Astrodynamics Standards Shared Library

Sensor

Version 9.4

May 2024

Contents

1. Introduction

Sensor provides the users with many library functions to load and manage ground sensor and orbiting sensor data.

If you are on Windows, the shared library files will end in ".dll". For example, "Sensor.dll". If you are on Linux, the shared library will begin with "lib" and end in ".so", and will be all lowercase. For example, libsensor.so.

Background

There are varieties of Space Surveillance sensor types for which there are a variety of sensor configuration parameters. This document is intended to clarify which sensor parameters are applicable to which sensor types and provides guidance on how to properly configure various types of sensors for obtaining proper sensor-satellite viewing opportunities for the user's or system's purposes using the Astrodynamics Standards suite of applications. Purposes for configuring sensor parameters could include for operational needs, for modeling and simulations such as for trade studies, for sensor-network architecture studies and Considerations of Alternative (COAs), or for ad hoc analytical "what-if" inquiries. Using this guide as a reference will help users ensure they are applying the correct parameters and settings for the sensor type they are intending to model in their use of the Astrodynamics Standards applications such as the Look Angle Module (LAMOD), Field of View (FOV), Area Overflight (AOF) and others.

2. Prerequisites

The following shared libraries MUST be loaded and initialized before using SENSOR:

- AstroFunc
- DllMain
- EnvConst
- TimeFunc

3. Getting Started

To get started, please read the README.txt file that came in the root directory of your distribution. In addition to an overall description contained in the distribution, it has a description of a "**wrapper**".

To get started with **Sensor**, there is a "wrapper" specific to Sensor, under the **SampleCode** directory. Under your language of choice, you will see a "**DriverExample/wrapper**" subdirectory. The files under this directory will have all the Application Programming Interfaces (APIs) available. For Sensor specific APIs, you should see a source file labelled with "Sensor" in the file name. This will be where you will find all the APIs for that specific library. The "DriverExample" directory will also contain several examples of applications that should run by simply running the runExample.bat or runExample.sh script. You can use these examples as a starting point for building your application.

If you do not see your programming language under "SampleCode", look in the HTML documentation for the APIs. Open a browser to the "Documentation/APIDocs/index.html" file. This document will show all the APIs regardless of programming language.

The Astrodynamics Standards libraries should work with any language capable of using Dynamic Link Library (on Windows) or Shared object (on Linux) files.

4. Understanding SENSOR

Internally, the library stores the loaded SENSORs in its own binary tree. Each SENSOR, when added successfully to the binary tree, will receive a unique key. This unique key, which is also the sensor number, is commonly called 'senKey' in the documentation. The senKey is used to retrieve the SENSOR data.

Any libraries working with SENSOR, such as LAMOD, will have access to the root of the SENSOR's binary tree. Therefore, the associated SENSOR data can be retrieved via its senKey.

5. Sensor Data Description

The purpose of this section is to identify and define sensor parameters that are applicable to the various sensor types and their possible configurations.

The parameters of the legacy sensor cards are the same parameters that must be configured and set prior to calling the Wrapper for the Astro Standards application. Users should consult the *Wrapper* examples for the language of their environment and unit tests delivered with the release. This section covers the breakdown of the parameters, controls, and configuration of various sensor types including Ground-Based Optical and Radar, Space-Based, and Mobile sensors.

The sensor specification cards represent the legacy mechanism to configure sensors for modeling Space Surveillance operations using the Astrodynamics Standards applications. The Sensor Card type-identifiers are captured in columns 79-80, or column 80 of the given sensor card. Sensor card types include:

1) **S** = S-Card for Sensor Location (ground-based sensors)
2) **OS** = Orbiting Sensor Card (Earth-orbiting satellite sensors)
3) **MS** = Mobile Sensor Card (ground-based or air-based mobile sensors)
4) **BS** = Sensor Biases and Sigmas Card (where Sigmas are also known as Weights)
5) **1L** = Sensor Limits 1L Card (1st set of sensor limits, required)
6) **2L** = Sensor Limits 2L Card (optional, 2nd set of sensor limits – if present must be preceded by a 1L Card).
8) **3L** = Sensor Limits 3L Card (optional, allows specification of up to 128 additional sets of limits – if present must be preceded by 1L and 2L cards)

5.1. Sensor Location Data Formats.

5.1.1. Ground-Based Sensor S-Card (Locations) Format:

Sensor '**S**' Card examples and decoder are provided below. The parameters used to specify a sensor's ground-site location is used by various Astro Standards applications, most notably the Look Angle Module (**LAMOD**). The *Wrappers* included with Astro Standards are reflective of these sensor location parameters and the *Drivers* included provide examples for properly configuring sensor locations to invoke the LAMOD and other applications.

The '**S**' card is used to specify sensor ground-locations and the '**OS**' card is used to identify the Satellite number for the Space-Based sensor on board the spacecraft. Like the '**S**' card, the '**OS**' card is used to specify the satellite number and, in turn, its corresponding element set that defines the sensor-satellite's orbit representation of the sensor's location as a function of time.

Column	Range	Format	Description
1-3	000-998	I3	Sensor number (sensor 999 reserved for eph type obs)
4		I1	Sensor location type, where: (apply to input data in column 23-49) 1 or blank = ECR position (default) 2 = EFG position 3 = LLH position (Lat/Lon/Height)
5-12	-90 to 90	F8.0	Astronomical Latitude (deg) decimal implied after second digit (N/A for optical sensor) + = North - = South
14-22	-360 to 360	F9.0	Astronomical Longitude (deg) decimal implied after third digit (N/A for optical sensor) + = West - = East
23-31		F9.0	ECR Position X (meters) / EFG Position X (meters) / LLH - sensor latitude (deg)
32-40		F9.0	ECR Position Y (meters) / EFG Position Y (meters) / LLH - sensor longitude (deg)
41-49		F9.0	ECR Position Z (meters) / EFG Position Z (meters) / LLH - sensor height (meters)
52	'U', 'C' or 'S'	A1	Classification of location, where 'U' = Unclassified 'C' = Confidential 'S' = Secret
54-57		A24	Sensor location description (optional)
79-80	' S'	A2	Format type (required)

NOTE: The principal direction of the X-axis is in the direction of the Greenwich meridian, and the Z-axis is positive along the North Pole.

5.1.2. Orbiting Sensor OS- / MS-Card, Format#1:

The '**OS**' card and the 'MS' card are special versions of the sensor locations '**S**' cards. Whereas the '**S**' card is used to define a fixed-location of a ground-based sensor, the **OS** and **MS** cards are used to indicate movement of mobile and orbiting sensors. Mobile sensors can be on ground or in air, such as a sensor mounted to a ground vehicle or aboard an aircraft. Orbiting sensor movement is established by indicating the 5-digit Space Control Center Identification (SCCID) number, or Satellite Number, upon which the sensor operates. Shown below is an example of an **OS** card for an orbiting sensor. Sensor 511 uses the fixed-format of the OS card for which only the 5-digit satellite number is included.

```
*        1         2         3         4         5         6         7         8
*2345678901234567890123456789012345678901234567890123456789012345678901234567890
511 42921                                          U  ORS-5                    OS
```

Column	Range	Format	Description
1-3	1-998	I3	Sensor number
5-9	1-99999	I5	Satellite number of orbiting sensor
52	'U', 'C' or 'S'	A1	Classification of location
54-57		A24	Description/narrative/notes
79-80	'OS'/ 'MS'	A2	Format type (required)

5.1.3. Orbiting Sensor OS- / MS-Card, Format#2 (Free-Format Style):

Sensor 504, as shown below, uses the optional free-format '**OS**' card that includes the use of '**SAT**' or '**SATELLITE**' preceding the 5-digit satellite number for the sensor. Note that Sensor Number 504 is not a ground-sensor, but rather a space-based orbiting sensor.

```
*        1         2         3         4         5         6         7         8
*2345678901234567890123456789012345678901234567890123456789012345678901234567890
504 SAT 37168                                      U  Block 10 (EO, DS)        OS
```

Column	Range	Format	Description
1-3	1-998	I3	Sensor number
*****			'SAT'/'SATELLITE' Identifier (any column before col 45)

*****	1-99999	I5	Satellite number (any column after above)
52	'U', 'C' or 'S'	A1	Classification of location, where 'U' = Unclassified 'C' = Confidential 'S' = Secret
54-57		A24	Description/narrative/notes
79	Any but 'B' or 'U'	A1	Optional part of format type; anything but 'B' or 'U' is allowed, but 'O' or 'M' preferred for readability (software format recognition logic keys on 'SAT' identifier and 'S' in col. 80, and ignores col. 79 once it
80	'S'	A1	Format type (required)

5.1.4. Sensor MS Card (mobile sensor, ground- sea- or air-based)

The Look Angles Module (LAMOD) determines at which angles and times a given sensor will have observing opportunity for a particular satellite. The observing sensor may be Earth-fixed or orbiting. In the case of mobile sensors (e.g., airborne, ship at sea, or ground mobile), a means is necessary to convey the position of the sensor as a function of time. The MS card and its associated parameters are used for that purpose. Movement of a mobile sensor is done via specification of waypoints (latitude, longitude points), or constant speed and heading. Mobile sensors with a constant heading that traverse longitude meridians at the same angle are also known as *loxodromic* mobile sensors. **Figure 1** shows the ground trace of an object moving along the Earth surface in a constant heading of angle β with respect to the meridians that follows a rhumb line cutting all meridians at the same angle and thereby eventually finding the North Pole.

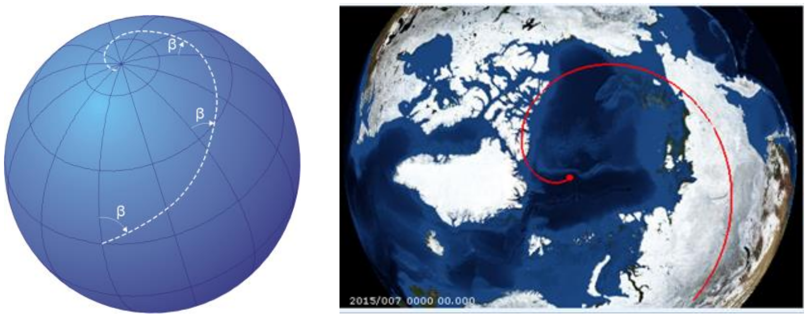


Figure 1:Loxodormic Rhumb-Line Mobile Sensor Path of Constant Heading β

Mobile sensor identification and movement uses the same mechanism as the Orbiting Sensor (OS) Card. The MS Card is structured like the OS fixed card. The MS card allows for a 3-digit number for the sensor number and up to 5-digits for the mobile sensor ID. The fixed MS format is used for mobile sensors such that no term such as 'SAT' or 'SATELLITE' is used in the MS specification. **Figure 2** shows example MS cards for two mobile sensors. Sensor 111 identifies the sensor aboard the USS Carl Vinson, with 11111 as the mobile identifier that correlates that sensor number to the path the mobile sensor will follow. Sensor 222 represents a mobile sensor aboard a Boeing 747 with flight path according to mobile ID 22222. **Figure 3** shows the format and contents of the MS card.

```
*         1         2         3         4         5         6         7         8
*2345678901234567890123456789012345678901234567890123456789012345678901234567890
111 11111                                         U  USS Carl Vinson          MS
222 22222                                         U  Boeing 747               MS
```

Figure 2. Mobile Sensor MS Card Examples

```
   MOBILE SENSOR, FIXED FORMAT

   Column    Format               Description

==================================================================

   1-3    I3                 Sensor number (1 – 998)
   5-9    I5                 Mobile Sensor ID
    51    A1                 Classification of Mobile Sensor (U,C,S)
 54-77    A24                Description / Name of Mobile Sensor
 79-80    A2                 'MS' Format type (required)
```

Figure 3. Mobile Sensor MS Card Format and Contents

5.1.5. Mobile Sensor External Ephemeris File for Heading Constant Speed

There are two ways primary ways to specify the path (mobile route) of a mobile sensor:

1) Heading, Constant Speed

Time, Starting Location (Lat, Lon), and if applicable Height (0 km for ground- or sea-based mobile; > 0 km for airborne mobile), Heading (azimuth direction), and Constant Speed [km/hr]; where the path of the mobile sensor can follow a rhumb line or a great circle path. *Rhumb-line* transit is covered in **Section 5.1.4**. Conversely, Great circle path is commonly used for navigation because it represents the shortest distance between two points on a sphere (such as Earth).

2) Times and Waypoints (MS Card):

Time, Latitude, Longitude for each waypoint, and if applicable Height (in the case of an airborne mobile sensor moving through the waypoints; height expressed in units of km). As with Heading Constant Speed configuration, the path of a mobile sensor traversing Waypoints can be configured to travel either a rhumb line or great-circle course.

