A GEODSS Sourcebook

Version of 2008-10-19

Contributions to this sourcebook are welcome
Please send them to thomsona@flash.net

http://www.af.mil/factsheets/factsheet.asp?id=170

U.S. Air Force Fact Sheet

GROUND-BASED ELECTRO-OPTICAL DEEP SPACE SURVEILLANCE

Mission

There are approximately 10,000 known objects in orbit around the Earth. These objects range from active payloads, such as satellites, to "space junk" such as launch vehicle debris and debris generated from satellite breakups.

U.S. Strategic Command's Space Control Center, located within Cheyenne Mountain Air Force Station in Colorado Springs, Colo., is responsible for tracking all man-made objects in orbit. The center receives orbital data from Ground-Based Electro-Optical Deep Space Surveillance sites assigned to Air Force Space Command. GEODSS sites play a vital role in tracking these deep space objects. Over 2,500 objects, including geostationary communications satellites, are in deep space orbits more than 3,000 miles from Earth.

There are three operational GEODSS sites that report to the 18th Space Surveillance Squadron, Edwards AFB Calif. - Socorro, N.M.; Maui, Hawaii; and Diego Garcia, British Indian Ocean Territories.

Features

GEODSS performs its mission using a telescope, low-light-level television cameras, and computers - three proven technologies. Each site has three telescopes, with the exception of Socorro with two main and one auxiliary. The main telescopes have a 40-inch aperture and a two-degree field of view. The auxiliary telescope at Det 1, has a 15-inch aperture and six-degree field of view. The telescopes are able to "see" objects 10,000 times dimmer than the human eye can detect. This sensitivity allows the system to only operate at night. As with any optical system, cloud cover and local weather conditions directly influence its effectiveness.

The GEODSS telescopes scan the sky at the same rate as the stars appear to move. This keeps the distant stars in the same positions in the field of view. As the telescopes slowly move, the GEODSS cameras take very rapid electronic snapshots of the field of view. Four computers then take these snapshots and overlay them on each other. Star images - which remain fixed - are electronically erased. Man-made space objects, however, do not remain fixed, and their movements show up as tiny streaks viewed on a console screen. Computers measure these streaks and use the data to figure the positions of objects such as satellites in orbits from 3,000 to 22,000 miles. This information is used to update the list of orbiting objects and sent nearly instantaneously from the sites to Cheyenne Mountain Air Station, Colo.

Background

The GEODSS system is the successor to the Baker-Nunn camera, a less accurate and older system developed in the mid-1950's to provide surveillance data. In January 1999, site hardware and software was modified and a new Optical Command, Control, and Communication Facility was placed at Edwards AFB, Calif., which became operational in February 2000. The OC3F optimizes tasking of all GEODSS telescopes through its dynamic scheduling program, increasing GEODSS accuracy by 75 percent. GEODSS system can track objects as small as a basketball more than 20,000 miles in space, and is a vital part of AFSPC's space sureviellance [sic] network.

Point of Contact
Air Force Space Command, Public Affairs Office; 150 Vandenberg St., Suite 1105; Peterson AFB, CO 80914-4500; DSN 692-3731, or (719) 554-3731.

January 2006

http://www.edwards.af.mil/archive/2001/space-surveillance.html

Space Surveillance Squadron scores top inspection marks

By Capt. Mike Hicks
18th Space Surveillance Squadron
March 9, 2001

EDWARDS AIR FORCE BASE, Calif. -- Almost a year after receiving its initial operations capability certification, the 18th Space Surveillance Squadron scored another first by receiving an outstanding rating on its recent 14th Air Force Standardization Evaluation Team inspection. This three-day inspection, which focused on how well the 18th SPSS performs its operational mission, marked the first time 14th Air Force used grading criteria for their inspection.

The 18th SPSS is an Air Force Space Command geographically separated unit of the 21st Operations Group, located at Peterson Air Force Base, Colo. Its mission is to detect, track and identify near- and deep- space objects using a network of optical sensors in four worldwide locations that can be remotely operated from Edwards.

As a 24-hour operation, the squadron works in crews. During the inspection, the unit received three crew evaluations that accounted for 75 percent of the overall rating. The first two crews scored a 4.9 out of five, while the last crew received a perfect score.

In addition to the top rating, 18th SPSS people garnered nine professional performer awards, six outstanding contributor awards, and six commendable program ratings.

"The operations crews and my staff sections worked as a team to make sure we were ready to prove to the rest of the world that the 18th SPSS is ops ready and will stay that way," said Lt. Col. Greg Boyette, 18th SPSS commander, during the outbrief.

That sentiment was echoed in the inspection report that stated, "The commander and director of operations have done an incredible job in turning this squadron into a real operational unit.

The transformation of this squadron from its hangar days at Peterson to become one of our premier space units, reflects greatly on the vision and dedication of Space Command personnel involved in turning the Optical Command, Control and Communications Facility concept into reality."

Garnering a top rating on the SET inspection culminated a year of excellence for the squadron. In August of last year, the 21st Space Wing conducted an Operational Standardization Team inspection.

The 18th SPSS emerged as the first unit to have no problem areas identified in an inspection after receiving its initial operations capability certification. What the inspectors did identify were three commendable programs and five professional performers.

Programs are not the only excellent areas in the squadron. In the past year, 18th SPSS people have earned multiple group, wing and numbered Air Force awards.

The unit also was selected as the first squadron in 14th Air Force to be assigned an individual mobilization augmentee reservist. This certified crew member and combat mission ready reservist is permanently assigned to Vandenberg Air Force Base and is responsible for providing Space Component Command with the optical space surveillance expertise needed.

The 18th SPSS is the only optical space surveillance squadron in the 21st Space Wing. It operates the Optical Command, Control and Communications Facility as well as four worldwide detachments. The squadron has 67 military members assigned, along with 78 contractors.

The detachments are located in Socorro, N.M.; Diego Garcia, in British Indian Ocean Territory; Maui, Hawaii; and Moron, Spain.

There are 30 certified operations crew members at the facility that comprises the only all-enlisted crew force in Air Force Space Command. Each crew is made up of three crew members, who are responsible for operational control of the optical sensors at each detachment as well as providing an interface with Space Command agencies.

