# GEODSS Present Configuration and Potential

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## Abstract

Ground-based Electro-Optical Deep Space Surveillance (GEODSS) is a dedicated Air Force Space Command (AFSPC) optical telescope system that supports United States Strategic Command's (USSTRATCOM) mission Space Surveillance awareness (SSA). The GEODSS generated data is used by the Joint Space Operations Center (JSpOC) and National Air and Space Intelligence Center (NASIC) situated on Wright-Patterson Air Force Base outside of Dayton Ohio, The system consists of three geographically dispersed sites; Detachment, Socorro, New Mexico on White Sands Missile Range (WSMR), Detachment 2 Diego Garcia, British Indian Ocean Territory, and Detachment 3 on the island of Maui, Hawaii. GEODS S has been operational since October of 1983 and has received two end of life extensions, the result of proven capability and timely upgrades. As GEODSS enters its fourth decade of service life, a look at its current configuration and potential to meet the ever growing needs of the SSA community are presented.

The Ground-based Electro-Optical Deep Space Surveillance (GEODSS) network is an optical telescope system that monitors and provides collected satellite data for the United States Strategic Command's (USSTRATCOM) mission and the National Air and Space Intelligence Center (NASIC). The GEODSS generated metric positional data is used by the Joint Space Operations Center (JSpOC), a command and control (C2) system dedicated to developing and achieving USSTRATCOM's Joint Functional Component Command for Space (JFCC SPACE) Space Situational Awareness (SSA) mission. Another GEODSS mission, Space Object Identification (SOI) is a function that measures the time variation of the brightness of a satellite. The resulting intensity versus time signature for the object is a product that is provided to NASIC.

The GEODSS network is currently comprised of three geographically distributed sites; Det 1 in Socorro, NM on White Sands Missile Range (WSMR), Det 2 in Diego Garcia, British Indian Ocean Territory, and Det 3 on the summit of Mt. Haleakala on the island of Maui, Hawaii. Each of the three sites is equipped with three independently tasked telescopes. Initial design and operational strategy projected GEODSS telescopes to primarily observe and collect data on tasked deep space satellites in the period range of 225 minutes and beyond. GEODSS collects data passively in the electro-optical visible wavelength. Detecting and tracking satellites in optical wavelengths with a GEODSS type sensor is highly desirable because of the alternative ground-based method, RAdio Detection And Ranging (RADAR), is extremely expensive to deploy and operate.

The telescope design provides a one-meter aperture low focus ratio f /2.15 telescope based on the Ritchey-Chretien design. As previously mentioned they currently collect exclusively in the electro-optical visible wavelength (app.780-390 nm) using Charge Coupling Device (CCD) technology. The CCD is modeled on the MIT/LL CCID-16 device, designed by Sarnoff Corporation. It has a monolithic array of 1960 by 2560 pixels. This large CCD, paired with the GEODSS optical package provides a field of view of 1.23° x 1.61[1]°. Thus at true geosynchronous range, the total field of view corresponds to about 860 x 1125 km. Each CCD pixel measures 24 $\mu$m square with a 100% active area. The singular pixels have an individual field of view of 2.27 x 2.27 arc-seconds, providing a single pixel a field of view at geosynchronous range of about 0.44

x 0.44 km. The chip covers just less than 60% of the 80 mm GEODSS telescope circular focal plane. The back-illuminated device has 8 channel outputs enabling, an approximate 3 frame per second read-out rate. The CCD has a split-frame-transfer architecture with eight output ports and a 2.0 MHz clock rate that gives a maximum frame rate of 2.7 per second (a frame time of 0.37 seconds) [1]. The CCD has a peak quantum efficiency (QE) of about 0.86, and its QE is greater than 0.3 across the entire 0.4 to 0.9 μm band. The solar-weighted QE averaged over this band is about 0.65. The CCD's well capacity is greater than 140,000 and it has 13 bits of dynamic range (indicating that its gain must be at least 17 electrons/count). The average dark current is less than 6 electrons/pixel/second and the readout noise is less than 12 electrons. Historically, GEODSS telescopes were typically operated in an electronic zoom mode that resulted in a circular field of view with a diameter of 1.05˚, for a total field of view of about 0.87 square degrees. Over the course of the past decade and with several upgrades, the system now has a rectangular field of view of 1.23˚ x 1.61˚ = 1.98˚ square degrees, an increase of over 200%. capability provided in the upgraded GEODSS telescope system were projected to able to search 840 degrees in a two hour span, or in tracking mode, make 4,600 observations per eight hour span. In its streak detection mode, GEODSS is capable of compiling a series of exposures for a total of six seconds. It then waits six seconds and takes a second set of exposures for another six seconds. Since the time required to step and settle to the next search position is about one second, the search of one field of view thus takes just under 20 seconds. It generates two streaks, and since an observation (an angular velocity position measurement) is made for the beginning and end of each streak, there are thus four observations every twenty seconds.