In either case, an external ephemeris file is needed to specify the path of the mobile sensor. **Figure 4** shows the External Ephemeris files for the US Carl Vinson (Sensor Number 111, Mobile Sensor ID 11111), and the Boeing 747 (Sensor Number 222, Mobile ID 22222):

```
*S_EXTEPHEM_V1.0 FFF SSSSSSSSS CCCCC

AS_EXTEPHEM_V1.0 FIX      11111 HCSGC

*        1         2         3         4         5         6         7         8         9         10        11

*2345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456
5678

*2345678901234567|1234567890123456789|1234567890123456789|1234567890123456789|1234567890123456789|1234567890123456
789|

*YYYDDDHHMMSS.SSS|       LAT deg      |       LON deg      |    Height Km      |Heading Azimuth deg| Ground speed
km/hr|

2015006000000.000          0.0000000           0.0000000                 0.0                87.5              55.5
```

```
*S_EXTEPHEM_V1.0 FFF SSSSSSSSS CCCCC

AS_EXTEPHEM_V1.0 FIX     22222 HCSRL

*        1         2         3         4         5         6         7         8         9         10        11

*234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678

*2345678901234567|1234567890123456789|1234567890123456789|1234567890123456789|1234567890123456789|1234567890123456789|

*YYYDDDHHMMSS.SSS|      LAT deg      |      LON deg      |     Height Km     |Heading Azimuth deg| Ground speed km/hr|

2015006000000.000          0.0000000           0.0000000               9.145                87.5           940.0
```

Figure 4. Mobile ID associates Sensor to Starting Location, Heading, Constant Speed (HCS)

In this example, both sensors start out at the same time and location at 0° Lat 0° Lon with heading 87.5° azimuth. The Carl Vinson is moving on the surface (0 km altitude) at 55.5 km/hr (~35 mph). The Boeing 747 has altitude of 9.145 km (~30,000 ft) and speed 940 km/hr (~585 mph). The file names (which are not depicted in Figure 11) for the two external ephemeris files are 11111.hcs and 22222.hcs, respectively. The prefixes of the external ephemeris files correspond to the mobile sensor ID for each sensor, and the .hcs file-name suffix indicates the files contain heading, constant speed specifications for each sensor. Note that in the examples above, the USS Carl Vinson with Mobile ID 11111 is configured to follow a Great Circle path (ref. 'HCSGC'), and the Boeing 747 with Mobile ID 22222 is configured to follow a Rhumb Line path (ref. 'HCSRL').

Figure 5 shows format definitions of external ephemeris files of type .hcs. This format correlates to the example external ephemeris files depicted in Figure 11, where the text lines of Figure 11 with '*' in column 1 are ignored by the processing.

```
Column  Format LINE 1 Description
============================================================================
 1-13   A13   'AS_EXTEPHEM_V'
14-16   A3    '1.0' designates Universal Format for either ECI, J2K,
               EFG, ECR, LLH, SEN, HCS, WPT ephemeris data types
18-20   A3    'FIX' or 'CSV'
26-30   I5     Sensor Id
32-34   A5    'ECI' Earth-Center Inertial Vector Ephemeris File
              'J2K' J2000 Vector Ephemeris File
              'EFG' Earth-Fixed Greenwich Vector Ephemeris File
              'ECR' Earth-Centered Rotating Vector Ephemeris File
              'LLH' Specific Location for Volume Penetration Report (VPR)
              'SEN' Sensor Location in ECR and an offsite vector (r, az, el)
              'HCSGC' Mobile Sensor Current Position w/Heading, Constant Speed
                      that follows Great Circle path
              'HCSRL' Mobile Sensor Pos Heading Constant Speed Rhumb Line path
              'WPTGC' or 'WPTRL' Waypoints w/Time, Lat, Lon, Height, Great
                      Circle or Rhumb Line path
Column  Format   LINE 2 Description, type 'HCSGC' Heading Constant Speed
============================================================================
 1-17   A17      Mobile Sensor Epoch Time, YYYYDDDHHMMSS.SSS format
19-37   F*       Epoch Latitude (deg)
39-57   F*       Epoch Longitude (deg)
59-77   F*       Epoch Height (km)
79-97   F*       Heading Azimuth (deg)
99-117  F*       Constant Ground Speed (km/hr)
```

Figure 5. AS_EXTEPHEM_V1.0 External Ephemeris File Format, Type HCS

Figure 6 depicts the relationship between information in the MS card for the USS Carl Vinson (Sensor Number 111, Mobile ID 11111) that is associated to external ephemeris file '11111.hcs'. The prefix of the file name is the mobile ID. The '.hcs' suffix indicates the external ephemeris file is of format for Time, Location, Heading, Constant Speed (HCS).

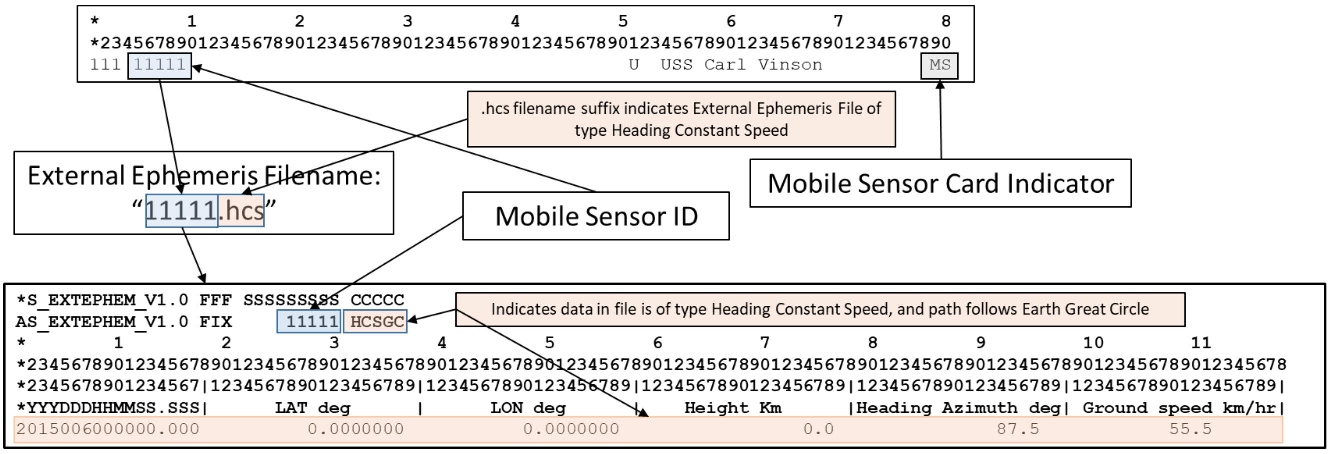


Figure 6: Relationship between MS Card and External Ephemeris File Type HCS

5.1.6. Mobile Sensor External Ephemeris File for Times and Waypoints

As previously shown by **Figure 2**, the primary purpose of the MS card is to associate a Sensor Number with its Mobile Sensor ID and further to provide a mechanism, i.e., via the Mobile Sensor ID, to the external ephemeris file that defines the mobile sensor's specific path. The previous section explains how mobile sensors with Heading and Constant Speed are configured. This section explains how to configure a mobile sensor that moves through times and waypoints.

Figure 7 provides an updated configuration for the Boeing 747 airborne sensor of the previous example. In this case, the same sensor is configured to follow times and waypoints on a Great Circle (GC) path (reference 'WPT**GC**' specification on line 1). The information shown in **Figure 7** would be configured in an external ephemeris file with file name '22222.wpt' where the .wpt extension indicates it contains waypoint times, and waypoint locations and altitudes.

```
*S_EXTEPHEM_V1.0 FFF SSSSSSSSS CCCCC
AS_EXTEPHEM_V1.0 FIX     22222 WPTGC
*         1         2         3         4         5         6         7         8         9
*234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
*2345678901234567|12345679012345678901234567890123456789012345678901234567890123456789|1234567890123
*YYYDDDHHMMSS.SSS         |       LAT deg        |       LON deg        |    Height Km       |
2015006000000.000                   2.000000             2.000000             9.145000
2015006003000.000                   2.000000            -2.000000             9.145000
2015006010000.000                  -2.000000            -2.000000             9.145000
2015006013000.000                  -2.000000             2.000000             9.145000
```

```
2015006020000.000                  2.000000             2.000000
9.145000
```

Figure 7. Mobile ID associates Sensor to Times, Waypoints, and Heights

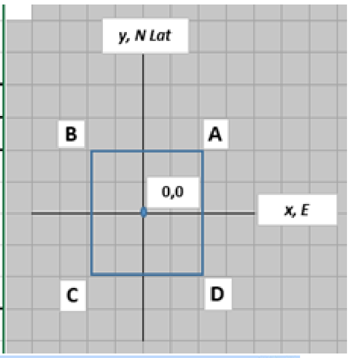
```
Column   Format   LINE 1 Description (reference Figure 12)
Column   Format   LINE 2+ Description, type 'WPTGC' Times and Waypoints
```

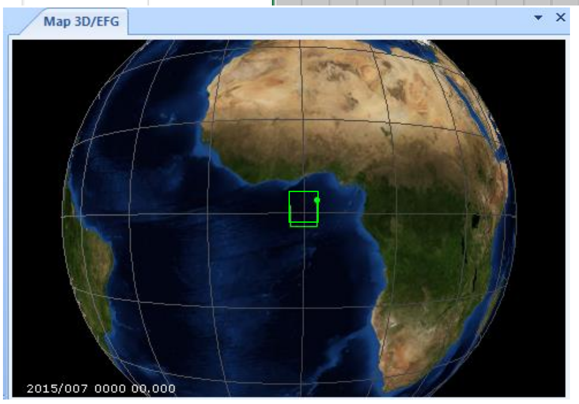
```
================================================================================
 1-17   A17       Waypoint Time, YYYYDDDHHMMSS.SSS format
28-46   F*        Waypoint Latitude (deg)
48-66   F*        Waypoint Longitude (deg)
68-86   F*        Waypoint Altitude (km)
```

Figure 8. AS_EXTEPHEM_V1.0 External Ephemeris File Format, Type WPT

Figure 9 shows how the waypoint latitudes and longitudes configured as depicted in **Figure 7** for an airborne mobile sensor layout against the Globe. The waypoints set the mobile sensor on a course that maps out a square centered on 0° Latitude, 0° Longitude and with altitude 9.145 km (~30,000 feet). Note that in the case of a mobile sensor moving through specified times and waypoints, no *speed* need be specified, as the speed is inherently defined by the distance between the waypoints to be covered during the time points specified. Also, note that to map out a square mobile-sensor path, *5 points* must be specified to ensure look angles are generated for the sensor's return back to its original starting location.

	N. Lat	E. Lon
	y	x
A	2.000	2.000
B	2.000	-2.000
C	-2.000	-2.000
D	2.000	-2.000
A	2.000	2.000





Note: Ref. http://www.nhc.noaa.gov/gccalc.shtml

Latitude/Longitude Distance Calculator, the line segment AB of the square above specified by the (E lon, N lat) ordered pairs, is **444 km** (240 nautical/air miles). Therefore, in ***1/2 hour (30 minutes)*** the Boeing 747 will traverse the segment between the waypoints at a speed of **888 km/hr** (480 nm/hr or **552 statute miles/hour**).

Figure 9. Ground-Trace for Airborne Mobile Sensor through Times and Waypoints

5.2. Sensor Limits Data Formats

5.2.1. 1L-Card Format:

Sensor limits define the range of metric observation measurements in terms of angles (azimuth and elevation or right ascension and declination), distance relative to the sensor (range), and how quickly the sensor can move within its defined ranges (azimuth rate, elevation rate, and range rate). Included with the limits is other essential information about the sensor including its coverage type, the type of metrics included with its observations, the boresight pointing in the case of a space-based sensor, and other controls such as optical visibility pass control. Parameters and controls of the 1L card are nearly always coupled with additional limits and settings of the 2L card, covered in the next sections.

