Data exported by the program for the Tested Satellite (BIIF-10)

Comparison

Time (UTCG)	True Anomaly (deg)	Mean Anomaly (deg)	Mean Motion (Revs/Day)	Eccentric Anomaly (deg)
12 Jan 2021 19:30:00.000	318.885	319.339	2.005510	319.112
12 Jan 2021 19:31:00.000	319.397	319.847	2.005507	319.622
12 Jan 2021 19:32:00.000	319.910	320.355	2.005503	320.133
12 Jan 2021 19:33:00.000	320.422	320.862	2.005500	320.643
12 Jan 2021 19:34:00.000	320.934	321.370	2.005496	321.152
12 Jan 2021 19:35:00.000	321.447	321.877	2.005493	321.662
12 Jan 2021 19:36:00.000	321.958	322.384	2.005490	322.172
12 Jan 2021 19:37:00.000	322.470	322.891	2.005486	322.681
12 Jan 2021 19:38:00.000	322.982	323.398	2.005483	323.190
12 Jan 2021 19:39:00.000	323.493	323.904	2.005480	323.699
12 Jan 2021 19:40:00.000	324.004	324.411	2.005476	324.208
12 Jan 2021 19:41:00.000	324.515	324.917	2.005473	324.716
12 Jan 2021 19:42:00.000	325.026	325.423	2.005470	325.225
12 Jan 2021 19:43:00.000	325.537	325.928	2.005466	325.733
12 Jan 2021 19:44:00.000	326.047	326.434	2.005463	326.241
12 Jan 2021 19:45:00.000	326.557	326.939	2.005460	326.748

Mean Anom @time	Mean Anom Motion (Rev/c	Eccentric Anomaly	Time	Satellite Name
321.1966007	2.005514754	321.4159749	2021-01-12 19:30	GPS BIIF-10 (PRN 08)
321.6979793	2.005514753	321.9149652	2021-01-12 19:31	GPS BIIF-10 (PRN 08)
322.199358	2.005514752	322.4139386	2021-01-12 19:32	GPS BIIF-10 (PRN 08)
322.7007367	2.005514751	322.9128953	2021-01-12 19:33	GPS BIIF-10 (PRN 08)
323.2021154	2.005514749	323.4118355	2021-01-12 19:34	GPS BIIF-10 (PRN 08)
323.7034941	2.005514748	323.9107594	2021-01-12 19:35	GPS BIIF-10 (PRN 08)
324.2048728	2.005514747	324.4096673	2021-01-12 19:36	GPS BIIF-10 (PRN 08)
324.7062515	2.005514746	324.9085592	2021-01-12 19:37	GPS BIIF-10 (PRN 08)
325.2076302	2.005514744	325.4074354	2021-01-12 19:38	GPS BIIF-10 (PRN 08)
325.7090088	2.005514743	325.9062961	2021-01-12 19:39	GPS BIIF-10 (PRN 08)
326.2103875	2.005514742	326.4051414	2021-01-12 19:40	GPS BIIF-10 (PRN 08)
326.7117662	2.005514741	326.9039716	2021-01-12 19:41	GPS BIIF-10 (PRN 08)
327.2131449	2.00551474	327.4027868	2021-01-12 19:42	GPS BIIF-10 (PRN 08)
327.7145236	2.005514738	327.9015873	2021-01-12 19:43	GPS BIIF-10 (PRN 08)
328.2159023	2.005514737	328.4003733	2021-01-12 19:44	GPS BIIF-10 (PRN 08)
328.717281	2.005514736	328.8991449	2021-01-12 19:45	GPS BIIF-10 (PRN 08)

Figure 4.16: Placing a snapshot of STK Generated Values next to the Program Generated Values we see that the Values are slightly off by a degree or two.

Azimuth Elevation and Range

This Example shows a comparison of the Azimuth Elevation and Range (AER) Report generated from STK and the Look Angle outputs of the Pointing Function in the Tracking Program.

STK Values

Setting up Pointing Link

Using the STK Scenario We created in the previous step, we can establish a link with the Algonquin Station and a Test Satellite.

Using Test Satellite BIIF-10

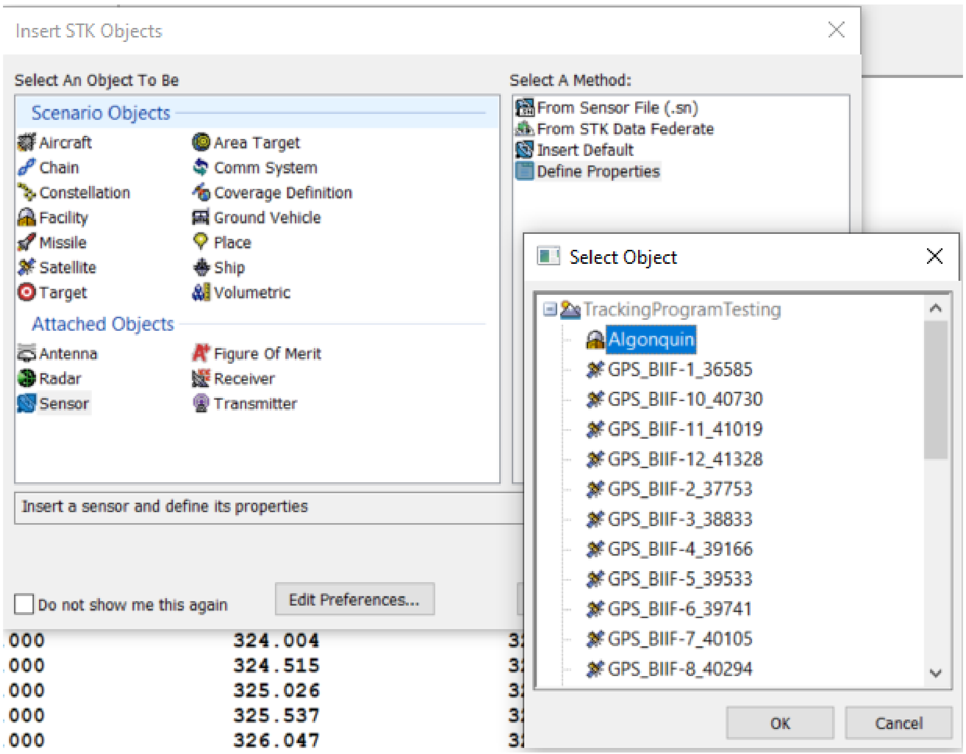


Figure 4.17: Adding Sensor to Algonquin Station

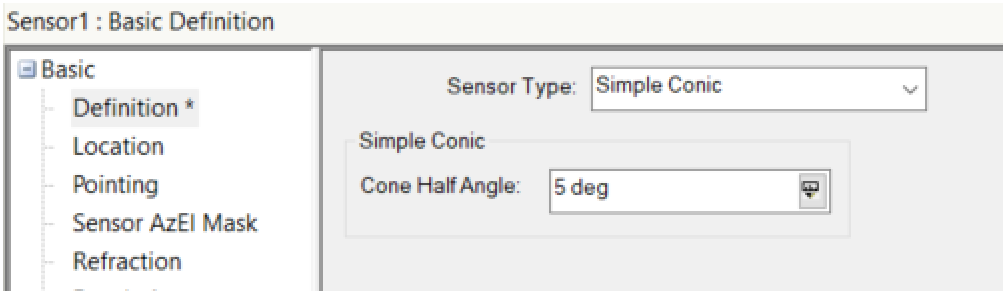


Figure 4.18: Leave Sensor as Simple Conic for Now and reduce Cone Half Angle to 5 degrees

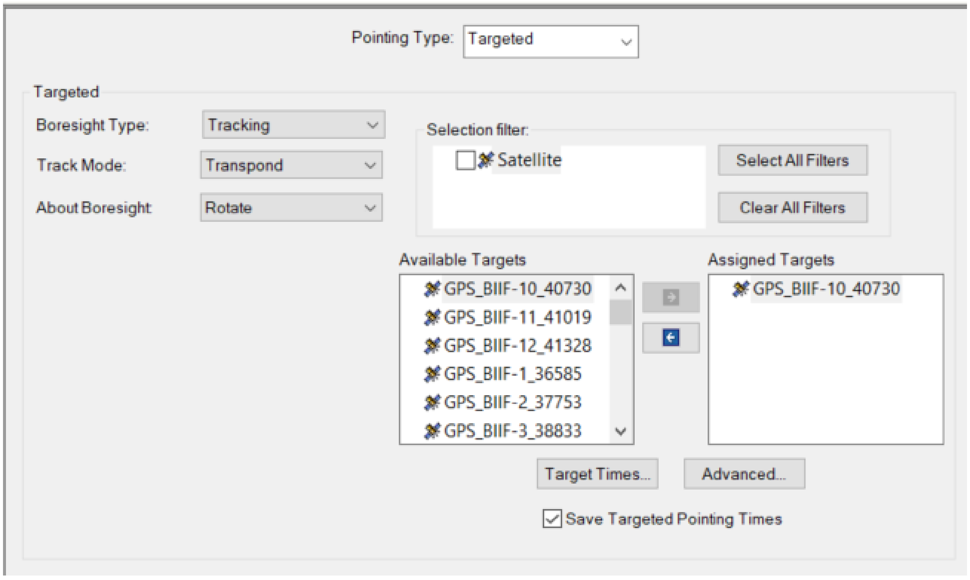


Figure 4.19: Change Sensor Pointing Settings to Targeted and place BIIF-10 as an Assigned Target

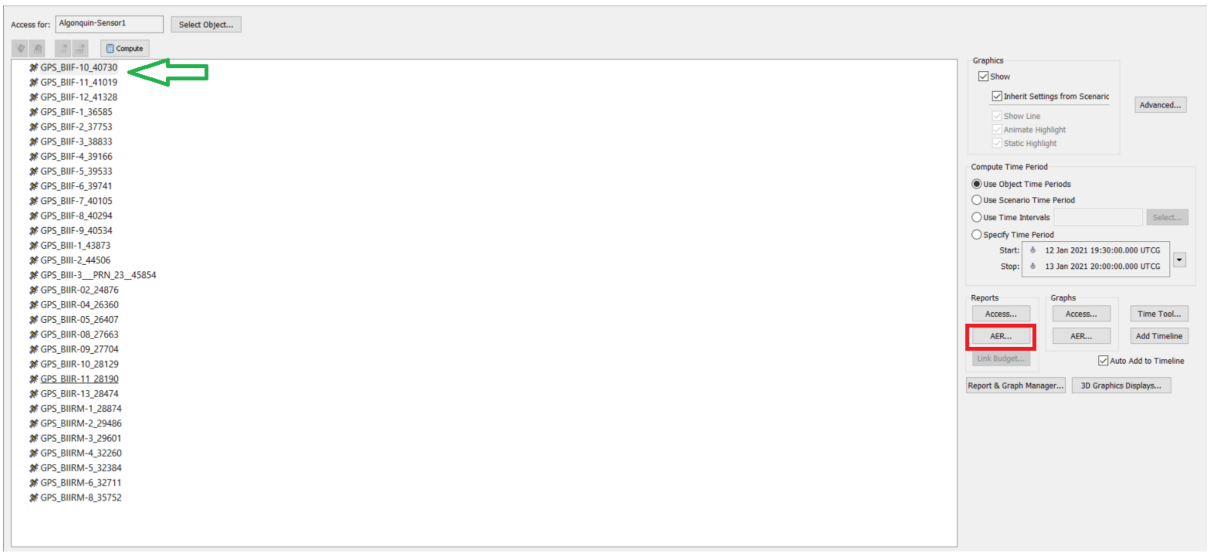


Figure 4.20:Open Analysis Workbench with Algonquin's Sensor registered to 'Access for', select targeted satellite and compute AER Report. Note that an Restrictions on Azimuth and Elevation are not implemented for the Sensor and thus will have values beyond those limits

Report

Jump Top

Start: 12 Jan 2021 19:43:04.649 UTCG
Stop: 13 Jan 2021 20:00:00.000 UTCG

Step: Using object's default time points Show Step Value

18 Jan 2021 01:28:54

FOR UNFUNDED EDUCATIONAL USE ONLY
Facility-Algonquin-Sensor-Sensor1-To-Satellite-GPS_BIIF-10_40730: Inview Azimuth, Elevation, & Range

Sensor1-To-GPS_BIIF-10_40730 - AER reported in the object's default AER frame

Time (UTCG)	Azimuth (deg)	Elevation (deg)	Range (km)
12 Jan 2021 19:43:04.649	185.323	0.001	25628.925233
12 Jan 2021 19:44:04.000	185.237	0.388	25585.177803
12 Jan 2021 19:45:04.000	185.152	0.780	25540.874069
12 Jan 2021 19:46:04.000	185.068	1.175	25496.495784
12 Jan 2021 19:47:04.000	184.985	1.570	25452.046726
12 Jan 2021 19:48:04.000	184.904	1.968	25407.530695
12 Jan 2021 19:49:04.000	184.824	2.366	25362.951510
12 Jan 2021 19:50:04.000	184.746	2.766	25318.313006
12 Jan 2021 19:51:04.000	184.669	3.168	25273.619041
12 Jan 2021 19:52:04.000	184.593	3.571	25228.873490
12 Jan 2021 19:53:04.000	184.519	3.975	25184.080244
12 Jan 2021 19:54:04.000	184.446	4.381	25139.243216
12 Jan 2021 19:55:04.000	184.374	4.789	25094.366333
12 Jan 2021 19:56:04.000	184.303	5.198	25049.453542
12 Jan 2021 19:57:04.000	184.234	5.608	25004.508806
12 Jan 2021 19:58:04.000	184.165	6.019	24959.536105
12 Jan 2021 19:59:04.000	184.099	6.432	24914.539437
12 Jan 2021 20:00:04.000	184.033	6.847	24869.522814
12 Jan 2021 20:01:04.000	183.968	7.263	24824.490267
12 Jan 2021 20:02:04.000	183.905	7.680	24779.445839
12 Jan 2021 20:03:04.000	183.842	8.098	24734.393592
12 Jan 2021 20:04:04.000	183.781	8.518	24689.337600
12 Jan 2021 20:05:04.000	183.721	8.940	24644.281955
12 Jan 2021 20:06:04.000	183.661	9.362	24599.230759
12 Jan 2021 20:07:04.000	183.603	9.786	24554.188134
12 Jan 2021 20:08:04.000	183.546	10.212	24509.158210
12 Jan 2021 20:09:04.000	183.490	10.638	24464.145133
12 Jan 2021 20:10:04.000	183.435	11.066	24419.153063
12 Jan 2021 20:11:04.000	183.380	11.496	24374.186170
12 Jan 2021 20:12:04.000	183.327	11.926	24329.248638

