# Optical Ground Based Space Surveillance Obscured Sky Mitigation

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Robert Bruck

Operations Superintendent, 20th Space Control Squadron Detachment 3, BAE Systems

Francis Lundy

Senior Sensor Analyst, Sensor Optimization, 18th Space Control Squadron

# Abstract

Space Situational Awareness (SSA), especially in deep space, has long relied on the contribution from ground based optical sensors. Terrestrial based astronomical and space track telescopes are subjected to weather constraints. Consequently, the Ground Based Electro Optical Deep Space Surveillance (GEODSS) telescope constellation is limited in its mission capability by impacting atmospheric circumstance and subsequently implemented weather restrictions on telescope operations. While weather will always play a limiting role to the GEODSS's mission, site personnel have initiated efforts to reduce the impact of these conditions. A collaborative effort between Air Force Space Command and its C2 interface examined this limiting factor, resulting in measures to minimize the mission impact of weather. Currently, weather is factored in three areas of consideration, humidity, wind and visibility. When completely obscured by clouds or 0% star visibility is perceived in the field of regard, the sensor domes are closed and the telescopes sit idle, unable to perform the SSA mission. This state is determined from an infrared sensor located in the center of the facility roof and the perception of the human eye in the form of an onsite crewmember. Two issues exist within which visibility is defined. The first is the sensitivity of the GEODSS optical system in comparison to the infrared sensor. The second is the human eye and its limited collection surface as opposed to the light collection ability of the GEODSS telescope. Both look at an entirely different spectrum of light. Testing between April and June of 2017 revealed that the GEODSS telescopes are extremely adept at detecting the reflected sun light from orbital bodies in a completely cloud obscured environment. By continuing to collect satellite tracks until the cloud density precludes any such activity versus terminating data collection when complete cloud coverage occurs, the GEODSS telescope provides a significant increase in data to the SSA community. While it is very difficult to determine the vertical cloud stratification, data collected in these circumstances has always proven useable. In fact, as the end user evaluates the accuracy of the data collected through the obscure sky testing, the metric collections exceed expectations. This augmented operational availability will increase GEODSS's availability and metric observations in support of actionable SSA.

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 (USSTRATCOM) and the National Air and Space Intelligence Center (NASIC). The GEODSS generated metric positional data is used by the Joint Space Operations Center (JSpOC) and the co-located 18th Space Control Squadron (18 SPCS), the command and control (C2) node responsible for USSTRATCOM's Space Situational Awareness (SSA) mission. Another GEODSS capability, 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 provided to NASIC. GEODSS is operated by the 20th Space Control Squadron (20 SPCS) and is currently comprised of three geographically distributed sites; 20 SPCS Det 1 at White Sands Missile Range, New Mexico (WSMR), 20 SPCS Det 2 at Naval Support Facility Diego Garcia, British Indian Ocean Territory (DGC), and 20 SPCS Det 3 at the Maui Space Surveillance Complex, Hawaii (MAU). Each of the three sites is equipped with three independently tasked telescopes. GEODSS collects data passively in the visible wavelengths.

In order for the GEODSS network to better serve the SSA mission, further improvements must be pursued and implemented to meet the ever increasing needs of this charge and extend the GEODSS system life. Increasing the area and availability of sensor coverage and mitigating external influences can better support increased metric observations on targets of interest. Daylight and weather play 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. Of interest, what issues can be mitigated to meet demands and improve availability?

This endeavor sought to mitigate one of the limiting factors experienced by all ground based optical sensors and diminish surveillance interruption. During the study period, cloud obscuration was determined to be the primary cause of data collection interruption at all GEODSS site locations. During the test period between 01 April 2017 and 10 July 2017, the GEODSS site at White Sands Missile Range, New Mexico experienced 32 nights where data collection ceased completely or partially for 0% visibility (completely obscured sky). The GEODSS site in Diego Garcia amassed 36 nights in that same period of complete or partial cessation for 0% visibility.

GEODSS sites follow procedures in which they cease operations with complete cloud obscuration. However, over a period of years, GEODSS personnel sporadically observed the telescopes collecting satellite tracks in complete cloud coverage when there were no stars visible to the human eye, and the Infrared Cloud Imagers (IRCI) indicated completely obscured skies. Based on these observations, it was determined that SSA support could be feasible through an absolutely masked upper atmosphere. But, what exactly were the instruments capable of viewing in complete cloud cover? And, how effective was the product when collected outside of the fringe of assumed capability?

Research has indicated the presence of fog and haze in the line of sight or propagation channel hampers other optical systems like optical wireless communication. In these systems, small water droplets scatter propagated light, causing attenuation due to the resultant spatial, angular, and temporal spread of the light signal. The ensuing low visibility may impede the operation of the tracking and pointing system so pointing errors occur (Kedar et al. 2003). The purpose of this study was to validate the feasibility of tracking in apparent obscured sky conditions aloft and evaluate the operational effectiveness and suitability of the data to support the space surveillance mission. All tests were conducted in accordance with approved test procedures with support from operations, maintenance, and systems engineering personnel. The test provided an opportunity to enhance the operational effectiveness of the GEODSS network by improving tracking and search system capabilities, correcting unnecessary mission interruption, and improving overall system availability.

