

SIMULATING SPACE SURVEILLANCE NETWORKS

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Generating observations for satellites is a difficult process because actual observations are usually withheld and sensor locations and performance are often unknown. While many tools exist, a comprehensive listing of sensor locations and characteristics is difficult to find. When sensor locations are known, the specific tracking frequency is very difficult to model as the observations generally result from ad hoc tasking directives, implemented by each sensor with individual constraints. Sensor operational open and close dates are not well known either for historical purposes. This paper summarizes open source data to establish a baseline of sensor locations, primarily using Google Earth. We also discuss techniques to accurately simulate the observations and arrive at realistic scheduling densities.

INTRODUCTION

Satellite mission design is often accompanied with detailed simulations of the sensor networks to determine the expected accuracy of the orbit determination. Obtaining observations for a particular satellite and time interval is a difficult process. Actual observations from one or more sensor networks that could support useful orbit determination error analysis but may be withheld from analysis efforts. Simulating the raw observation data (range, azimuth, and elevation) from scratch is difficult because the sensor locations and performance characteristics may not be known. Sensor locations are often inferred from various sources, but may not have sufficient fidelity for mission design applications.

Generating simulated observational data that accurately reflects the capabilities, policies, and tendencies of current operational use is key. The observational data should mimic what would be expected from the actual sensor networks, and sensor locations should be close enough to provide realism to subsequent analyses. This paper summarizes open source data to establish a baseline of sensor locations, primarily using Google Earth for verification of the sensor coordinates. These data provide a common baseline from which to simulate satellite observations, as well as a vehicle to input precise locations for actual operations. We also include information concerning the operational open and close dates where possible, and various notes on the sensors. We also describe a process to simulate realistic observations, accounting for tasking schedules, and real-world constraints on each sensor system. We note that Secure World Foundation (<http://swfound.org>) is planning to host information of this type on the web in the fall of 2011.

OBJECTIVE

This paper develops a baseline set of sensors to reflect the generic characteristics of several large space surveillance tracking systems. Using these pre-defined sensors, we simulate observations for analysis with the appropriate scheduling constraints. We group the sensor systems in broad categories. Major existing governmental networks include the Air Force Space Command Space Surveillance System (AFSPC SSN), Russian Space Surveillance System (RSSS), and the European Space Surveillance System (ESSS). Other governmental systems that are more focused include the AF Space Control Network (AFSCN), and smaller networks in Canada, India, Japan, Kazakhstan, Korea, and Ukraine. We note the International Scientific Optical Network (ISON) as a comprehensive system that maintains a complete geosynchronous (GEO) catalog. There is a network of amateur observers that interact to track objects. Their sites are much less defined than the other systems we discuss, but are very well organized. Finally, we include the Satellite Laser Ranging System (SLR) system as an excellent resource for developing reference orbits. We hope that these data will provide a common baseline from which to simulate

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satellite observations, as well as a vehicle to collect precise locations for actual operations. Vallado¹ showed that orbital propagations could be aligned between various flight dynamics programs by careful treatment of the input data and parameters. Likewise, better aligned sensor databases will enable better simulated observations for use with different orbit determination programs.

We note an important caveat that. *The intent is to have the sites be close enough to the actual site locations to provide a sense of realism for analytical studies, but if the locations are used for operational processing, bias values will need adjustment for uncertainties from the actual locations.* Further, we provide files compatible with Analytical Graphics Inc. ODTK program for ease of implementation and commonality. To underscore the importance of the approximate nature of these locations, we use “APPROX” in the title with each .tso file for ODTK, and each .kml file for Google Earth.

PROCESS

A variety of sources were used to develop the baseline parameters. The Internet provides access to a wealth of information, from determining overall sensor systems to research, to gathering specific site and sensor information. Generic site names and approximate locations are given in many places. We used Google Earth to refine these parameters and develop “closer” coordinates. We acknowledge that the geo-registration (tying a satellite image to specific latitude-longitude coordinates) of the images may not be precise, but for our purposes, it was assumed to be close enough for simulation purposes. Google Earth also gave us an approximate altitude. In some cases, searches took considerable time as little information was known. In other cases, it showed intentional imagery degradation or denial.* The operational dates represent probably the toughest and least accurate information we assembled.



Figure 1: Geo-Registration Errors: Finding the positions in Google Earth is not without error. Notice the apparent jump in a straight road. This represents at least an uncertainty of about 10 m. This is probably from a difference in elevation angle between the two images.

We list primary relevant web sites throughout the paper. Jaramillo² lists general information about worldwide space surveillance systems, and was a starting point for many of the analyses. Some sensor numbers were derived from the Minor Planet Observatory Codes[†]. In cases where the numbers were unknown, radars were given “555”

* PCMag, Jul 2011. <http://www.pcmag.com/article2/0,2817,2386907,00.asp>

[†] MinorPlanet, Jul 2011. <http://www.minorplanetcenter.net/iau/lists/ObsCodesF.html>

ESO, Jul 2011. http://www.eso.org/~ndelmott/obs_sites.html

prefixes, phased arrays a “666” prefix, and optical sensors were given a “999” prefix within each sensor network. Distinguishing between radars and phased array radars was done only for nomenclature, and not physical operation. So numbers like 9992, 5551, and 6663 are possible for unknown sensor numbers.

Sensor Characteristics

We included several types of sensors (radar, optical, phased array, interferometer, and transponder), although we did not attempt to meticulously attribute a specific design to each sensor. Detailing the specific azimuth, elevation, and range limits, frequencies, etc. is left to future work, although we did accumulate some information on this. We did include information where it was readily available, but it’s not comprehensive.

A complete sensor characterization would also include sensor parameters. We note some general characteristics used for simulations in this paper. For phased array radars, we assumed range limits of 0 – 6000 km. However, we know that some radars (i.e. Millstone Hill) and phased arrays (i.e. Eglin) can observe GEO orbits, so we permitted a deep space radar class that was capable of observing GEO objects, 0 – 40000 km. Optical sensors were all rated for 0 – 99999 km. Simulations should incorporate visual magnitude limitations for a specific sensor if that is a limiting factor.

Because some SSN phased array radar faces are mounted on slanted planes relative to their zenith direction, each phased array face can actually track objects at any azimuth from 0-360°. However, it can be easier to specify each face's directionality if we allow elevations to exceed 90°. With this, the phased arrays can scan $\pm 60^\circ$ in both azimuth and elevation relative to their boresight direction. Thus, in elevation from 0-120°. Phased array face directions were noted in the notes where they were known, but not in all cases. For simulation, a specifically tailored sensor is probably best (as opposed to a generic line-of-sight visibility) as discussed previously. In STK, this can be modeled using sensor objects and combining the constraints and objects.

Finally, interferometers consist of receiver and transmitter locations. Both are needed for operation, but simulations should only use the receivers. Some systems employ transponder operations, but we did not provide any special definitions for these sensors as they are specific to manufacturers’ design.

We do not exhaustively list frequencies for systems because if the observations are calibrated, there is no need for the frequency. If the observations are not calibrated, then the frequency could be of use. For our purposes, we didn’t consider this information at this time.

All longitude values are positive East, negative West.

United States Air Force Space Command Space Surveillance System - AFSPC SSN

The United States Air Force Space Command Space Surveillance Network (AFSPC SSN) system developed initially as a missile warning network. Over time, the missile warning functionality was modified into the current space surveillance operation. As a result, some sensors are not ideally situated for space observation, but rather potential ICBM incoming routes to the United States. This can limit some coverage, but there are usually redundant sensors.

The AFSPC SSN sensor locations in the paper are the result of consolidating data from numerous sources. Vallado³ provides a general introduction into the AFSPC SSN system. These values are modified here with additional data from numerous Internet and literature sources^{*, 4, 5}. Determining the geoid was difficult. For the SSN, we assume WGS-84/EGM-96. For all others, we assume EGM-96.

* Au Chap 19. Apr 2011. http://space.au.af.mil/au-18-2009/au-18_chap19.pdf

Au Usspc. Apr 2011. <http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm>

Fas Chap 07. Apr 2011. http://www.fas.org/spp/military/docops/army/ref_text/chap07f.htm

Fas Geodss. Apr 2011. <http://www.fas.org/spp/military/program/track/geodss.pdf>

Fas Overview. Apr 2011. <http://www.fas.org/spp/military/program/track/overview.htm>

Peterson factsheet. Apr 2011. <http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4745>

Peterson Lib. Apr 2011. <http://www.peterson.af.mil/shared/resource/lib.css>

Wikipedia AFSSS. Apr 2011. http://en.wikipedia.org/wiki/Air_Force_Space_Surveillance_System

Wikipedia SSN. Apr 2011. http://en.wikipedia.org/wiki/United_States_Space_Surveillance_Network

The Phased array and GEODSS systems often have multiple sensors at a single location. For some simulation purposes, it may be useful to have a single point at the center of each sensor, rather than the individual sensors. The following table shows these central locations, along with the remaining SSN sensors. The numbers for these central locations have been multiplied by 10 to distinguish them from the individual sensors. We use the same practice with phased array radars where there are separate numbers for each face.