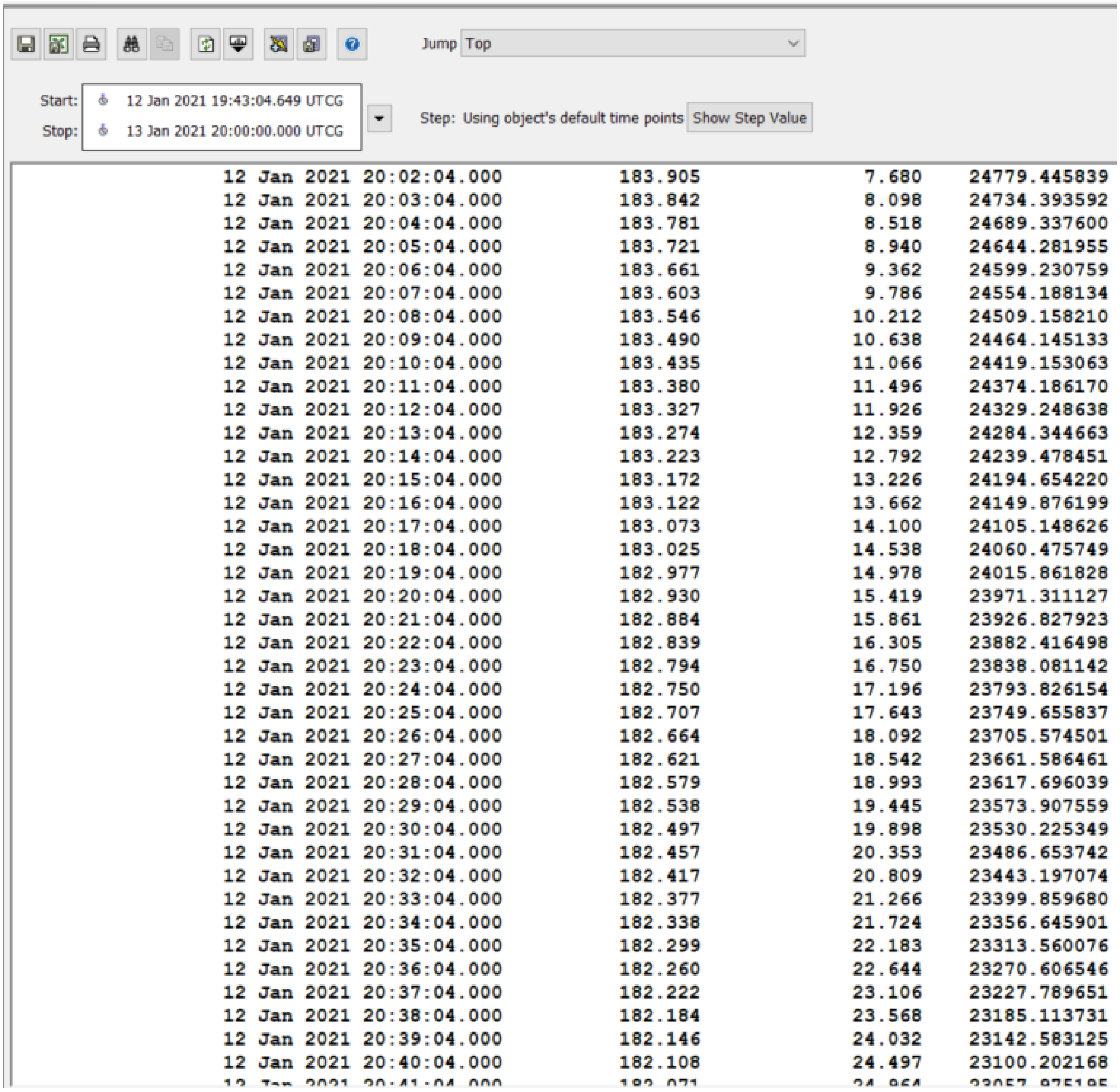
Figure 4.21: Inview Azimuth,Elevation and Range. Remembering that our STK Station does not consider Azimuth and Elevation limits we can refer back to our Station.dat file to realize the limits.

Station - Notepad

File Edit Format View Help

```
ARO
45.955503333333333
281.9269597222222
260.42
-4.0
1
0.0,9.0, 89.0
3.0
3.0
```

Figure 4.22:ARO Station File. Minimum Elevation Limit: 9 degrees



Jump Top

Start: 12 Jan 2021 19:43:04.649 UTCG
Stop: 13 Jan 2021 20:00:00.000 UTCG

Step: Using object's default time points Show Step Value

12 Jan 2021 20:02:04.000	183.905	7.680	24779.445839
12 Jan 2021 20:03:04.000	183.842	8.098	24734.393592
12 Jan 2021 20:04:04.000	183.781	8.518	24689.337600
12 Jan 2021 20:05:04.000	183.721	8.940	24644.281955
12 Jan 2021 20:06:04.000	183.661	9.362	24599.230759
12 Jan 2021 20:07:04.000	183.603	9.786	24554.188134
12 Jan 2021 20:08:04.000	183.546	10.212	24509.158210
12 Jan 2021 20:09:04.000	183.490	10.638	24464.145133
12 Jan 2021 20:10:04.000	183.435	11.066	24419.153063
12 Jan 2021 20:11:04.000	183.380	11.496	24374.186170
12 Jan 2021 20:12:04.000	183.327	11.926	24329.248638
12 Jan 2021 20:13:04.000	183.274	12.359	24284.344663
12 Jan 2021 20:14:04.000	183.223	12.792	24239.478451
12 Jan 2021 20:15:04.000	183.172	13.226	24194.654220
12 Jan 2021 20:16:04.000	183.122	13.662	24149.876199
12 Jan 2021 20:17:04.000	183.073	14.100	24105.148626
12 Jan 2021 20:18:04.000	183.025	14.538	24060.475749
12 Jan 2021 20:19:04.000	182.977	14.978	24015.861828
12 Jan 2021 20:20:04.000	182.930	15.419	23971.311127
12 Jan 2021 20:21:04.000	182.884	15.861	23926.827923
12 Jan 2021 20:22:04.000	182.839	16.305	23882.416498
12 Jan 2021 20:23:04.000	182.794	16.750	23838.081142
12 Jan 2021 20:24:04.000	182.750	17.196	23793.826154
12 Jan 2021 20:25:04.000	182.707	17.643	23749.655837
12 Jan 2021 20:26:04.000	182.664	18.092	23705.574501
12 Jan 2021 20:27:04.000	182.621	18.542	23661.586461
12 Jan 2021 20:28:04.000	182.579	18.993	23617.696039
12 Jan 2021 20:29:04.000	182.538	19.445	23573.907559
12 Jan 2021 20:30:04.000	182.497	19.898	23530.225349
12 Jan 2021 20:31:04.000	182.457	20.353	23486.653742
12 Jan 2021 20:32:04.000	182.417	20.809	23443.197074
12 Jan 2021 20:33:04.000	182.377	21.266	23399.859680
12 Jan 2021 20:34:04.000	182.338	21.724	23356.645901
12 Jan 2021 20:35:04.000	182.299	22.183	23313.560076
12 Jan 2021 20:36:04.000	182.260	22.644	23270.606546
12 Jan 2021 20:37:04.000	182.222	23.106	23227.789651
12 Jan 2021 20:38:04.000	182.184	23.568	23185.113731
12 Jan 2021 20:39:04.000	182.146	24.032	23142.583125
12 Jan 2021 20:40:04.000	182.108	24.497	23100.202168

Figure 23: Snapshot of AER Report when minimum Elevation has been met.

Program Calculated Values

To create the Program’s Azimuth and Elevation Table we follow a similar process for running the program as above.

Setting up the Program

What differs between running the code for the AER Report and the mean anomaly is to ensure that the proper Satellite is chosen when prompted by the program and that the Data is considered Acceptable.

```
GPS BIIF-10 (PRN 08)
 Satellite has been registered as Satellite: 25 Array index: [ 24 ]
GPS BIIF-11 (PRN 10)
 Satellite has been registered as Satellite: 26 Array index: [ 25 ]
GPS BIIF-12 (PRN 32)
 Satellite has been registered as Satellite: 27 Array index: [ 26 ]
GPS BIII-1  (PRN 04)
 Satellite has been registered as Satellite: 28 Array index: [ 27 ]
GPS BIII-2  (PRN 18)
 Satellite has been registered as Satellite: 29 Array index: [ 28 ]
GPS BIII-3  (PRN 23)
 Satellite has been registered as Satellite: 30 Array index: [ 29 ]

Enter the Satellite Index to Output in .sp and .e file:24
```

Figure 4.24: User choosing the right test Satellite. Simply hit enter when the index is correct to start Calculations.

```
2021-013-01:41:00  71.58  10.76  -0.10  -0.10  24660   8.429 -184

2021-013-01:42:00  71.82  10.41  -0.10  -0.09  24698   7.972 -184

2021-013-01:43:00  72.06  10.07  -0.10  -0.09  24736   7.531 -184

2021-013-01:44:00  72.30   9.72  -0.10  -0.09  24775   7.107 -184

2021-013-01:45:00  72.54   9.38  -0.09  -0.09  24813   6.699 -184

2021-013-01:46:00  72.79   9.04  -0.09  -0.09  24851   6.307 -184


Is this data acceptable?(Y/N)Y
```

Figure 4.25: User choosing Y when the Azimuth and Elevation Angles are deemed Acceptable

Report

A Report will be generated, by default it is called “Chosen_Satellite_AZ_EL.txt” It contains the Azimuth, ELevation, their rates, range to the Satellite in km, Doppler Shift and Minimum Level required to communicate with the Satellite (Given Required Eb/No is 0.8).

```
OUTPUT_Chosen_Satellite_AZ_EL - Notepad
File  Edit  Format  View  Help

 UTC      AZ (Deg) EL Deg AZ-Vel (deg/sec) El-Vel (deg/sec) Range (km) Doppler KHz Level dBm
2021-012-20:07:00 183.40  9.33 -0.02  0.06  24492 -167.279 171
2021-012-20:08:00 183.35  9.75 -0.02  0.06  24446 -165.282 171
2021-012-20:09:00 183.29 10.17 -0.02  0.06  24400 -163.231 171
2021-012-20:10:00 183.24 10.60 -0.02  0.05  24353 -161.129 171
2021-012-20:11:00 183.19 11.02 -0.02  0.05  24307 -158.973 171
2021-012-20:12:00 183.14 11.45 -0.02  0.05  24261 -156.766 171
2021-012-20:13:00 183.09 11.87 -0.02  0.05  24215 -154.507 171
2021-012-20:14:00 183.04 12.30 -0.02  0.05  24169 -152.196 171
2021-012-20:15:00 182.99 12.73 -0.02  0.05  24122 -149.834 171
2021-012-20:16:00 182.95 13.16 -0.02  0.05  24076 -147.422 171
2021-012-20:17:00 182.90 13.60 -0.02  0.05  24030 -144.959 171
2021-012-20:18:00 182.85 14.03 -0.02  0.04  23984 -142.447 171
2021-012-20:19:00 182.81 14.46 -0.02  0.04  23938 -139.885 171
2021-012-20:20:00 182.77 14.90 -0.02  0.04  23892 -137.274 171
2021-012-20:21:00 182.72 15.34 -0.02  0.04  23847 -134.615 171
2021-012-20:22:00 182.68 15.78 -0.02  0.04  23801 -131.908 171
2021-012-20:23:00 182.64 16.22 -0.02  0.04  23755 -129.153 171
2021-012-20:24:00 182.60 16.66 -0.02  0.04  23710 -126.352 171
2021-012-20:25:00 182.56 17.10 -0.02  0.04  23664 -123.504 171
2021-012-20:26:00 182.52 17.54 -0.02  0.03  23619 -120.610 171
2021-012-20:27:00 182.48 17.99 -0.02  0.03  23573 -117.672 171
2021-012-20:28:00 182.44 18.43 -0.02  0.03  23528 -114.689 171
```

Figure 4.26: Snippet of Satellite _AZ_EL Generated for BIIF-10 Test Satellite.

Comparison

Jump Top

Start: 12 Jan 2021 19:43:04.649 UTCG
Stop: 13 Jan 2021 20:00:00.000 UTCG

Step: Using object's default time points Show Step Value

12 Jan 2021 20:02:04.000	183.905	7.680	24779.445839
12 Jan 2021 20:03:04.000	183.842	8.098	24734.393592
12 Jan 2021 20:04:04.000	183.781	8.518	24689.337600
12 Jan 2021 20:05:04.000	183.721	8.940	24644.281955
12 Jan 2021 20:06:04.000	183.661	9.362	24599.230759
12 Jan 2021 20:07:04.000	183.603	9.786	24554.188134
12 Jan 2021 20:08:04.000	183.546	10.212	24509.158210
12 Jan 2021 20:09:04.000	183.490	10.638	24464.145133
12 Jan 2021 20:10:04.000	183.435	11.066	24419.153063
12 Jan 2021 20:11:04.000	183.380	11.496	24374.186170
12 Jan 2021 20:12:04.000	183.327	11.926	24329.248638
12 Jan 2021 20:13:04.000	183.274	12.359	24284.344663
12 Jan 2021 20:14:04.000	183.223	12.792	24239.478451
12 Jan 2021 20:15:04.000	183.172	13.226	24194.654220
12 Jan 2021 20:16:04.000	183.122	13.662	24149.876199
12 Jan 2021 20:17:04.000	183.073	14.100	24105.148626
12 Jan 2021 20:18:04.000	183.025	14.538	24060.475749
12 Jan 2021 20:19:04.000	182.977	14.978	24015.861828
12 Jan 2021 20:20:04.000	182.930	15.419	23971.311127
12 Jan 2021 20:21:04.000	182.884	15.861	23926.827923
12 Jan 2021 20:22:04.000	182.839	16.305	23882.416498
12 Jan 2021 20:23:04.000	182.794	16.750	23838.081142
12 Jan 2021 20:24:04.000	182.750	17.196	23793.826154
12 Jan 2021 20:25:04.000	182.707	17.643	23749.655837
12 Jan 2021 20:26:04.000	182.664	18.092	23705.574501
12 Jan 2021 20:27:04.000	182.621	18.542	23661.586461
12 Jan 2021 20:28:04.000	182.579	18.993	23617.696039
12 Jan 2021 20:29:04.000	182.538	19.445	23573.907559
12 Jan 2021 20:30:04.000	182.497	19.898	23530.225349
12 Jan 2021 20:31:04.000	182.457	20.353	23486.653742
12 Jan 2021 20:32:04.000	182.417	20.809	23443.197074