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
6		A1	Sensor viewing type (also called "coverage type"): 0 = (zero) constant elevation type (reverts to 3) 1 = non-constant elevation fan (reverts to 3) 2 = bounded-cone tracker (conical sensor) 3 = conventional tracker 4 = optical tracker 5 = general fan defined by 2 unit vectors (reverts to 3) 6 = constant azimuth fan sweeping to vertical (reverts to 3) 7 = constant azimuth fan sweeping vertical plane (available since v9.2) 9 = orbiting sensor (also "M" or "O")
7		A1	Sensor Observation Type; where: 0 = range-rate only 1 = azimuth, elevation 2 = azimuth, elevation, range 3 = azimuth, elevation, range, range-rate 4 = same as 3 with az-rate, el-rate 5 = right ascension, declination 6 = range only 7 = rotating EFG vector

			8 = azimuth, elevation, and sensor rotating EFG vector 9 = right ascension, declination, and sensor rotating EFG vector V = ECI position/velocity vector P = ECI position vector M= same as 8, with range added O= same as 9, with range added
8		I1	Units on range and range-rate; where: 0 = km, km/sec 1 = nm, nm/sec
9		I1	Special case for mobile sensor (ground- sea- or air-based) 0 = non mobile sensor 1 = mobile sensor
10-15	0 to 9.E9	F6.0	Max observable range (km)
16		A1	Orbiting sensor boresight vector; where: N/A for ground based sensor, so typically left blank; blank = no limits in orbiting sensor case N = D = 'Down' or Nadir (to geocenter) U = 'Up'; anti-nadir (from geocenter) F = V = A = 'Ahead', direction of Velocity, Forward B = 'Back', opposite of velocity vector W = L = 'Left', direction of W-vector R = 'Right' opposite of W-vector
17-20	-90 to 90 0-180	F4.0	• Elevation limit #1 (low, deg) [-90] OR • Orbiting sensor off-boresight angle (0-90) OR • Conical sensor boresight elevation angle
22-25	90 to 90 0-180	F4.0	• Elevation limit #2 (high, deg) [90] OR • Orbiting sensor off-boresight angle (0-90) OR • Conical sensor minimum elevation angle

27-31	0 to 360 preferred, but see note	F5.0	• Azimuth limit #1 (left, deg) OR • Orbiting sensor clock angle (0-360) OR • Conical sensor boresight azimuth angle
33-37	0 to 360 preferred, but see note	F5.0	• Azimuth limit #2 (right, deg) OR • Orbiting sensor clock angle (0-360) OR • Conical sensor off-boresight azimuth angle (0-90)
39-45		F6.0	Output interval (min) [1.0] Note: This flag could be overwritten by the LAMOD's 1P-Card/column 17-20 unless that column is set to 0 (see LAMOD document)
49		I1	Visual pass control flag (for ground-based optical sensors only); where: 0 = accept all passes, regardless of optical visibility 1 = accept optically visible passes only 2 = same as 1, with solar aspect angle restrictions (if missing from P-card, will compute from solar exclusion angle) 3 = (for IR sensors) sensor must be in dark, but no restriction on satellite, since it glows in the infrared even when not illuminated Note: This flag could be overwritten by the LAMOD's 1P-Card/column 66 unless that column is set to 9 (see LAMOD document)
55		I1	Range limits control flag; where: 0 = apply min/max range limits 1 = accept passes regardless of range
59-61	0 to 999	I3	Maximum number of points per pass (0=unlimited)
63-67	0 to 99999	F5.0	Minimum range limit (km)
71		I1	Orbiting sensor planetary restrictions: 0 = all (sun, moon, & earth) 1 = earth only 2 = moon only 3 = sun only 4 = sun and moon only 5 = none; allow any interference

73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

NOTE: For azimuth fields, 0. to 360. is preferred, but anything that fits in 5-character field is accepted, being subjected to a modulo 360 degrees regularization.

5.2.2. 2L-Card Format (optional: if present, must be preceded by 1L card):

The limits of the optional 2L card provide a mechanism for specifying a second set of sensor limits. If a second set of limits is specified for a given sensor, the specification must be preceded by a first set of limits for that sensor as described previously.

Unlike the first set of limits, the second set allows for specifying the boresight pointing definition of an orbiting sensor. Correct boresight vector specification of an orbiting sensor is essential for generating proper sensor-satellite look angles as the sensor/satellite moves through its orbit while scanning other objects that enter its Field of View. The second set of limits also include settings for various viewing and lighting restrictions to be applied in modeling the sensor for satellite look-angle generation. In particular, these include the Earth limb exclusion distance, and solar and lunar exclusion angles. These restrictions ensure the sensor-satellite geometry is not occluded by viewing through Earth's atmosphere, or by the sensor looking too directly toward the light of the Sun or Moon, that in turn affects the sensor's ability to acquire objects against the background sky.

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
16		A1	Orbiting sensor boresight vector; where: N/A for ground based sensor, so typically left blank; blank = no second boresight limits N = D = 'Down' or Nadir (to geocenter) U = 'Up'; anti-nadir (from geocenter) F = V = A = 'Ahead', direction of Velocity, Forward B = 'Back', opposite of velocity vector W = L = 'Left', direction of W-vector R = 'Right' opposite of W-vector
17-20	-90 to 90 0-180	F4.0	• Elevation limit #3 (low, deg) OR • Orbiting sensor off-boresight angle (0-90)

22-25	90 to 90 0-180	F4.0	• Elevation limit #4 (high, deg) OR • Orbiting sensor off-boresight angle (0-90)
27-31	0 to 360 preferred, but see note	F5.0	• Azimuth limit #3 (left, deg) OR • Orbiting sensor clock angle (0-360)
33-37	0 to 360 preferred, but see note	F5.0	• Azimuth limit #4 (right, deg) OR • Orbiting sensor clock angle (0-360)
43		I1	Flag; if set, allow orbiting sensor to view satellite against the earth background [0]
45-49		F5.0	Orbiting sensor earth limb exclusion distance (km) [100]
51-55		F5.0	Optical sensor solar exclusion angle (deg) [30] (Can also be used to compute solar aspect angle, if missing from P-card)
57-61		F5.0	Orbiting sensor lunar exclusion angle (deg) [15]
63-67		F5.0	Orbiting sensor min illumination angle (deg) [90]
69-73		F5.0	Ground site twilight offset angle (deg) [6.25]
79-80	'2L'	A2	Identifier/Format type (required)

NOTE: For azimuth fields, 0. to 360. is preferred, but anything that fits in 5-character field is accepted, being subjected to a modulo 360 degrees regularization.

5.3. Sensor Limits Data Formats (categorized by sensor type)

5.2.1 Conventional Tracker/Radar

5.2.1.1 1L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
6		A1	3 = conventional tracker
7		A1	Sensor Observation Type

8		I1	Units on range and range-rate
9		I1	Special case for mobile sensor (ground- sea- or air-based)
10-15	0 to 9.E9	F6.0	Max observable range (km)
17-20	-90 to 90	F4.0	• Elevation limit #1 (low, deg) [-90]
22-25	90 to 90	F4.0	• Elevation limit #2 (high, deg) [90]
27-31	0 to 360	F5.0	• Azimuth limit #1 (left, deg)
33-37	0 to 360	F5.0	• Azimuth limit #2 (right, deg)
39-45		F6.0	Output interval (min) [1.0]
55		I1	Range limits control flag; where
59-61	0 to 999	I3	Maximum number of points per pass (0=unlimited)
63-67	0 to 99999	F5.0	Minimum range limit (km)
73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

5.2.1.2 2L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
17-20	0 to 90	F4.0	• Elevation limit #3 (low, deg)
22-25	0 to 90	F4.0	• Elevation limit #4 (high, deg)
27-31	0 to 360	F5.0	• Azimuth limit #3 (left, deg)
33-37	0 to 360	F5.0	• Azimuth limit #4 (right, deg)
79-80	'2L'	A2	Identifier/Format type (required)

5.2.2 Bounded-Cone Tracker/Conical Sensor (1L-Card Format only)

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
6		A1	Sensor viewing type (also called "coverage type"): 2 = bounded-cone tracker (conical sensor)
7		A1	Sensor Observation Type
8		I1	Units on range and range-rate
10-15	0 to 9.E9	F6.0	Max observable range (km)
17-20	0 to 90	F4.0	• Conical sensor boresight elevation angle
22-25	0 to 90	F4.0	• Conical sensor minimum elevation angle
27-31	0 to 360	F5.0	• Conical sensor boresight azimuth angle
33-37	0 to 90	F5.0	• Conical sensor off-boresight angle (half-cone angle)
39-45		F6.0	Output interval (min)
55		I1	Range limits control flag
59-61	0 to 999	I3	Maximum number of points per pass (0=unlimited)
63-67	0 to 99999	F5.0	Minimum range limit (km)
73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

5.2.3 Optical Sensor (ground-based sensor)

5.2.3.1 1L-Card Format

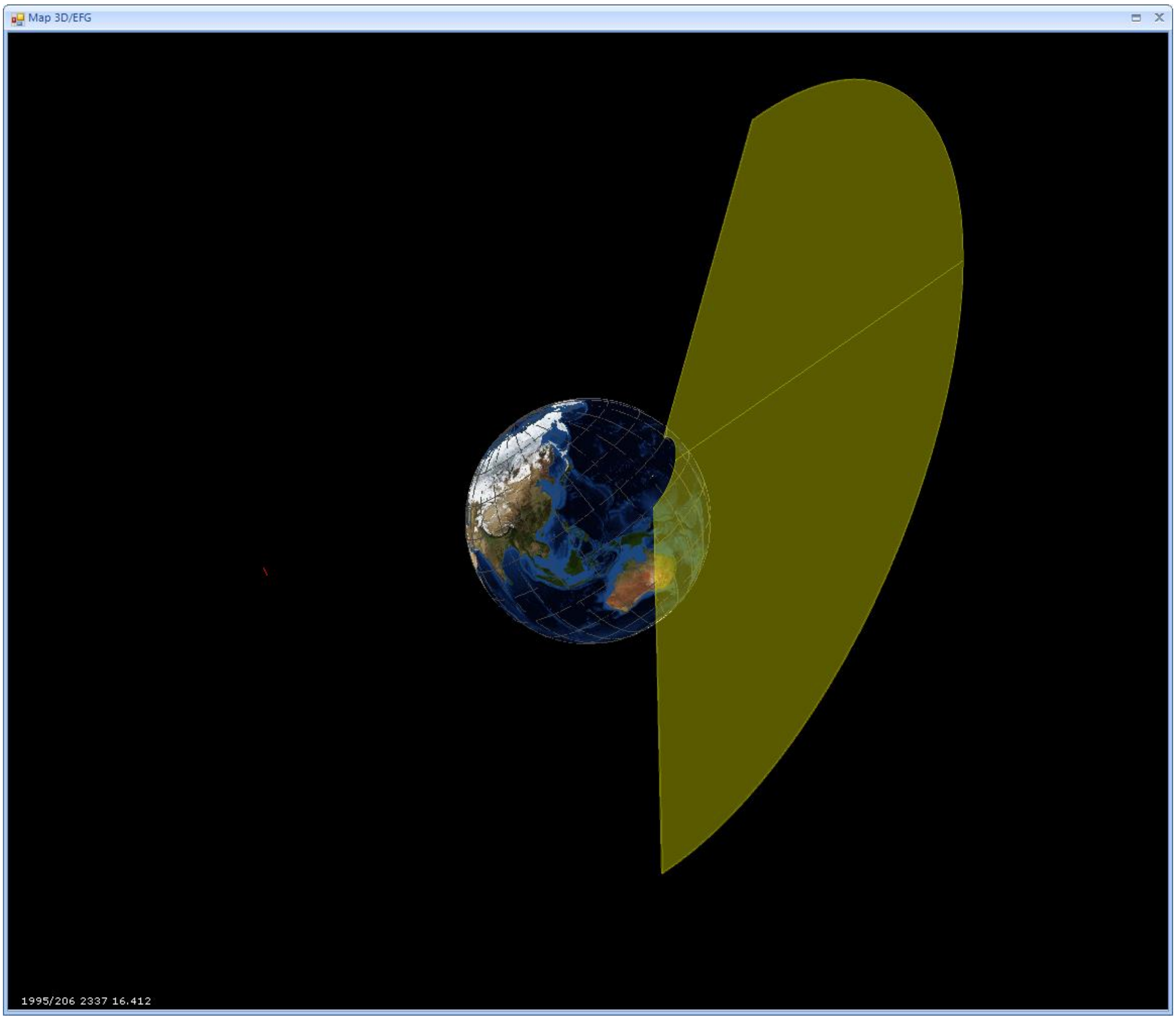
Column	Range	Format	Description
3-5	1-998	I3	Sensor number