The squadron and detachments track deep-space objects orbiting earth. Since receiving its initial operations capability certification, observations by the Space Control Center have increased by 180 percent. The accuracy of data being sent to customers has also greatly improved as a result of the new high tech optical space surveillance squadron.

http://www.csmng.com/images/spaceobserver/spaceobserver_2002-07-03.pdf

Space Observer

Wednesday, July 3, 2002 Peterson Air Force Base, Colorado Vol. 46 No. 25

21st Space Wing

GSU At a Glance

Unit: 18th Space Surveillance Squadron

Location: Edwards Air Force Base, Calif.

Mission: The 18th Space Surveillence Squadron is responsible for command and control of three Ground–based Electro–Optical Deep Space Surveillance Systems located at Detachment 1, Socorro, N.M.; Detachment 2, Diego Garcia, British Indian Ocean Territories; and Detachment 3, Maui, Hawaii. The unit also provides command and control for the Moron Optical Space Surveillance System, or MOSS, a stand-alone system located at Detachment 4, Moron, Spain.

Besides providing staffing support and quality assurance management to a work force of more than 150 military and contractors at the worldwide detachments, the unit began operating the Optical Command, Control and Communications Facility, or OC3F, in February 2000.

The OC3F is the centralized node for the control of the 18th SPSS optical detachments around the world. The GEODSS and MOSS sites play a vital role in tracking some 2,000 objects in space, all of which are at least 3,000 miles from the Earth's surface.

Courtesy photo

Check 1,2,3

Staff Sgt. Jose Venegas, 18th Space Surveillance Squadron, performs communication line test using a firebird.

http://www.edwards.af.mil/base_guide/pdfs/2004/associates-2004.pdf

18TH SPACE CONTROL SQUADRON
12 Laboratory Rd.
(661) 277-8672 or DSN 527-8672

18th SPCS, located at Edwards since 1994, is an Air Force Space Command geographically separated unit of the 21st Operations Group, Peterson Air Force Base, Colo. The mission of the squadron is direct support to the U.S. commander in chief and Space Command's space control mission through optical space surveillance, including detection, tracking, identification and special signature collection of near-space and deep-space objects.

To accomplish the unit's mission, the squadron controls a network of optical sensors in four worldwide locations. Three ground-based electro-optical deep-space surveillance, or GEODSS, units are located in Socorro, N.M.; Diego Garcia; and Maui, Hawaii. In addition to GEODSS sensors, the squadron operates the Maui Space Surveillance System and the transportable optical system, Moron Air Base, Spain. 18th SPCSS operators control GEODSS remote telescopes from Edwards.

http://www.edwards.af.mil/archive/2004/2004-archive-18_space.html

18th Space Control here celebrates job well done

Article by Jackie Robertson
Staff Writer Public Affairs
June 4, 2004

6/4/04 – EDWARDS AIR FORCE BASE, Calif. – Edwards witnessed the end of an era Tuesday as the 18th Space Control Squadron was inactivated.

Nearly 75 people, including several members of Edwards' base leadership, attended the hour-long ceremony held on North Base that marked the conclusion of 18th SPCS's mission, which was to provide direct support to Space Command's space control mission through optical space surveillance.

This included detection, tracking, identification and special signature collection of near space and deep space objects, according to Staff Sgt. Jason Jorgensen, NCO-in-charge 18th Space Control Squadron, standardization/evaluation.

"We are here to say goodbye this early evening," said Lt. Col. Juan Holguin, 18th Space Control Squadron commander. "I appreciate the strong support we have received from the 95th Air Base Wing for our mission."

Despite all the work the 18th SPCS did to successfully complete what they were tasked to do, they had a good time, he said. "I was actually the lucky one getting to be the commander of this group, and I wish them the best as they continue with their Air Force careers."

The 18th SPCS headquarters relocated to Edwards in November 1994 and began official operations in February 2000. The Optical Command, Control and Communications Facility provided staffing support and quality assurance management to more than 180 military personnel and contractors worldwide. Additionally, the 24-hour operations facility scheduled tasking for all optical surveillance sensors and routed data back to the requesting organization, Sergeant Jorgensen said.

The 18th SPCS operationally inactivates July 1. Its mission will continue on through work at the Air Force's four Ground-based Electro-Optical Deep Space Surveillance units located at Socorro, N.M.; Diego Garcia; Maui, Hawaii; and Moron Air Base, Spain.

http://esc.hanscom.af.mil/ESC-PA/NEWS/2003/Dec%202003/ESC%2003-25.HTM

ESC provides major GEODSS upgrade

HANSCOM AFB, Mass. (Dec 9, 2003) -- The Electronic Systems Center, here, has successfully completed integrating the Infra-Red Cloud Imager capability into the Ground-based Eletro-Opitical Deep Space Surveillance System. This upgrade assists GEODSS operators by allowing them to work in extreme cloud cover, a feat that was not possible before.

GEODSS is a system of nine one-meter telescopes, controlled by computer and located three per site at Socorro, N.M.; Mt. Haleakala, Maui, Hawaii; and at Diego Garcia. The high-powered telescopes track orbiting space objects for the Space Control Center at Cheyenne Mountain Air Force Station, Colo. This system is operated by Air Force Space Command's 18th Space Control Squadron and supports the U.S. Strategic Command space control mission.

The IRCI program was completed half a million dollars under budget and nine months ahead of schedule. The IRCI program, a Warfighter Rapid Acquisition Process project, began in August 2002 and was slated to finish with three fully operational sites in August 2004. The third and final site at Diego Garcia was fully operational in early October.

The overall impact of IRCI was an increase in system throughput, thereby making GEODSS a more valuable contributor to the space control mission, said Lisa Mackesy, Imaging Improvement Branch chief of the Strategic C2 System Program office.

Before the implementation of IRCI, operators had to divide up the sky into 25 sectors and then manually input the cloud cover data into the controlling computer. Now site operators have a system with an automated connection between the cloud sensor and telescopes.