Table 1: US AF Space Surveillance Network Sensors: The phased arrays generally separate each face to a separate sensor. We list a single location here and include the faces in the notes. These sensors also have sensor numbers multiplied by 10 (for example Sensor 382 is 3820). Note that the open date for Fylingdales is when the phased array conversion was complete.

| SSN Sensors | | | | | | | | | |
|-------------|----------------------|----------------|---------|------------|-------------|---------|-----------|-------|-------------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 3820 | Clear, AK | ClearPA | PhArray | 64.300233 | -149.190964 | 175.0 | 1-Jun-61 | | AN/FPS-123 |
| 3860 | Cape Cod, MA | CapeCod | PhArray | 41.752408 | -70.538342 | 67.0 | 4-Apr-80 | | FPS-115 |
| 3880 | Beale, CA | Beale | PhArray | 39.136050 | -121.350628 | 117.0 | 15-Aug-80 | | FPS-115 |
| 393 | Shemya, AK | CobraDane | PhArray | 52.737175 | 174.091528 | 68.0 | 13-Jul-77 | | AN/FPS-108, #3 |
| 3940 | Thule, Greenland | ThuleSE | PhArray | 76.569456 | -68.298956 | 424.0 | 24-Jun-87 | | FPS-120 |
| 396 | Cavalier, ND | PARCS | PhArray | 48.724594 | -97.899894 | 344.0 | 31-Mar-75 | | FPQ-16 |
| 3450 | Fylingdales, UK | Fylingdales | PhArray | 54.361775 | -0.670033 | 258.0 | 18-Aug-92 | | PA FPS-120 |
| 2100 | Socorro, NM | Socorro | Opt | 33.817192 | -106.659867 | 1510.0 | 1-Mar-83 | | 40" FSQ 114, az |
| 2300 | Maui, HI | Maui | Opt | 20.708400 | -156.257433 | 3058.0 | 1-Mar-83 | | generic, also 235 |
| 2400 | Diego Garcia | DiegoGarcia | Opt | -7.411714 | 72.452208 | -61.2 | 30-Nov-86 | | generic |
| 260 | Moron, Spain | MOSS | Opt | 37.150111 | -5.591386 | 93.0 | 1-Sep-98 | | AN/FSQ-224 |
| 951 | Maui, HI | MOTIF | Opt | 20.708625 | -156.257661 | 3026.0 | 1-Jan-79 | | 1.2 m |
| 952 | Maui, HI | AMOS | Opt | 20.708467 | -156.257206 | 3026.0 | 1-Jan-63 | | 0.6 m |
| 961 | Maui, HI | BDT | Opt | 20.708549 | -156.257564 | 3058.8 | 1-Jun-88 | | 0.8 m |
| 965 | Maui, HI | AEOS | Opt | 20.708228 | -156.256636 | 3029.0 | 1-Jun-00 | | 3.6 m |
| 970 | Maui, HI | Raven_MSSS | Opt | 20.708463 | -156.257488 | 3058.5 | | | |
| 998 | Maui, HI | RMERaven | Opt | 20.746206 | -156.431650 | 83.0 | | | |
| 996 | Flagstaff, AZ | USNO | Opt | 35.184114 | -111.740714 | 2303.0 | | | 1.3 m |
| 9991 | Albuquerque, NM | SOR | Opt | 34.964231 | -106.463869 | 1891.0 | | | |
| 9992 | Cerro Tololo, Chile | MODEST | Opt | -30.169031 | -70.806308 | 2205.0 | | | |
| 9993 | Kirtland (AlbuRaven) | KirtlandRAVEN | Opt | 34.963050 | -106.497256 | 1725.0 | | | |
| 9994 | Socorro, NM | SST | Opt | 33.739408 | -106.364325 | 2432.0 | 1-Jul-11 | | |
| 333 | Kwajalein Atoll | ALCOR | Radar | 9.398614 | 167.482883 | 47.0 | 1-Jan-70 | | 5670 MHz (C) |
| 334 | Kwajalein Atoll | ALTAIR | Radar | 9.395472 | 167.479328 | 66.0 | 1-Jan-72 | | 160 MHz (VHF) |
| 335 | Kwajalein Atoll | TRADEX | Radar | 9.398733 | 167.482217 | 5.0 | 1-Jan-82 | | 1320 MHz (L), 2 |
| 354 | Ascension | Ascension15 | Radar | -7.906608 | -14.402497 | 59.0 | 1-Jan-57 | | FPQ-15 |
| 355 | Ascension | Ascension18 | Radar | -7.974386 | -14.391703 | 143.0 | 1-Jan-57 | | |
| 359 | Clear, AK | ClearR | Radar | 64.291242 | -149.194103 | 213.0 | 1-Jun-61 | | CW FPS-92 |
| 363 | Antigua | Antigua | Radar | 17.143614 | -61.792475 | 6.0 | 1-Jan-57 | | FPQ-14 |
| 369 | Millstone Hill, MA | MILLH | Radar | 42.617442 | -71.490967 | 127.0 | 5-Oct-57 | | old 331, 1a, 1295 |
| 371 | Millstone Hill, MA | MILLFIRE | Radar | 42.617567 | -71.492383 | 124.0 | | | laser |
| 372 | Millstone Hill, MA | MILLHAY | Radar | 42.623272 | -71.488206 | 120.0 | 17-May-65 | | 10 GHz (X), 96 C |
| 373 | Millstone Hill, MA | MILLHAX | Radar | 42.622792 | -71.487222 | 120.0 | 1-Jan-94 | | 16 GHz (Ku) |
| 375 | Vardo, Norway | GlobusII | Radar | 70.367153 | 31.127711 | 63.0 | | | |
| 399 | Eglin, FL | Eglin | Radar | 30.572394 | -86.214692 | 36.0 | 29-Jan-69 | | FPS-85, also #39 |
| 932 | Kaena Point, HI | KaenaPt | Radar | 21.572056 | -158.266578 | 300.0 | 1-Jan-72 | | FPQ-14 |
| 741 | San Diego, CA | SanDiegoR | Intf | 32.577492 | -116.974731 | 125.4 | | | rec |
| 742 | Elephant Butte, NM | ElephantButteR | Intf | 33.445544 | -106.998122 | 1443.6 | | | rec |
| 743 | Silver Lake, MS | SilverLakeR | Intf | 33.147342 | -91.020897 | 10.5 | | | rec |
| 744 | Tattnel, GA | TattnellR | Intf | 32.043725 | -81.926017 | 28.3 | 27-Oct-87 | | rec |
| 745 | Lake Kickapoo, TX | LakeKickapooT | Intf | 33.553978 | -98.762908 | 309.9 | 1-Jan-61 | | trans |
| 746 | Red River, AR | RedRiverR | Intf | 33.330772 | -93.550056 | 91.8 | | | rec |
| 747 | Hawkingsville, GA | HawkingsvilleR | Intf | 32.288950 | -83.536283 | 77.2 | | | rec |
| 748 | Gila River, AZ | GilaRiverT | Intf | 33.113389 | -112.030725 | 321.0 | | | trans |
| 749 | Jordan Lake, AL | JordanLakeT | Intf | 32.659064 | -86.263514 | 99.2 | | | trans |
| 9995 | LEO Satellite 34903 | STSS ATRR | SB | 0.000000 | 0.000000 | 0.0 | 31-Jan-11 | | no elements avail |
| 9996 | LEO Satellite 37168 | SBSS-1 | SB | 0.000000 | 0.000000 | 0.0 | 23-Feb-11 | | a=634 km, i = 98 |

Some sites have several types of sensors at a single location (radar, optical, etc). Physically this is usually antennae or telescopes at separate locations within a certain facility. It may also be the specific directions the sensor can observe – or the obscura map (an azimuth elevation depiction of directions that are impossible to observe). For applications requiring the individual sensors for the SSN, we can use the parameters from Table 2.

Table 2: US AF Space Surveillance Network Sensors: This listing shows the various faces for the phased arrays and different camera directions for some optical sensors.

| SSN Sensors | | | | | | | | | |
|-------------|-------------------|-------------|---------|-----------|-------------|---------|------------|----------|-------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 211 | Socorro, NM | SocorroCAM1 | Opt | 33.817267 | -106.660092 | 1510.0 | 1-Mar-83 | | 40" FSQ 114 |
| 212 | Socorro, NM | SocorroCAM2 | Opt | 33.817269 | -106.659619 | 1510.0 | 1-Mar-83 | | 40" FSQ 114 |
| 213 | Socorro, NM | SocorroCAM3 | Opt | 33.817061 | -106.659619 | 1510.0 | 1-Mar-83 | | 40" FSQ 114 |
| 231 | Maui, HI | MauiCAM1 | Opt | 20.708158 | -156.257633 | 3067.0 | 1-Mar-83 | | 40" FSQ 114 |
| 232 | Maui, HI | MauiCAM2 | Opt | 20.708158 | -156.257319 | 3067.0 | 1-Mar-83 | | 40" FSQ 114 |
| 233 | Maui, HI | MauiCAM3 | Opt | 20.708633 | -156.257294 | 3067.0 | 1-Mar-83 | | 15" FSQ 114 |
| 241 | Diego Garcia | DiegoCAM1 | Opt | -7.411622 | 72.452025 | -61.2 | 30-Nov-86 | | 40" FSQ 114 |
| 242 | Diego Garcia | DiegoCAM2 | Opt | -7.411625 | 72.452431 | -61.2 | 30-Nov-86 | | 40" FSQ 114 |
| 243 | Diego Garcia | DiegoCAM3 | Opt | -7.411861 | 72.452369 | -61.2 | 30-Nov-86 | | 40" FSQ 114 |
| 344 | UK | FylingA | PhArray | 54.361775 | -0.670033 | 326.0 | 18-Aug-92 | | PA FPS-120 |
| 345 | UK | FylingB | PhArray | 54.361775 | -0.670033 | 326.0 | 18-Aug-92 | | PA FPS-120 |
| 346 | UK | FylingC | PhArray | 54.361775 | -0.670033 | 326.0 | 18-Aug-92 | | PA FPS-120 |
| 382 | Clear, AK | ClearPA | PhArray | 64.300233 | -149.190964 | 213.0 | mid 1990's | | AN/FPS-123 |
| 383 | Clear, AK | ClearPA | PhArray | 64.300233 | -149.190964 | 213.0 | mid 1990's | | AN/FPS-123 |
| 386 | Cape Cod, MA (NE) | CapecodNE | PhArray | 41.752408 | -70.538342 | 67.0 | 4-Apr-80 | | FPS-115 |
| 387 | Cape Cod, MA (SE) | CapecodSE | PhArray | 41.752408 | -70.538342 | 67.0 | 4-Apr-80 | | FPS-115 |
| 388 | Beale, CA (S) | BealeS | PhArray | 39.136050 | -121.350628 | 117.0 | 15-Aug-80 | | FPS-115 |
| 389 | Beale, CA (NW) | BealeNW | PhArray | 39.136050 | -121.350628 | 117.0 | 15-Aug-80 | | FPS-115 |
| 392 | Shmeya, AK | CobraDaneWE | PhArray | 52.737175 | 174.091528 | 68.0 | 13-Jul-77 | 1-Nov-94 | |
| 393 | Shmeya, AK | CobraDane | PhArray | 52.737175 | 174.091528 | 68.0 | 13-Jul-77 | | AN/FPS-108 |
| 394 | Thule, Greenland | ThuleSE | PhArray | 76.569456 | -68.298956 | 424.0 | 24-Jun-87 | | FPS-120 |
| 395 | Thule, Greenland | ThuleN | PhArray | 76.569456 | -68.298956 | 424.0 | 24-Jun-87 | | FPS-120 |
| 398 | Eglin, FL | EglinDS | Radar | 30.572394 | -86.214692 | 36.0 | 1-Jan-88 | | FPS-85 |
| 399 | Eglin, FL | Eglin | Radar | 30.572394 | -86.214692 | 36.0 | 29-Jan-69 | | FPS-85 |

An example of how we used Google Earth is shown for the Diego-Garcia GEODSS facility. Photographs were sometimes valuable to understand the local orientation and setup (Fig. 2).