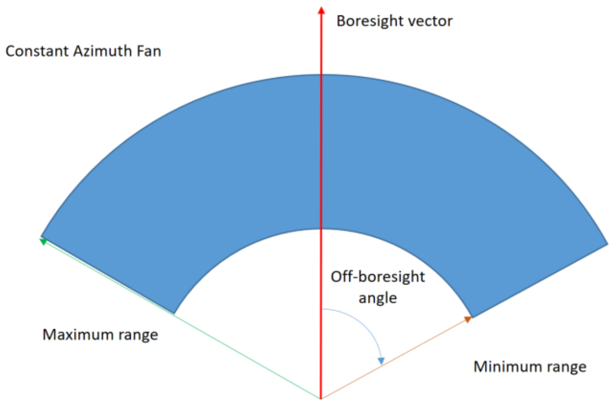
6		A1	Sensor viewing type (also called "coverage type"): 4 = optical tracker
7		A1	Sensor Observation Type
8		I1	Units on range and range-rate
9		I1	Special case for mobile sensor (ground- sea- or air-based)
10-15	0 to 9.E9	F6.0	Max observable range (km)
17-20	0 to 90	F4.0	• Elevation limit #1 (low, deg)
22-25	0 to 90	F4.0	• Elevation limit #2 (high, deg)
27-31	0 to 360	F5.0	• Azimuth limit #1 (left, deg)
33-37	0 to 360	F5.0	• Azimuth limit #2 (right, deg)
39-45		F6.0	Output interval (min)
49		I1	Visual pass control flag (for ground-based optical sensors only); where: 0 = accept all passes, regardless of optical visibility 1 = accept optically visible passes only 2 = same as 1, with solar aspect angle restrictions (if missing from P-card, will compute from solar exclusion angle) 3 = (for IR sensors) sensor must be in dark, but no restriction on satellite, since it glows in the infrared even when not illuminated Note: This flag could be overwritten by the LAMOD's 1P-Card/column 66 unless that column is set to 9 (see LAMOD document)
55		I1	Range limits control flag
59-61	0 to 999	I3	Maximum number of points per pass (0=unlimited)
63-67	0 to 99999	F5.0	Minimum range limit (km)
73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

5.2.3.2 2L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
17-20	0 to 90	F4.0	• Elevation limit #3 (low, deg)
22-25	0 to 90	F4.0	• Elevation limit #4 (high, deg)
27-31	0 to 360	F5.0	• Azimuth limit #3 (left, deg)
33-37	0 to 360	F5.0	• Azimuth limit #4 (right, deg)
51-55		F5.0	Optical sensor solar exclusion angle (deg) [30] (Can also be used to compute solar aspect angle, if missing from P-card)
69-73		F5.0	Ground site twilight offset angle (deg) [6.25]
79-80	'2L'	A2	Identifier/Format type (required)

5.2.4 Constant Azimuth Fan (ground-based sensor)





5.2.4.1 1L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
6		A1	Sensor viewing type (also called "coverage type"): 7 = constant azimuth fan
7		A1	Sensor Observation Type
8		I1	Units on range and range-rate
10-15	0 to 9.E9	F6.0	Max observable range (km)
17-20	0 to 90	F4.0	N/A Note: From v9.3 on, this parameter is no longer applied to constant azimuth fan. Since the fan can be tilted to the point it coincides with the local horizontal plane (tilt angle = +/- 90 degrees), the minimum elevation, if not set to a negative value, can inadvertently affect the result
22-25	0 to 90	F4.0	Fan's tilt angle (deg), where: • Negative value: tilt to the north or west (0 azimuth) side • Positive value: tilt to the south or east (0 azimuth) side Note: This constant azimuth fan can be tilted to either side of the vertical plane
27-31	0 to 360	F5.0	Fan's constant azimuth (deg)
33-37	0 to 90	F5.0	Fan's off-boresight angle (deg) [90]
55		I1	Range limits control flag
63-67	0 to 99999	F5.0	Minimum range limit (km)
73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

5.2.4.2 2L-Card Format (Not applicable for Constant Azimuth Fan)

5.2.5 Orbiting Sensor

5.2.5.1 1L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
6		A1	Sensor viewing type (also called "coverage type"): 9 = orbiting sensor
7		A1	Sensor Observation Type
8		I1	Units on range and range-rate
10-15	0 to 9.E9	F6.0	Max observable range (km)
16		A1	Orbiting sensor boresight vector; where: blank = no limits in orbiting sensor case N = D = 'Down' or Nadir (to geocenter) U = 'Up'; anti-nadir (from geocenter) F = V = A = 'Ahead', direction of Velocity, Forward B = 'Back', opposite of velocity vector W = L = 'Left', direction of W-vector R = 'Right' opposite of W-vector
17-20	0 to 90	F4.0	• Orbiting sensor off-boresight angle – low elevation limit #1
22-25	0 to 90	F4.0	• Orbiting sensor off-boresight angle – high elevation limit #1
27-31	0 to 360	F5.0	• Orbiting sensor clock angle – low azimuth limit #1
33-37	0 to 360	F5.0	• Orbiting sensor clock angle – high azimuth limit #1
39-45		F6.0	Output interval (min)
55		I1	Range limits control flag
59-61	0 to 999	I3	Maximum number of points per pass (0=unlimited)
63-67	0 to 99999	F5.0	Minimum range limit (km)

71		I1	Orbiting sensor planetary restrictions: 0 = all (sun, moon, & earth) 1 = earth only 2 = moon only 3 = sun only 4 = sun and moon only 5 = none; allow any interference
73-77		F5.0	Range-rate/relative velocity limit (km/sec)
79-80	'1L'	A2	Identifier/Format type (required)

5.2.5.2 2L-Card Format

Column	Range	Format	Description
3-5	1-998	I3	Sensor number
16		A1	Orbiting sensor boresight vector; where: blank = no second boresight limits N = D = 'Down' or Nadir (to geocenter) U = 'Up'; anti-nadir (from geocenter) F = V = A = 'Ahead', direction of Velocity, Forward B = 'Back', opposite of velocity vector W = L = 'Left', direction of W-vector R = 'Right' opposite of W-vector
17-20	0 to 90	F4.0	• Orbiting sensor off-boresight angle – low elevation limit #2
22-25	0 to 90	F4.0	• Orbiting sensor off-boresight angle – high elevation limit #2
27-31	0 to 360	F5.0	• Orbiting sensor clock angle – low azimuth limit #2
33-37	0 to 360	F5.0	• Orbiting sensor clock angle – low azimuth limit #2
43		I1	Flag; if set, allow orbiting sensor to view satellite against the earth background [0]

45-49		F5.0	Orbiting sensor earth limb exclusion distance (km) [100]
51-55		F5.0	Orbiting sensor solar exclusion angle (deg) [30]
57-61		F5.0	Orbiting sensor lunar exclusion angle (deg) [15]
63-67		F5.0	Orbiting sensor min illumination angle (deg) [90]
79-80	'2L'	A2	Identifier/Format type (required)

5.4. Sensor Weights (sigmas) and Biases Data Formats.

'BS' cards and their contents define the sensor's biases and sigmas (also known as *weights*). *Biases* are determined through the sensor calibration process and are used to correct-out known biases (errors) in the sensor's reported observation data (e.g. azimuth, elevation, or range). Operationally sensor biases are determined periodically every 10 days or so by the sensor calibration process. *Sigmas/weights* are indicative of the relative qualities of measurements provided by the sensors. For example, Optical sensors tend to give more accurate angle measurements (azimuth, elevation) than do Radars. Sigmas are *primarily* used in the least squares weighted differential correction (DC) process used to optimally-fit the recent metric observations to a new computed orbit. Also, some optical sensors and Radars give better-quality measurements than other sensors and therefore are weighted more heavily in the DC orbit determination process. The figure below gives the decoder for the format and contents of the BS cards.

BS (Bias/Sigma)-Card Format:

Column	Range	Format	Description
1-3	1-998	I3	Sensor number
5		A1	Sensor observation type, identical to column 7 of 1L-Card, which see for details. Provided for convenience of application not having convenient access to L-Card data.
8-14		F7.3	Azimuth/RtAsc sigma, deg
15-21		F7.3	Elevation/Decl sigma, deg
22-28		F7.3	Range sigma, km
29-35		F7.3	Range-rate sigma, km/sec
37-44		F8.3	Azimuth/RtAsc bias, deg
45-52		F8.3	Elevation/Decl bias, deg

53-60		F8.3	Range bias, km
61-68		F8.3	Range-rate bias, km/sec
69-76		F8.3	Time bias, sec
79-80	'BS'	A2	Format type (required)

NOTE: Names and terminology inherited from legacy source code are confusing. The external format (BS-card record) contains sigmas (standard deviations). These are initially read by subroutine SENSOR_READ into the xxSIGMA structure elements (xx = AZ, EL, RG, RR). But then each xxSIGMA, if non-zero, is immediately replaced by its inverse and the units are changed to internal units, so that from then on internally the xxSIGMA elements are weights, not sigmas.

5.5. Sensor Suppress Data Format.

US (Sensor Data Suppress)-Card Format:

Column	Range	Format	Description
1-3	1-998	I3	Sensor number
8		A1	'A' or 'D' = suppress all data (L/W/B/L) 'P' = suppress location data only 'W' = suppress weight/sigma data only 'B' = suppress bias data only 'L' = suppress limits data only
9		A1	'P' or 'W' or 'B' or 'L': see above
10		A1	'P' or 'W' or 'B' or 'L': see above
79-80	'US'	A2	Format type (required)

5.5.1. 3L-Card Format (optional: up to 128 additional sets of sensor limits):

The sensor 3L Card and its associated sensor configuration data and settings are new for V8.0 Astro Standards. The 3L Card and sensor limits specification include azimuth and elevation ranges for both Dome and Cone FoV segment definitions. The Dome-segment specification in particular was needed to allow proper configuration of the ORS-5 orbiting sensor, deployed in recent years as a bridge capability in anticipation of SBSS Block-20 being planned to replace the legacy SBSS Block 10 orbiting sensor.

With the proliferation of commercial and military space sensor/satellite deployments, the additional limits specifications afforded by the 3L card offer considerable flexibility for configuring complex space-based sensor FoVs. Where there can be only one instance of a 1L card and a 2L card configuration can only be present if there is a 1L card, the 3L card allows for up to 128 additional sets of sensor limits specifications. The 3L card and associated settings should be used in cases of sensors with multiple fields of view, and each field of view must be specified separately.

Figure 10 shows the orbiting sensor location (OS specification) and 1L, 2L, and 3L limits specifications for the ORS-5 Sensorsat.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
511  42921                                                    ORS-5                   OS
  5119900.00000 .000 90.0 .0000 360.0 1.00000    1      1 0    0 .0000    0 .0000 1L
  511                                 0 0 0 .0000 45.00 .0000 90.00 .0000      2L
  511   85.00   95.00   18.00   22.00                                         D 3L
```

Figure 10. ORS-5 Sensor Dome Segment FoV Limits Specifications Example

The OS, 1L, and 2L cards are described in Sections 2.1.2, 2.1.5, and 2.1.6. The 3L allows specification of two-new segment definition types; where 'D' indicates Dome segment definition according to the elevation and azimuth range specifications included with the 3L, or 'C' indicates Cone segment definitions according to the elevation and azimuth specifications.

5.6. Sample Sensor Data File (unclassified).

[Note: Formerly, a blank record in-line in a in run specification file was treated, for backwards-compatibility reasons, as an end-of-job indicator; now it is treated as a comment and ignored. Currently a sensor file (also limits file) record beginning with the Astro Standard comment character, asterisk ("*") is treated as a comment and ignored. Currently a sensor file record that is blank is treated as an end of file indicator and all subsequent records are ignored. TBD is whether this logic too will be changed so that blank records in sensor files will simply be ignored. Be aware of possible change in this area when composing sensor files or using old sensor files.]

Copy

```
200   3382167  10665666 -1520767 -5082948  3530885 PU SOCORRO NM ETS              S
211   3381724  10666030 -1521161 -5083089  3530462  U CAMERA 1,SOCORRO            S
212   3381736  10665983 -1521119 -5083101  3530461  U CAMERA 2,SOCORRO            S
213   3381702  10665989 -1521128 -5083113  3530441  U CAMERA 3,SOCORRO            S
215   3381723  10666030 -1521161 -5083089  3530461  U SOCORRO NM                   S
230   2071126  15626028 -5466020 -2403936  2242596  U GEODSS - MAUI                S
231   2071126  15626059 -5466032 -2403906  2242596  U SENSOR 1 MAUI                S
232   2070800  15625760 -5466040 -2404246  2242266  U SENSOR 2 MAUI                S
233   2070850  15625760 -5466022 -2404241  2242316  U SENSOR 3 MAUI                S
235   2070801  15625794 -5466053 -2404217  2242266 PU MAUI GEODSS                  S
240   -741159  28754810  1907068  6030998  -817291  U DIEGO GARCIA                 S
241   -741159  28754810  1907068  6030998  -817291  U DIEGO GARCIA                 S
242   -741159  28754810  1907068  6030792  -817291  U DIEGO GARCIA                 S
243   -740971  28754444  1906712  6030998  -817087  U DIEGO GARCIA                 S
245   -741165  28754809  1907068  6030791  -817291 PU DIEGO GARCIA - GENERIC       S
```