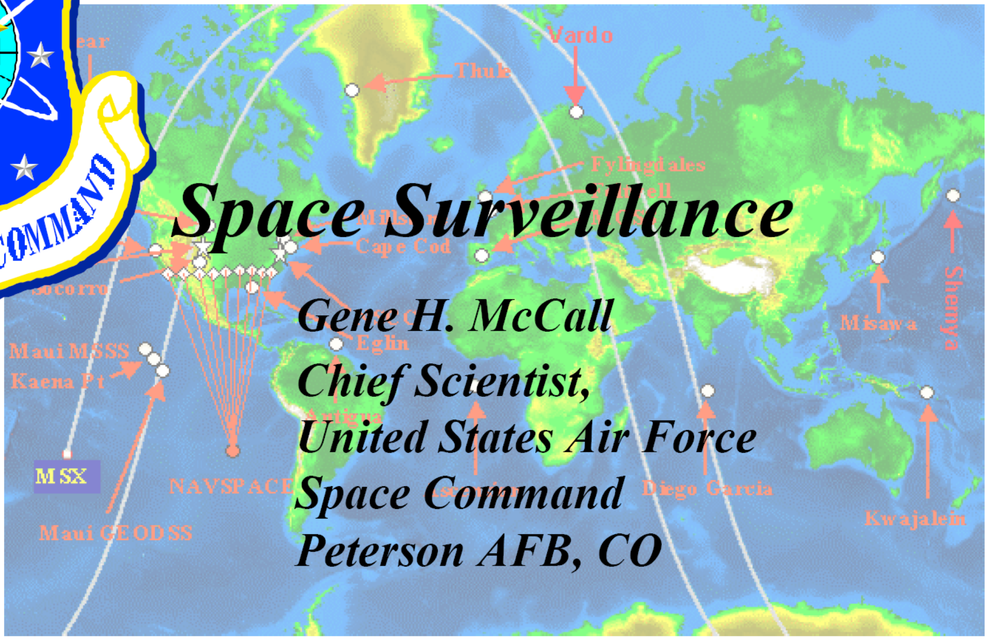
"Instead of having to physically go outside and check the sky for cloud cover one or more times every hour, they now have the IRCI that automatically collects this data and feeds it to the telescope computer," said Mackesy.

This system has "increased the amount of time that we are able to operate upwards of approximately 15 to 20 percent per month," said Jim Finely, Northrop Grumman contractor site manager. Along with increased productivity, the system has made meeting mission goals easier.

"This system is fantastic," said Capt. Samuel Lowrance, GEODSS Detachment 1 commander. "Before, when we were under red weather, cloud cover that makes operations impossible, observations could not be done, but now IRCI lets the operators shoot through the smallest breaks in the clouds, allowing for observations to occur during weather previously thought too bad to operate in."

http://www.fas.org/spp/military/program/track/mccall.pdf

This Briefing Is Unclassified

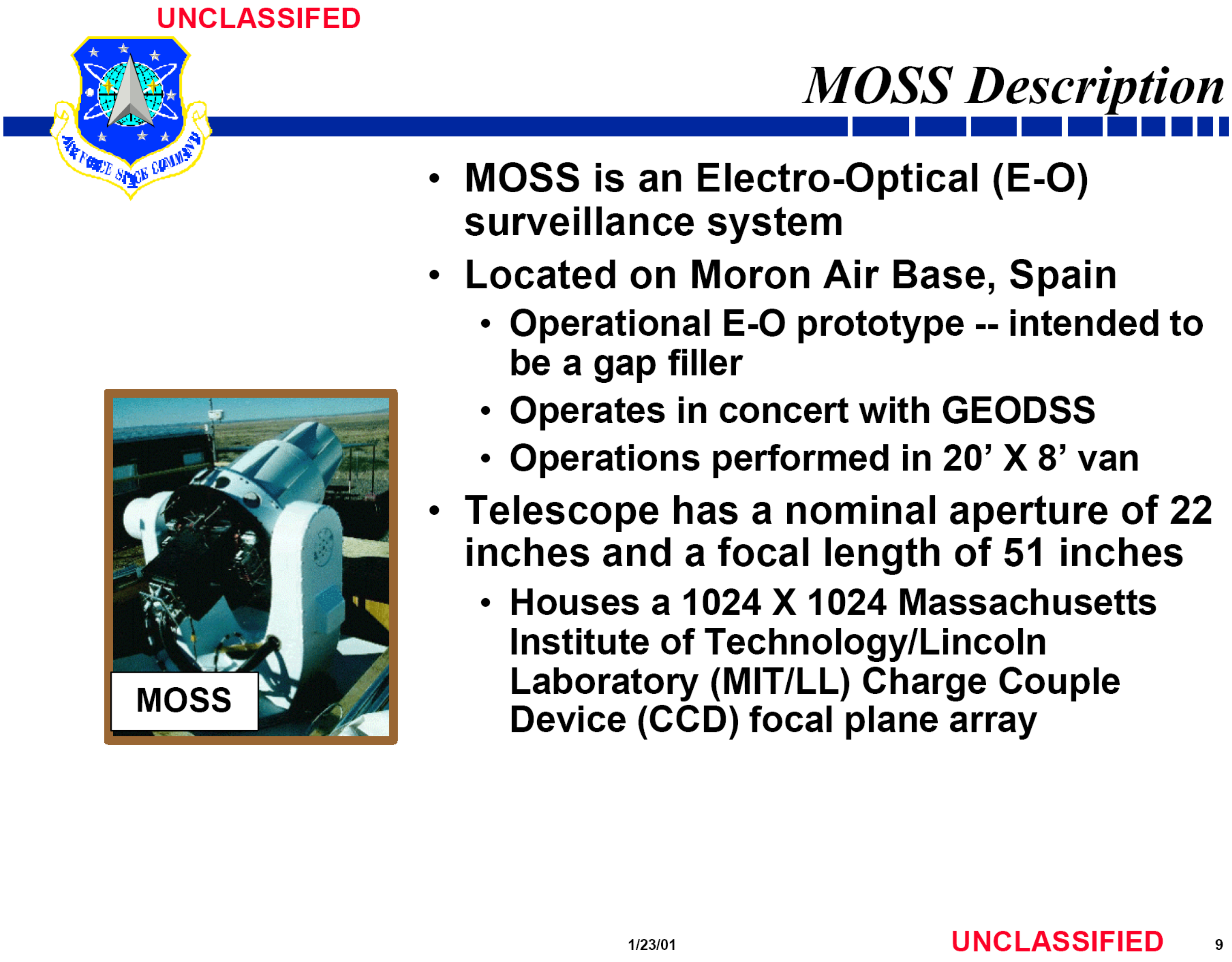


Space Surveillance

Gene H. McCall
Chief Scientist,
United States Air Force
Space Command
Peterson AFB, CO

www.moron.af.mil/units2.htm

http://www.fas.org/spp/military/program/track/mccall.pdf



UNCLASSIFED

MOSS Description

- MOSS is an Electro-Optical (E-O) surveillance system
- Located on Moron Air Base, Spain
  - Operational E-O prototype -- intended to be a gap filler
  - Operates in concert with GEODSS
  - Operations performed in 20’ X 8’ van
- Telescope has a nominal aperture of 22 inches and a focal length of 51 inches
  - Houses a 1024 X 1024 Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL) Charge Couple Device (CCD) focal plane array

MOSS

1/23/01 UNCLASSIFIED


MORÓN OPTICAL SPACE SURVEILLANCE SYSTEM
NOWHERE TO RUN, NOWHERE TO HIDE!
DET 4 18SPSS
SIEMPRE VIGILANTES DEL CIELO

http://www.af.mil/news/airman/0398/index.html

Airman
Viva Espana!
March, 1998
[EXCERPT]

At first glance, Moron Air Base looks like someone forgot to lock the gate and turn off the lights. A handful of tan buildings squats low in the Spanish desert next to an 11,000-foot flight line slashed across the rocky terrain.