Figure 2: AFSPC Space Surveillance Network Sensors: The optical systems at Diego Garcia are shown in a picture (left) and from Google Earth (right). Notice the centrally located position for simulation of the facility, and not the individual telescopes. For simulations, a central location (red circle) is probably sufficient for many applications. Photo from http://upload.wikimedia.org/wikipedia/commons/2/22/GEODSS_Diego_Garcia_2006-05-01.jpg

Russian Space Surveillance System - RSSS

The Russian Space Surveillance System has evolved over the years similar to the AFSPC SSN network. Beginning as a large network of phased array radars and radars forming a missile warning system, some of the sensors were gradually transitioned to perform space surveillance roles. Coverage of geosynchronous region seems to have been limited in the past. ISON (discussed later) covers the geosynchronous regime, but it's not part of the RSSS. Today, the Russian Space Agency (Roscosmos) is responsible for the safety of Russian space activities. The Ministry of Defense is responsible for Russian military operations in space and space surveillance in support of

these operations. Other organizations (Russian Academy of Sciences, Foreign Ministry etc.) are taking part in the development of SSA policy, data collection and sharing, and establishing international cooperation.

Globalsecurity* indicates that the primary radars for space surveillance are the Dnepr (1960's) and Daryal (1980's) EW systems. These systems include radars at Irkutsk (Mishelevka), Murmansk (Olenegorsk), Pechora, Balkhash and Mingechaur (Gabala). More recent listings suggest many of the phased array radars have closed, or been demolished.† However, the sensor at Mishelevka discussed as being demolished was actually the Dar'yal-U station at Mishelevka which actually was never finished. Podvig^{6, 7} provides additional information on the radar systems. The ABM system near Moscow can also perform some space surveillance functions. Geimint‡ provides detailed information on many of the sites, as well as an initial Google Earth .kmz file. Jaramillo¹ and Ausairpower[§] provide site locations and descriptions. There are optical sites located in Russia and Tajikistan.

Table 3: Russian Space Surveillance Sensors: The RSSS includes a number of accurate sensors. Additional optical sensors are listed under the ISON network.

| RSSS Sensors | | | | | | | | | |
|--------------|----------------------|-------------|---------|-----------|------------|---------|----------|-------|-----------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 6661 | Olenegorsk, Russia | Olenegorsk | PhArray | 68.113500 | 33.910500 | 240.0 | 1-Jun-76 | | 325, 295 |
| 6662 | Olenegorsk, Russia | Olenegorsk | PhArray | 68.116600 | 33.920500 | 241.0 | 1-Jun-78 | | 310, Dnepr |
| 6663 | Balkhash, Kazakhstan | Balkhash | PhArray | 46.602890 | 74.528500 | 348.0 | 1-Jan-72 | | Dnepr |
| 6664 | Balkhash, Kazakhstan | Balkhash | PhArray | 46.604460 | 74.532600 | 348.0 | | | Dnepr |
| 6665 | Mishelevka, Russia | Mishelevka | PhArray | 52.877936 | 103.272944 | 513.0 | 1-Jan-68 | | 70, 200 |
| 6666 | Mishelevka, Russia | Mishelevka | PhArray | 52.874986 | 103.260700 | 493.0 | 1-Jan-68 | | 130, Dnepr |
| 6667 | Pechora, Russia | Pechora | PhArray | 65.210600 | 57.295600 | 102.0 | 1-Jan-84 | | Dar'yal |
| 6668 | Gabala, Azerbaijan | Gabala | PhArray | 40.871514 | 47.808928 | 628.0 | 1-Jan-85 | | 160, Dar'yal |
| 6669 | Baranovichi, Belarus | Baranovichi | PhArray | 52.862000 | 26.467700 | 169.0 | 1-Jan-02 | | 263, Volga |
| 66610 | Moscow, Russia | Moscow | PhArray | 55.231090 | 37.294300 | 226.0 | | | |
| 66611 | Moscow, Russia | Moscow | PhArray | 56.173314 | 37.769239 | 263.0 | | | 60, 150, Don-2N |
| 66612 | Pavlovsk, Russia | Krona | PhArray | 42.935333 | 132.577056 | 210.0 | | | |
| 66613 | Lekhtusi, Russia | Lekhtusi | PhArray | 60.275456 | 30.545033 | 92.0 | 1-Jan-06 | | Voronezh-M |
| 66614 | Armavir, Russia | Armavir | PhArray | 44.925425 | 40.983892 | 254.0 | 1-Jun-09 | | Voronezh-DM |
| 66615 | Storozhevaya, Russia | Krona20ZH6 | PhArray | 43.825361 | 41.342739 | 1107.0 | | | |
| 191 | Nurek, Tajikistan | Nurek | Opt | 38.281592 | 69.223300 | 2217.0 | | | |
| 9992 | Storozhevaya, Russia | Krona30ZH6 | Opt | 43.718331 | 41.226253 | 2115.0 | | | |

European Space Agency Space Surveillance System – European SSS

The European Space Agency (ESA) is moving towards development of a highly accurate and modern space surveillance tracking system. Recent conferences at ESAC (2010) and INTA Headquarters near Madrid Spain (2011) have brought space professionals from all over the world to share ideas, techniques, and tools. They have many sensors, located in several countries. Initial planning is underway for a comprehensive coalition. Klinkrad⁸ provides a good reference into the activities that are on-going. See also the Internet references.**

* GlobalSecurity Russia Apr 2011 <http://www.globalsecurity.org/space/world/russia/network.htm>

† RussianForces, Jul 2011. http://russianforces.org/blog/2011/06/daryal-u_radar_in_mishelevka_d.shtml

‡ Geimint Soviet May 2011 <http://geimint.blogspot.com/2008/06/soviet-russian-space-surveillance.html>

§ Ausairpower May 2011 <http://www.ausairpower.net/APA-Rus-ABM-Systems.html>

** Assembly, Apr 2011. http://www.assembly-weu.org/en/documents/sessions_ordinaires/rpt/2009/2035.php

Eiscat Mar 2011. <http://www.e7.eiscat.se/about/coordinates>

ESA Bulletin33, Apr 2011. http://www.esa.int/esapub/bulletin/bulletin133/bul133f_klinkrad.pdf

Minorplanets, Mar 2011. <http://www.minorplanets.org/OLS/index.html>

Table 4: European Space Surveillance Sensors: ESA is developing a growing number of high quality sensors to perform space surveillance. Locations referenced in the literature, but not found in Google Earth are identified with a “??” in the Notes.

| European Sensors | | | | | | | | | |
|------------------|-----------------------------|------------|-----------|------------|------------|---------|--------------|-------|-----------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 5551 | Apt, France, receiver | GRAVESr | Radar | 44.071508 | 5.534578 | 932.0 | Dec 15, 2005 | | |
| 5552 | Dijon, France transmitter | GRAVESf | Radar | 47.347778 | 5.515000 | 202.0 | Dec 15, 2005 | | 143.050MHz |
| 5553 | Wachtberg, Germany | TIRAFHR | Radar | 50.616631 | 7.129611 | 270.0 | | | |
| 5554 | Winchester, UK | Chilbolton | Radar | 51.145022 | -1.438447 | 83.0 | | | |
| 5555 | Tromso, Norway | EISCATn | Radar | 69.586439 | 19.226111 | 69.0 | | | |
| 5556 | Kiruna, Sweden | EISCATs | Radar | 67.860778 | 20.433806 | 473.0 | | | |
| 5557 | Sodankyla, Finland | EISCATt | Radar | 67.363903 | 26.630417 | 204.0 | | | |
| 5558 | Longyearbyen, Svalbard | EISCATsv | Radar | 78.152669 | 16.058706 | 432.0 | | | |
| 5559 | Effelsberg, Germany | TIRAEF | RadioTele | 50.524803 | 6.883597 | 368.0 | | | radio telescope |
| J04 | Tenerife | OGS | Opt | 28.300939 | -16.511903 | 2392.0 | | | |
| 26 | Zimmerwald, Switzerland | ZimLAT | Opt | 46.877225 | 7.465225 | 897.0 | | | |
| 27 | Zimmerwald, Switzerland | ZimSMART | Opt | 46.876947 | 7.465086 | 897.0 | | | |
| 262 | La Silla, Chile | TarotS | Opt | -29.261053 | -70.731775 | 2385.0 | | | |
| 20 | Nice France | TarotN | Opt | 43.727458 | 7.299061 | 314.0 | | | |
| 511 | Haute-Provence Observatory | ROSACE | Opt | 43.931508 | 5.712447 | 653.0 | Feb 2001 | | |
| J75 | LaSagra, Spain | LaSagra | Opt | 37.982600 | -2.565600 | 1530.0 | | | NEO |
| 620 | Mallorca | Mallorca | Opt | 39.642842 | 2.950828 | 161.0 | 1-May-91 | | NEO |
| 9991 | Plateau de Caussols, France | Tarot | Opt | 43.752056 | 6.923386 | 1270.0 | | | |
| 9992 | Odeillo, France | SPOC | Opt | 42.494775 | 2.030278 | 1543.0 | | | ?? |
| 9993 | Castelgrande, Italy | TT1 | Opt | 40.940000 | 15.190000 | 904.0 | | | ?? |
| 9994 | Montsec, Spain | FabraROA | Opt | 42.051650 | 0.729639 | 1570.0 | | | |

Europe also has mobile tracking radars. The French General Directorate for Armament (DGA) MONGE hosts Normandie and ARMOR tracking radars and is shown in Fig. 3.