The GEODSS CCD also contains a 32 X 32 array of identical pixel architecture used for obtaining SOI signatures. Its characteristics are similar to that of the larger array, except that it is capable of a frame rate of 1,000 frames/second at a 1.25 MHz clock rate. In SOI mode, the GEODSS system measures the time variation of the brightness of an object, producing an intensity versus time signature of a specific space object. In SOI mode, the telescope is operated in a target-track (rate track) mode. Since important brightness variations can occur on time scales much shorter than the integration times used for search or tracking (0.37 seconds) a much shorter integration time, typically 0.01 seconds, is used. Accordingly, in SOI mode, the minimum target brightness is several magnitudes less than in tracking or search mode. In SOI mode, all the target energy is collected (that is, the signal is collected from multiple pixels centered on the target) and the sky background is also measured, so that an absolute measurement of the target brightness can be made.

Another design feature ideally suited for the GEODSS mission is the Equatorial Mount. An equatorial mount is typically used for instruments that follow the rotation of the sky as the GEODSS Telescopes normally task, operating in sidereal track mode. The rotation of the celestial sphere is accomplished by having one rotational axis parallel to the Earth's axis of rotation. The advantage of an equatorial mount is in having the ability to fix the optical instrument attached to it on any object in the sky that has circadian motion by driving one axis at a constant speed. This configuration is commonly referred to as sidereal drive, hence the term sidereal track... On the GEODSS telescope mounts, the equatorial axis, right ascension, is paired with a second perpendicular axis of motion, declination.

In order for the GEODSS Network to better serve the JFCC SSA mission, further improvements must be pursued and implemented to meet the ever increasing needs of this task and to extend the GEODSS system life. In improving an existent, cost efficient system to meet evolving mission requirements, funding otherwise required for design, engineering, manufacture and construction of replacement systems is circumvented. Increasing the area and availability of sensor coverage and mitigating external influences are areas in which significant improvement can be provided to assist the JFCC mission. There are several options that can be evaluated in order to reach this goal.

One of the areas in which extended coverage can be implemented is the GEODSS non-shooting period of sunrise to sunset. Optical daytime detection of geosynchronous earth-orbiting (GEO) satellites in visible or infrared (IR) wavelengths is little accomplished or reported in available literary works. Conversely, Low Earth Orbit (LEO) optical satellite tracking is routinely accomplished at a myriad of sites across the planet. Daytime GEODSS optical tracking would have significant SSA applications. In addition to the current workload, one of the proposed day operations cameras currently in the development stage would be capable of characterizing the attitude, shape, and size of satellites using photometric light curves. That particular camera has since engaged in a test observation in which stars of brightness comparable to GEO satellites were imaged during the daytime at the NASA Infrared Telescope Facility (IRTF).

Weather also plays a limiting role in the availability of the GEODSS system to support the SSA mission. Wind, visibility and humidity are all limiting factors to telescope operations in general. Prior to the CCD upgrade, a GEODSS study indicated that the telescope had ideal operational capabilities of about nine hundred and thirty one tracks per eight hours or one hundred and sixteen observations per hour and a search rate of 583 $deg^2$ per hour. With five observations per track, this translated to a rate of about 23 tracks per hour (per telescope). However, statistically, the track rate was significantly less as GEODSS was actually producing 40,658 tracks. This corresponded to less than 5 tracks per hour per telescope. The actual track rate of the original GEODSS system was about five tracks per hour per telescope, approximately a fourth of the ideal operational capability of twenty tracks per hour per telescope. Although not exclusively implicating weather as the sole source of the discrepancy the report stated that one of the reasons the actual tracking rate would be expected to be less than ideal operational rate is that GEODSS requires good weather. That alone could account for the reduced number of tracks by a factor of two or more. Cloud cover data from that time indicated that at the Socorro site, the sky is clear just over 50% of the time, for Maui just under 50% of the time, and for Diego Garcia, less than 40% of the time. The system is also affected by adverse wind and humidity conditions and by the Moon.

Measures can be imposed to minimize the mission impact of weather. Currently specific weather limitations are imposed on the areas of consideration, humidity, winds and visibility. Wind speeds in excess of approximately 25 knots initiate operations cessation.