But, as any of the roughly 75 bluesuiters and about 100 family members living at the base would say, appearances are deceiving. These days, Moron is more boomtown than ghost town.

[deletia]

In fact, although the U.S. Air Forces in Europe recently said the base will remain as it is, O'Connell is busy lobbying the Air Force for more people to support the increased deployments. The most significant increase he's seen in manning at the base occurred in July when Air Force Space Command established Detachment 4 of the 18th Space Surveillance Squadron at the base, bringing in about 14 more bluesuiters.

http://www.e-publishing.af.mil/pubfiles/afspc/10/afi10-503_afspcsup1/afi10-503_afspcsup1.pdf

AIR FORCE INSTRUCTION 10-503

AIR FORCE SPACE COMMAND
Supplement 1
2 MARCH 1998
Operations
BASE UNIT BEDDOWN PROGRAM

COMPLIANCE WITH THIS PUBLICATION IS MANDATORY

[Extensive deletia]

SAMPLE SITE SURVEY MEETING LETTER

MEMORANDUM FOR DISTRIBUTION LIST
FROM: HQ AFSPC/XP
150 Vandenberg Street, Suite 1105
Peterson AFB CO 80914-4570
SUBJECT: TOS Site Survey Working Group Meeting

1. The Concept of Operations (CONOPS) for the Transportable Optical System (TOS) specifies that AFSPC is re-fielding TOS as a stopgap system to fulfill critical geosynchronous belt coverage in the Mediterranean region. In preparation for this beddown, site surveys are required at proposed sites. USSPACECOM has requested USEUCOM assistance in identifying potential beddown locations. In order to meet a FY96/4 timeline, site surveys need to be conducted by Jan 96. As the first step in this process, a Site Survey Working Group meeting has been scheduled for 29 Nov 95 in the HQ AFSPC/SC conference room from 1200 to 1330.

2. Request each addressee appoint a project officer and respond via E-mail or by indorsement (Atch 1) to HQ AFSPC/XPPB NLT 27 Nov 95. This working group meeting will be used to identify the site survey team members and begin preparations for conducting the surveys in Jan 96.

3. OPR for all TOS Site Survey actions is Lt Col Schlafli, HQ AFSPC/XPPB, 4-2469.

5. DISCUSSION:

a. Inbrief: In his welcoming remarks, Col Allison made it clear that the 496ABS would welcome Det 4, 18 SPSS and TOS, and was prepared to help make it happen if beddown is approved. I introduced our site survey team and explained the purpose of our visit. MSgt Steininger briefed TOS operations, the systems history and requirements.

b. Survey: Following inbrief, team was given a windshield tour of base, and proceeded to a previous Navy Radio Transmitter (NRT) area to survey facilities. The NRT area is in a relatively remote site on Southwest corner of Moron AB. After examining available facilities, survey team broke for lunch, and proceeded back to headquarters meeting room for discussions with 496ABS/CC and base functional area representatives.

c. Surveyed Facilities/Initial Assessment : Moron AB offers an open, flat area within a fenced compound with available office space close by. This area is away from the major light sources on base and has an unobscured, low ambient light, south facing exposure.

(1) NRT area is made up of one large, two story admin/warehouse building (Bldg #1301) one large power generation building (Bldg #1302) and five very small additional buildings. The buildings are surrounded by eight foot chain-link fence topped with three strands of barbed wire. The fence has two lockable gates. The Southwest corner of this compound is a flat grassy area approximately 130 feet square, butted on two sides by fence and on the other two sides by roads one of which has an extended paved area which could be marked off for parking (see attached drawing showing possible lay out of TOS.) The physical lay out of the area would allow the use of the two large buildings to block the light of an antenna field, the glow from the ramp area and the airfield's rotating beacon. Two unused antennas may obstruct the view and should be removed.

(2) Building 1301 has the bottom floor of one wing which is 50% vacant. This area contains three rooms which could be made available for TOS admin functions. One room is about 100 sq ft and would work well for the Det CC office. The other two rooms are about 300 sq ft each and could be used for military admin functions and ops/maintenance functions. Phone lines with DSN and commercial access would be available in all three rooms.

d. Functional Area Discussions:

(1) Base Supply: Current capacity capable of supporting TOS admin and fuels requirements.

SAMPLE SITE SURVEY REPORT
19 Apr 96
MEMORANDUM FORHQ AFSPC/XPPB
HQ AFSPC/XPP
HQ AFSPC/XP
FROM: HQ AFSPC/XPPB
150 Vandenberg St Ste 1105
Peterson AFB CO 80914-4620
SUBJECT: Moron AB Site Survey Trip Report

1. PURPOSE: To determine feasibility of locating the Transportable Optical System (TOS) on Moron AB, Spain.

2. TRAVELERS:
Lt Col Bill Schlafli AFSPC/XPPB
Maj Edgard Millan 16AF/XPS
Capt Eric Payne AFSPC/LGX
MSgt Edward Dwornick 18SPSS/LG
MSgt Brad Steininger AFSPC/DOYO
Mr. David Beatty MIT Lincoln Laboratory

3. ITINERARY: Traveled to Moron AB, Spain on 15/16 Apr 96, completed night ambient light check on 16 Apr 97, inbriefed 496ABS/CC and staff, surveyed facilities and outbriefed on 17 Apr. Capt Payne and I traveled to Ramstein AB, Germany and briefed HQ USAFE/XPFB on 18 Apr 96 and returned to Peterson AFB on 19 Apr 96.

4. KEY PERSONNEL CONTACTED:
Lt Col Bob Allison 496ABS/CC
Capt Glenn Ferguson 496ABS/LG
Capt Art Canne 496ABS/SC
MSgt Jorge Mitchell 496ABS/SP & CCF
MSgt Bart Roberts 496ABS/LGX
MSgt Rick West 496ABS/CE
TSgt David Means 496ABS/LGC
Mr. Bob Smothers 496ABS/CEC

(2) FM: Support is provided through 31FW/FM at Aviano AB, Italy.