Figure 3: DGA Monge Tracking Ship: This system provides the capability to make observations from many parts of the world. (Photo from Military-today Jul 2011, http://www.military-today.com/navy/monge_ship.htm)

Other Governmental Systems

We group these sensors in a special section because the resources are generally smaller or more focused than the previous networks. Nevertheless, there is tremendous opportunity here for collaboration. Jaramillo² lists general information of many other sensor systems. We note them here, but do not provide details as they are very specialized at this time.

A. United States Air Force Satellite Control Network - AFSCN

The AFSCN was developed in the 1960's to track active satellites. Wikipedia* suggests the sensor network operations began in about 1959, with a command center in Palo Alto CA. The center moved to Sunnyvale (Onizuka) CA, and is now at Schriever AFB in Colorado. The AFSCN network has published approximate locations for their sensor sites, but Coster⁹ provides a concise listing. For simulation purposes, these are often useful for owner-operator like tracking.

Table 5: AF Satellite Control Network Sensors: These sensors work with satellite transponders. We do not list a sensor on Kodiak island indicated to have closed in 1975.

| AFSCN Sensors | | | | | | | | | |
|---------------|----------------------|-------|------|-----------|-------------|---------|------|-------|----------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 657 | New Boston, NH | BossA | Trp | 42.945986 | -71.629423 | 199.0 | | | SGLS-60 3607 |
| 623 | New Boston, NH | BossB | Trp | 42.944755 | -71.630325 | 193.3 | | | SGLS-46 3603 |
| 649 | VAFB, CA | CookA | Trp | 34.822614 | -120.501857 | 268.7 | | | SGLS-60 3107 |
| 620 | VAFB, CA | CookB | Trp | 34.825639 | -120.505408 | 267.4 | | | SGLS-46 3103 |
| 660 | Guam | GuamA | Trp | 13.615192 | 144.856049 | 216.0 | | | SGLS-60 3707 |
| 625 | Guam | GuamB | Trp | 13.615874 | 144.855430 | 209.4 | | | SGLS-46 3703 |
| 654 | Kaena Point, HI | HulaA | Trp | 21.562281 | -158.242121 | 429.7 | | | SGLS-60 3507 |
| 622 | Kaena Point, HI | HulaB | Trp | 21.568980 | -158.262308 | 319.0 | | | SGLS-46 3503 |
| 626 | Oakhanger, UK | LionA | Trp | 51.115097 | -0.906110 | 143.9 | | | SGLS-60 3407 |
| 629 | Oakhanger, UK | LionB | Trp | 51.117873 | -0.906446 | 142.9 | | | ARTS-51 3405 |
| 633 | Colorado Springs, CO | PikeA | Trp | 38.805938 | -104.528484 | 1909.7 | | | ARTS-51 3305 |
| 624 | Thule, Greenland | PogoA | Trp | 76.515191 | -68.595725 | 148.0 | | | SGLS-14 3907 |
| 628 | Thule, Greenland | PogoB | Trp | 76.515362 | -68.598864 | 147.4 | | | SGLS-46 3903 |
| 634 | Thule, Greenland | PogoC | Trp | 76.515701 | -68.605081 | 144.8 | | | ARTS-51 3905 |
| 637 | Diego Garcia | ReefA | Trp | -7.270031 | 72.369998 | -58.5 | | | transp-23 4105 |

B. China

The Chinese Space Surveillance System (CSSS) is very difficult to obtain information on as there is very little information on the Internet. However, some links provided insight from which we performed additional searches. We found some phased array radars sites, most likely used with missile tests, but also possibly for space surveillance. Jaramillo¹ list general information about the Chinese system. It states that the CSSS includes 6 ground stations in China, 1 Pakistan ground station, 1 Namibia ground station, and optical facilities at Purple Mountain. It's possible that many of these systems are designed for missile testing, but there could be space surveillance applications as well. Papers have discussed work on radar technology within China, but again, information regarding specific locations is lacking.^{10, 11, 12}

Table 6: Chinese Space Surveillance System (CSSS): Information is very limited on these sensors and locations. Locations referenced in the literature, but not found in Google Earth are identified with a "???" in the Notes.

| CSSS Sensors | | | | | | | | | |
|--------------|----------------------------|----------|---------|-----------|------------|---------|------|--------|-------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 330 | Purple Mtn, Xinjian, China | XOS | Opt | 32.737044 | 118.463981 | 174.0 | | | |
| 337 | Shanghai, Sheshan Obs | SHAO1 | Opt | 31.096378 | 121.188542 | 85.0 | | | |
| 9991 | Guanxing Mtn, Qingdao | QOS | Opt | 36.070181 | 120.321114 | 66.0 | | | |
| 9992 | Huairou | HSOS | Opt | 40.315494 | 116.594225 | 56.0 | | | |
| 9993 | Shanghai, Xujiahui Obs | SHAO | Opt | 31.190164 | 121.429419 | 17.0 | | | |
| 9994 | Xinglong | LAMOST3 | Opt | 40.395744 | 117.575861 | 875.0 | | | |
| 9995 | Xinglong | LAMOST | Opt | 40.389094 | 117.489433 | 656.0 | | | |
| 9996 | Heilongjiang | HOS | Opt | 47.500000 | 133.420000 | 153.0 | | | ?? |
| 9997 | Yaoan, Yunan | YOS | Opt | 25.600000 | 101.100000 | 153.0 | | | ?? |
| 5551 | Xuanhua | Xuanhua | PhArray | 26.621667 | 107.698056 | 875.0 | | | ?? |
| 5552 | Xuanhua | Xuanhua1 | PhArray | 40.447829 | 115.117107 | 1286.0 | | closed | |
| 5553 | Xinjiang | LPAR | PhArray | 41.641458 | 86.236956 | 933.0 | | | |

* Wikipedia, AFSCN, May 2011. <http://en.wikipedia.org/wiki/AFSCN>

Like the European system, the Chinese system includes mobile sensors, including information suggesting there are at least 6 such systems. Wikipedia* suggests the ships have C- and S-band capabilities.



Figure 4: Chinese Space Surveillance Tracking Ship: Note the several large tracking dishes, similar to the Millstone Hill SSN tracking system. There are several other likely optical trackers, and since the ship designation is number 5, it is likely there are other ships with similar capabilities. Photo from Wikipedia*

C. Other Governmental

Canada, India, Japan, Kazakhstan, Korea, and Ukraine all have sensors capable of performing space surveillance activities. Each country has emerging space programs that require better SSA. Cooperation in the form of sharing observations does not yet exist, but the number of sensors indicates that such an activity would be highly valuable for sensor bias estimation, more complete close approach analyses, and general space operations.

Canada will operate the Sapphire satellite that hosts an optical sensor for space surveillance. The sensor acts as a contributing sensor to the US SSN.† They also have several optical sensors.

Japan resources consist of radars and optical sensors.‡ India has an ever expanding space program and has optical sensors capable of performing space surveillance. Korea has a few optical sensors.

* Wikipedia Yuanwang. Jul 2011. <http://en.wikipedia.org/wiki/Yuanwang>

† Cfd-cdf Jul 2011. <http://www.cfd-cdf.forces.gc.ca/sites/page-eng.asp?page=6250>

‡ Lab26. Jul 2011. <http://www-lab26.kuee.kyoto-u.ac.jp/~t-sakamo/pdf/debris.pdf>

Spaceguard. Jul 2011. <http://www.spaceguard.or.jp/BSGC/eng/>

Table 7: Other Governmental Space Surveillance System: Information is limited on these sensors and locations. However, each country is pursuing development of sensors to support space operations activities.

| Other Sensors | | | | | | | | | |
|---------------|----------------------|---------------|---------|-----------|-------------|---------|----------|-------|------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 9991 | Suffield, Alberta | CANSUF | Opt | 50.293059 | -111.104803 | 750.7 | | | |
| 9992 | Valcartier, Quebec | CANVAL | Opt | 46.875551 | -71.470690 | 147.9 | | | |
| 9993 | Ottawa, Ontario | CANOTT | Opt | 45.354550 | -75.891016 | 90.0 | | | |
| 9994 | RMC, Kingston | CASTOR | Opt | 44.231101 | -76.467252 | 65.3 | | | |
| 9991 | Udaipur, India | U1 | Opt | 24.604622 | 73.674200 | 587.0 | | | |
| 6661 | Kamisaibara, Japan | KSGC | PhArray | 35.331253 | 133.930308 | 750.0 | | | 3.265 MHz |
| 9991 | Ibaraki, Japan | NICTKashima | Opt | 35.956269 | 140.657592 | 21.0 | | | |
| 9992 | Bisei, Japan | BSGC | Opt | 34.672000 | 133.545347 | 417.0 | | | |
| 9993 | Nyukasa, Nagano | JAXANyukasa | Opt | 35.901389 | 138.171667 | 1870.0 | | | |
| 9994 | Chofu, Japan | JAXALEO | Opt | 35.678719 | 139.556917 | 65.0 | | | |
| 5551 | Shigaraki, Japan | MURadar | Radar | 34.853908 | 136.105633 | 378.0 | 2-Sep-84 | | atmos, VHF |
| 5552 | Kagoshima, Japan | JAXAUchinoura | Radar | 31.254464 | 131.078478 | 312.0 | | | |
| 5553 | Nagano, Japan | JAXAUsuda | Radar | 36.132997 | 138.362139 | 1462.0 | | | |
| 9991 | Daejeon, Korea | KASI | Opt | 36.397597 | 127.375036 | 107.0 | | | |
| 9991 | Cirnea, Ukraine | Yevpatoria | Opt | 45.189103 | 33.187047 | 16.0 | | | |
| 10018 | Yevpatoria, Ukraine | YevpAZT8 | Opt | 45.219465 | 33.162594 | 9.4 | | | |
| 6661 | Sevastopol, Ukraine | x14 | PhArray | 44.578756 | 33.386436 | 7.0 | 1-Jun-79 | | 228, 173 |
| 6662 | Mukachevo, Ukraine | x15 | PhArray | 48.377753 | 22.707628 | 138.0 | 1-Jun-79 | | 194, 258 |
| 9991 | Majdanak, Uzbekistan | Majd2 | Opt | 38.684789 | 66.943058 | 2727.0 | | | Min of Def |

International Scientific Optical Network - ISON

Beginning in about 2001, a loose cooperation of optical observatories began, and by 2005 the International Scientific Optical Network (ISON) was created.¹³ Additional observatories have been added since then and they primarily study scientific and applied problems in space, specializing on geosynchronous satellites. Equipment modernization and updated software has taken place to provide increased capabilities. The Keldysh Institute of Applied Mathematics in the Russian Academy of Sciences (KIAM RAS) has been the principal scientific and organizational coordinator of ISON. By 2010, 33 telescopes at 23 observatories in 11 countries were operating around the world with over 90 researchers. The current tasks include regular GEO monitoring, new object discovery and tracking, and maintenance of as complete a catalog as possible. ISON is currently tracking 1557 objects in GEO compared to the TLE catalog of 1016 objects. The observers track between 150 up to 800 individual objects each night. The primary difference in the catalogs is faint objects (high area to mass ratios), debris not seen by the SSN, and classified objects. The data are stored at the KIAM Ballistic Center upon collection. The processing and analysis of information on space debris is also executed at the Center.