OUTPUT_Chosen_Satellite_AZ_EL - Notepad

File Edit Format View Help

```
 UTC      AZ (Deg) EL Deg AZ-Vel (deg/sec) El-Vel (deg/sec) Range (km) Doppler KHz Level dBm
2021-012-20:07:00 183.40  9.33 -0.02  0.06  24492 -167.279 171
2021-012-20:08:00 183.35  9.75 -0.02  0.06  24446 -165.282 171
2021-012-20:09:00 183.29 10.17 -0.02  0.06  24400 -163.231 171
2021-012-20:10:00 183.24 10.60 -0.02  0.05  24353 -161.129 171
2021-012-20:11:00 183.19 11.02 -0.02  0.05  24307 -158.973 171
2021-012-20:12:00 183.14 11.45 -0.02  0.05  24261 -156.766 171
2021-012-20:13:00 183.09 11.87 -0.02  0.05  24215 -154.507 171
2021-012-20:14:00 183.04 12.30 -0.02  0.05  24169 -152.196 171
2021-012-20:15:00 182.99 12.73 -0.02  0.05  24122 -149.834 171
2021-012-20:16:00 182.95 13.16 -0.02  0.05  24076 -147.422 171
2021-012-20:17:00 182.90 13.60 -0.02  0.05  24030 -144.959 171
2021-012-20:18:00 182.85 14.03 -0.02  0.04  23984 -142.447 171
2021-012-20:19:00 182.81 14.46 -0.02  0.04  23938 -139.885 171
2021-012-20:20:00 182.77 14.90 -0.02  0.04  23892 -137.274 171
2021-012-20:21:00 182.72 15.34 -0.02  0.04  23847 -134.615 171
2021-012-20:22:00 182.68 15.78 -0.02  0.04  23801 -131.908 171
2021-012-20:23:00 182.64 16.22 -0.02  0.04  23755 -129.153 171
2021-012-20:24:00 182.60 16.66 -0.02  0.04  23710 -126.352 171
2021-012-20:25:00 182.56 17.10 -0.02  0.04  23664 -123.504 171
2021-012-20:26:00 182.52 17.54 -0.02  0.03  23619 -120.610 171
2021-012-20:27:00 182.48 17.99 -0.02  0.03  23573 -117.672 171
2021-012-20:28:00 182.44 18.43 -0.02  0.03  23528 -114.689 171
```

Figure 4.27:Comparison of Both sets of values

Looking at both sets of data side by side the results are almost identical with Azimuth only featuring 0.2 degrees of difference and elevation only having 0.7 degrees of difference at time 20:07 on the 12th. At this timestamp, there is only 62km in difference in the range as well which is also very good

AOS/ LOS

For this Example it is recommended to have a time difference between the Start and Stop time of at least a day.

STK Reports

Using our Link Established in the previous step, let’s ensure that our AOS and LOS are the Same.

```
                                                  20 Jan 2021 20:15:06
FOR UNFUNDED EDUCATIONAL USE ONLY
Facility-Algonquin-Sensor-Sensor1-To-Satellite-GPS_BIIF-10_40730


    Start Time (UTCG)
------------------------
12 Jan 2021 19:43:04.649
13 Jan 2021 11:33:04.933
13 Jan 2021 19:39:04.983
```

Figure 4.28A: Running the AOS Installed Style built to STK

```
                                                 20 Jan 2021 20:15:35
FOR UNFUNDED EDUCATIONAL USE ONLY
Facility-Algonquin-Sensor-Sensor1-To-Satellite-GPS_BIIF-10_40730


    Stop Time (UTCG)
------------------------
13 Jan 2021 02:14:18.496
13 Jan 2021 13:56:37.946
13 Jan 2021 20:00:00.000
```

Figure 4.28B: Running the LOS Installed Style built into STK

Program Reports

Sat No.	Sat Name	AOS Time	LOS Time	Min Expected Level		
24	GPS BIIF-10 (PRN 08)	2021-01-12 20:10	2021-01-13 1:50	-92.1253		
24	GPS BIIF-10 (PRN 08)	2021-01-13 20:05	2021-01-13 21:55	-92.1167		

Figure4.29 :Running the Program and Opening up the AOS LOS Excel Report only shows us two values

Comparison and Discussion

Looking at both sets of Reports, we notice discrepancy in our data. Keep in mind that the STK Sensor does not implement Azimuth and Elevation bounds like the Program does.
To show this numerically, I've extended the time until the end of the observation period of that to 22:00:00. The excel sheet now shows that a signal is acquired at 20:05:00- several minutes after STK picks it up.
To show that this error might be part of the difference in data we can set our STK Animation Time to the various AOS and LOS reported in the STK Simulation to tell if this is something to be concerned about

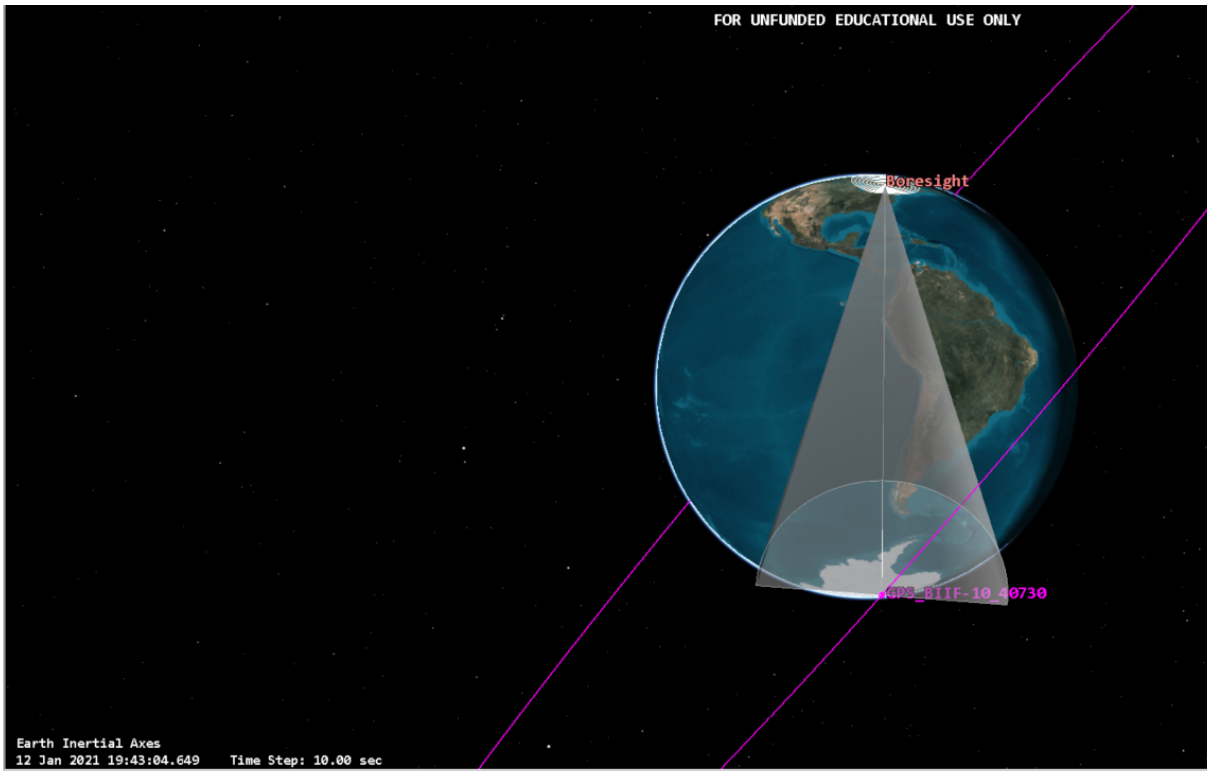


Figure 4.30: STK simulation at 12 Jan 20201 19:43:04.649 AOS Time. Notice the Boresight is cut in half, showing that there is a steep angle. This would explain eh AOS time difference between the Program's Report

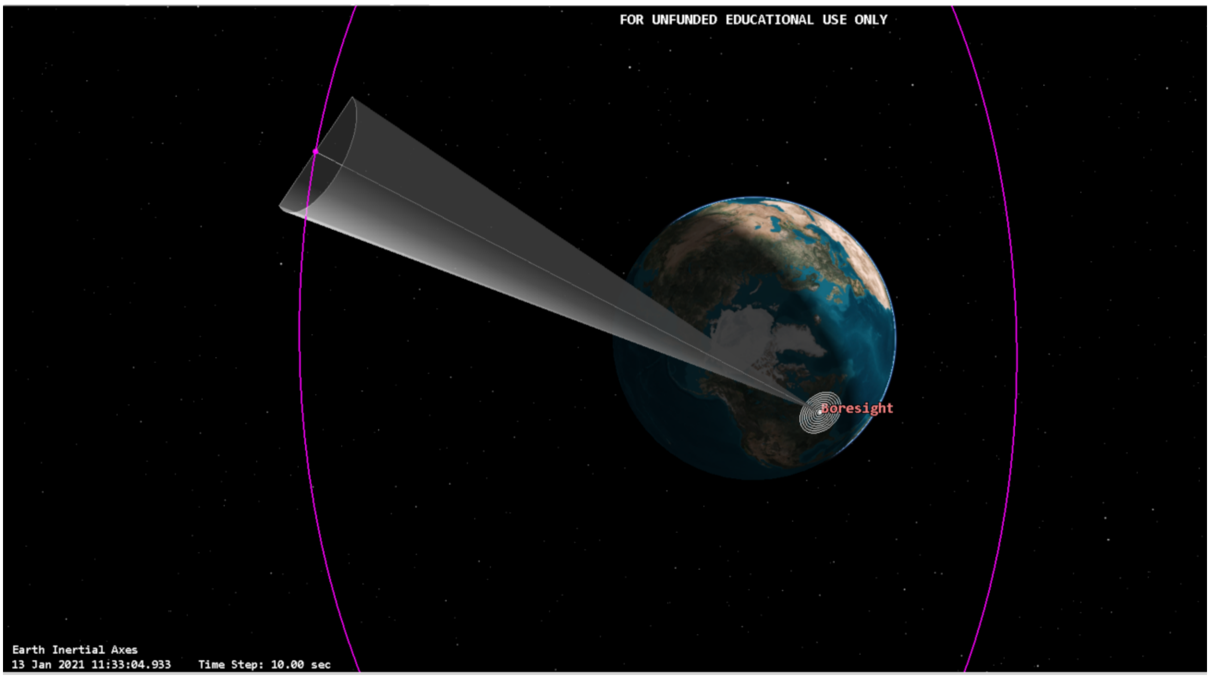


Figure 4.31: STK Simulation at 13 Jan 11:33:04.933 AOS Time. Notice again the steep angle.

Repeating this process, and looking at the AER Report from STK shows us that the Program is not at fault for this discrepancy

Ephemeris File Outputs

The Program Outputs Multiple Ephemeris Files, One of which uses the ECF coordinate system and the other which is produced from the ECI system. Using STK we can import these files to ensure that our Satellite produced by STK SPG4 Propagtor matches that of the Program's Generation.

When Running the code ensure that the Satellite's index is properly typed out when prompted.

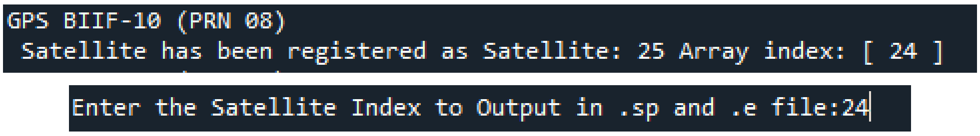


Figure 4.32: Typing in our Test Satellite's index will output it's Ephemeris and a Pointing File.

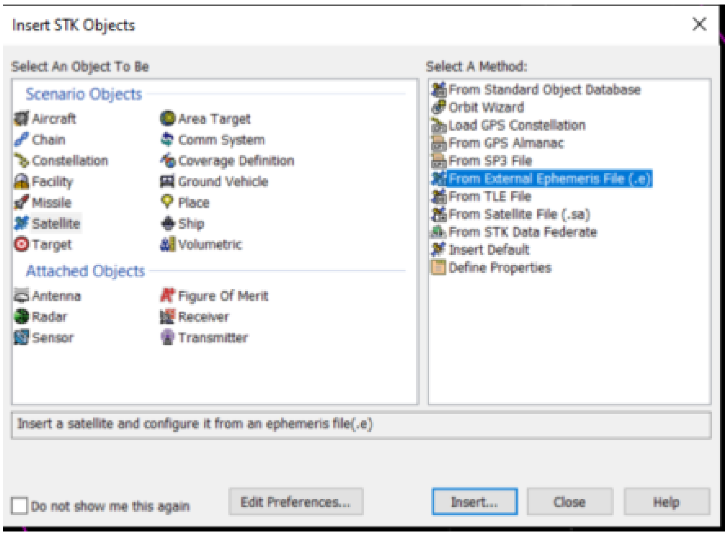


Figure 4.33: Inserting Satellite using External Ephim file

Results

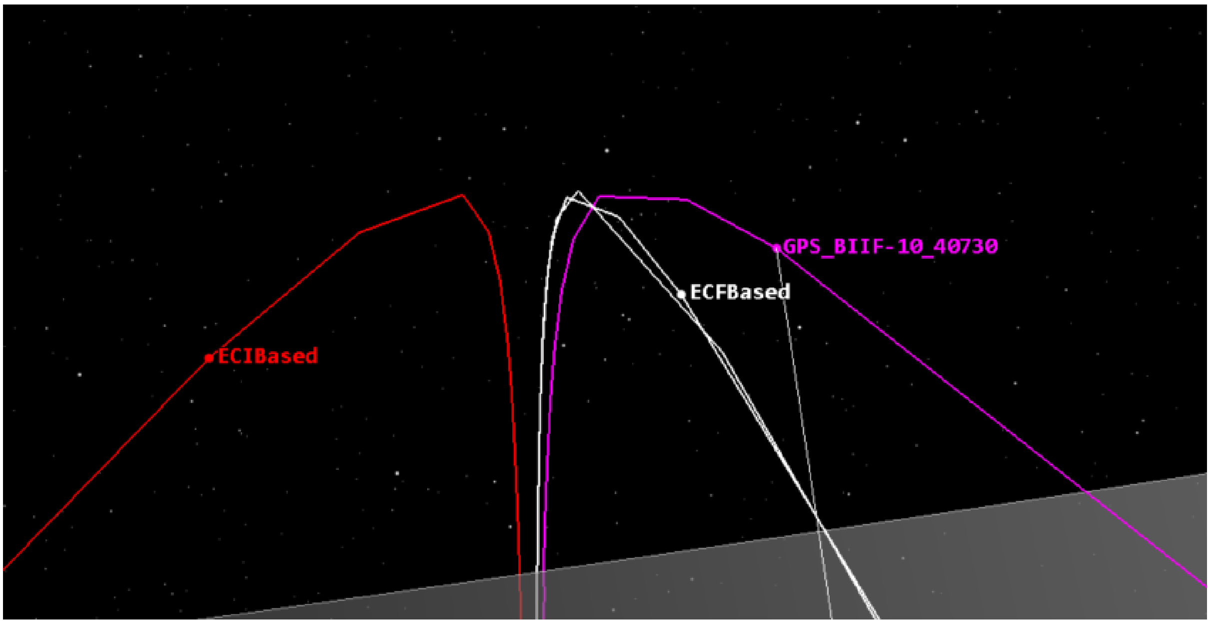


Figure4.34: Zooming into our Satellites, we see that the Ephemeris files for the ECI Based and ECF based calculations are very close to our Test Satellite BIIF 10.