(3) Communications: Current communications connectivity in building 1301 will support the admin requirements of TOS. System requirements, one commercial line dedicated to data transfer and one additional line with DSN and commercial access will be available, but lines will need to be run from building 1301 or 1302 to ops enclosure.

(4) PMEL: Support available on reimbursable basis through 31FW

(5) Transportation: UDI vehicles will be available on a limited basis. If the detachment requires a permanent assigned vehicle, AFSPC will have to work the authorization. Oversize cargo can be road hauled from the port at Rota (75 miles away.) TMO support is available on base. Household Goods shipment may transfer to Rota in the near future.

(6) Civil Engineering: Required power is available from building 1302 but installation needs engineering. Cable is available locally. Construction of concrete pads for the system is locally available and a ROM cost was $90K. Contracts office requested 60 - 90 days from submitting requirement to completion of construction. Removal of two unused antennas may fall to AFSPC to remove them from the view area. Military Family Housing is currently under renovation and once complete, assignment will be by standard AF policy. With current use rate, 75% (8 of 12) of our people could live on base if all are accompanied. Dorm rooms are short today but plans are in work to upgrade an old dorm to the 1 + 1 standard by July 97 and at that time there would be room for our unaccompanied personnel.

(7) Dining Hall: Breakfast and lunch are served Monday through Friday only. Separate rations will be required.

(8) Medical Support: Two med techs are assigned to 496ABS but can treat active duty personnel only. Other medical and dental care is available from Rota and through TRICARE. Personnel with dependents in the Exceptional Family Member Program will be assignment restricted.

(9) Schools: K - 8th grades are available on Moron. High School students are bussed to Rota (2 hours each way.) Personnel with dependents in the Exceptional Family Member Program will be assignment restricted.

6. ACTION ITEMS:

a. Provide detail drawing, to include proposed power lines, of proposed beddown area to HQ AFSPC/DOYO. OPR: 496ABS/CC Site Survey Guide Attachment 4-3

Probable NRT facility described in the above dcument http://space.au.af.mil/primer/space_surveillance_network.pdf

MOSS

The Moron Optical Space Surveillance (MOSS) system was fielded at Moron AB, Spain during the first quarter of Fiscal Year (FY) 1998. MOSS will operate in conjunction with the existing GEODSS network. The GEODSS network called for an additional site in the Mediterranean to provide contiguous geosynchronous coverage. Air Force Space Command (AFSPC) is fielding MOSS to provide this critical geosynchronous belt metric and Space Object Identification (SOI) coverage.

MOSS consists of one high resolution electro-optical telescope and the MOSS Space Operations Center (MOSC) van. The telescope has a nominal aperture of 22 inches and a charge-coupled device (CCD) focal plane array. The telescope is housed in a dome structure and is positioned by an Uninterruptible Power Supply (UPS) and backed up by a diesel generator.

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http://www.it.northropgrumman.com/pressroom/press/2003/pr146.html

U.S. AIR FORCE AWARDS NORTHROP GRUMMAN SPACE SURVEILLANCE CONTRACT [EXCERPTS]

HERNDON, Va. -- Sept. 9, 2003 -- Northrop Grumman Corporation (NYSE: NOC) has been awarded a contract to continue supporting the U.S. Air Force Space Command's Ground-Based Electro-Optical Deep-Space Surveillance System (GEODSS).

The contract value is $5.7 million over one year with four one-year options to Northrop Grumman's Information Technology (IT) sector.

Northrop Grumman IT will provide operations, maintenance and support services to the Air Force Space Command, 21st Space Wing for the three geographically dispersed GEODSS sites: Site 1, at White Sands Missile Range, N.M.; Site 2, on Diego Garcia, British Indian Ocean Territory; and Site 3, Maui, Hawaii. The Air Force anticipates adding a fourth site in Moron, Spain, by the contract's first option year.

Commerce Business Daily
A-76 Det 4, Moron, AB, Moron, Spain Request for Information
General Information
Document Type: SRCSGT
Posted Date: Jun 21, 2006
Category: Operation of Government-Owned Facilities
Set Aside: N/A

Contracting Office Address
Department of the Air Force, Air Force Space Command, 21CONS (Bldg 982), Base Support Flight
700 Suffolk Street, STE 1200, Peterson AFB, CO, 80914-1200

Description
Reference No: P-3 A-76 RFI Det 4, Moron AB, Spain 17. This is a Request For Information (RFI) Only. Air Force Space Command has started the preliminary planning process (P3) required by Office of Management and Budget (OMB) Circular A-76 and the 1 Nov 05 USAF Commercial Activities A-76 Preliminary Planning Guidebook for the Det 4, Moron AB, Moron, Spain, Ground-Based Electro-Optical Deep-Space Surveillance System (GEODSS).

As part of P3, the team conducts preliminary market research to determine the existence of viable commercial source(s) capable of providing the necessary services and to determine the appropriate groupings of activities as business units. (Extensive market research necessary to support acquisition strategy decisions may/will be conducted if a streamlined or standard competition is announced in accordance with OMB Circular A-76.)

Detachment 4, of the 21st Operations Group, provides optical surveillance for the space surveillance network and is located within government facilities at Moron Air Base, Spain. The scope of operations follows: To detect, track, identify all man-made objects in space; provide satellite tracking and Space Object Identification (SOI) data to support catalog maintenance of deep-space satellites and priority United States (U.S) space programs; search for space objects beginning at the top of the earth?s atmosphere extending beyond the geosynchronous orbit using government?furnished mission systems in accordance with USSTRATCOM Directive 505-1, Volumes I and II. The objects may include rocket bodies, payloads, debris, and unknown items. Specialized knowledge is necessary to perform space control operations to include an understanding of orbital mechanics and the Space Surveillance Network (SSN).

The system maintenance consists of organizational/user-level maintenance to include: (a) fault isolation and troubleshooting through the use of built-in test equipment and diagnostic procedures; (b) restoration of prime mission equipment, generally limited to removal and replacement of faulty components, such as assemblies or subassemblies; (c) inspection, servicing, alignment, and lubrication; (d) preventative (scheduled) maintenance and testing; (e) corrosion control, and (f) accomplishment of organizational level Time Compliance Technical Orders.