```
329  6429361  14919610 -2382988 -1420766  5724529 PU CLEAR MEWS AK              S
334   939539  19252087 -6143526  1364335  1034341 PU ALTAIR, KWAJALEIN IS       S
344  5436189     67008  3724493   -43560  5160592 PU FYLINGDALES BMEWS (N)      S
345  5436180     67010  3724495   -43561  5160575  U FYLINGDALES (W) *          S
346  5436180     67010  3724495   -43561  5160575  U FYLINGDALES (SE) *         S
349  6429332  14919545 -2382979 -1420936  5724060 PU CLEAR AK BMEWS             S
354  -790392   1440414  6119393 -1571495  -871565 PU ASCENSION IS               S
359  6429340  14919570 -2382980 -1420926  5724062  U CLEAR AK BMEWS             S
363  1714460   6178970  2881603 -5372513  1868035 PU ANTIGUA IS                 S
369  4261690   7149210  1492321 -4457760  4296412 PU MILLSTONE HILL MA          S
370  4261955   7149139  1492241 -4457613  4296572  U MILLSTONE (UHF)            S
384  3258120   8356940   602527 -5345848  3414963 PU PAVE PAWS                  S
385  3258120   8356940   602528 -5345848  3414963 PU PAVE PAWS                  S
386  4175242   7053827  1587727 -4493137  4225181 PU PAVE PAWS COD (NE)         S
387  4175242   7053827  1587727 -4493137  4225181  U PAVE PAWS COD (SE)         S
388  3913604  12135087 -2577401 -4230613  4004115 PU PAVE PAWS BLE (S)          S
389  3913604  12135087 -2577401 -4230613  4004115  U PAVE PAWS BLE (NW)         S
394  7657029   6829923   549517 -1380820  6182219 PU THULE (SE)                 S
395  7657029   6829923   549518 -1380820  6182219  U THULE (N)                  S
396  4872480   9789990  -579420 -4175700  4770685 PU PARCS ND                   S
398  3057242   8621484   362839 -5484292  3225187 PU EGLIN FL (DEEPSPACE)       S
399  3057240   8621430   362838 -5484286  3225197 PU EGLIN FL                   S
504  0000000  33900000  5954502  2285719  0000000 PU MSX SPACE BASED OPTICAL * S
741  3257834  11697003 -2439923 -4794819  3414724  U NAV SAN DIEGO CA           S
742  3344371  10699811 -1557790 -5095903  3495904  U NAV ELEPHANT BUTTE NM      S
743  3314566   9102099   -95252 -5344808  3467495  U NAV SILVER LAKE AL        S
744  3197725   8150924   799579 -5356016  3358278  U NAV FT STEWART GA         S
745  3355400   9876310  -810649 -5258902  3505491 PU NAV MAIN LAKE KICKAPOO TX S
746  3333067   9355051  -330353 -5324212  3484684  U NAV RED RIVER AR          S
747  3228914   8353626   607570 -5362744  3387612  U NAV HAWKINGSVILLE GA      S
748  3311330  11253640 -2006012 -4957399  3464667  U NAV GILA RIVER AZ *       S
749  3265940   8626380   350256 -5363613  3422268  U NAV JORDAN LAKE *         S
753  5248100  35947950  3892503    35362  5035599 PU DSTS FELTWELL *           S
755  4071360  21861710 -3782794  3021613  4138417 PU DSTS MISAWA *             S
932  2157210  15826670 -5512521 -2197405  2330525 PU KAENA POINT                S
951  2070710  15625830 -5466038 -2404206  2242313 PU MOTIF MAUI                 S
952  2070848  15625823 -5466040 -2404177  2242311  U AMOS MAUI                  S
961  2070821  15625785 -5466041 -2404221  2242287  U LASER DOME MAUI            S
200 0    0.0050 0.0050 0.0000 0.0000   0.0000  0.0000  0.0000  0.0000  0.0000  BS
210 5    0.0050 0.0050 0.0000 0.0000   0.0000  0.0000  0.0000  0.0000  0.0000  BS
211 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
212 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
213 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
215 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
230 5    0.0050 0.0050 0.0000 0.0000   0.0000  0.0000  0.0000  0.0000  0.0000  BS
231 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
232 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
233 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
235 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
240 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
241 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
242 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
243 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
245 5    0.0050 0.0040 0.0000 0.0000  -0.0060  0.0000  0.0000  0.0000  0.0000  BS
329 3    0.0540 0.0560 1.6930 0.0019  -0.0120 -0.0120  0.2100 -0.0008  0.0000  BS
334 3    0.0169 0.0154 0.0189 0.0000   0.0019 -0.0037  0.0026  0.0000  0.0000  BS
337 3    0.0258 0.0245 0.0480 0.0057  -0.0018  0.0053  0.0009  0.0001  0.0000  BS
344 3    0.0218 0.0139 0.0082 0.0001  -0.0139  0.0070  0.0071  0.0000  0.0000  BS
345 3    0.0213 0.0189 0.0175 0.0002  -0.0108  0.0040 -0.0036  0.0000  0.0000  BS
```

```
346 3   0.0176 0.0131 0.0089 0.0002  -0.0196  0.0104  0.0086  0.0000  0.0000  BS
349 3   0.0540 0.0560 1.6930 0.0019  -0.0120 -0.0120  0.2100 -0.0008  0.0000  BS
354 3   0.0176 0.0135 0.0804 0.0294  -0.0010 -0.0021  0.0118  0.0005  0.0000  BS
359 3   0.0594 0.0678 0.0251 0.0031   0.0201  0.0007  0.1007  0.0087  0.0000  BS
363 3   0.0151 0.0154 0.0251 0.0064  -0.0054 -0.0013 -0.0061  0.0001  0.0000  BS
369 3   0.0073 0.0081 0.0054 0.0001   0.0004  0.0022 -0.0024  0.0000  0.0000  BS
382 3   0.0462 0.0469 0.0194 0.0027  -0.0090  0.0517 -0.0080  0.0002  0.0000  BS
383 3   0.0321 0.0308 0.0190 0.0027   0.0177  0.0048  0.0000  0.0003  0.0000  BS
384 3   0.0362 0.0248 0.0136 0.0026  -0.0130  0.0134  0.0312  0.0002  0.0000  BS
385 3   0.0403 0.0258 0.0180 0.0025  -0.0022  0.0281  0.0235  0.0004  0.0000  BS
386 3   0.0324 0.0269 0.0139 0.0022  -0.0211  0.0181 -0.0245  0.0001  0.0000  BS
387 3   0.0370 0.0313 0.0165 0.0023   0.0175  0.0443 -0.0077  0.0002  0.0000  BS
388 3   0.0264 0.0219 0.0177 0.0022   0.0122  0.0035  0.0419  0.0002  0.0000  BS
389 3   0.0242 0.0238 0.0134 0.0024  -0.0037 -0.0177  0.0093  0.0003  0.0000  BS
394 3   0.0449 0.0329 0.0143 0.0013  -0.0184 -0.0184  0.0107 -0.0002  0.0000  BS
395 3   0.0481 0.0327 0.0117 0.0007  -0.0325 -0.0104  0.0036 -0.0002  0.0000  BS
396 3   0.0175 0.0129 0.0244 0.0014   0.0056 -0.0128 -0.0149  0.0005  0.0000  BS
398 3   0.0470 0.0462 0.1623 0.0002   0.0062 -0.0023  0.0047  0.0000  0.0000  BS
399 2   0.0180 0.0169 0.0277 0.0000  -0.0004 -0.0017 -0.0077  0.0000  0.0000  BS
404 3   0.0711 0.0666 0.0661 0.0005   0.0042  0.0063 -0.0126  0.0003  0.0000  BS
504 9   0.0025 0.0025   0.00 0.0000   0.0     0.0     0.0     0.0     0.0     BS
745 2   0.0153 0.0181 1.2237 0.0000  -0.0024 -0.0008 -0.1228  0.0000  0.0000  BS
932 3   0.0076 0.0071 0.0063 0.0016  -0.0004  0.0053  0.0003  0.0000  0.0000  BS
951 5   0.0046 0.0042 0.0000 0.0000   0.0008  0.0014  0.0000  0.0000  0.0000  BS
952 5   0.0100 0.0100 0.0000 0.0000   0.0000  0.0000  0.0000  0.0000  0.0000  BS
961 5   0.0100 0.0100 0.0000 0.0000  -0.0050  0.0010  0.0000  0.0000  0.0000  BS
  200350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  200           0.0  0.0   0.0   0.0 0 0                                     2L
  210350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  210           0.0  0.0   0.0   0.0 0 0                                     2L
  211350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  211           0.0  0.0   0.0   0.0 0 0                                     2L
  212350  90000 20.0 90.0   0.0 360.0 .166667   0     1 0 100     0          1L
  212           0.0  0.0   0.0   0.0 0 0                                     2L
  213350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  213           0.0  0.0   0.0   0.0 0 0                                     2L
  215350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  215           0.0  0.0   0.0   0.0 0 0                                     2L
  230350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  230           0.0  0.0   0.0   0.0 0 0                                     2L
  231350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  231           0.0  0.0   0.0   0.0 0 0                                     2L
  232350  90000 20.0 90.0   0.0 360.0 .166667   0     1 0 100     0          1L
  232           0.0  0.0   0.0   0.0 0 0                                     2L
  233350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  233           0.0  0.0   0.0   0.0 0 0                                     2L
  235350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  235           0.0  0.0   0.0   0.0 0 0                                     2L
  240350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  240           0.0  0.0   0.0   0.0 0 0                                     2L
  241350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  241           0.0  0.0   0.0   0.0 0 0                                     2L
  242350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  242           0.0  0.0   0.0   0.0 0 0                                     2L
  243350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  243           0.0  0.0   0.0   0.0 0 0                                     2L
  245350  90000 20.0 90.0   0.0 360.0 .166667   1     1 0 100     0          1L
  245           0.0  0.0   0.0   0.0 0 0                                     2L
  329340   5000  2.0 90.0   0.0 360.0 .166667   0     0 0 100   182          1L
```

```
329          0.0  0.0   0.0   0.0 0 0                                 2L
334330  90000  2.0 90.0   0.0 360.0 .166667   0     0 0 100   100      1L
334          0.0  0.0   0.0   0.0 0 0                                 2L
344340   5600  3.0 80.0 307.0 360.0 .166667   0     0 0 100    80      1L
344          3.0 80.0   0.0  67.0 0 0                                 2L
345340   5600  3.0 80.0 187.0 307.0 .166667   0     0 0 100    80      1L
345          0.0  0.0   0.0   0.0 0 0                                 2L
346340   5600  3.0 80.0  67.0 187.0 .166667   0     0 0 100    80      1L
346          0.0  0.0   0.0   0.0 0 0                                 2L
349340   5000  2.0 90.0   0.0 360.0 .166667   0     0 0 100   182      1L
349          0.0  0.0   0.0   0.0 0 0                                 2L
354370  59264  0.0 90.0   0.0 360.0 .166667   0     0 0 100   2 9      1L
354          0.0  0.0   0.0   0.0 0 0                                 2L
359340   5000  2.0 90.0   0.0 360.0 .166667   0     0 0 100   182      1L
359          0.0  0.0   0.0   0.0 0 0                                 2L
363370  50000  0.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
363          0.0  0.0   0.0   0.0 0 0                                 2L
369330  90000  1.0 90.0   0.0 360.0 .166667   0     0 0 100 15050      1L
369          0.0  0.0   0.0   0.0 0 0                                 2L
370330  90000  4.0 90.0   0.0 360.0 .166667   0     0 0 100 15050      1L
370          0.0  0.0   0.0   0.0 0 0                                 2L
384440   5600  3.0 80.0 347.0 360.0 .166667   0     0 0 100   085      1L
384          3.0 80.0   0.0 107.0 0 0                                 2L
385440   5600  3.0 80.0 107.0 227.0 .166667   0     0 0 100   085      1L
385          0.0  0.0   0.0   0.0 0 0                                 2L
386440   5600  3.0 80.0 347.0 107.0 .166667   0     0 0 100   085      1L
386          0.0  0.0   0.0   0.0 0 0                                 2L
387440   5600  3.0 80.0 107.0 227.0 .166667   0     0 0 100   085      1L
387          0.0  0.0   0.0   0.0 0 0                                 2L
388440   5600  3.0 80.0 126.0 246.0 .166667   0     0 0 100   085      1L
388          0.0  0.0   0.0   0.0 0 0                                 2L
389440   5600  3.0 80.0 246.0 360.0 .166667   0     0 0 100   085      1L
389          3.0 80.0   0.0   6.0 0 0                                 2L
394340   6000  3.0 80.0  57.0 177.0 .166667   0     0 0 100   100      1L
394          0.0  0.0   0.0   0.0 0 0                                 2L
395340   6000  3.0 80.0 297.0 360.0 .166667   0     0 0 100   100      1L
395          3.0 80.0   0.0  57.0 0 0                                 2L
396440   3300  1.9 90.0 298.0 360.0 .166667   0     0 0 100   408      1L
396          1.9 90.0   0.0  78.0 0 0                                 2L
398320  90000  1.0 90.0 120.0 240.0 .166667   0     1 0 100     0      1L
398         75.0 90.0 300.0  60.0 0 0                                 2L
399420  14000  1.0 90.0 120.0 240.0 .166667   0     0 0 100   408      1L
399         75.0 90.0 300.0 420.0 0 0                                 2L
504430  90000 10.0 90.0   0.0 360.0 .166667   0     0 0 100     0      1L
504          0.0  0.0   0.0   0.0 0 0                                 2L
741420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
741          0.0  0.0   0.0   0.0 0 0                                 2L
742420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
742          0.0  0.0   0.0   0.0 0 0                                 2L
743420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
743          0.0  0.0   0.0   0.0 0 0                                 2L
744420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
744          0.0  0.0   0.0   0.0 0 0                                 2L
745420  15000  0.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
745          0.0  0.0   0.0   0.0 0 0                                 2L
746420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
746          0.0  0.0   0.0   0.0 0 0                                 2L
747420  15000  5.0 90.0   0.0 360.0 .166667   0     0 0 100     1      1L
747          0.0  0.0   0.0   0.0 0 0                                 2L
```