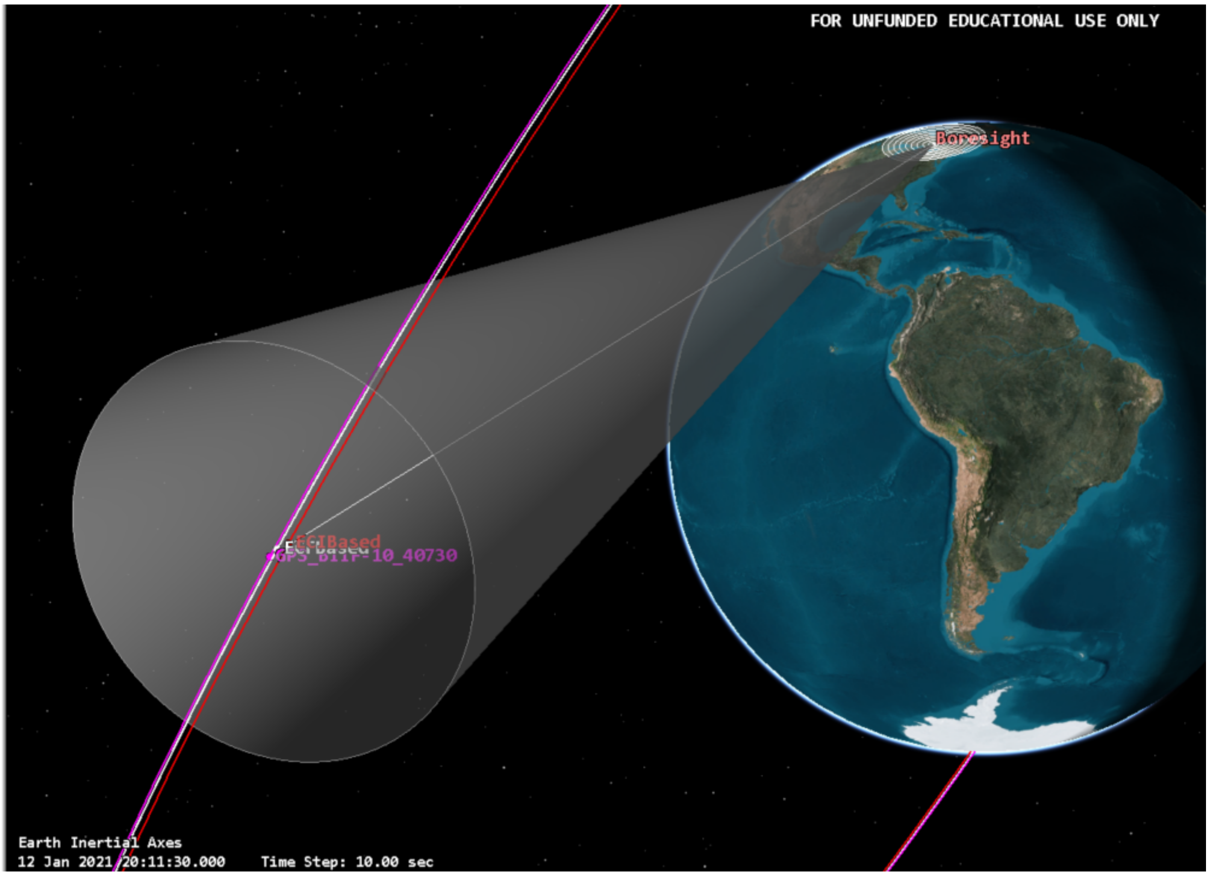


Figure4.35: Another Perspective of the imported Satellites.

We can also numerically compare these values:
Our TLE Propagated Satellite:

Start: 12 Jan 2021 19:30:00.000 UTCG
Stop: 12 Jan 2021 22:00:00.000 UTCG
Step: 60 sec

22 Jan 2021 02:28:49

FOR UNFUNDED EDUCATIONAL USE ONLY
Satellite-GPS_BIIF-10_40730: J2000 Position & Velocity

Time (UTCG)	x (km)	y (km)	z (km)	vx (km/sec)	vy (km/sec)	vz (km/sec)
12 Jan 2021 19:30:00.000	16282.892599	-14319.984905	-15128.775585	2.975412	0.966288	2.314691
12 Jan 2021 19:31:00.000	16460.782489	-14261.452778	-14989.308912	2.954228	0.984779	2.334179
12 Jan 2021 19:32:00.000	16637.394404	-14201.813437	-14848.678282	2.932813	1.003195	2.353489
12 Jan 2021 19:33:00.000	16812.714496	-14141.071395	-14706.894494	2.911167	1.021535	2.372618
12 Jan 2021 19:34:00.000	16986.729015	-14079.231254	-14563.968438	2.889294	1.039798	2.391564
12 Jan 2021 19:35:00.000	17159.424311	-14016.297702	-14419.911097	2.867194	1.057982	2.410327
12 Jan 2021 19:36:00.000	17330.786835	-13952.275514	-14274.733547	2.844868	1.076086	2.428904
12 Jan 2021 19:37:00.000	17500.803140	-13887.169553	-14128.446951	2.822320	1.094108	2.447295
12 Jan 2021 19:38:00.000	17669.459883	-13820.984767	-13981.062566	2.799550	1.112047	2.465497
12 Jan 2021 19:39:00.000	17836.743825	-13753.726192	-13832.591735	2.776560	1.129901	2.483509
12 Jan 2021 19:40:00.000	18002.641833	-13685.398947	-13683.045889	2.753352	1.147669	2.501331
12 Jan 2021 19:41:00.000	18167.140880	-13616.008239	-13532.436548	2.729928	1.165350	2.518959
12 Jan 2021 19:42:00.000	18330.228048	-13545.559357	-13380.775315	2.706290	1.182942	2.536393
12 Jan 2021 19:43:00.000	18491.890528	-13474.057677	-13228.073882	2.682439	1.200443	2.553632

Figure 4.6A: BIIF-10 J2000 STK Generated Position and Velocity Values

Start: 12 Jan 2021 19:30:00.000 UTCG
Stop: 12 Jan 2021 22:00:00.000 UTCG
Step: Using object's default time points Show Step Value

22 Jan 2021 02:27:43

FOR UNFUNDED EDUCATIONAL USE ONLY
Satellite-Fixed: J2000 Position & Velocity

Time (UTCG)	x (km)	y (km)	z (km)	vx (km/sec)	vy (km/sec)	vz (km/sec)
12 Jan 2021 19:30:59.127	16612.724693	-14190.695419	-14879.955165	3.972014	2.215931	2.347207
12 Jan 2021 19:31:59.127	16786.634738	-14130.591677	-14739.782294	3.946216	2.246752	2.366208
12 Jan 2021 19:32:59.127	16959.254126	-14069.415091	-14598.495429	3.920116	2.277401	2.385030
12 Jan 2021 19:33:59.127	17130.569960	-14007.170385	-14456.105345	3.893717	2.307877	2.403670
12 Jan 2021 19:34:59.127	17300.569441	-13943.862360	-14312.622892	3.867020	2.338177	2.422128
12 Jan 2021 19:35:59.127	17469.239873	-13879.495896	-14168.059004	3.840029	2.368298	2.440402
12 Jan 2021 19:36:59.127	17636.568658	-13814.075951	-14022.424690	3.812745	2.398239	2.458490
12 Jan 2021 19:37:59.127	17802.543302	-13747.607560	-13875.731037	3.785170	2.427996	2.476392
12 Jan 2021 19:38:59.127	17967.151414	-13680.095834	-13727.989209	3.757306	2.457569	2.494105
12 Jan 2021 19:39:59.127	18130.380707	-13611.545963	-13579.210446	3.729156	2.486954	2.511629
12 Jan 2021 19:40:59.127	18292.218997	-13541.963210	-13429.406062	3.700721	2.516149	2.528963
12 Jan 2021 19:41:59.127	18452.654208	-13471.352915	-13278.587445	3.672004	2.545152	2.546103
12 Jan 2021 19:42:59.127	18611.674369	-13399.720495	-13126.766057	3.643006	2.573961	2.563051

Figure 4.36B: BIIF-10 Program Generated Ephemeris Fixed System Satellite. Note that the Velocity values are off by around 1 km/s

Start: 12 Jan 2021 19:30:00.000 UTCG
Stop: 12 Jan 2021 22:00:00.000 UTCG
Step: Using object's default time points Show Step Value

22 Jan 2021 02:27:48

FOR UNFUNDED EDUCATIONAL USE ONLY
Satellite-inertial: J2000 Position & Velocity

Time (UTCG)	x (km)	y (km)	z (km)	vx (km/sec)	vy (km/sec)	vz (km/sec)
12 Jan 2021 19:30:59.127	16710.113438	-14111.157611	-14846.510151	2.927669	1.016292	2.355205
12 Jan 2021 19:31:59.127	16883.452406	-14050.227137	-14705.987259	2.906129	1.034350	2.374155
12 Jan 2021 19:32:59.127	17055.493378	-13988.229998	-14564.352972	2.884366	1.052329	2.392924
12 Jan 2021 19:33:59.127	17226.223499	-13925.170978	-14421.618089	2.862383	1.070228	2.411511
12 Jan 2021 19:34:59.127	17395.630016	-13861.054939	-14277.793488	2.840181	1.088047	2.429915
12 Jan 2021 19:35:59.127	17563.700278	-13795.886823	-14132.890127	2.817762	1.105783	2.448135
12 Jan 2021 19:36:59.127	17730.421734	-13729.671646	-13986.919041	2.795127	1.123436	2.466168
12 Jan 2021 19:37:59.127	17895.781935	-13662.414503	-13839.891341	2.772279	1.141003	2.484014
12 Jan 2021 19:38:59.127	18059.768538	-13594.120565	-13691.818218	2.749219	1.158484	2.501672
12 Jan 2021 19:39:59.127	18222.369304	-13524.795078	-13542.710935	2.725949	1.175877	2.519139
12 Jan 2021 19:40:59.127	18383.572096	-13454.443365	-13392.580831	2.702471	1.193181	2.536415
12 Jan 2021 19:41:59.127	18543.364886	-13383.070823	-13241.439319	2.678786	1.210395	2.553498
12 Jan 2021 19:42:59.127	18701.735754	-13310.682925	-13089.297885	2.654896	1.227517	2.570387

Figure 4.36C: BIIF-10 Program Generated Ephemeris Inertial System Satellite.

The ECI Propagated Satellite seems to possess the greatest difference in the J2000 Position but the ECF Propagated Satellite seems to possess the greatest difference in J2000 Velocities. The difference in these values aren't too concerning.

Link Budgets

Using the GPS Directorate Systems Engineering and integration interface specification: https://www.navcen.uscg.gov/pdf/gps/IRN_IS_200H_001_002_003_rollup.pdf
We see that GPS Satellites use BPSK Modulation that the ARO will be using an L1 C/A Band with it's nominal center frequency of 1575.42 MHz. The document also provides a set of requirements on the minimum amount of power to be received by a user. We can compare this to our end values to ensure that they are above the minimum Power required.

Consulting the AMSAT IAUR Calculator: http://www.amsatuk.me.uk/iaru/spreadsheet.htm
. We see that the Required EbNo of the BPSK is 9.6 without any coding. We will use this as a benchmark for our STK Testing.

Finding Power Required

Using an EbNo requirement of 9.6, we can rearrange the Link Budget Equation to solve for the Transmitted Power Required. This is done through the Tracking Program. Results for these equations are found in the Master file.

```
        #Using link Budget Calculation

        #Trasnmitter Gain
        A=np.pi/4*d**2 #Area of dish


        #Trasmitter Gain
        G_dBi_t=10*np.log10(n*4*np.pi/(3e8/(freq))**2*A)

        Rq_EbNo=9.6 #BPSK Required EbNo


        gT=10*np.log10(10**(R_gain/10)/T) #dB/K

        k_dB=-10*np.log10(1.38e-23) #bBJ/K

        R_dB=-10*np.log10(R*1000) #Converts r to m then converts to Db

        #Reference Equations
        #EbNo=EIRP+L_s+gT+R+k_dB--taken from 4360
        #EIRP=PdBW+L_1+G_dBi_t

        #solve for PdBW
        #EbNo-L_1-G_dBi_t-L_s-gT-R-k_dB=PdBW

        Xmtr_pwr_dBW=Rq_EbNo-G_dBi_t-L_s-gT-R_dB-k_dB #gives minimum Power Required in dBW

        Xmtr_pwr_dBm=Xmtr_pwr_dBW+30 #Covnerts from dBW to dBm
```