The Moron Optical Space Surveillance System (MOSS) consists of a windowed 56cm (22 inch) f/2.3 modified Ritchy-Chretien telescope mounted on a light-weight azimuth/elevation NIKE-AJAX mount.

The telescope is equipped with an up-to-date frame transfer Charge Coupled Device camera. The operational structure consists of four (4) operator consoles, five (5) control computers, a data processor, image processor, camera processor, and a communications processor using a Red Hat Enterprise LINUX AS v3 based operating system.

All services are required 24 hours per day/seven days per week. Service provider employees must be U.S. citizens with at least a secret security clearance.

This RFI is published under the North American Industry Classification System (NAICS) code 517910 with an associated Small Business Administration (SBA) size standard of $12.5 million. The 517910 NAICS code best describes the mission system support and Satellite tracking requirement.

If as a result of the P3 Competitive Sourcing Decision Package a "GO" decision is identified, the decision will be synopsized and posted to Fed Biz Ops. In an effort to provide prospective offerors current and relevant information to assist them in making informed business decisions and manage their resources in the most effective way possible, the following is provided: Det 4, Moron AB, Spain, is currently an Un-priced Contract Line Item (CLIN) on the existing Ground-Based Electro-Optical Deep-Space Surveillance System (GEODSS) contract F05604-03-C-0007, awarded 01 Oct 03 with a base year and four Option Years. The GEODSS contract is currently in the third option year. The GEODSS contract optical sites are located at Socorro NM, Diego Garcia BIOT, and Maui HI. The 21st Contracting Squadron and Program Management Offices have initiated the re-acquisition process to insure a new GEODSS contract is ready for performance commencement on 1 Oct 2008. Performance on the existing GEODSS contract will conclude on 30 Sep 08.

If the P-3 process results in a "GO" decision and the A-76 study results in contract award, the Det 4, Moron, Spain, Operations, Maintenance and Logistical Support (OM&S) would have a performance period of two years or less to align the work as a GEODSS Contract Line Item on the GEODSS re-acquisition solicitation.

Please note: this RFI is not for the re-acquisition of the current GEODSS contract. This RFI is posted to identify offerors who may be interested in providing OM&S at Det 4, Moron, Spain for two years or less. Request companies that are interested in performing the services described above provide an electronic capabilities package to the contracting officer not later than 10 July 2006.

[deletia]

21 CONS POC William Conner, Contracting Officer, Phone (719) 556-4045, Fax (719) 556-7396, Email William.Conner@peterson.af.mil ? James McLaughlin, Contracting Officer, Phone (719) 556-3849, Fax (719) 556-7396, Email james.mclaughlin@peterson.af.mil

Original Point of Contact
Place of Performance
Address:
Det 4, Moron AB, Moron, Spain
N/A, SPAIN

FBO DAILY ISSUE OF JULY 17, 2008 FBO #2425
SOURCES SOUGHT

M -- A76P3MarketResearchforMoronAFB

Notice Date
7/15/2008

Notice Type
Sources Sought

NAICS
517919 — All Other Telecommunications

Contracting Office
Department of the Air Force, Air Force Space Command, 21CONS (Bldg 350), Specialized Flight-IT, O&M, Tech Serv, IT Resources, 135 E ENT Ave STE 1055, Peterson AFB, Colorado, 80914-1385

ZIP Code
80914-1385

Solicitation Number
A76P3MoronRFI

Response Due
7/30/2008

Archive Date
8/14/2008

Point of Contact
Robin E Cramer,, Phone: 719-556-6366, William M Conner,, Phone: 719-556-4045

E-Mail Address
robin.cramer@peterson.af.mil, william.conner@peterson.af.mil

Small Business Set-Aside
N/A

Description
This is a Request For Information (RFI) Only. Air Force Space Command has started the preliminary planning process (P3) required by Office of Management and Budget (OMB) Circular A-76 and the 20 June 2008 Air Force Instruction 38-203, Commercial Activities Program, for the Det 4, Moron AB, Moron, Spain, Ground-Based Electro-Optical Deep-Space Surveillance System (GEODSS).

As part of P3, the team conducts preliminary market research to determine the existence of viable commercial source(s) capable of providing the necessary services and to determine the appropriate groupings of activities as business units. (Extensive market research necessary to support acquisition strategy decisions may/will be conducted if a streamlined or standard competition is announced in accordance with OMB Circular A-76.)

Detachment 4, of the 21st Operations Group, provides optical surveillance for the space surveillance network and is located within government facilities at Moron Air Base, Spain. The scope of operations follows: To detect, track, identify all man-made objects in space; provide satellite tracking and Space Object Identification (SOI) data to support catalog maintenance of deep-space satellites and priority United States (U.S) space programs; search for space objects beginning at the top of the earth's atmosphere extending beyond the geosynchronous orbit using government furnished mission systems in accordance with USSTRATCOM Directive 505-1, Volumes I and II. The objects may include rocket bodies, payloads, debris, and unknown items. Specialized knowledge is necessary to perform space control operations to include an understanding of orbital mechanics and the Space Surveillance Network (SSN).

The system maintenance consists of organizational/user-level maintenance to include: (a) fault isolation and troubleshooting through the use of built-in test equipment and diagnostic procedures; (b) restoration of prime mission equipment, generally limited to removal and replacement of faulty components, such as assemblies or subassemblies; (c) inspection, servicing, alignment, and lubrication; (d) preventative (scheduled) maintenance and testing; (e) corrosion control, and (f) accomplishment of organizational level Time Compliance Technical Orders.

The Moron Optical Space Surveillance System (MOSS) consists of a windowed 56cm (22 inch) f/2.3 modified Ritchy-Chretien telescope mounted on a light-weight azimuth/elevation NIKE-AJAX mount. The telescope is equipped with an up-to-date frame transfer Charge Coupled Device camera. The operational structure consists of four (4) operator consoles, five (5) control computers, a data processor, image processor, camera processor, and a communications processor using a Red Hat Enterprise LINUX AS v3 based operating system.