The study was based on the simple premise of continued data collection efforts with GEODSS telescopes when indicators implied completely obscured upper atmospheric conditions. In essence, the GEODSS system would determine the point in which data could not be collected due to obscuration. Analysis of the collected data would then be used to either validate the endeavor or corroborate the existing protocol of terminating collection efforts while experiencing complete cloud cover.

Direction and approval was obtained through 18 SPCS and the 21st Operations Group (21 OG). A test plan was developed with the intention of validating the capability of the GEODSS sensors to accurately track orbital objects during severe cloud cover conditions and develop CONOPS for sensor use in downtime due to weather. The requirements for the study were:

1. All required resources must be available to support testing
2. A configuration control system must be established for hardware and software
3. A deficiency documentation system must be in place
4. Technical documentation must be available and sufficient to operate and maintain all systems, subsystems, and equipment safely and effectively
5. Detailed evaluation procedures including any data collection, analysis and reporting tools must be complete and available
6. Analysts are available for evaluation of test data on initial track, near real time basis with in-depth analysis within 24 hours
7. Actual testing can only be conducted under the right environmental conditions (weather), specifically high cloud cover precluding any star visibility to the human eye or IRCI sensor set at default settings

18 SPCS set the standards regarding correlating cloud thickness with data optimization for 20 SPCS Det 1 and Det 3. Its stated purpose was to establish a validation process for observations made through cloud cover of a defined thickness to increase optical sensor efficiency. For permissible testing, it stipulated the following conditions and participants had to be available:

1. 20 SPCS Det 1 and/or Det 3 tracking satellites with complete cloud cover
2. 18 SPCS Sensor Optimization Cell providing analysis on observation quality
3. The 614th Combat Training Squadron (CTS) Weather Flight providing weather reports with times and varying cloud cover and densities with 2-day positive/negative cloud reports for the 20 SPCS Det 1 and/or Det 3 area(s). The monitored layers would be between 3,048 meters to 12,192 meters above Mean Sea Level (MSL). The cloud layer densities would be evaluated in 305-meter increments. The 614 CTS Weather Flight was to provide Sensor Optimization with the actual cloud thickness during the time the test data was collected.
4. The 18 SPCS Operations Crew was to provide specified tasking for the GEODSS Sensor if in receipt of positive cloud report from the 614 CTS Weather Flight.

A Test Plan was then developed in which the Method of Test included:

- Environmental sensors and site software (Infrared Cloud Imager (IRCI)) to determine sensor is not operationally capable (OPSCAP RED) due to cloud cover
- Site analysts override IRCI inputs to enable telescope operations
- Sensor continues regular CTL tasking and special tasking
- Crew periodically attempts to track eight calibration objects furnished by 18 SPCS Sensor Optimization Cell
- Crew records actual downtime periods during the night

A subsequent Evaluation Method was then put into place:

- Object is acquired successfully if track contains at least three observations in accordance with HHQ requirements
- Observations must correlate to a known object's two-line element set with an Association Status (ASTAT) 2 or better (i.e. Close or Full correlation)
- Observations must be used in the update of an object's element set

Other considerations for the Evaluation Method included:

- Calibration satellite tracking were used to determine accuracy of metric observations and proof of custody
- 614 CTS Weather Flight utilized National Weather Service data to determine the level of cloud cover

A series of satellites were selected by Sensor Optimization for testing, representing a variety of orbital regimes. Those objects were 39741, 27663, 32258, 35788, 27566, 39070, 36411, 24876, 22195 and 8820. 20 SPCS Det 1 and Det 3 was tasked with the selected satellites the evening of the expected cloud cover. If in receipt of a negative cloud report from the 614 CTS Weather Flight, and clouds were unexpectedly covering the site, GEODSS sites called the 18 SPCS Operations Crew on-duty Mission Commander to initiate voice tasking for the testing. Within 24 hours of receiving GEODSS test data, the Sensor Optimization Cell provided the 614 CTS Weather Flight the time window during which the test data was collected in order to receive cloud characterization. The Sensor Optimization Cell factored in the actual cloud thickness while comparing the observation accuracy to that of clear sky observations, and looked for a response rate of at least 50%. The Sensor Optimization Cell conducted the cumulative data collection and analysis over the course of the test and shared at the end of the testing period.