Although a comprehensive study may be required, options to mitigate the operational impact of wind are under review. The set humidity limit of 90% may soon be a non-factor. Initially, the GEODSS telescope mirrors were exposed to the elements creating a potential damage peril with the advent of humidity. All GEODSS Telescopes now have a lens sealed aperture and an active environmental control system that precludes susceptibility and the damage risk of humidity. With this in place, humidity is not necessarily a legitimate criterion for weather directed preclusion of operations... It should also be noted that humidity greater than 90% is not always an indicator of precipitation. The domes automatically close when precipitation is detected at which point operational cessation for precipitation is unavoidable. Visibility is factored as a data collection interruption as well when it is perceived to be at 0%, indicating no star visibility. The values used to derive satellite visibility are monitored on an infrared cloud sensor located on the roof and/or through the eye of an onsite crew member. Thus, visibility pits the sensitivity of the GEODSS Telescope against an infrared sensor looking at an entirely different spectrum of light or the human eye and its limited collection surface. Initial indications show that the GEODSS telescopes are sensitive enough to capture usable observations through clouds when the infrared sensor indicates otherwise.

Other optical sites have precluded weather concerns through the use of innovative design features. One such innovation is the Lanphier Shutter System (LSS). The Lanphier shutter is a 1.22 meter square pane of optical quality glass that allows the operation of the telescope in inclement weather conditions[2]. In addition it also allows the interior of the dome to be climate controlled. Even though there are currently nine observatories in the world utilizing the LSS, the concept is still poorly understood and largely untested. A site in Arizona, one of the first that deployed this system is the Windowpane Observatory (WP) [3]. The WPO achieved great success using the LSS optical glass that climate-controls the observatory even with large temperature differences of up to 70 degrees Fahrenheit. between the outside of the dome and the interior temperature.. The WPO glass plate became the subject of several research studies in climate controlled observatories and was presented in a series of papers and lectures at the University of Texas McDonald. According to WPO results, the key to high resolution imagery was to make sure that the flat plane of the primary mirror was exactly parallel to the plane of the windowpane optical glass portal. In addition to protection from the elements, the research found that the windowpane glass portal eliminated the problem of wind tunneling from high wind gusts as the entire dome environment was draft free.

Employing a fish eye lens in some capacity to the GEODSS System would increase the volume of sky coverage exponentially. Systems such as the Hemispherical Optical Sensor Tracker (HOST) have been developed to provide concurrent and uninterrupted coverage, from -7˚ through zenith elevation and 360 ˚azimuth[4]. The entire Field Of View (FOV) is imaged onto a single, rectangular Focal Plane Array (FPA). The optical system consists of dual optical paths, a panoramic optical path for low elevation angles and a fisheye optical path for higher elevation detection. The design provides improved resolution and radiometric throughput at low elevation angles versus a single fisheye optical strategy. Both optical systems are imaged onto a single focal plane, with the result that a target moving through the overall sensor Field Of View (FOV) from one optical system to the other, will exhibit non-linear and discontinuous motion on the focal plane. In order to handle the non-linear and disjointed movement of a target on the focal plane, tracking must be accomplished in azimuth and elevation coordinates, requiring the use of a unique pixel to Line Of Sight (LOS) conversion method. Like GEODSS and other passive electro-optic sensors, the HOST is an angles only sensor which does not provide range to targets. Although the HOST system concept has also been tested in pairs to support LOS triangulation in order to obtain triangulated ranging...

GEODSS CCD’s are characterized as highly sensitive, with very linear response, and possess large dynamic range. Large CCDs can typically detect some ultraviolet, all of the visible and much of the near infrared spectrum; they are characteristically responsive from about three hundred and fifty nm to approximately one thousand nm. The possible application of Ultra violet and infrared filters coupled with software modifications may also provide a cost effective measure to increase the amount of surveillance provided by the GEODSS System

The GEODSS Mobile Platform is an antiquated albeit highly coveted concept. Earlier, similar concepts can be found in Optical Space Surveillance Sensor (OSSS) and Transportable Optical Sensor (TOS)-OSSS was originally developed by Lincoln Laboratory as a field-able prototype in 1989-1990 and deployed to San Vito Air Force Station in Italy[5]. The sensor was designed to provide critical metric tracking capacity for deep space catalog maintenance. The follow-up TOS designed as a deployable gap filler in SSN deep space coverage. The TOS required minimal site preparation and was intended to be operational at a new site three days after arrival. The TOS was designed to be transported in a single C-141 aircraft. TOS was sold to AFSPC as a pre-deployment pathfinder for the GEODSS Upgrade Prototype System (GUPS)

.GEODSS remains a viable cost effective essential of the Air Force Space Command Mission. Originally slated to cease operations and shut down by the year 2000, its cost saving and value added contribution to the SSA community was deemed too valuable to lose in the budget constrained fiscal environment that existed both then and now. By investing a comparatively small percentage of the allotted space budget to improve capability and upgrade the GEODSS System, the SSA mission has a capable and proven asset to rely on.

Citations:

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