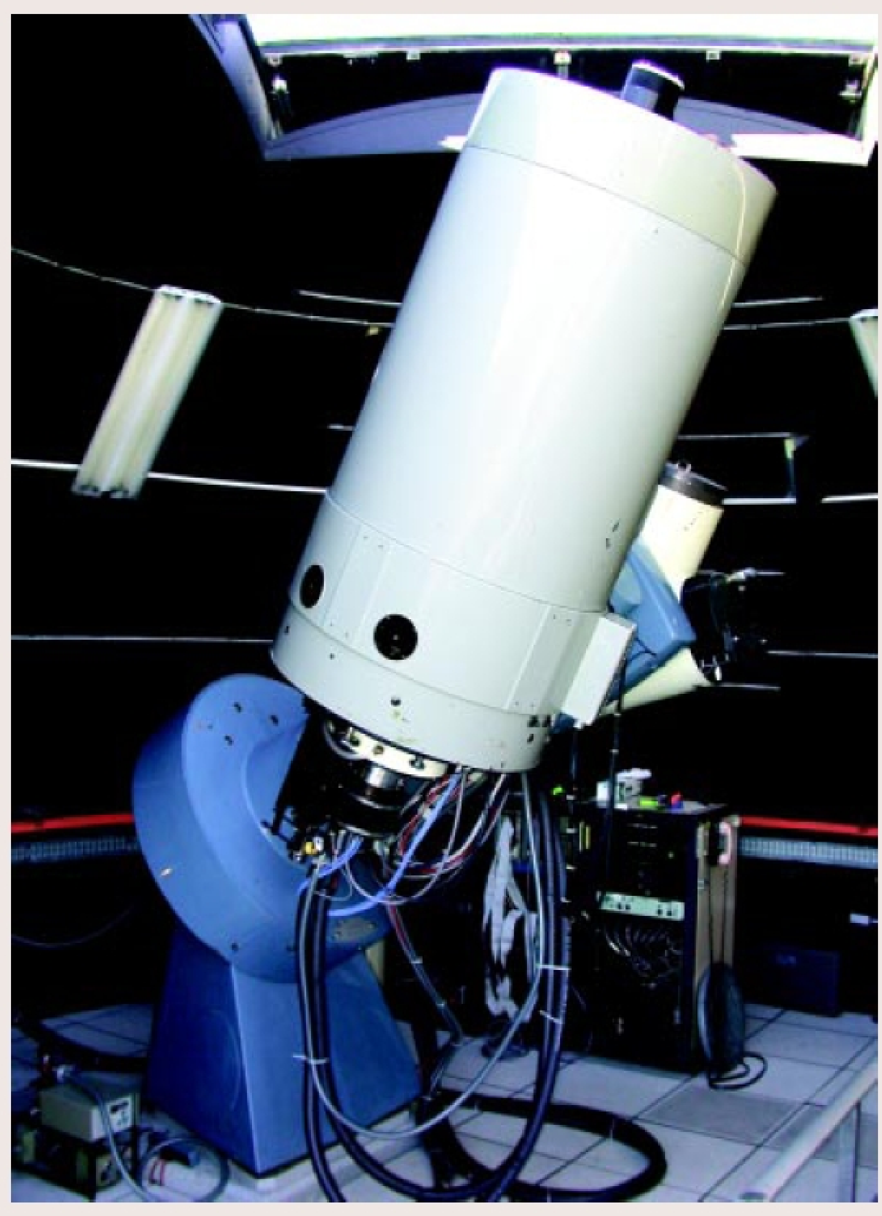
All services are required 24 hours per day/seven days per week. Service provider employees must be U.S. citizens with at least a secret security clearance. This RFI is published under the North American Industry Classification System (NAICS) code 517910 (old), 517919 (new) with an associated Small Business Administration (SBA) size standard of $12.5 million. The 517910,517919 NAICS code best describes the mission system support and Satellite tracking requirement. If as a result of the P3 Competitive Sourcing Decision Package a GO decision is identified, the decision will be synopsized and posted to Fed Biz Ops. Similar GEODSS contract optical sites are located at Socorro NM, Diego Garcia BIOT, and Maui HI.

Please note: This RFI is not for the re-acquisition of the current GEODSS contract. This RFI is posted to identify offerors who may be interested in providing OM&S at Det 4, Moron, Spain. Request companies that are interested in performing the services described above provide an electronic capabilities package to the contracting officer not later than 30 July 2008. Please send all responses by COB 30 Jul 2008 containing : 1. Company Name and address 2. A brief summary of capability which matches the requirement 3. A point of contact (name,email & phone number) 4. If your company has facility clearances 5. If intending to bid as a prime contractor on this effort, IAW FAR 52.219-4, is your company able to perform 51 percent of the required estimated labor dollars involved. 6. Provide a summary and customer points of contact on past contracts for similar services. 7. Which, if any, parts of the effort would you likely subcontract rather than using in-house resources and why? 8. Discuss your ability and sources to obtain and retain qualified personnel. 9. Address recommendations regarding selection of NAICS code. 10. Address business size status (to include specific identification as an 8a, HUB Zone, or service-disabled veteran-owned small business) based on proposed and your recommended NAICS codes.

Web Link
FedBizOpps Complete View
(https://www.fbo.gov/?s=opportunity&mode=form&id=e84b798cb88e125380a87bc947c5a82c&tab=core&_cview=1)