Table 8. International Scientific Optical Network Sensors: This collection of optical sensors enables a very complete GEO catalog to be maintained.

| ISON Sensors | | | | | | | | | |
|--------------|-------------------------|----------------|------|------------|------------|---------|------|-------|-------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 10003 | Mondy, Russia | MondyAZT14 | Opt | 51.621953 | 100.918758 | 2008.0 | | | |
| 10010 | Arkhyz, Russia | ArkhyzZeiss600 | Opt | 43.650132 | 41.431058 | 2029.7 | | | |
| 10012 | Terskol, Russia | Zeiss2000 | Opt | 43.276347 | 42.499483 | 3084.0 | | | |
| 10016 | Mayaki, Ukraine | Mayaki600 | Opt | 46.397439 | 30.271719 | 22.0 | | | |
| 10019 | Simeiz, Ukraine | SimeizZ1000 | Opt | 44.412381 | 33.991497 | 334.0 | | | |
| 10024 | Pulkovo, Russia | Pulkovo200 | Opt | 59.771811 | 30.326025 | 92.0 | | | |
| 10031 | Nauchnyi, Ukraine | CrAOATA64 | Opt | 44.726864 | 34.015689 | 595.0 | | | |
| 10041 | Majdanak, Uzbekistan | MajdAZT22 | Opt | 38.673375 | 66.895545 | 2575.9 | | | |
| 10042 | Arkhyz, Russia | SAOZeiss | Opt | 43.646821 | 41.440380 | 2058.0 | | | |
| 10044 | Dushanbe, Tajikistan | AZT8 | Opt | 38.490922 | 68.682582 | 732.2 | | | |
| 10059 | Kitab, Uzbekistan | KitabORI2 | Opt | 39.133531 | 66.884678 | 658.0 | | | |
| 10064 | Tiraspol, Moldova | TiraspSR220 | Opt | 46.836333 | 29.631347 | 35.0 | | | |
| 10067 | Ussuriysk, Russia | UssuriyskORI | Opt | 43.698564 | 132.165618 | 273.0 | | | |
| 10072 | Tarija, Bolivia | TarijaORI | Opt | -21.595689 | -64.624061 | 1850.0 | | | |
| 10077 | Blagoveshchensk, Russia | Blagov250 | Opt | 50.318646 | 127.482078 | 220.0 | | | |
| 10078 | Artem, Russia | Artem20 | Opt | 43.340189 | 132.070668 | 16.0 | | | |
| 10083 | Milkovo, Russia | Milkovo220 | Opt | 54.694557 | 158.625927 | 174.4 | | | |
| 10092 | Uzhgorod, Ukraine | UzhgT25 | Opt | 48.563551 | 22.453751 | 231.0 | | | |
| 10103 | Mondy, Russia | AZT33IK | Opt | 51.620292 | 100.921468 | 1993.0 | | | |
| 10112 | Kharkov, Ukraine | Chuguyev25 | Opt | 49.641410 | 36.935380 | 174.0 | | | |
| 10240 | Colleparado, Italy | CollepORI22 | Opt | 41.765283 | 13.375028 | 562.0 | | | |
| 10517 | Zvenigorod, Russia | Zvenig50 | Opt | 55.699453 | 36.757308 | 196.0 | | | |
| 10526 | Lesosibirsk, Russia | Lesosibirsk | Opt | 58.183399 | 92.531017 | 93.0 | | | |
| 10531 | Nauchnyi, Ukraine | CrAOZTSh | Opt | 44.727919 | 34.015914 | 601.0 | | | |
| 10532 | Nauchnyi, Ukraine | GAISHZ600 | Opt | 44.729719 | 34.016708 | 590.0 | | | |
| 10533 | Nauchnyi, Ukraine | CrAOPH1 | Opt | 44.726950 | 34.017239 | 592.0 | | | |
| 10541 | Nauchnyi, Ukraine | CrAORST221 | Opt | 44.729583 | 34.016236 | 594.0 | | | |
| 10901 | Andrushivka, Ukraine | AbdrZ600 | Opt | 50.000844 | 28.997289 | 228.0 | | | |

Non-governmental Systems

Satellite owner operators use a vast international network of sensors to communicate with their satellites. During communication transmissions, transponders provide very accurate range, and sometimes angular information for orbit determination. We do not list these sites because there are literally hundreds of sites around the world. In addition, like the AFSCN, they are specifically for communication with the satellite, and not for passive satellite detection.

Amateur Observers

Not often discussed, but becoming widely popular, the amateur community is beginning to be capable of delivering routine high quality observations to support integrated SSA. Vallado¹⁴ introduced the notion that many distributed sensors could solve numerous difficulties and deficiencies in SSA. With the advent of the internet and significantly cheaper telescopes, amateurs can now take numerous observations, have the data processed, and even distribute catalogs to users.

Amateurs maintain reasonably current orbital elements on about 300 classified objects, including nearly all in LEO, and a large fraction of those in Molniya and GEO. Equipment ranges from binoculars and stopwatches, to telescopic video cameras with GPS time inserters. Automated and semi-automated data reduction is commonly used. The primary orbital model is SGP4; however, numerical methods are employed for long-term propagation of HEO and GEO orbits.

In the year ending in June 2011, twenty-six observers contributed 22,700 positional observations. Thirteen observers accounted for 95 percent of the data. Observers are located in the United States, United Kingdom, Canada, France, Italy, Netherlands, and South Africa.

SLR Ranging Network - SLR

There are numerous sensors in the SLR Network and they are used in conjunction with satellites having laser retro-reflectors.* See <ftp://cddis.gsfc.nasa.gov/pub/slr/data/fr/> for a complete listing including some older satellites. These satellites are particularly useful for establishing truth and reference orbits[†].

While not all satellites have these retro-reflectors, sufficient numbers of satellites do to warrant including these sites in the discussion. We have attempted to provide just the active sites as many have closed, moved, or are inactive. It is prudent to check the Internet sites to find out the current status of these sites.[‡] Current data may show that older sites have closed.

Figure 5 shows some sensor system locations.

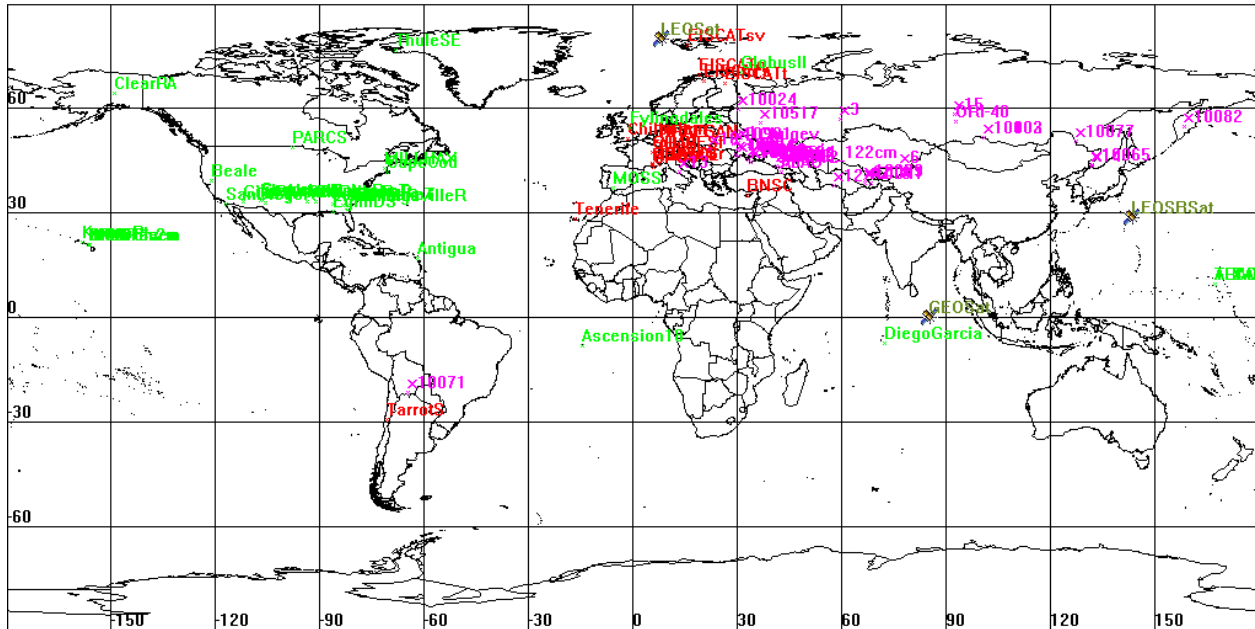


Figure 5: Sample Space Surveillance Site Locations: Representative sensor sites from the SSN (green), European (red), and ISON (magenta) networks are shown. Note the geographic distributions. Image courtesy of STK.

* http://ilrs.gsfc.nasa.gov/products_formats_procedures/site_positions_velocities/itrf2000.txt

[†] We note that many satellites now carry GPS receivers and they transmit data to the ground consisting of processed NAVSOL states, or raw signal observations. A comprehensive listing of satellites having GPS receivers is difficult to find. Some observations can be found at <ftp://cddis.gsfc.nasa.gov/gps/data/satellite/>.