```
748420  15000  0.0 90.0   0.0 360.0 .166667   0     0 0 100     1           1L
748            0.0  0.0   0.0   0.0 0 0                                     2L
749420  15000  0.0 90.0   0.0 360.0 .166667   0     0 0 100     1           1L
749            0.0  0.0   0.0   0.0 0 0                                     2L
753350  90000  5.0 90.0   0.0 360.0 .166667   0     1 0 100   100           1L
753            0.0  0.0   0.0   0.0 0 0                                     2L
755350  90000  5.0 90.0   0.0 360.0 .166667   0     1 0 100   100           1L
755            0.0  0.0   0.0   0.0 0 0                                     2L
932370   3200  0.0 90.0   0.0 360.0 .166667   0     0 0 100     0           1L
932            0.0  0.0   0.0   0.0 0 0                                     2L
951350  90000 15.0 90.0   0.0 360.0 .166667   0     1 0 100     0           1L
951            0.0  0.0   0.0   0.0 0 0                                     2L
952350  90000 18.0 90.0   0.0 360.0 .166667   0     1 0 100     0           1L
952            0.0  0.0   0.0   0.0 0 0                                     2L
961350  90000 20.0 90.0   0.0 360.0 .166667   0     1 0 100     0           1L
961            0.0  0.0   0.0   0.0 0 0                                     2L
```

6. Orbiting Sensor Boresight Vector Definitions

Both the 1L and 2L sensor specifications include an optional sensor boresight vector pointing control. If the control is left blank, as it is for ground-based sensors, the elevation ranges apply traditionally; i.e., relative to the local horizon, and the azimuth range applies 0 to 360 degrees, where 0 degrees is due north.

In the case of an orbiting sensor specification, the boresight vector pointing control becomes very important because it specifies the direction the on-board sensor is looking relative to the satellite direction of motion. For orbiting sensors, the elevation and azimuth range specifications are meaningless without the boresight vector pointing control. The boresight pointing control can be set as follows, where all directions are based on the UVW asset-centered coordinate frame, where +U is Up away from Geocenter, +V is in the direction of motion, and +W is out-of-orbital plane left.

'N' or 'D' indicates "Nadir" or "Down" pointing toward the Geocenter. This would be the appropriate setting for an orbiting sensor with a mission to surveil the Earth.

'U' indicating "Up" pointing radially away from the direction to the Geocenter.

'V' or **'A'** indicating pointing in the direction of the "Velocity" vector or "Ahead" in the direction of the orbiting sensor-satellite.

'B' indicating pointing "Back" in the direction opposition the sensor-satellite direction of motion.

'W' or **'L'** indicating pointing in the direction of the positive w-vector or to the "Left" (out of plane and orthogonal to the radial vector).

'R' indicating pointing to the "Right", relative to the direction of motion of the sensor-satellite and orthogonal to the positive radial-vector.

Figure 11 to **Figure 16** provide graphical representations of some of the various boresight vector-pointing control directions for an orbiting sensor. Each diagram uses the sensor-satellite, UVW coordinate frame, with the sensor satellite centered at the origin.

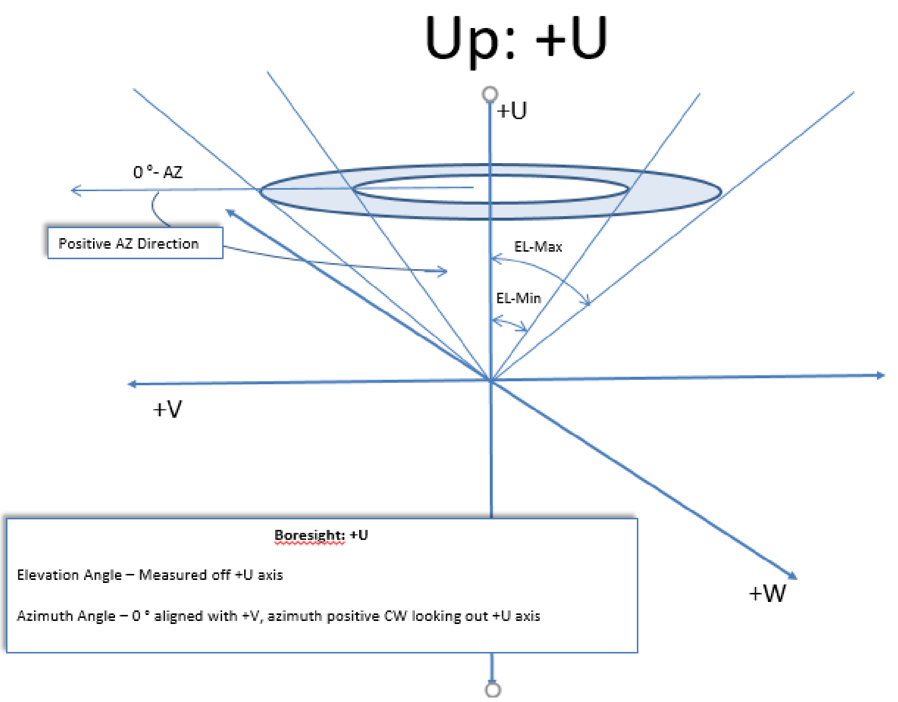


Figure 11. Boresight +U, Upward Orbiting Sensor Pointing

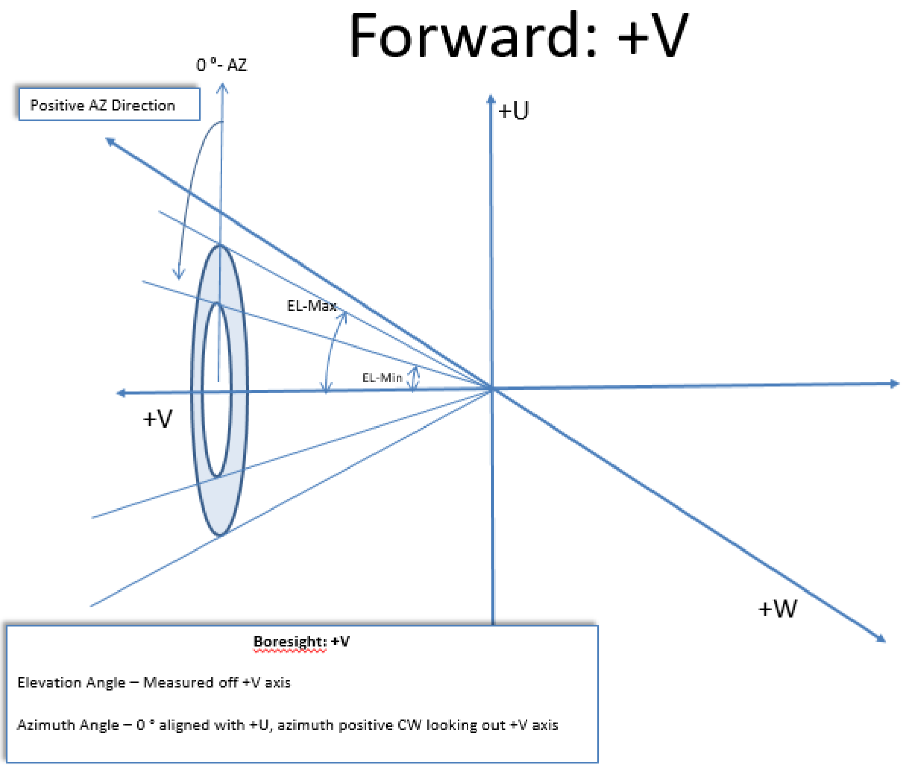


Figure 12. Boresight +V, Forward Orbiting Sensor Pointing

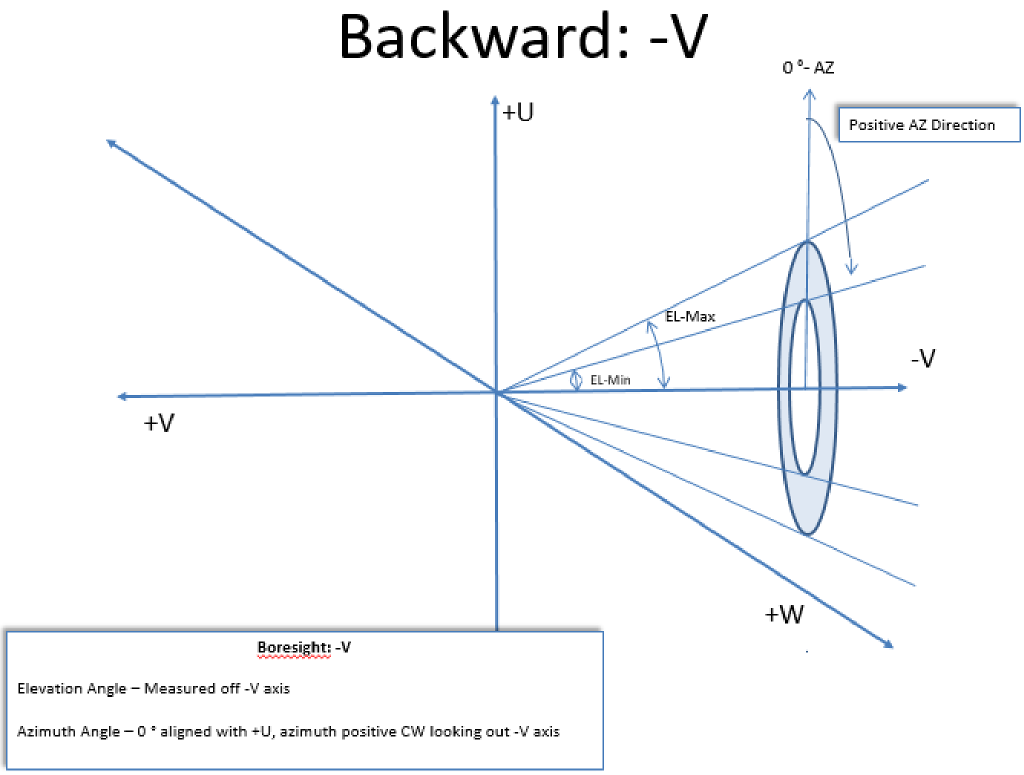


Figure 13. Boresight –V, Backward Orbiting Sensor Pointing

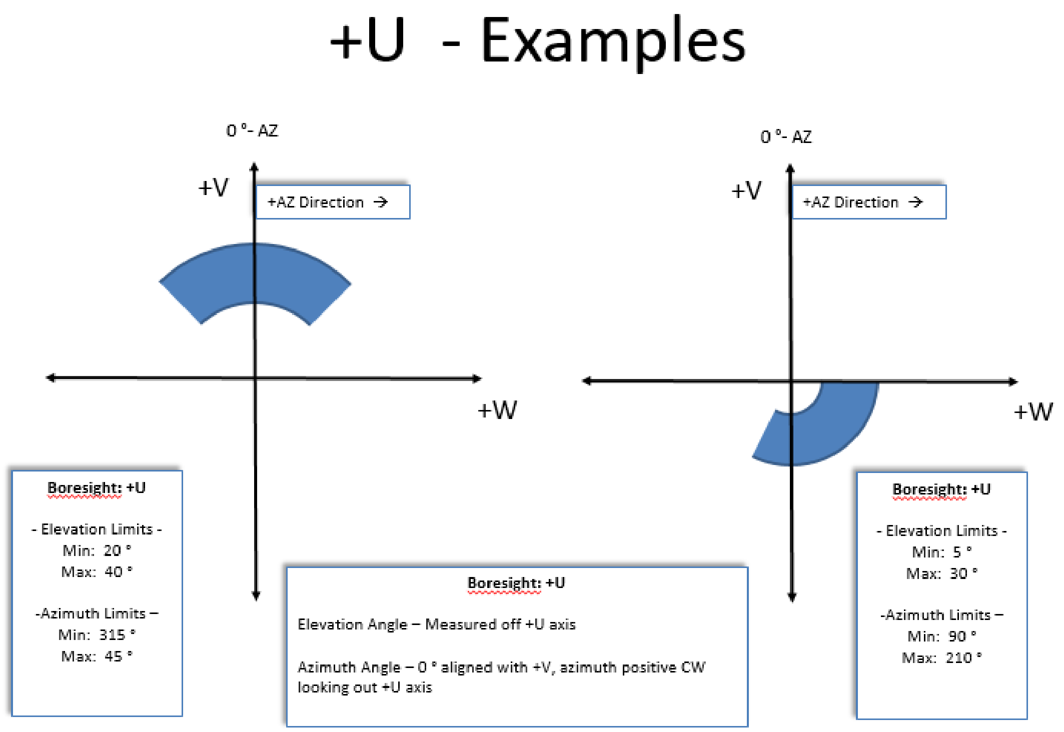


Figure 14. Boresight +U, Upward Pointing Orbiting Sensor Configuraton Examples

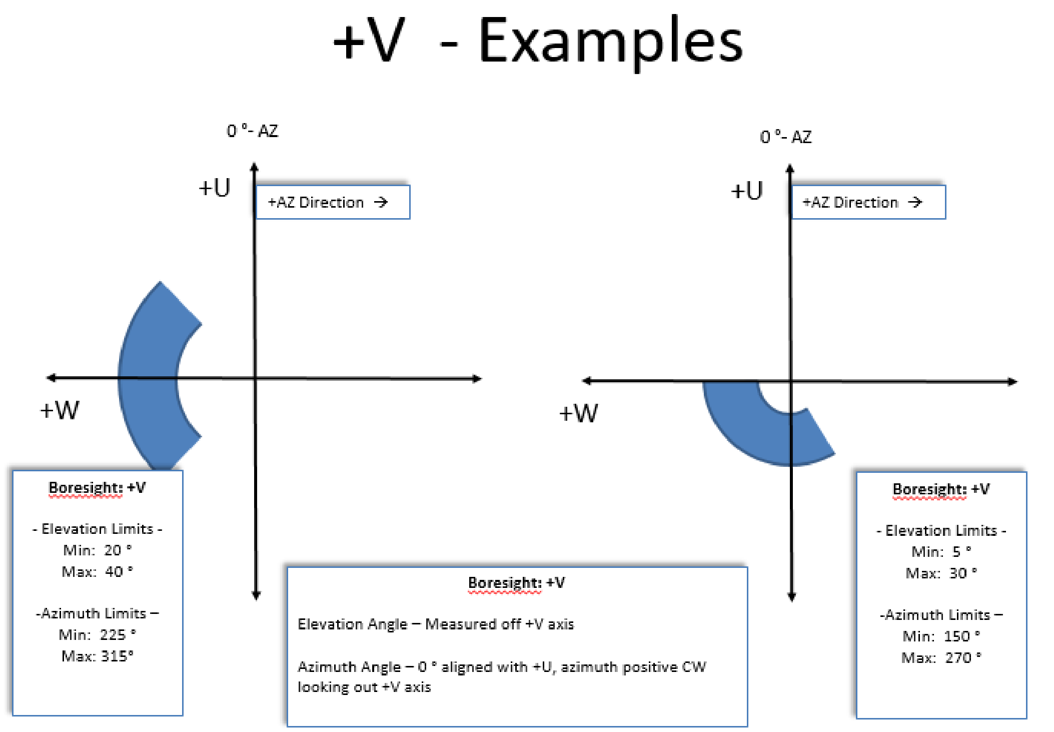


Figure 15. Boresight +V, Forward Pointing Orbiting Sensor Configuration Examples

-V - Examples

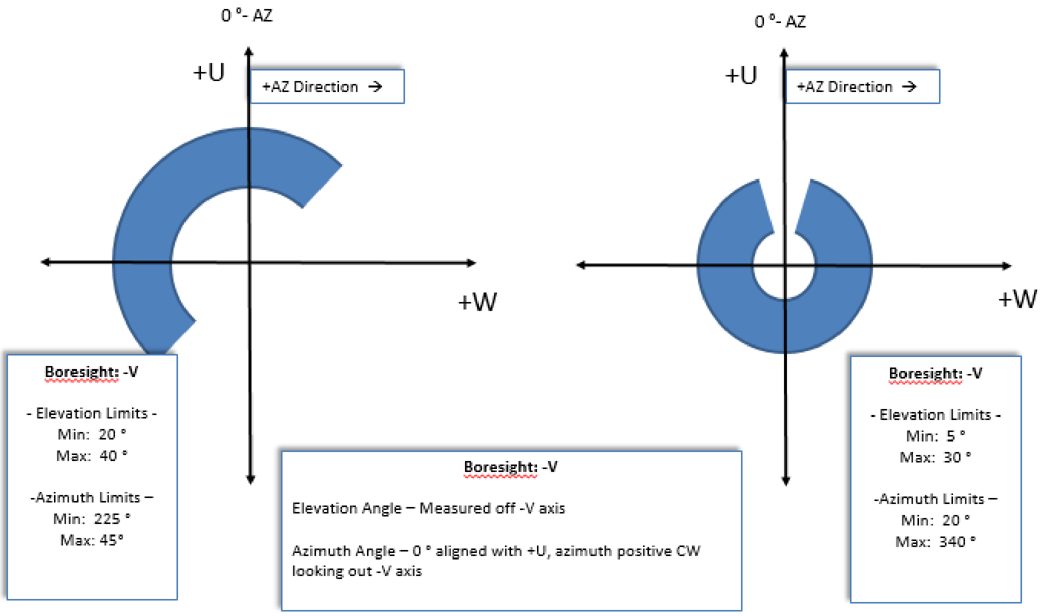
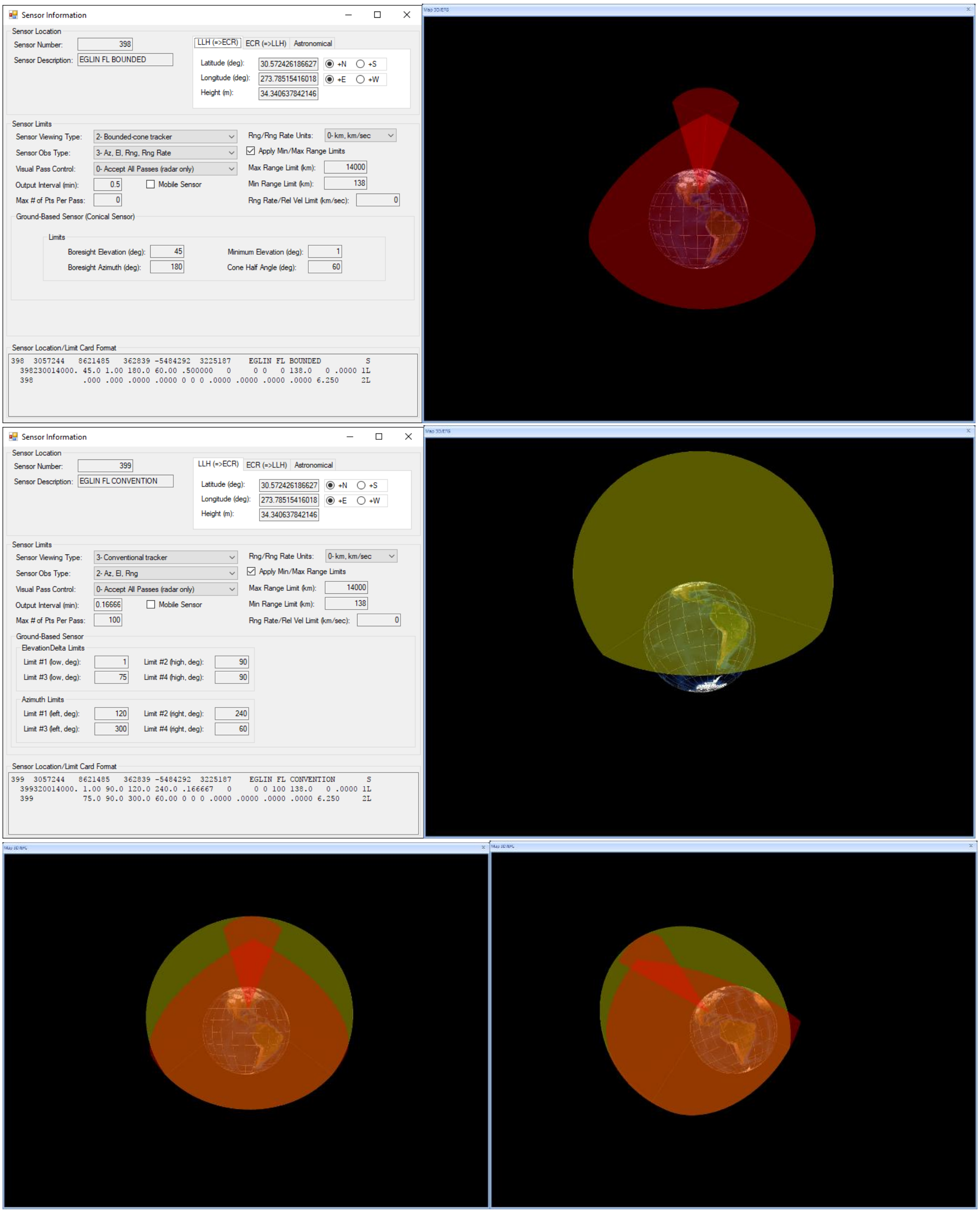


Figure 16. Boresight –V, Backward Pointing Orbiting Sensor Configuration Examples

7. Difference between bounded-cone versus conventional tracker

The pictures below are to demonstrate the difference between **bounded-cone** (399/yellow) and **conventional tracker** (398/red) models. The **bounded-cone** model is the more accurate representation of the actual sensor coverage of Eglin.



8. Various Categories used for specifying Sensor Types

There are many ways to characterize sensors by Type. Sensors may be Ground-Based, Mobile (Ground or Air), or Space-Based. Sensors may be Optical, Infrared, or Radar. Sensors may be capable of tracking objects in Near Earth (NE) or Deep-Space (DS), or both.

If the sensor is a Radar, it might be characterized by its frequency band; e.g., UHF, C-Band, L-Band, S-Band, or X-Band; and it may further be characterized as a "small-object" tracker if its frequency is sufficiently high. If the sensor is a Radar, it might further be characterized by the type of Radar; e.g., Mechanical Tracker (MT), Phased Array (PA), or Solid State Phased-Array Radar (SSPAR) with multiple faces.