Figure 4.37: Solving for Minimum Transmitter Power in Tracking Program

1	Time	Satellite Name	Minimum Power Required(dBm)	Signal Los	DopplerShift(Hertz)
3266	2021-01-12 19:30	GPS BIIF-10 (PRN 08)	-17.65474216	-184.75	3899.769
3296	2021-01-12 19:35	GPS BIIF-10 (PRN 08)	-17.76567289	-184.676	3954.431
3326	2021-01-12 19:40	GPS BIIF-10 (PRN 08)	-17.87897406	-184.6	4001.154
3356	2021-01-12 19:45	GPS BIIF-10 (PRN 08)	-17.99446849	-184.523	4039.705
3386	2021-01-12 19:50	GPS BIIF-10 (PRN 08)	-18.11196657	-184.445	4069.863
3416	2021-01-12 19:55	GPS BIIF-10 (PRN 08)	-18.23126573	-184.365	4091.416
3446	2021-01-12 20:00	GPS BIIF-10 (PRN 08)	-18.35215004	-184.285	4104.164
3476	2021-01-12 20:05	GPS BIIF-10 (PRN 08)	-18.47438988	-184.203	4107.925
3506	2021-01-12 20:10	GPS BIIF-10 (PRN 08)	-18.59774157	-184.121	4102.529
3536	2021-01-12 20:15	GPS BIIF-10 (PRN 08)	-18.72194724	-184.038	4087.827
3566	2021-01-12 20:20	GPS BIIF-10 (PRN 08)	-18.84673464	-183.955	4063.687
3596	2021-01-12 20:25	GPS BIIF-10 (PRN 08)	-18.9718172	-183.872	4030
3626	2021-01-12 20:30	GPS BIIF-10 (PRN 08)	-19.09689419	-183.788	3986.682
3656	2021-01-12 20:35	GPS BIIF-10 (PRN 08)	-19.22165097	-183.705	3933.675
3686	2021-01-12 20:40	GPS BIIF-10 (PRN 08)	-19.34575958	-183.622	3870.95
3716	2021-01-12 20:45	GPS BIIF-10 (PRN 08)	-19.46887937	-183.54	3798.511
3746	2021-01-12 20:50	GPS BIIF-10 (PRN 08)	-19.59065799	-183.459	3716.393
3776	2021-01-12 20:55	GPS BIIF-10 (PRN 08)	-19.71073253	-183.379	3624.673
3806	2021-01-12 21:00	GPS BIIF-10 (PRN 08)	-19.82873098	-183.3	3523.464
3836	2021-01-12 21:05	GPS BIIF-10 (PRN 08)	-19.94427396	-183.223	3412.923
3866	2021-01-12 21:10	GPS BIIF-10 (PRN 08)	-20.05697667	-183.148	3293.25
3896	2021-01-12 21:15	GPS BIIF-10 (PRN 08)	-20.16645121	-183.075	3164.694
3926	2021-01-12 21:20	GPS BIIF-10 (PRN 08)	-20.27230907	-183.005	3027.55
3956	2021-01-12 21:25	GPS BIIF-10 (PRN 08)	-20.374164	-182.937	2882.162
3986	2021-01-12 21:30	GPS BIIF-10 (PRN 08)	-20.47163498	-182.872	2728.925
4016	2021-01-12 21:35	GPS BIIF-10 (PRN 08)	-20.56434953	-182.81	2568.285
4046	2021-01-12 21:40	GPS BIIF-10 (PRN 08)	-20.65194701	-182.751	2400.735
4076	2021-01-12 21:45	GPS BIIF-10 (PRN 08)	-20.73408218	-182.697	2226.817
4106	2021-01-12 21:50	GPS BIIF-10 (PRN 08)	-20.8104287	-182.646	2047.118
4136	2021-01-12 21:55	GPS BIIF-10 (PRN 08)	-20.88068262	-182.599	1862.268

Figure 4.38: Resultant Master File with Minimum Power Required for the Transmitter in dBm.

STK Transmitter Attachment

Frequency band center, F_cnt	MHz	1575.42
Antenna efficiency, AE	η	0.50
Antenna diameter, D	m	46
Bandwidth max, B	MHz	2
RCV gain, RG	dB	56
RCV noise temperature, RNT	deg K	200

Figure 4.39: ARO Test Data that will be used in this Test

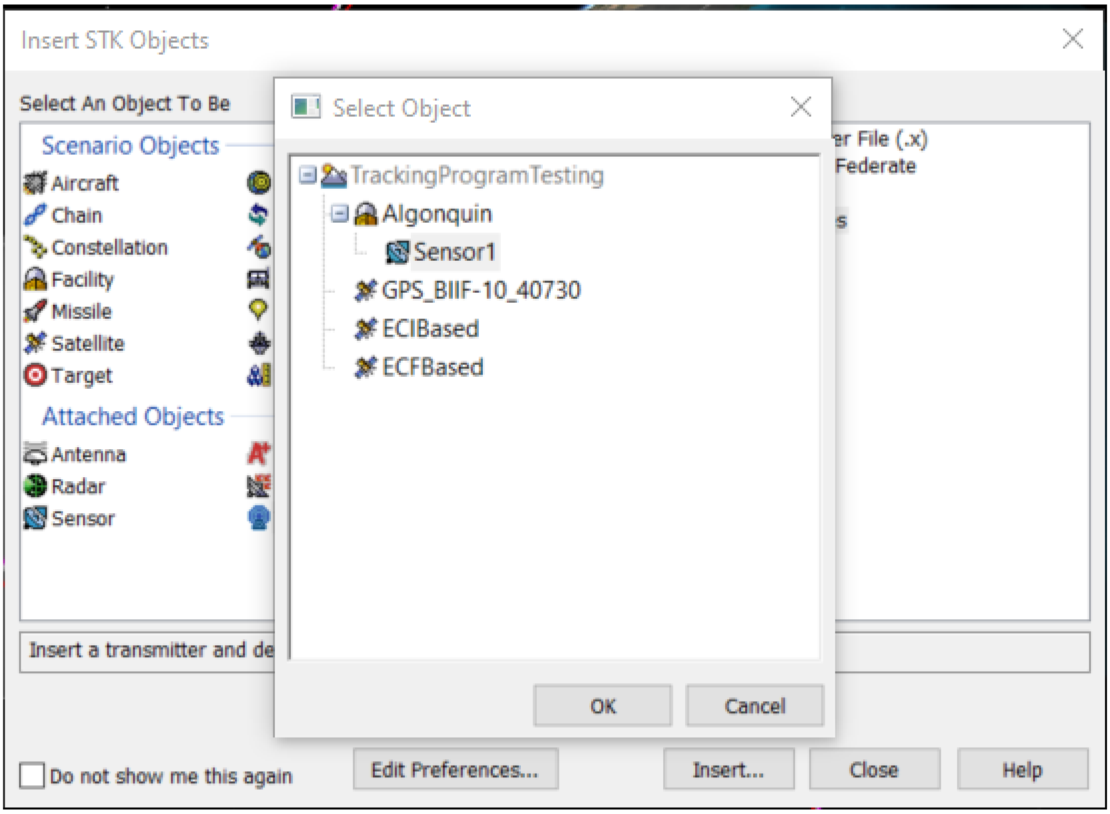


Figure 4.40: Adding Transmitter to Algonquin Sensor

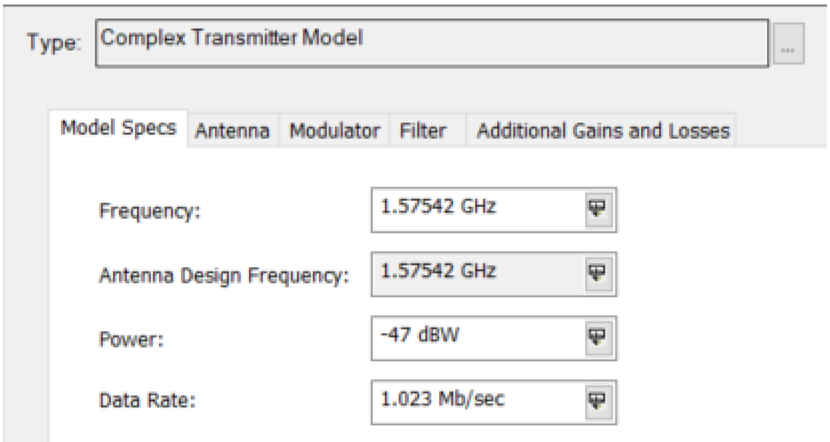


Figure4.41 Setting the Antenna in STK to ARO settings using -17dBm (as discovered in the previous step) as our estimate. Data Rate obtained from https://en.wikipedia.org/wiki/GPS_signals .

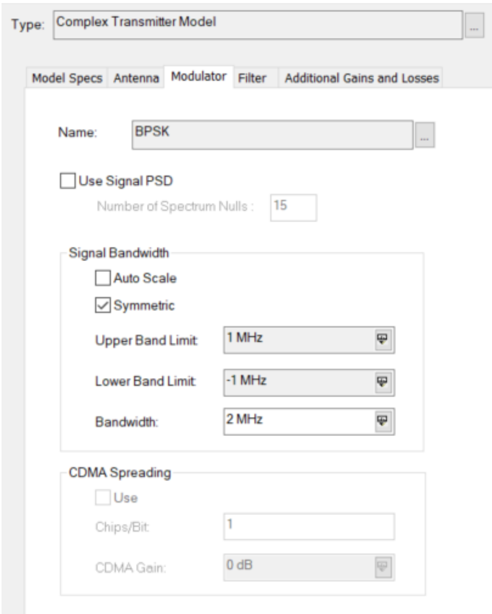


Figure4.42 Setting Antenna Modulator is Bandwidth of 2MHz and BPSK Modulation

STK Receiver

A simple Receiver must be created to create a link budget

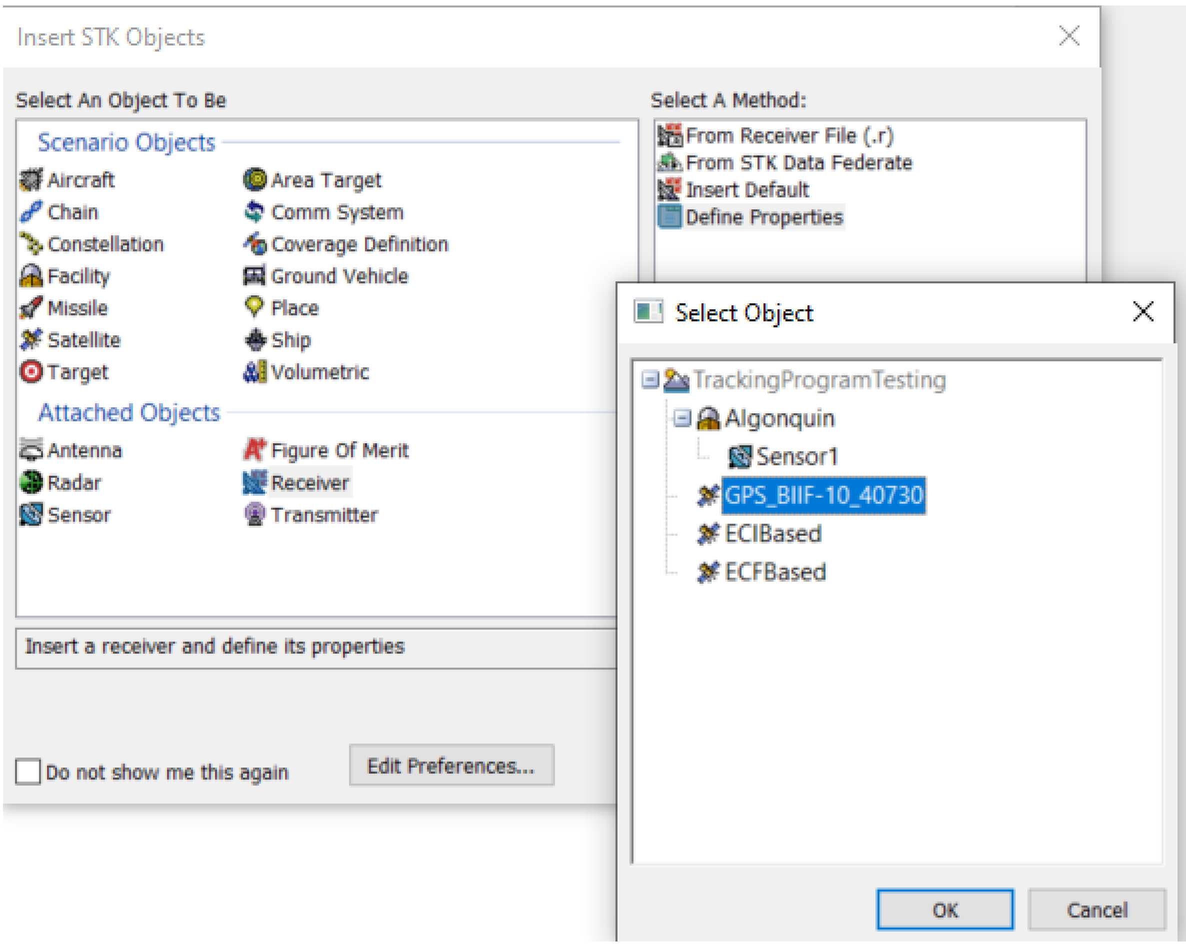


Figure4.43 : Adding a Simple Receiver to BIIF-10

```
10*np.log10(10**(56/10)/200)
32.98970004336019
```

Figure 4.44 : Quickly Calculating G/T for The Receiver using ARO Data in python

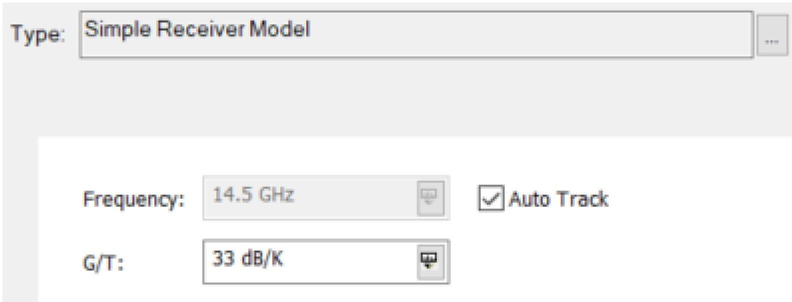


Figure 4.45: Setting Simple Receiver to G/T of around 33 dB

Generating Report

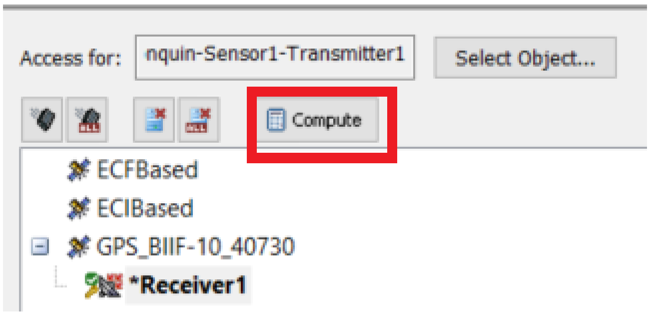


Figure 4.46: Compute Link between Transmitter on Algonquin Sensor to Receiver on BIIF-10