[‡] GSFC May 2011. <http://ilrs.gsfc.nasa.gov/stations/sitelist/>

Table 9: Satellite Laser Ranging Sites: This table shows the currently active stations that provide SLR measurements. The data is current for May 2011.

| SLR Sensors | | | | | | | | | |
|-------------|------------------------------|------|------|------------|-------------|---------|-----------|-----------|--------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 1824 | Golosiiv, Ukraine | GLSL | SLR | 50.363300 | 30.496100 | 212.9 | 1-Apr-97 | | |
| 1831 | Lviv, Ukraine | LVIL | SLR | 49.917600 | 23.957200 | 359.4 | 1-Oct-98 | | |
| 1863 | Maidanak 2, Uzbekistan | MAID | SLR | 38.685737 | 66.943149 | 2711.3 | 1-Oct-90 | | |
| 1864 | Maidanak 1, Uzbekistan | MAIL | SLR | 38.684894 | 66.943085 | 2713.6 | 1-Oct-90 | | |
| 1868 | Komsomolsk-na-Amure, Rus | KOML | SLR | 50.694612 | 136.743828 | 269.5 | 1-May-92 | | |
| 1870 | Mendeleevo 1, Russia | MDVL | SLR | 56.026700 | 37.223400 | 256.7 | 17-Apr-94 | | |
| 1873 | Simeiz, Ukraine | SIML | SLR | 44.413186 | 33.990950 | 364.6 | 1-May-88 | | |
| 1874 | Mendeleevo 2, Russia | MDVS | SLR | 56.027700 | 37.224900 | 228.3 | | | |
| 1879 | Altay, Russia | ALTL | SLR | 51.200000 | 82.300000 | 270.0 | | | |
| 1884 | Riga, Latvia | RIGL | SLR | 56.948550 | 24.059073 | 31.3 | 1-Sep-87 | | |
| 1893 | Katzively, Ukraine | KTZL | SLR | 44.393173 | 33.970122 | 68.1 | 20-Sep-82 | | |
| 7040 | Wrightwood, CA | OCTL | SLR | 34.382000 | -117.683000 | 2200.0 | | | |
| 7045 | Apache Point, NM | APOL | SLR | 32.780361 | -105.820417 | 2788.0 | | | |
| 7080 | McDonald Observatory, TX | MDOL | SLR | 30.680276 | 255.984818 | 2004.4 | 1-Jan-88 | | |
| 7090 | Yarragadee, Australia | YARL | SLR | -29.046518 | 115.346719 | 241.1 | 1-Jul-79 | | |
| 7105 | Greenbelt, MD | GODL | SLR | 39.020615 | 283.172334 | 20.9 | 1-Mar-81 | | |
| 7110 | Monument Peak, CA | MONL | SLR | 32.891757 | 243.577356 | 1839.0 | 15-Aug-83 | | |
| 7119 | Haleakala, HI | HA4T | SLR | 20.706486 | 203.743084 | 3056.3 | 15-Sep-06 | | |
| 7124 | Tahiti, French Polynesia | THTL | SLR | -17.576800 | 210.393700 | 82.2 | 1-Aug-97 | | |
| 7125 | Greenbelt, MD | GF8Q | SLR | 39.020269 | 283.172553 | 18.6 | | | |
| 7130 | Greenbelt, MD | GO4T | SLR | 39.020917 | 283.172571 | 19.9 | | | |
| 7231 | Wuhan, China | WUHL | SLR | 30.515700 | 114.489700 | 86.6 | 28-Dec-99 | | |
| 7237 | Changchun, China | CHAL | SLR | 43.790513 | 125.443457 | 274.3 | 1-Jan-83 | | |
| 7249 | Beijing, China | BEIL | SLR | 39.606935 | 115.892052 | 81.7 | 12-Dec-88 | | |
| 7308 | Koganei, Japan(CRL) | KOGC | SLR | 35.710085 | 139.489124 | 122.5 | 1-Mar-88 | | |
| 7343 | Beijing (TROS), China** | BEIT | SLR | 39.607600 | 115.892100 | 75.2 | | | |
| 7355 | Urumqi, China* | URUL | SLR | 43.810000 | 87.710000 | 845.5 | 15-Apr-03 | | closed |
| 7356 | Lhasa, China | LHAL | SLR | 29.634900 | 91.037700 | 3604.1 | | | |
| 7357 | Beijing-A, China | BEIA | SLR | 39.607700 | 115.892700 | 72.0 | | | |
| 7358 | Tanegashima, Japan | GMSL | SLR | 30.556512 | 131.015413 | 141.1 | 25-Mar-04 | | |
| 7370 | Burnie, Tasmania | BURF | SLR | -41.062214 | 145.881391 | 129.6 | | | |
| 7403 | Arequipa, Peru | AREL | SLR | -16.465721 | 288.507067 | 2489.9 | 10-Jul-92 | | |
| 7405 | Concepcion, Chile | CONL | SLR | -36.843000 | -73.025300 | 169.3 | 17-Apr-02 | | |
| 7406 | San Jaun, Argentina | SJUL | SLR | -31.508625 | -68.623160 | 727.2 | 28-Nov-05 | | |
| 7501 | Hartebeesthoek, South Africa | HARL | SLR | -25.889735 | 27.686173 | 1408.1 | 12-Sep-93 | | |
| 7604 | Brest, France* | BREF | SLR | 48.407861 | -4.503833 | 104.8 | 10-Sep-04 | 31-Oct-04 | |
| 7806 | Metsahovi (new) | METL | SLR | 60.217200 | 24.394600 | 74.0 | 15-Oct-96 | | |
| 7810 | Zimmerwald, Switzerland | ZIML | SLR | 46.877228 | 7.465219 | 951.1 | 3-Jul-95 | | |
| 7811 | Borowiec, Poland | BORL | SLR | 52.276980 | 17.074585 | 122.6 | 13-May-88 | | |
| 7820 | Kunming, China | KUNL | SLR | 25.029900 | 102.797200 | 1991.8 | 20-May-89 | | |
| 7821 | Shanghai, China | SHA2 | SLR | 31.096100 | 121.186600 | 100.0 | 10-Jul-05 | | |
| 7823 | San Fernando, Spain | SFEF | SLR | 36.462730 | -6.206190 | 64.0 | | | |
| 7824 | San Fernando, Spain (new) | SFEL | SLR | 36.465000 | -6.205500 | 98.2 | 4-Apr-99 | | |
| 7825 | Mt Stromlo, Australia | STL3 | SLR | -35.316100 | 149.009900 | 805.0 | 1-Aug-04 | | |
| 7826 | Mt Stromlo, Australia | STRK | SLR | -35.316300 | 149.009800 | 806.6 | | | |
| 7828 | Paris, France (FTLRS) | PARF | SLR | 0.000000 | 0.000000 | 0.0 | | | |
| 7829 | Grasse, France (FTLRS) | GRAF | SLR | 43.754680 | 6.921120 | 1321.3 | 20-Mar-07 | | |
| 7830 | Chania, Crete, Greece | CHAF | SLR | 35.533100 | 24.070500 | 157.0 | | | |
| 7831 | Helwan, Egypt** | HLWL | SLR | 29.859009 | 31.342703 | 131.9 | 1-May-83 | | |
| 7832 | Riyadh, Saudi Arabia | RIYL | SLR | 24.910200 | 46.400400 | 773.0 | 1-Aug-95 | | |
| 7835 | Grasse, France (SLR) | GRSL | SLR | 43.754691 | 6.921122 | 1322.9 | | | |
| 7836 | Potsdam, Germany | POTL | SLR | 52.380018 | 13.064892 | 133.5 | 8-May-92 | | |
| 7837 | Shanghai, China | SHAL | SLR | 31.097540 | 121.191739 | 27.8 | | | |
| 7838 | Simosato, Japan | SISL | SLR | 33.577694 | 135.937039 | 101.6 | 31-Jan-82 | | |
| 7839 | Graz, Austria | GRZL | SLR | 47.067135 | 15.493360 | 539.4 | 1-Nov-81 | | |
| 7840 | Herstmonceux, United Kingd | HERL | SLR | 50.867380 | 0.336123 | 75.4 | 1-Jan-82 | | |
| 7841 | Potsdam, Germany | POT3 | SLR | 52.383000 | 13.061400 | 123.5 | 20-Jul-01 | | |
| 7845 | Grasse, France (LLR) | GRSM | SLR | 43.754600 | 6.921600 | 1323.1 | 1-Sep-80 | | |
| 7848 | Ajaccio, France (FTLRS) | AJAF | SLR | 41.927400 | 8.762700 | 96.8 | 1-Sep-96 | | |
| 7865 | Stafford, Virginia | STAL | SLR | 38.499215 | -77.371107 | 23.9 | | | |
| 7941 | Matera, Italy (MLRO) | MATM | SLR | 40.648600 | 16.704600 | 536.9 | 1-Jan-00 | | |
| 8834 | Wetzell, Germany (WLRS) | WETL | SLR | 49.144417 | 12.878007 | 665.4 | 1-Mar-89 | | |

Simulating Realistic Tracking Schedules

To complete the analysis process, a method of accurately producing the simulated measurements is crucial for realism, and hence, accurate mission requirements verification. Too many observations give too conservative an answer. Too few obs can result in no solution at all. Recognizing that there are many flight dynamics programs in existence, we chose to use the STK ASCII report format of the accesses between a sensor and a satellite so that other programs could use the same simulation routines we developed. The only requirement would be to output sensor-satellite access times in the STK format. The Matlab and script routines will be placed on the web at <http://centerforspace.com/>.

We define the following terms. A *revolution* is completed each time the satellite makes one complete orbit about the Earth. This requires a reference point, often from the ascending node or perigee. A *pass* is made each time a satellite crosses above the horizon from a sensor. A *track* is the time period that a sensor actually observes a satellite as it passes overhead. For a Molnyia, a pass may last 7-8 hours. A track may only be 5-6 minutes in that time period. Within each track, we can further distinguish how often the sensor makes an *observation*. This includes the time to gather radar impulses, or to acquire a CCD image, and it is often 20-30 seconds. The observation itself consists of the actual measurements, range, azimuth, elevation, right-ascension and declination, etc.