If the sensor is orbiting, it might be characterized by the type of orbit the sensor operates in and what object-orbits the sensor primarily tracks; e.g., a Low-Earth Orbit (LEO) 0-degree inclination optical sensor that tracks objects in Geosynchronous Orbit (GEO), such as the SBSS or ORS-5. Furthermore, the field of view (FOV) for orbiting sensors can be defined as a bounded-cone or a dome-type FOV with specific boresight (bounded cone) or azimuth/elevation range definitions (dome segment or cone segment).

A sensor can also be characterized by the type of metric observation data it provides with its observations. Metric sensor observation data types include some combination of azimuth, elevation, right ascension, declination, range, range-rate, azimuth-rate, elevation-rate, or Earth-Fixed Greenwich (EFG) rotating vector.

And lastly, sensors are often characterized as *Dedicated*, *Collateral*, or *Contributing*.

> ***Dedicated*** sensors are USSTRATCOM subordinate sensors with a primary mission of Space Surveillance support. Dedicated sensor examples include the GEODSS Electro-Optical optical sensors at Maui, Diego Garcia, and Socorro; and the X-Band Radar Globus II at Vardo Norway.
>
> ***Collateral*** sensors are sensors subordinate to USSTRATCOM but with a primary mission other than Space Surveillance support. Good examples of Collateral sensors are the many Missile Warning sensors in the northern hemisphere such as Beale, Cape Cod, Cavalier PARCS, Clear, Fylingdales, and Thule.
>
> ***Contributing*** sensors are non-USSTRATCOM sensors under contract or agreement to support Space Surveillance; e.g., the Millstone Hill Radar operated by Lincoln Space Surveillance Center, Massachusetts; and various Radars at the Reagan Test Site (RTS) on Kwajalein, Marshall Islands.

Figure 17 summarizes the many Sensor-Type Categories and Types within each Category. **Figure 18** provides an Information Matrix for Sensors of the Space Surveillance Network (SSN).

Sensor Type Categories				
Operating Location Types	**Sensor Range Types**	**Collector Types**	**Radar Frequency Band Types**	**Sensor Equipment Types**
Ground-Based Fixed	Near-Earth (NE)	Radar	UHF	Detection Fence Radar
Ground-Based Mobile	Deep-Space (DS)	Optical	C-Band	Mechanical Tracker (MT) Radar
Air Mobile	NE & DS	Infrared	L-Band	Phased Array (PA) Radar
Space-Based Orbiting			S-Band	Solid State Phased Array Radar (SSPAR)
XYZ Sensor Location			X-Band	Millimeter Wave (MMW) Radar
				Electro-Optical (E-O)

View Types
Bounded-Cone Tracker
Conventional Tracker
Optical Tracker
Orbiting Sensor
Mobile Sensor
Space Fence FOR
Space Fence FOV

Mission Types
Dedicated
Collateral
Contributing

Observation Types
0 - range-rate only
1 - azimuth, elevation
2 - azimuth, elevation, range
3 - azimuth, elevation, range, range-rate
4 - same as 3 + az-rate, el-rate
5 - right ascension, declination
6 - range only
7 - rotating EFG vector
8 - azimuth, elevation, & sensor rotating EFG vector
9 - right ascension & declination and rotating EFG vector

Observation Types (continued)
V - ECI position & Velocity vector
P - ECI Position Vector
M - same as 8 + range
O - same as 9 + range

Data Collection Types
Metric (positional information)
Space Object Identification (SOI)
Radar Image SOI
Optical Image/Signature SOI
Radar Cross Size (RCS)
Visual Magnitude (VisMag) Brightness

Field of View (FOV) Specification Types
Min Max Azimuth Limits
Min Max Elevation Limits
Min Max Range Limits
Range-Rate Limit
Visual Passes Only Flag
Look-Angle Interval
Dome Azimuth From Azimuth To
Dome Elevation From Elevation To
Dome Min Max Range Limits
Cone Boresight Azimuth and Elevation Specs
Cone Off-Boresight Lower Upper Angle Specs
Cone Min Max Range Limits
Cone Min Cut-Off Elevation Spec
Orbiting Sensor Boresight Vector UVW Limits
Orbiting Sensor Allow Earth in Background Flag
Orbiting Sensor Earth Limb Exclusion Distance
Orbiting Sensor Planetary Restrictions Flag

Figure 17: Sensor Type Categories

Metric Sensor #	Site Name System Name	Short Name	Location	LAT/LONG [Deg:min:sec]	ELEV [Meters]	Sensor Type	Orbit Track Capability	Az & El [degrees]	Frequency Band	Observation Type	Category	Remarks
231 232 233	Maui GEODSS	MAU	Mt. Haleakala, Maui, HI	20:42:29N 156:15:29 W	3058.6	Electro-Optical (E-O)	DS	Az 0 to 360 El 20 to 90	N/A Optical	5	Dedicated	GEODSS
241 242 243	Diego Garcia GEODSS	DGC Camera 1, 2, 3	Diego Garcia	7:24:40 S 72:27:7 E	-61.14	E-O	DS	Az 0 to 360 El 20 to 90	N/A Optical	5	Dedicated	Ground-Based Electro-Optical Deep-Space Surveillance (GEODSS)
333	RTS- ALCOR	RTS ALC ALCOR	Kwajalein, Marshall Islands	9:23:55N 167:28:58E	42.3	MT	None	Az 0 to 360 El -3.2 to 95.8	C-Band	3	Contributing	Reagan Test Site (RTS)
334 732	RTS ALTAIR	RTS ALT ALTAIR	Kwajalein, Marshall Islands	9:23:44N 167:32:44 E	62.72	MT	NE/DS	Az 0 to 360 El 0 to 92	U/UHF V/VHF	3	Contributing	RTS