GEODSS Operations Crews monitored atmospheric conditions and began testing when cloud levels obscured the entire sky. The operators initially tracked a designated calibration satellite and called 18 SPCS to verify the quality of the data. Activities and results were logged on a separate Obscured Sky Test Record Sheet for each period of testing. The crews then collected data on satellites from the Test Satellite List every 30 minutes per sensor, alternating between all three sensors on each cycle. Sensors not actively tracking the test satellites were released into auto tasking mode, and the Tracks/Hour value from the GEODSS Main Menu were monitored and logged on the Obscured Sky Test Record Sheet at thirty-minute increments. 18 SPCS also logged the quality of data response and sky conditions as indicated visually to the operator and through the Infrared Cloud Imager (IRCI) functioning in default setting.

Participants expected varying results based on cloud thickness and the Sensor Optimization Cell acknowledged that due to lack of previous data, they did not have metrics for when observations would lose accuracy. It must be noted that the GEODSS operators were able to evaluate relative accuracy based upon correlation values received on each data point collected. Correlation values were assigned to each metric collect by the GEODSS Data Processing Group (DPG) based upon a comparison to the continually updated full set of satellite orbital elements. The elements define orbital paths of each individual satellite. The values assigned by the DPG range from 0, up to 99, with 0 indicating near perfect fit and all collects exceeding 99 failing correlation to known satellites. Thus, the operators were able to effectively evaluate the data as it was collected in real time, but could not absolutely determine the point or value reached that deemed the data ineffectual or untenable to 18 SPCS. The Sensor Optimization Cell was able to evaluate and confirm data each day following the respective tracking period. Sensor Optimization results for the test period were as follows:

OPSCAP RED TIME TRACKING RESULTS 20 SPCS DET 1

| Day | Duration of Red Time | Objects | Obs | ASTAT 1 (Full) | ASTAT 2 (Close) | ASTAT 3 (Plane) | Elset Updated |
|---|---|---|---|---|---|---|---|
| 031 | 0227 - 0607 | 58 | 384 | 297 | 69 | 18 | 55 |
| 034 | 1055 – 1336 | 46 | 243 | 150 | 87 | 6 | 46 |
| 036 | 1130 – 1334 | 3 | 12 | 12 | 0 | 0 | 1 |
| 042 | 0738 – 0822 | 66 | 429 | 368 | 61 | 0 | 66 |
| 042 | 0649 – 0722 | 62 | 511 | 395 | 110 | 6 | 62 |
| 052 | 1049 – 1300 | 45 | 237 | 147 | 84 | 6 | 45 |
| 053 | 0615 – 1245 | 297 | 2211 | 1675 | 510 | 26 | 295 |
| 058 | 0500 – 1300 | 328 | 2568 | 1945 | 579 | 44 | 326 |
| 059 | 0841 – 1010 | 0 | 0 | 0 | 0 | 0 | 0 |

OPSCAP RED TIME TRACKING RESULTS 20 SPCS DET 3

| Day | Duration of Red Time | Objects | Obs | ASTAT 1 (Full) | ASTAT 2 (Close) | ASTAT 3 (Plane) | Elset Updated |
|---|---|---|---|---|---|---|---|
| 032 | 0437 - 0630 | 89 | 642 | 480 | 120 | 42 | 81 |
| 036 | 0700 - 0725 | 4 | 15 | 15 | 0 | 0 | 4 |

COMBINED OPSCAP RED TIME TRACKING RESULTS

| **Site** | **Number of Visible Tracks in Red Time** | **Number of Times Calibration Satellite Actually Tracked** |
|---|---|---|
| 20 SPCS Det 1 | 102 | 10 |
| 20 SPCS Det 3 | 29 | 14 |

In conclusion, the testing revealed that:

- GEODSS Sensors are able to accurately track satellites during obscured skies traditionally reported as OPSCAP RED
- The quantity of metric observations collected in obscured skies appears to be lower than in clear skies, but the quality of metric observations collected remains consistent
- The results indicate a capability for the sensors to increase the overall quantity of and availability to collect metric observations by operating in obscured sky conditions

The evaluation process continues with the Sensor Optimization Cell and the results have continued a consistent trend. At the collection point, the metric data has yet to fail the correlation process and the Sensor Optimization Cell has found the data usable in satellite catalog efforts. In the long term, this endeavor met its intent to better-define the sensor's ability to collect usable observations through cloud cover and create potential for a favorable change in the operations criteria for all optical sensors. Based upon this study, 20 SPCS changed the operational status criteria for GEODSS to increase its operational availability. The presence of a completely obscured sky no longer renders the mission OPSCAP RED if the GEODSS sensors are capable of collecting metric observations. The increased operational availability of GEODSS directly enhances 20 SPCS and 18 SPCS's ability to characterize threats in the space domain and provide actionable space situational awareness in support of our nation and allies.

*Citations:*

*Debbie Kedar and Shlomi Arnon, "Optical wireless communication through fog in the presence of pointing errors," Appl. Opt. 42, 4946-4954 (2003)*