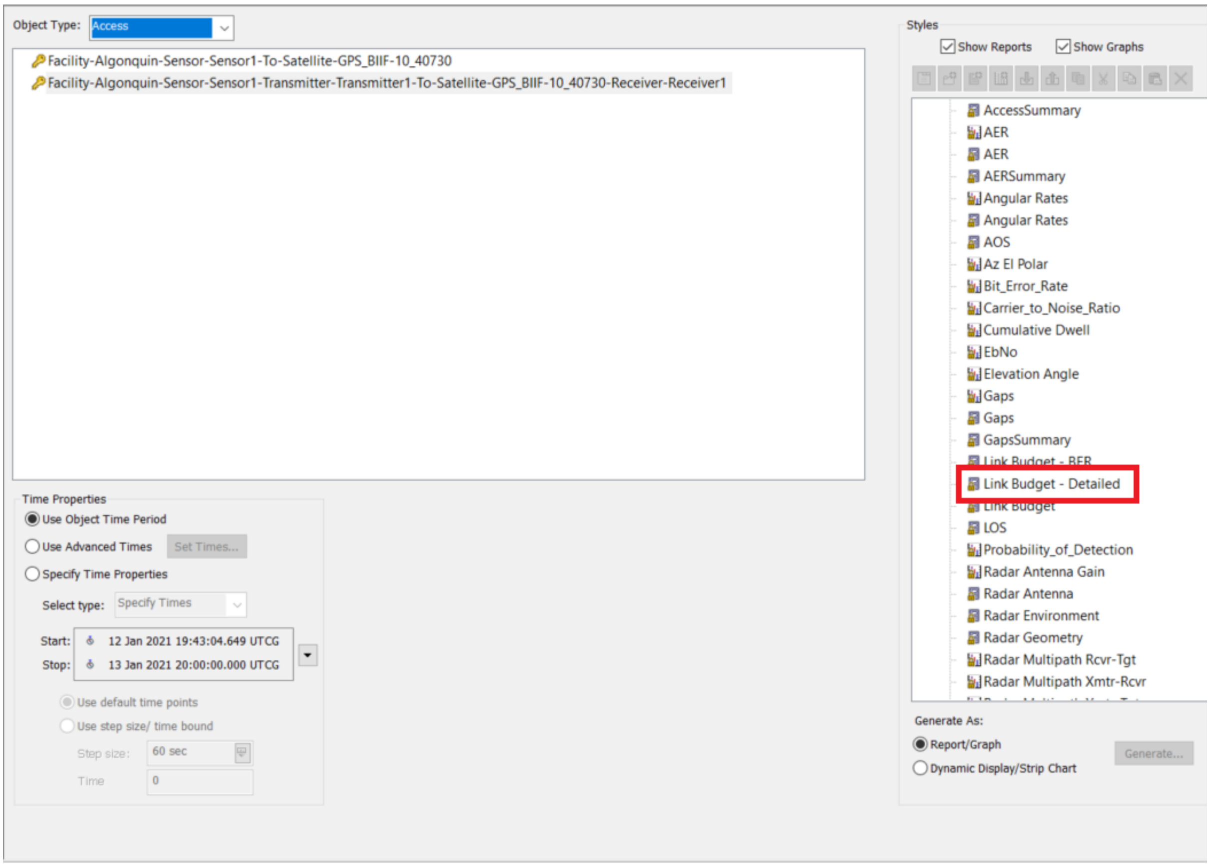
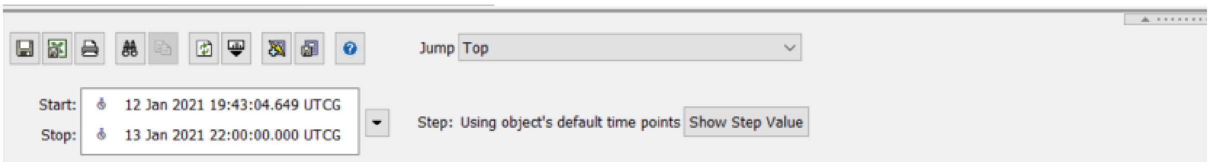


Figure4.47:Select and Generate Detailed Link Budget

Comparing Report to Program Values



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Facility-Algonquin-Sensor-Sensor1-Transmitter-Transmitter1-To-Satellite-GPS_BIIF-10_40730-Receiver-Rece

Time (UTCG)	Xmtr Power (dBW)	Xmtr Gain (dB)	EIRP (dBW)	Free Space Loss (dB)
12 Jan 2021 19:43:04.649	-47.000	54.5993	7.599	184.5703
12 Jan 2021 19:44:04.000	-47.000	54.5993	7.599	184.5555
12 Jan 2021 19:45:04.000	-47.000	54.5993	7.599	184.5404
12 Jan 2021 19:46:04.000	-47.000	54.5993	7.599	184.5253
12 Jan 2021 19:47:04.000	-47.000	54.5993	7.599	184.5102
12 Jan 2021 19:48:04.000	-47.000	54.5993	7.599	184.4950
12 Jan 2021 19:49:04.000	-47.000	54.5993	7.599	184.4797
12 Jan 2021 19:50:04.000	-47.000	54.5993	7.599	184.4644
12 Jan 2021 19:51:04.000	-47.000	54.5993	7.599	184.4491
12 Jan 2021 19:52:04.000	-47.000	54.5993	7.599	184.4337
12 Jan 2021 19:53:04.000	-47.000	54.5993	7.599	184.4182
12 Jan 2021 19:54:04.000	-47.000	54.5993	7.599	184.4028
12 Jan 2021 19:55:04.000	-47.000	54.5993	7.599	184.3872

Figure 4.48: The Generated Link Budget Report Provides important values for comparison. Notably Free Space Loss (dB), Transmitter Gain which is calculated from our Dish Diameter and center frequency.

Time	Satellite Name	Minimum Power Required(dBm)	Signal Loss(dB)	DopplerShift(Hertz)
2021-01-12 19:40	GPS BIIF-10 (PRN 08)	-17.87897406	-184.6000939	4001.153726
2021-01-12 19:45	GPS BIIF-10 (PRN 08)	-17.99446849	-184.5230976	4039.705454
2021-01-12 19:50	GPS BIIF-10 (PRN 08)	-18.11196657	-184.4447656	4069.863175
2021-01-12 19:55	GPS BIIF-10 (PRN 08)	-18.23126573	-184.3652328	4091.415646
2021-01-12 20:00	GPS BIIF-10 (PRN 08)	-18.35215004	-184.2846433	4104.164356
2021-01-12 20:05	GPS BIIF-10 (PRN 08)	-18.47438988	-184.20315	4107.925052
2021-01-12 20:10	GPS BIIF-10 (PRN 08)	-18.59774157	-184.1209156	4102.529417
2021-01-12 20:15	GPS BIIF-10 (PRN 08)	-18.72194724	-184.0381118	4087.826908
2021-01-12 20:20	GPS BIIF-10 (PRN 08)	-18.84673464	-183.9549202	4063.686747
2021-01-12 20:25	GPS BIIF-10 (PRN 08)	-18.9718172	-183.8715318	4030.00008
2021-01-12 20:30	GPS BIIF-10 (PRN 08)	-19.09689419	-183.7881472	3986.682268
2021-01-12 20:35	GPS BIIF-10 (PRN 08)	-19.22165097	-183.704976	3933.675317
2021-01-12 20:40	GPS BIIF-10 (PRN 08)	-19.34575958	-183.6222369	3870.950413
2021-01-12 20:45	GPS BIIF-10 (PRN 08)	-19.46887937	-183.540157	3798.510542
2021-01-12 20:50	GPS BIIF-10 (PRN 08)	-19.59065799	-183.4589713	3716.393153
2021-01-12 20:55	GPS BIIF-10 (PRN 08)	-19.71073253	-183.3789216	3624.672812

Figure 4.49: Using the Master File we can Filter for our Test Satellite. Comparing them we see that our Signal Losses are very similar. This is because our Signal Losses in our Program only factor in Free Space Loss. Another value of importance we should also consider the value of the Doppler Shift .

Prop Loss (dB)	Freq. Doppler Shift (kHz)	Rcvd. Frequency (GHz)	Rcvd. Iso. Power (dBW)
184.5703	3.870010	1.575424	-176.971
184.5555	3.876955	1.575424	-176.956
184.5404	3.883649	1.575424	-176.941
184.5253	3.890014	1.575424	-176.926
184.5102	3.896046	1.575424	-176.911
184.4950	3.901745	1.575424	-176.896
184.4797	3.907108	1.575424	-176.880
184.4644	3.912135	1.575424	-176.865
184.4491	3.916823	1.575424	-176.850
184.4337	3.921171	1.575424	-176.834
184.4182	3.925177	1.575424	-176.819
184.4028	3.928840	1.575424	-176.803
184.3872	3.932158	1.575424	-176.788
184.3717	3.935130	1.575424	-176.772
184.3561	3.937753	1.575424	-176.757
184.3404	3.940028	1.575424	-176.741

Figure 4.50: Scrolling Horizontally across our STK Report we see the Doppler Shift for this Satellite. Note that the Values are only 300 Hertz off from the the Values found on the Master.csv file and Azimuth and elevation files. Also Note the Received Isotropic Power, this is the Power Recived without Reciver Gain. Adding the Receiver Gain (described in Link Data file 56 dB) on top of this value gives us a value of -120.271 dBW or around -90 dBm.

H36

	A	B	C	D	E	F
1	Sat No.	Sat Name	AOS Time	LOS Time	Min Expected Level	
29	24	GPS BIIF-10 (PRN 08)	2021-01-12 20:10	2021-01-12 21:55	-92.125301	

OUTPUT_AOS_LOS - Notepad

File Edit Format View Help

```
027    PRN 04    2021-01-12 17:10:00    2021-01-12 21:55:00 -92
003    PRN 16    2021-01-12 17:15:00    2021-01-12 21:55:00 -92
021    PRN 09    2021-01-12 18:45:00    2021-01-12 21:55:00 -92
018    PRN 27    2021-01-12 19:05:00    2021-01-12 21:55:00 -92
013    PRN 07    2021-01-12 20:00:00    2021-01-12 21:55:00 -91
024    PRN 08    2021-01-12 20:10:00    2021-01-12 21:55:00 -92
028    PRN 18    2021-01-12 21:05:00    2021-01-12 21:30:00 -92
```

Ln 17, Col 63 | 100% | Windows (CRLF) | UTF-8

Figure 4.:51 Running the Program Outputs our Minimal Expected Receiver Level in both the Azimuth and Elevation files,AOS and LOS files and in the Master File. Note that the Minimum Expected Received signal in the AOS and LOS files has the minimum level at Acquisition of Signal

Discussion

The Directorate Systems Engineering and Integration Interface Specification describes the requirements for GPS Satellites. This is their worst case scenario: minimum received power.

TABLE 3-VA. RECEIVED MINIMUM RF SIGNAL STRENGTH FOR BLOCK IIA, IIR, IIR-M, IIF AND III SATELLITES (20.46 MHZ BANDWIDTH)

SV Blocks	Channel	Signal	
		P(Y)	C/A or L2 C
IIA/IIR	L1	-161.5 dBW	-158.5 dBW
	L2	-164.5 dBW	-164.5 dBW
IIR-M/IIF	L1	-161.5 dBW	-158.5 dBW
	L2	-161.5 dBW	-160.0 dBW
III	L1	-161.5 dBW	-158.5 dBW
	L2	-161.5 dBW	-158.5 dBW

TABLE 3-VB. RECEIVED MINIMUM RF SIGNAL STRENGTH FOR GPS III (30.69 MHZ BANDWIDTH)

SV Blocks	Channel	Signal	
		P(Y)	C/A or L2 C
III	L1	-161.5 dBW	-158.5 dBW
	L2	-161.5 dBW	-158.5 dBW

Figure 4.52: Table of Minimum Level Received.

These Values are similar to our Isotropic Received Power in our STK Report, but have a higher Required Received Power. It could be that these signals use the a different Required Eb/No, have higher transmitter gains (maybe bigger dishes, or higher efficiency), or they are able to maintain a constant higher Isotropic Transmitted Power.

Comparing to ARO values

Although Testing of the Tracking of the Satellite could not be done during the ARO virtual visit, measurements of PRN 20 were gathered to reference.

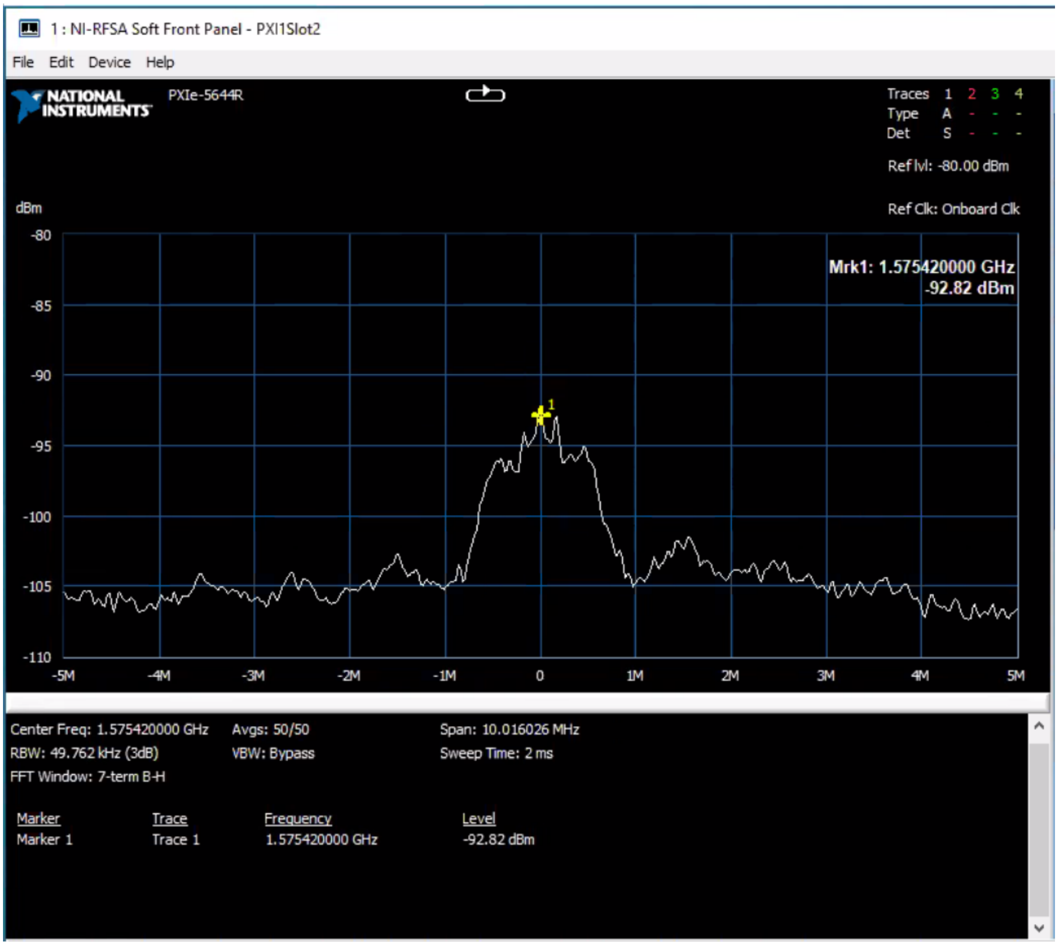

Figure 4.53: PRN 20 GPS Satellite measures a Level of -92.82 dBm

Running our Program for PRN 20 we get:

OUTPUT_Chosen_Satellite_AZ_EL - Notepad

File Edit Format View Help

UTC	AZ (Deg)	EL Deg	AZ-Vel (deg/sec)	El-Vel (deg/sec)	Range (km)	Doppler KHz	Level dBm
2021-012-10:30:00	279.26	35.24	0.00	0.01	22249	2.722	-93
2021-012-10:35:00	280.75	37.11	0.00	0.01	22094	2.666	-93
2021-012-10:40:00	282.24	39.01	0.00	0.01	21942	2.607	-93
2021-012-10:45:00	283.74	40.91	0.01	0.01	21794	2.545	-93
2021-012-10:50:00	285.25	42.84	0.01	0.01	21650	2.480	-93
2021-012-10:55:00	286.77	44.78	0.01	0.01	21510	2.412	-93
2021-012-11:00:00	288.31	46.74	0.01	0.01	21374	2.340	-93
2021-012-11:05:00	289.87	48.72	0.01	0.01	21242	2.265	-93
2021-012-11:10:00	291.44	50.72	0.01	0.01	21115	2.186	-93
2021-012-11:15:00	293.04	52.74	0.01	0.01	20992	2.103	-93
2021-012-11:20:00	294.67	54.78	0.01	0.01	20874	2.017	-93
2021-012-11:25:00	296.32	56.83	0.01	0.01	20762	1.926	-93
2021-012-11:30:00	298.02	58.90	0.01	0.01	20655	1.832	-93
2021-012-11:35:00	299.76	61.00	0.01	0.01	20553	1.733	-93
2021-012-11:40:00	301.58	63.11	0.01	0.01	20457	1.630	-93
2021-012-11:45:00	303.47	65.24	0.01	0.00	20367	1.524	-93
2021-012-11:50:00	305.48	67.38	0.01	0.00	20284	1.412	-93
2021-012-11:55:00	307.63	69.54	0.01	0.00	20207	1.297	-93
2021-012-12:00:00	310.00	71.72	0.01	0.00	20137	1.177	-93
2021-012-12:05:00	312.66	73.90	0.01	0.00	20073	1.053	-93
2021-012-12:10:00	315.78	76.09	0.01	0.00	20017	0.925	-93
2021-012-12:15:00	319.61	78.28	0.01	0.00	19968	0.793	-93
2021-012-12:20:00	324.64	80.44	0.02	0.00	19927	0.657	-93
2021-012-12:25:00	331.91	82.56	0.03	0.00	19894	0.518	-93

Figure 4.54: PRN 20 Program Output. Minimum Level is around -93 dBm. This means that our Program is very close but is overshooting the minimum level a little bit. This could be because our EbNo is 9.6 not 10.5. We also don’t factor in any other types of losses besides Space Loss.

Tracking Control File Format Assurance

As mentioned earlier, formats are important for the import files of the program, but what wasn't mentioned is that they were important for the output of the program as well, especially for the Tracking Control File . The Tracking Control file is to be used by Observatories such as ARO to properly track the satellite or object defined in the .
To confirm that our Tracking File was able to be read by the Algonquin Radio Observatory we used a modified LabView Program which checks to see if the output file is in the proper format.

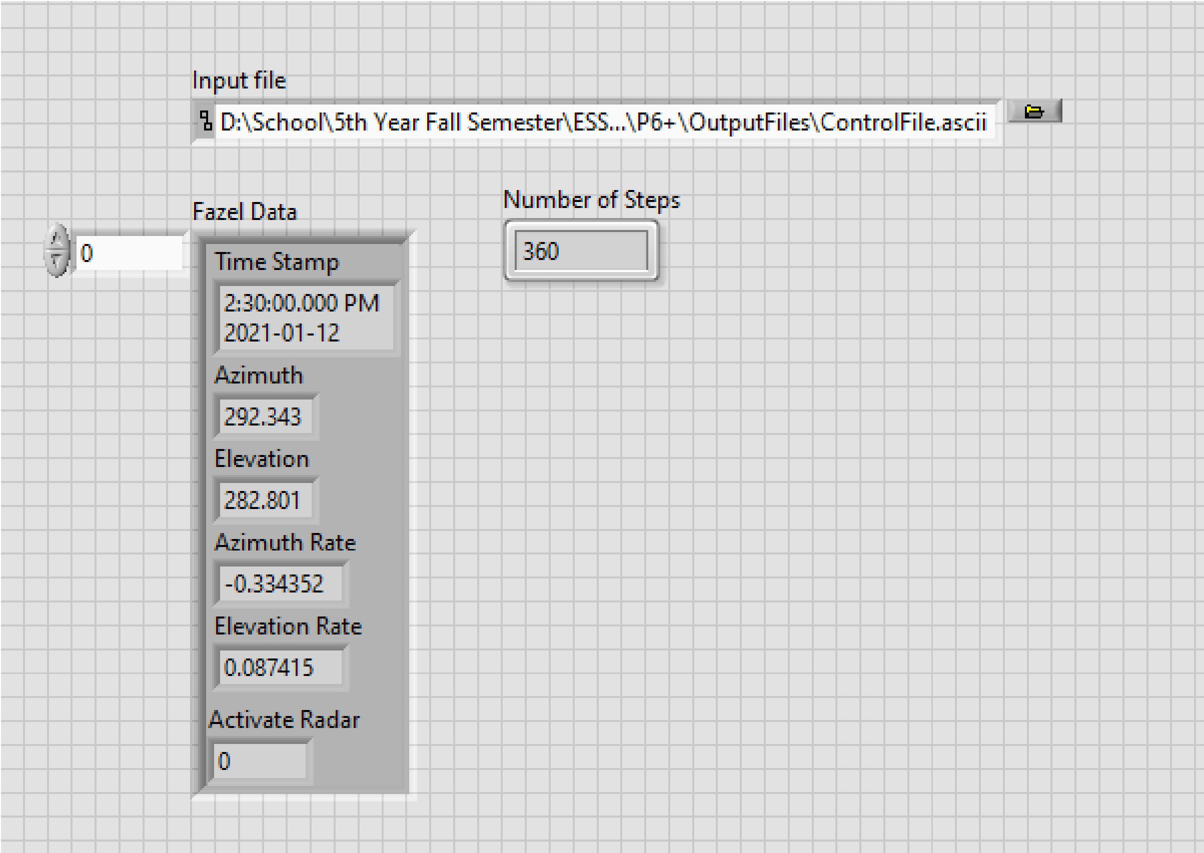

Figure 4.55: The Results of runningThe LabView program give us Fazel Data which means that the Control File is readable by the ARO.

Unfortunately we could not submit our file to ARO, due to numerous bugs in our program at the time.

Known Issues

As is evident in the STK Comparison Testing the values STK AER (Azimuth,Elevation, Range), our values aren't entirely accurate. This can be chalked down mostly to the Eccentric Anomaly and Mean Anomaly issues noticed.

It should also be noted that the Kepler Equation function of the code possesses a variable labeled “permitted_error” and is set to 0.05 as of writing this. A smaller permitted error will allow for higher precision calculations going from Mean Anomaly at time t to Eccentric Anomaly but will increase the amount of time required to calculated

Points of Confusion

The Software Specification Document provided an outline of what the program should look like and do although there were a few points that the students weren’t sure about.

Tracking Data Control File and Visibility

It is stated in Section 5.2 of the Software Specifications that “If the data is acceptable, the software should generate a file for the ARO control computer in an ASCII text file in the following format...” but it was unclear to Michael and Abdul what “Acceptable ” Entailed. “Acceptable” was thus coded into the program as being both a user prompt after a list of azimuth and elevations was printed on the command line and that it was available for viewing for that observatory.

Relative Position and Velocity

Some confusion was to be had about the relative velocity equation used in the software specification. Specifically what the exponential X meant

$$\{v_{rel-bi}\} = [T_{ECI \leftarrow ECI}]\{v_{Ii} - [\dot{\Theta}\boldsymbol{b}_z{}^X]\{r_{Ii}\}\}$$

The following equation was used in its place:

$$[\boldsymbol{v_{rel}}] = [T_{ECF \leftarrow ECI}][v_{Ii}] - (-\dot{\theta})\begin{bmatrix} -\sin\Theta(t) & \cos\Theta(t) & 0 \\ -\cos\Theta(t) & -\sin\Theta(t) & 0 \\ 0 & 0 & 0 \end{bmatrix}[r_{Ii}]$$

With

$$\dot{\theta} = \frac{2\pi}{23h\ 56m\ 4.091\ s} = \frac{2\pi}{86164.091000} = 0.000{,}072{,}921{,}158{,}533{,}0\ rad/s$$

Optimisation

With little to no experience of the Python Programming language this program is the result of 4 months of uncertainty and confusion.

As of the latest revision of the Program, The Program will contains two main areas of poor optimisation:

Abundance of Global variables

As the remnants of a poorly executed low level debugging system, the Global variables with the prefix “zTest” reduces the processing speed of the project by using a good chunk of RAM that the user’s computer has. If RAM becomes filled, the computer will start writing and reading back from the Hard Disk Drive or Solid State Drive increasing the processing time by approximately 10 fold. Unfortunately these variables have been integrated into functions such as Master_csv which will use them

All Satellite Calculations

The Program to date calculates all variables for all satellites and stores them in Global variable lists. Some of these calculations aren’t necessarily needed for AOS/LOS data or the Azimuth/Elevation Table outputted for a single satellite. Most notably, the Range calculations aren’t needed for all satellites. It is recommended to re-format the recommended software structure to request which satellite in which Range should be calculated for.

Bugs and Attempted Debugging

Eccentric Anomaly and Mean Anomaly

Test Satellite= **GPS_BIIR-02**

One area of concerns that we had was the errors in Mean Anomaly and Mean Anomaly Motion.

Multiple Attempts were tried to debug this calculation but values would not match that of STK

To attempt to Debug this the following procedure was held:

1. Test Satellite was chosen (BIIR-02)

2. Start and Stop Times were chosen for Observations
    a. Start Time: 27 Oct 2020 16:00:00
    b. Stop Time: 27 Oct 2020 20:00:00

3. STK Scenario was created

a. using the TLE Data provided in the gps-ops chose satellite BIIR-02
b. ARO Facility created
c. Start times and Stop Times set

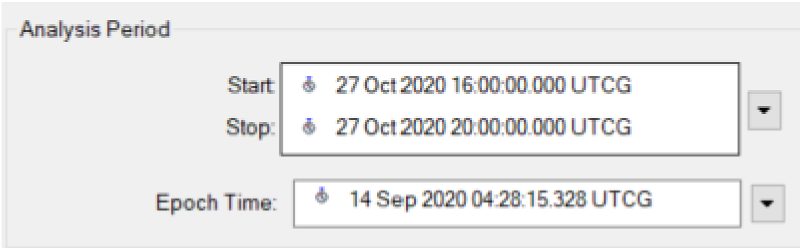

Figure 5.1: Setting Start time and Stop Time of STK Scenario.

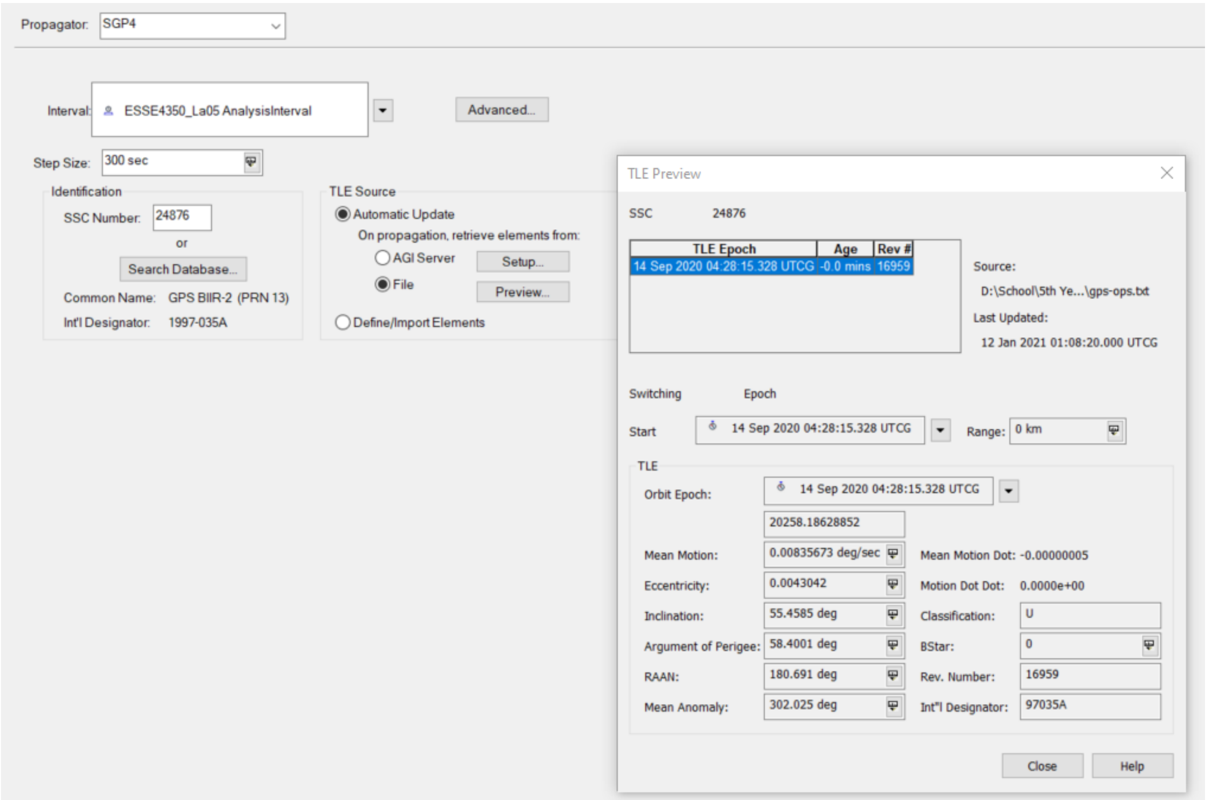

Figure 5.2: Orbital Elements confirmation from SPG4 Propagation

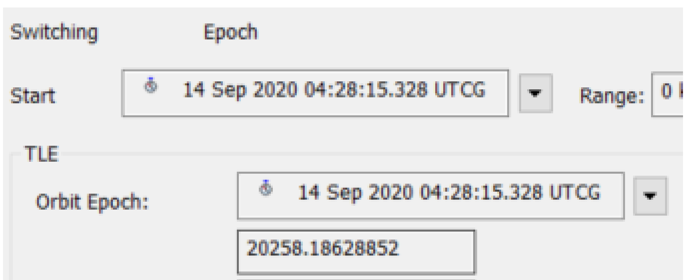

Figure 5.3: Setting Scenario Epoch Time to Orbit Epoch

4. Create Report
   a. Using “Anomalies” Report described earlier

11 Jan 2021 20:36:44

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Satellite-GPS_BIIR-02_24876

Epoch (UTCG)	Mean Motion (revs/day)	Mean Anomaly (deg)
14 Sep 2020 04:28:15.328	2.005614	302.025