344 N 345 S 346 E	Fylingdales BMEWS	FYL Faces N, S, E	RAF Fylingdales	54:21:42 N 00:40:12 W	338.9	Three Face SSPAR	NE	Az 0 to 360 El 3 to 85	UHF	3	Collateral	Ballistic Missile Early Warning System (BMEWS)
354	Ascension	ASC	Ascension Island, UK	7:54:22 S 14:24:9 W	56.1	MT	NE	AZ 0 to 360 EL -5 to 90	C-Band	3	Collateral	Eastern Range Radar
375	Globus II	GB II	Vardø Norway	70:22:01 N 31:07:40 E	95	MT	DS	AZ 0 to 360 EL 1 to 86	X-Band	3	Dedicated	High-Frequency DS Radar
382 S 383 N	Clear BMEWS	CLR Faces S, N	Clear AFS, AK	64:18:01 N 149:11:23 W	213.3	Two Face SSPAR	NE	AZ 184 to 064 EL 3 to 85	UHF	3	Collateral	BMEWS
386 NE 387 SE	Cape Cod PAVE PAWS	COD Faces NE, SE	Cape Cod AFS, MA	41:45:09 N 70:32:17 W	80.3	Two Face SSPAR	NE	AZ 347 to 227 EL 3 to 85	UHF	3	Collateral	PAVE PAWS
388 SW 389 NW	Beale PAVE PAWS	BLE Faces SW, NW	Beale AFB, CA	39:08:10 N 121:21:4 W	115.7	Two Face SSPAR	NE	AZ 126 to 006 EL 3 to 85	UHF	3	Collateral	PAVE Phased Array Warning System
396	Cavalier PARCS	CAV	Cavalier AFS, ND	48:43:29 N 97:53:59 W	347.3	Single Face PA	NE	AZ 298 to 078 El 1.9 to 95	UHF	3	Collateral	Perimeter Acquisition Radar Attack Characterization System (PARCS)
399	Eglin	EGL	Eglin AFB, FL	30:34:20 N 86:12:52 W	34.7	Single Face PA and Fence	NE/DS	AZ 120 to 240 EL 1 to 105	UHF	3	Dedicated	Only dedicated Phased Array Radar
369	Millstone– LSSC L-Band	MIL MHR	Westford, MA	42:37:03 N 71:29:28 W	123.1	MT	NE/DS Narrowband (NB)	AZ 0 to 360 EL 1 to 90	L-Band	3	Contributing	Lincoln Laboratory Space Surveillance Complex (LSSC)
370	Millstone – LSSC UHF Band	MIL	Westford, MA	42:37:10 N 71:29:29 W	113.1	MT	DS	AZ 0 to 360 El 0.5 to 90	UHF	3	Contributing	LSSC
951	MSSS - 1.2M	MSSS MOT MOTIF 1.2-m	Mt. Haleakala, Maui, HI	20:42:30 N 156:15:28 W	3059.6	E-O	DS	Az 0 to 360 El 15 to 90	N/A Optical	5	Contributing	MSSS
952	MSSS - 1.6M	MSSS AMS AMOS 1.6-m	Mt. Haleakala, Maui, HI	20:42:30 N 156:15:26 W	3060.5	E-O	DS	Az 0 to 360 El 5 to 90	N/A Optical	5	Contributing	MSSS
961	MSSS - 0.8M	MSSS BDT 0.8-m	Mt. Haleakala, Maui, HI	20:42:30 N, 156:15:27 W	3058.7	E-O	DS	Az 0 to 360 El 20 to 90	N/A Optical	5	Contributing	MSSS
970	MSSS - RAVEN	MSSS RAV Raven	Mt. Haleakala, Maui, HI	20:42:30 N, 156:15:26 W	3058.5	E-O	DS	Az 0 to 360 El 20 to 90	N/A Optical	5	Contributing	MSSS
504	SBSS	SBSS	On Orbit	N/A, Space-Based (900 km circular orbit, 99 deg inclination)	N/A	E-O	NE/DS	Az 0 to 720 El Unlimited	N/A Optical	9	Dedicated	Space-Based Sensor

Figure 18: SSN Information Matrix

Appendix A. Distinction between Astronomical Geocentric & Geodetic Locations

While an oblate Earth introduces no unique problems in the definition or measurement of terrestrial longitude, it does complicate the concept of latitude [ref. Bate, Mueller, White]. Latitude in particular is related to the reference ellipsoid used in the applicable coordinate reference system. Since there are many reference ellipsoids, the latitude of a feature on the surface of Earth is not unique. The ISO (International Standards Organization) stresses, "Without the full specification of the coordinate reference system, coordinates (that is latitude and longitude) are ambiguous at best and meaningless at worst." Essentially, the reference ellipsoid is based on the chosen datum (EGM-96, WGS-84, WGS-72, et al), and the latitude for a given point on the surface of Earth (such as the location of a sensor site) is determined by the respective definition of coordinate reference system and datum used.

Latitude Definitions. Three commonly used definitions of latitude are *Geocentric*, *Astronomical*, and *Geodetic*. Of those, Astronomical and Geocentric Latitudes are commonly used in Space Operations systems and applications as shown in the S-card examples above. The distinctions between the three forms of latitude reference are best understood via illustration, **Figure 19**:

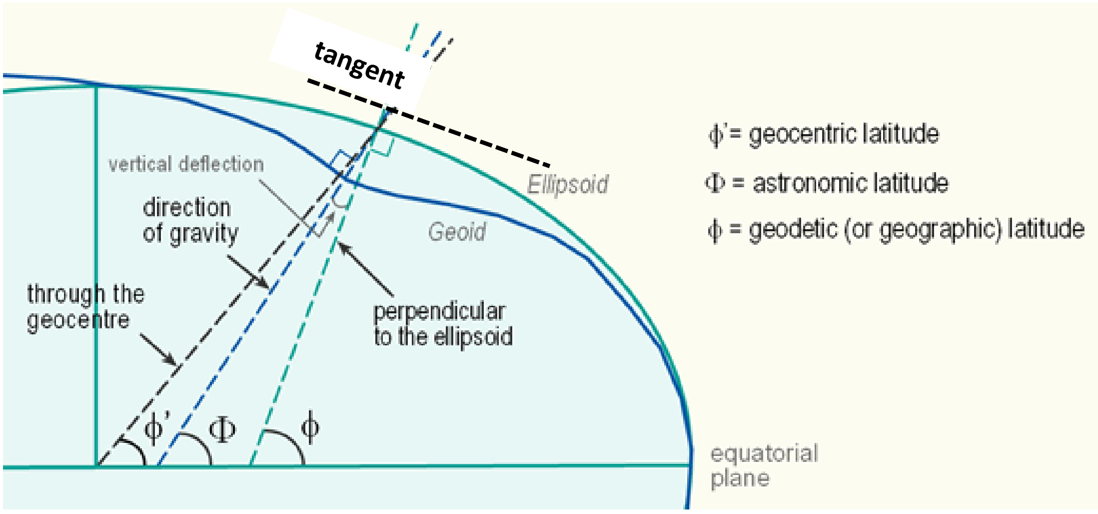


Figure 19. Three different Latitude definitions: Geodetic (ϕ), Astronomic (Φ), and Geodetic (ϕ')

Geocentric Latitude is the angle between the equatorial plane and the radius from the Geocenter. The standard notion in English for Geocentric Latitude is lower-case phi-Prime: **ϕ'.**

Geodetic Latitude is the angle between the equatorial plan and the normal to the surface of the ellipsoid. The normal to the surface of the ellipsoid is essentially a plumb line from the Geoid to the ellipsoid surface. The standard notion in English for Geodetic Latitude is lower-case phi **ϕ.**

Astronomical Latitude is the latitude that results directly from the stars, *uncorrected* for vertical deflection. Vertical deflection of the plumb line accounts for how far the direction of the local gravity field has been shifted by local anomalies such as nearby mountains. Here 'gravity' refers to *apparent* gravity, which is gravity reduced by the Earth's spin. Astronomical Latitude applies only to positions on the surface of the Earth. The standard notion in English for Astronomical Latitude is Upper case PHI: **Φ.**