The usual approach to simulating observations is a simple line-of-site access between the sensor and the satellite. While easy to program, this approach will certainly yield too many observations. Consider a sensor tracking a GEO satellite. By definition, it will simulate observations continuously! As the number of constraints increases, the access times are more limited, and the resulting simulated observations better model the actual system. Constraints include items such as:

- Line of Sight
- Range, azimuth and elevation limits (angles and rates, az-el masks)
- Lighting (Direct, umbra, penumbra)
- Exclusions (Sun, Moon)
- Special Angular (grazing, beta, squint, etc angles)
- Local terrain and topography
- Custom (dynamic exclusions, target exclusions, boresight, vector, other advanced constraints)
- Communication limitations (signal, frequencies, SNR, etc)
- Sensor constraints (boresight, etc)
- Special user written constraints

We used STK as it already has these constraints (and more) embedded. Matlab scripts were generated to accomplish the actual observation thinning and the input was an ASCII output from a report in STK. Because the format depends on an STK chain access report, we provide an example report should another program be used in the initial access generation. The ASCII report contains start/stop times, and we felt this was the easiest point to provide an interface to accommodate different flight dynamics programs.

Each sensor has physical limitations and operational constraints that dictate to some extent how the system operates. Table 10 lists the control parameters we used. Although the sensor type seems to indicate a particular type of sensor has these characteristics, we felt it was better to allow individual sensors to have individual performance parameters. For instance, an optical observatory in NM will have a much lower missed track probability than a similar site at Diego Garcia, primarily due to weather considerations. The revisit time is intended primarily for sensors that might have continuous, or extended periods of time where the objects are observable. It limits the number of distinct tracks that can occur. We label these sensor type constraints. Note the inclusion of a missed track probability, which incorporates the random nature of events such as weather or over-scheduling into the simulated observations. We also include a way of integrating various sensors together so that the integrated simulation has a reasonable number of observations from the ensemble of sensors, and not just a single sensor operating in isolation with the inter-revisit time. This is the time interval after which no sensor will re-acquire the satellite.

Table 10. Sensor Tracking Parameters. This table shows the physical parameters that affect the number and frequency of observations from a given sensor. The Type is used to further refine the sensor characteristics in a later process. The revisit times specify an interval in which a given sensor, or sensor network will not re-look at a satellite for the specified time. All values are strictly notional.

| | Pass length (min) | Obs Step (sec) | Revisit time (hr) | Inter-revisit time (hr) | Missed-Track Probability | Type |
|---------------------|-------------------|----------------|-------------------|-------------------------|--------------------------|--------------------------------|
| BNSC | 6.0 | 20.0 | 8 | 3 | 25% | Optical |
| Diego Garcia | 5.0 | 20.0 | 6 | 6 | 25% | Optical |
| KRAO | 7.0 | 20.0 | 8 | 3 | 35% | Optical |
| ORI | 8.0 | 10 | 8 | 3 | 20% | Optical |
| Tenerife | 6.0 | 20.0 | 8 | 3 | 15% | Optical |
| LEO SBSat | 8.0 | 30.0 | 6 | N/A | 5% | Space Based Optical |

ODTK OBSERVATION GENERATION

For our test simulation, we considered a LEO and GEO satellite being observed from the SSN (Diego Garcia), a Space Based satellite, and European (Cyprus and Tenerife) and ISON (KRAO, ORI) sensors. Having these sensor all collaborate may seem far fetched, but data fusion represents a viable option to enhance SSA. The LEO satellite is in a typical Sun-synchronous orbit. The GEO satellite is at about 85 deg E longitude where the SSN coverage is very poor. Here, the European and ISON sensors can readily achieve information. However, each sensor system working independently is constrained by angles-only observations, or lack of measurements due to physical limitations. We compare the results for both individual and fused data.

The process is as follows. In STK, setup a Chain of the sensors to the satellites, including the SB satellite observing the other satellites. Then compute accesses and output the Individual Strand Access report for the chain. The ASCII output lists times where the sensor satellite pair is visible. An example is shown below.

Chain-SSN2Sats: Individual Strand Access

BNSC to LEOSat

| | Start Time (UTCG) | Stop Time (UTCG) | Duration (sec) |
|-----------------------|-------------------------|-------------------------|----------------|
| | ----- | ----- | ----- |
| | 15 Jul 2011 05:45:25.40 | 15 Jul 2011 05:52:19.59 | 414.187 |
| | 15 Jul 2011 07:15:58.33 | 15 Jul 2011 07:27:13.07 | 674.743 |
| ... | | | |
| | 21 Jul 2011 20:53:18.35 | 21 Jul 2011 21:02:43.39 | 565.044 |
| Min Duration | 19 Jul 2011 21:47:18.02 | 19 Jul 2011 21:49:19.18 | 121.159 |
| Max Duration | 15 Jul 2011 07:15:58.33 | 15 Jul 2011 07:27:13.07 | 674.743 |
| Mean Duration | | | 525.674 |
| Total Duration | | | 17347.246 |

BNSC to GEOSat

| | Start Time (UTCG) | Stop Time (UTCG) | Duration (sec) |
|--|-------------------------|-------------------------|----------------|
| | ----- | ----- | ----- |
| | 15 Jul 2011 00:00:00.00 | 22 Jul 2011 00:00:00.00 | 604800.000 |

Figure 6: Sample Access Report: A sample access report is shown. The ASCII format enables other programs to create a similarly formatted report and then use the simulation routines to produce realistic simulated observations.

Next, process this access textfile and make individual files that specify the target and sensor names in each filename (LEOSat#BNSC.int specifies BNSC observing the LEOSat).

```
Fixhpintervals c:\stkodfiles\worldsensors\ testchain.txt testchain.out
```

Now find the realistic scheduling using Matlab. (**writeaccessint2.m**) This process specifies each observation, so the files can become large. It's best to place all the interval files in a new directory (here called Int)

```
writeaccessint('c:\stkodfiles\worldsensors\testchain.out',  
'TaskScheduleInt.txt', 'c:\stkodfiles\worldsensors\int\')
```

The results need to be loaded back into ODTK via another script (**AR_PopODTKIntervals.html**). In this script, you can specify the filename, Sensor names, and observation time steps. Note that the time step is generally not needed because the Matlab script writes out each observation time. As the intervals are loaded into the ODTK simulator, you can clear the list, or keep the previous interval listing.

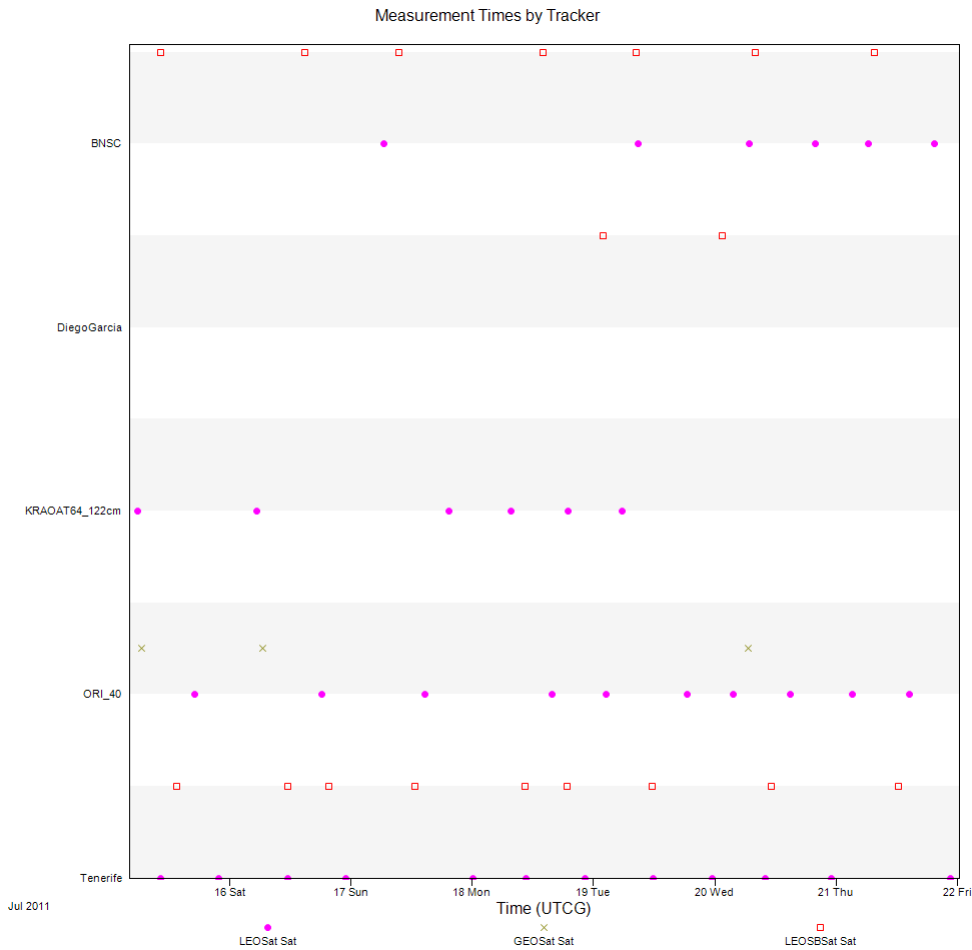


Figure 7: Simulated Observation Times. Observation times are shown for the LEO and GEO satellite.

Notice that the sensors observe relatively infrequently – our original intent. For comparison, if we had not thinned the observations, we would have found observations shown in Fig. 8. The increased observations will surely give more optimistic results in any resulting analysis.