Time (EpSec)	True Anomaly (deg)	Mean Anomaly (deg)	Mean Motion (Revs/Day)	Eccentric Anomaly (deg)
3756704.672	14.634	14.505	2.005781	14.569
3756764.000	15.145	15.011	2.005783	15.078
3756824.000	15.662	15.524	2.005784	15.593
3756884.000	16.179	16.036	2.005786	16.107
3756944.000	16.696	16.549	2.005787	16.622
3757004.000	17.213	17.061	2.005789	17.137
3757064.000	17.730	17.574	2.005790	17.652
3757124.000	18.247	18.086	2.005792	18.166
3757184.000	18.764	18.599	2.005793	18.681
3757244.000	19.281	19.111	2.005794	19.196
3757304.000	19.797	19.624	2.005795	19.711
3757364.000	20.314	20.137	2.005796	20.225
3757424.000	20.831	20.649	2.005797	20.740
3757484.000	21.348	21.162	2.005798	21.255
3757544.000	21.865	21.674	2.005799	21.770
3757604.000	22.382	22.187	2.005800	22.284
3757664.000	22.898	22.699	2.005801	22.799
3757724.000	23.415	23.212	2.005802	23.313
3757784.000	23.931	23.724	2.005802	23.828
3757844.000	24.448	24.236	2.005803	24.342
3757904.000	24.964	24.748	2.005804	24.856
3757964.000	25.480	25.260	2.005804	25.370
3758024.000	25.996	25.772	2.005805	25.884
3758084.000	26.512	26.284	2.005805	26.398
3758144.000	27.028	26.795	2.005805	26.912
3758204.000	27.544	27.307	2.005806	27.425
3758264.000	28.059	27.818	2.005806	27.939

Figure 5.4: “Anomalies” Report with Epoch Seconds displayed instead of default format. This assists in ensuring we have the right time in seconds when doing comparative calculations

5. Program was ran with
    a. ARO Station file was fed in
    b. Same gps-ops file
    c. Tracking Data using Start time and Stop Time

K	L	O	P	Q
Mean Anom @time	Mean Anom Motion @time	Time	Time Since Epoch	Satellite Name
15.73975845	2.005609712	2020-10-27 16:00	3756704.672	GPS BIIR-2 (PRN 13)
16.24116088	2.005609712	2020-10-27 16:01	3756764.672	GPS BIIR-2 (PRN 13)
16.74256331	2.005609712	2020-10-27 16:02	3756824.672	GPS BIIR-2 (PRN 13)
17.24396574	2.005609712	2020-10-27 16:03	3756884.672	GPS BIIR-2 (PRN 13)
17.74536817	2.005609712	2020-10-27 16:04	3756944.672	GPS BIIR-2 (PRN 13)
18.24677059	2.005609712	2020-10-27 16:05	3757004.672	GPS BIIR-2 (PRN 13)
18.74817302	2.005609712	2020-10-27 16:06	3757064.672	GPS BIIR-2 (PRN 13)
19.24957545	2.005609711	2020-10-27 16:07	3757124.672	GPS BIIR-2 (PRN 13)
19.75097788	2.005609711	2020-10-27 16:08	3757184.672	GPS BIIR-2 (PRN 13)
20.25238031	2.005609711	2020-10-27 16:09	3757244.672	GPS BIIR-2 (PRN 13)
20.75378273	2.005609711	2020-10-27 16:10	3757304.672	GPS BIIR-2 (PRN 13)
21.25518516	2.005609711	2020-10-27 16:11	3757364.672	GPS BIIR-2 (PRN 13)
21.75658759	2.005609711	2020-10-27 16:12	3757424.672	GPS BIIR-2 (PRN 13)
22.25799002	2.005609711	2020-10-27 16:13	3757484.672	GPS BIIR-2 (PRN 13)
22.75939245	2.005609711	2020-10-27 16:14	3757544.672	GPS BIIR-2 (PRN 13)
23.26079487	2.005609711	2020-10-27 16:15	3757604.672	GPS BIIR-2 (PRN 13)
23.7621973	2.005609711	2020-10-27 16:16	3757664.672	GPS BIIR-2 (PRN 13)
24.26359973	2.005609711	2020-10-27 16:17	3757724.672	GPS BIIR-2 (PRN 13)
24.76500216	2.005609711	2020-10-27 16:18	3757784.672	GPS BIIR-2 (PRN 13)
25.26640458	2.005609711	2020-10-27 16:19	3757844.672	GPS BIIR-2 (PRN 13)
25.76780701	2.005609711	2020-10-27 16:20	3757904.672	GPS BIIR-2 (PRN 13)
26.26920944	2.005609711	2020-10-27 16:21	3757964.672	GPS BIIR-2 (PRN 13)
26.77061187	2.00560971	2020-10-27 16:22	3758024.672	GPS BIIR-2 (PRN 13)
27.27201429	2.00560971	2020-10-27 16:23	3758084.672	GPS BIIR-2 (PRN 13)
27.77341672	2.00560971	2020-10-27 16:24	3758144.672	GPS BIIR-2 (PRN 13)
28.27481915	2.00560971	2020-10-27 16:25	3758204.672	GPS BIIR-2 (PRN 13)
28.77622158	2.00560971	2020-10-27 16:26	3758264.672	GPS BIIR-2 (PRN 13)
29.277624	2.00560971	2020-10-27 16:27	3758324.672	GPS BIIR-2 (PRN 13)
29.77902643	2.00560971	2020-10-27 16:28	3758384.672	GPS BIIR-2 (PRN 13)
30.28042886	2.00560971	2020-10-27 16:29	3758444.672	GPS BIIR-2 (PRN 13)
30.78183129	2.00560971	2020-10-27 16:30	3758504.672	GPS BIIR-2 (PRN 13)
31.28323371	2.00560971	2020-10-27 16:31	3758564.672	GPS BIIR-2 (PRN 13)
31.78463614	2.00560971	2020-10-27 16:32	3758624.672	GPS BIIR-2 (PRN 13)
32.28603857	2.00560971	2020-10-27 16:33	3758684.672	GPS BIIR-2 (PRN 13)
32.787441	2.00560971	2020-10-27 16:34	3758744.672	GPS BIIR-2 (PRN 13)

Figure5.5: snippet of Master.csv file with BIIR-2 filtered

6. Compare Reports and Master.csv File

Comparing the values we see the Mean Anomaly is off by around ~1° which will cause issues further down the line- specifically eccentric anomaly, ECI coordinate systems and thus will negatively affect our look angles

7. Attempt to Isolate Problem

With the provided Equation from the Software Specifications we tried to isolate the issue

2. Calculate the satellite mean anomaly $M(t)$ and mean motion $n(t)$ at time:

$$M(t)=M_0+n_0\frac{360t}{86400}+360\frac{\dot{n}}{2}\left(\frac{t}{86400}\right)^2+360\frac{\ddot{n}}{6}\left(\frac{t}{86400}\right)^3$$

$$\dot{M}(t)=n(t)=n_0\frac{360}{86400}+2(360)\frac{\dot{n}}{2}\left(\frac{t}{86400^2}\right)+3(360)\frac{\ddot{n}}{6}\left(\frac{t^2}{86400^3}\right)$$

where n_0, $\frac{\dot{n}}{2}$, $\frac{\ddot{n}}{6}$ are given in the satellite TLE.

8. Test if parsing error occurred

To test and see if we made a parsing error in our program or whether it's a calculation error we created an isolated calculation which utilizes the values provided in STK.

```
In [16]:  # BIIR -2
          t=3756704.672 #secs Obtained from STK or Time difference calculations
          #time it takes from epoch to start of observations
          M0=302.025 #degs #obtained from TLE Data
          N0=2.005614 #revs/day
          ndot=-0.00000005 #This is actually ndot/2 obtained from TLE Data
          n2dot=0 #this is actually n2dot/6 obtained from TLE data

          Mt=M0+N0*(360*t/86400)+360*(ndot)*(t/86400)**2+360*(n2dot)*(t/86400)**3
          Mt%360 #output in degrees

Out[16]:  15.738820340084203
```

Figure 5.6: Calculating Mean Anomaly Using the variables from STK or TLE Data

Noting that there is some deviation between this result and the first listed mean anomaly provided by STK we know that this calculation isn't completely accurate.

a. Since our STK inputs and equation still results in a different answer than STK, we look at external causes.

9. New Hypothesis

The equation given to us in Software Specification is a simple cubic equation whose only dependence is of time. Now we suspect that nature doesn't bid by these simple rules, so accuracy would decrease as we increase the time since Epoch.

10. Test New Hypothesis
    a. Change Start and Stop Time in STK

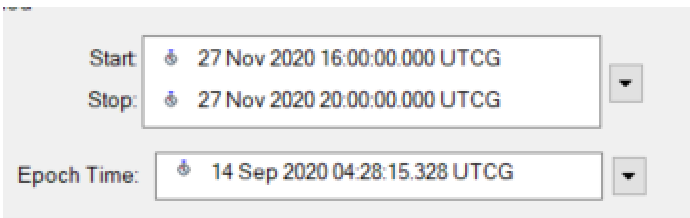

Figure 5.7: Changed Scenario Start and Stop Time to one month later.

b. Re run report

```
                                                                    11 Jan 2021 22:23:28
FOR UNFUNDED EDUCATIONAL USE ONLY
Satellite-GPS_BIIR-02_24876
```

Epoch (UTCG)	Mean Motion (deg/sec)	Mean Anomaly (deg)
14 Sep 2020 04:28:15.328	0.008357	302.025

Time (EpSec)	True Anomaly (deg)	Mean Anomaly (deg)	Mean Motion (Revs/Day)	Eccentric Anomaly (deg)
6435104.672	77.797	77.285	2.005587	77.541
6435164.000	78.280	77.767	2.005583	78.024
6435224.000	78.768	78.255	2.005580	78.512
6435284.000	79.257	78.742	2.005577	79.000
6435344.000	79.745	79.230	2.005574	79.488
6435404.000	80.234	79.718	2.005570	79.976
6435464.000	80.722	80.205	2.005567	80.464
6435524.000	81.211	80.693	2.005564	80.952
6435584.000	81.699	81.181	2.005561	81.440
6435644.000	82.187	81.668	2.005557	81.928
6435704.000	82.676	82.156	2.005554	82.416
6435764.000	83.164	82.644	2.005551	82.904
6435824.000	83.653	83.132	2.005548	83.392
6435884.000	84.141	83.620	2.005545	83.881
6435944.000	84.630	84.108	2.005542	84.369
6436004.000	85.118	84.597	2.005539	84.857
6436064.000	85.607	85.085	2.005535	85.346
6436124.000	86.096	85.573	2.005532	85.835
6436184.000	86.585	86.062	2.005529	86.323
6436244.000	87.074	86.551	2.005526	86.812
6436304.000	87.563	87.040	2.005523	87.301
6436364.000	88.052	87.529	2.005521	87.790
6436424.000	88.541	88.018	2.005518	88.279
6436484.000	89.031	88.507	2.005515	88.769
6436544.000	89.520	88.996	2.005512	89.258
6436604.000	90.010	89.486	2.005509	89.748
6436664.000	90.499	89.976	2.005506	90.238
6436724.000	90.988	90.466	2.005504	90.728

Figure 5.8:Result of re-running the “Anomalies” Report. Note: the Epoch Seconds has increased

11. Plug new variables into our Test Environment in Jupyter Notebook

- Changed variable t- time since epoch in seconds to the new Epoch Seconds in the chart above

In [17]:
```
# BIIR -2
t=6435104.672 #secs Obtained from STK or Time difference calculations
#time it takes from epoch to start of observations
M0=302.025 #degs #obtained from TLE Data
N0=2.005614 #revs/day
ndot=-0.00000005 #This is actually ndot/2 obtained from TLE Data
n2dot=0 #this is actually n2dot/6 obtained from TLE data

Mt=M0+N0*(360*t/86400)+360*(ndot)*(t/86400)**2+360*(n2dot)*(t/86400)**3
Mt%360 #output in degrees
```
Out[17]:
```
78.32523823807423
```

Figure 5.9 : Calculating with new values

12. Difference Calculations

Difference: 0.5282238 between the STK Generated values and in Testing Environment

13. Discussion

This disproves our theory, noting that Mean Anomaly accuracy increases as time increases.

14. Conclusion

More tests and more data needs to be gathered to improve the accuracy of the Eccentric and Mean Anomalies. The disparity between the Eccentric anomaly could be caused by the “permitted_error” value being 0.05.

Conclusion

The Program Produces mostly accurate results for it’s Look Angles, their Rates, Acquisition of and Loss of Signal Data, Link Budgets and Doppler Shift. Ranges generated from STK vs computed in this Program showed a difference of around 600km maximum with their velocities varying by 1km/s or so. Mean Anomaly and Eccentric Anomaly was off by a degree or so and this issue was attempted to be solved. The Results for the Link Budget, specifically the Minimum Received Power was really close to the levels measured, they were actually a little bit higher than desired, but it is important to keep in mind that we only factor in Free Space Loss and have a 0 system Gain. Overall the Results are reasonable, higher accuracies would be preferred but that would also require many more hours of debugging. The nomenclature used in this lab activity was relatively confusing, especially when there were typos or unfamiliar language used.

Appendix

GLOBAL POSITIONING SYSTEMS DIRECTORATE SYSTEMS ENGINEERING & INTEGRATION INTERFACE SPECIFICATION IS-GPS-200. NAVSTAR GPS Space Segment/ Navigation User Segment Interfaces. Pdf: https://www.navcen.uscg.gov/pdf/gps/IRN_IS_200H_001_002_003_rollup.pdf

AMSAT/IARU Annotated Link Model Systems. Jan A King Spreadsheet: http://www.amsatuk.me.uk/iaru/spreadsheet.htm