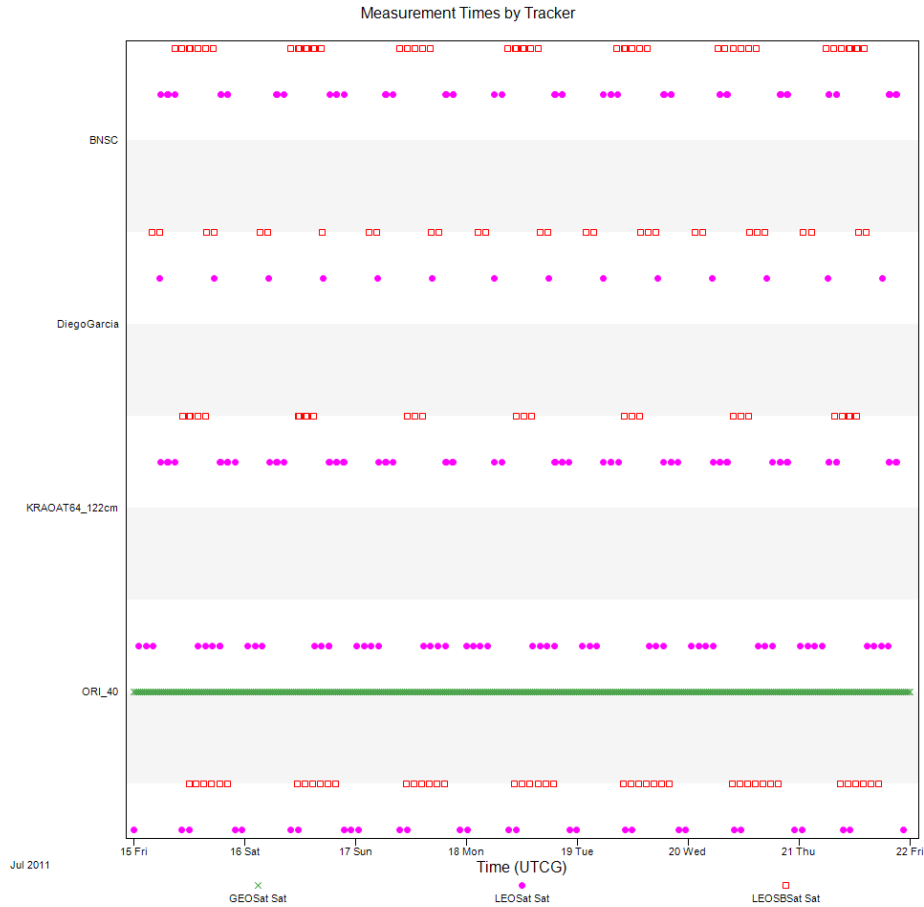


Figure 8: Simulated Observation Times. Observation times are shown for the LEO and GEO satellite without thinning. Note the continuous access for the GEO satellite.

SUMMARY and CONCLUSIONS

A comprehensive list of the larger space surveillance tracking systems has been developed. Sample limit characteristics are given to establish a baseline for use in developing simulated observational data for joint cooperative research and analysis. The overall goal is to establish the means to conduct reasonably accurate studies and to determine the benefits of doing joint tracking and processing of data. A framework is established for users to request simulated observations from the given sets of sensors. This will enhance the accuracy of studies and permit observational data to be formed for analysis purposes. Secure World Foundation is planning to host information of this type on the web in the Fall of 2011.

We hope an outcome of this paper will be several fold. First, awareness of what sensors exist for space surveillance. Second, commonality in simulation studies. Finally and not least, opportunities to collaborate and share data and observations to develop and maintain more accurate satellite catalogs to support better Close Approach and RFI analyses and ensure safer operation in space (e.g., see Vallado¹⁵ or Lam¹⁶ when mixing angle data with range data to achieve better OD estimation). Global SSA is certainly possible if all these systems shared data.

If you have questions, comments, or corrections, please let us know!

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amateur operations as well as reviewing the entire document. Brian Weeden also provided excellent insight, and he will head the effort of Secure World Foundation to maintain a website listing of these sensors and additional information.¹⁷ Papers are in progress to describe this activity in additional detail. Jaganath Sankaran has also assembled an impressive list of sensor sites which we used to cross-check many of the sensor sites.

References

1. Vallado, David A. 2005. An Analysis of State Vector Propagation for Differing Flight Dynamics Programs. Paper AAS 05-199 presented at the AAS/AIAA Spaceflight Mechanics Conference, January 23-27. Copper Mountain, CO.
2. Jaramillo, Cesar (Managing Editor), et al. 2010. Space Security 2010. Annual Report from <http://www.spacesecurity.org/>. Waterloo, Ontario, Canada.
3. Vallado, David A. 2007. *Fundamentals of Astrodynamics and Applications*. Third Edition. Microcosm, Hawthorne, CA.
4. Fischer, Jack. 1998. The evolution of Highly Eccentric Orbits. M. S. Thesis, CSDL-T-1310. Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.
5. Gott, Cherie D. 1996. Space Surveillance Network Sensor Site Information 1960-1996. HQ USSPACECOM/AN. Version 1.0.
6. Podvig, Pavel. 2002. History and the Current Status of the Russian Early-Warning System. *Science and Global Security*, 10:21-60, 2002.
7. Podvig, Pavel. 2006. Reducing the Risk of an Accidental Launch. Routledge Taylor and France Group. *Science and Global Security*: 14:75-115.
8. Klinkrad, H. Monitoring Space – Efforts Made by European Countries. Paper presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l’Air et de l’Espace, Toulouse, France (27-28 November 2002), online: Federation of American Scientists, <http://www.fas.org/spp/military/program/track/klinkrad.pdf>
9. Coster, A. J., R. Abbot, L. E. Thornton and D. Durand. 2001. Exploiting AFSCN Ranging Data for Catalog Maintenance. Paper presented at the MIT Lincoln Laboratory Space Surveillance Conference, Project STK-256, ESC-TR-2000-053. S.E. Andrews Editor, 3-5 April.
10. CAO Zhi-bin Et al. 2009. A Research on the Orbit Determination Method by Means of Sparse Data of Electronic Fences. *Chinese Astronomy and Astrophysics*. 33, pg 194-205.
11. Zhang Guangyi. 1996. The Research Work of NRIET in Phased – Array Radar Technology.
12. Wen Xun Zhang, Antenna Development in China. *IEEE Antennas and Propagation Magazine*, Vol. 38, No. 6, December 1996
13. Molotov I., Agapov V. et al. 2008. International scientific optical network for space debris research, *Advances in Space Research*, Volume 41, Issue 7, 1022-1028.
14. Vallado, David, and Salvatore Alfano. 1999. “A Future Look at Space Surveillance and Operations.” Paper AAS 99-113 presented at the AAS/AIAA Space Flight Mechanics Conference. Breckenridge, CO.
15. Vallado, David A. and Vladimir Agapov. 2010. Orbit Determination Results from Optical Measurements. Paper AIAA-10-7525 presented at the AAS/AIAA Astrodynamics Specialist Conference, August 2-5. Toronto, Canada.
16. Lam, Quang M., and Daniel Junker, David Anhalt, and David A. Vallado. 2010. Analysis of an Extended Kalman Filter Based Orbit Determination System. Paper AIAA-10-7600 presented at the AAS/AIAA Astrodynamics Specialist Conference, August 2-5. Toronto, Canada.
17. Weeden, Brian, Paul Cefola and Jaganath Sankaran. 2010. Global Space Situational Awareness Sensors. Paper presented at the AMOS Conference.

APPENDIX – CLOSED SITES

Table A1: Closed Sensor Sites: This table shows some common sites that are closed. The information is provided for historical purposes only.

| Closed Sensors | | | | | | | | | |
|----------------|---------------------------|-------------|---------|-----------|-------------|---------|-----------|----------|-----------------|
| ID # | Location | Name | Type | Latitude | Longitude | Alt (m) | Open | Close | Notes |
| 3820 | Eldorado | Eldorado | PhArray | 30.978328 | -100.552953 | 741.0 | 8-May-87 | 1-Sep-95 | |
| 3840 | Robins, GA | Robins | PhArray | 32.581250 | -83.569167 | 83.0 | 29-Sep-86 | 1-Sep-95 | AN/FPS-115 |
| 2200 | Taegu, Korea | Korea | Opt | 35.744072 | 128.608572 | 744.0 | | | |
| 315 | Diyarbakir, Turkey | Pirincilik | Radar | 37.905239 | 39.993372 | 844.0 | | 1-Jan-95 | fan FPS 17 |
| 329 | Clear, AK | Clear | BMEWS | 64.289475 | -149.195081 | 181.0 | 1-Jun-61 | | FAN FPS-50 |
| 362 | Grand Turk | Grandturk | Radar | 21.462594 | -71.132097 | 23.0 | | | FPQ-13 |
| 365 | Grand Bahama | GrandBahama | Radar | 26.615778 | -78.347769 | 7.0 | | | FPQ-13 |
| 5 | Malabar, FL | Malabar | BN | 28.024522 | -80.685028 | 7.0 | | 1-Sep-95 | |
| 9993 | Yuzhno-Sakhalinsk, Russia | x211 | Opt | 46.950000 | 142.730000 | 25.0 | | | Closed |
| 6663 | Balkhash, Kazakhstan | x10 | PhArray | 46.602906 | 74.528508 | 344.0 | | 1-Sep-04 | 120, 184 |
| 6664 | Balkhash, Kazakhstan | x11 | PhArray | 46.604683 | 74.532778 | 361.0 | | 1-Sep-04 | 62 |
| 66619 | Skundra, Latvia | x35 | PhArray | 56.715225 | 21.962917 | 0.0 | | 1-May-95 | |
| 66620 | Skundra, Latvia | x36 | PhArray | 56.708236 | 21.940967 | 0.0 | | 1-May-95 | |
| 55510 | x | x39 | Radar | 51.637772 | 30.702892 | 0.0 | | | Closed |
| 55511 | x | x40 | Radar | 50.892961 | 136.836772 | 0.0 | | | Closed |
| 55512 | x | x41 | Radar | 50.385550 | 137.328297 | 0.0 | | | Closed |
| 55510 | Old Nike radar | Billig | Radar | 50.622825 | 6.744797 | 856.0 | | | Closed Nike Rad |
| B34 | Cyprus | BNSC | Opt | 34.912181 | 32.883725 | 1760.0 | | | |
| 501 | Herstmonceux, UK | PIMS | Opt | 50.870164 | 0.345878 | 41.0 | | | Closed |
| 993 | Gibraltar | PIMS | Opt | 36.118589 | -5.346164 | 121.0 | | | Closed |