Place of Performance
Address: Det 4 Moron AB Moron, Spain, Spain

http://www.ll.mit.edu/news/journal/pdf/vol14_no2/14_2linear.pdf

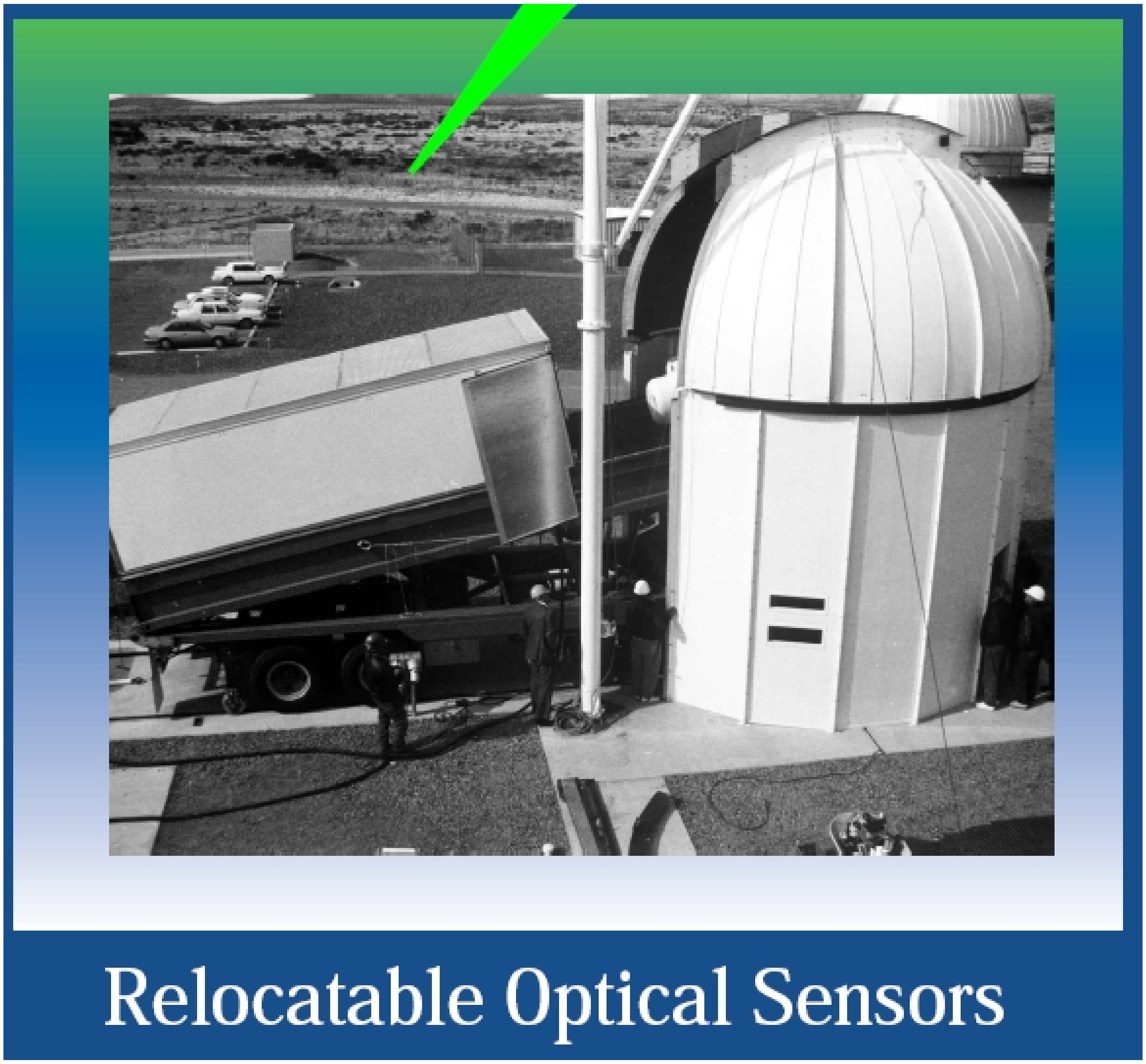


http://www.ll.mit.edu/news/journal/pdf/vol14_no2/14_2linear.pdf

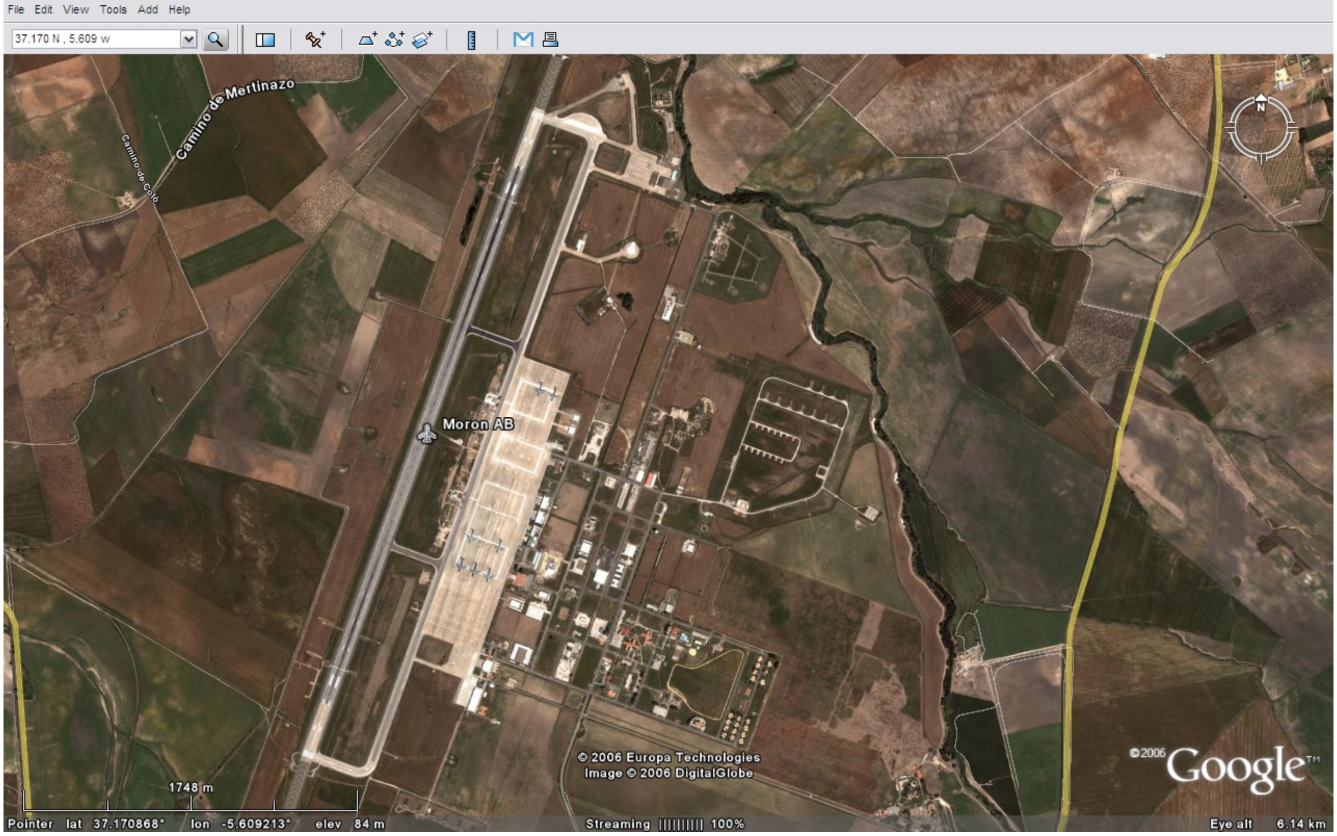
FIGURE B. The LINEAR 3 telescope and its dome at the Lincoln Laboratory–operated Experimental Test System in New Mexico. It is a Cassegrain telescope with a thirty-inch aperture and a 0.5 square-degree field of view. It can routinely detect objects with a visual magnitude of 19.0 with forty seconds of integration. (Photographs courtesy of Peter Trujillo.)

Figure B shows this telescope system, called LINEAR 3, or L3 for short. It enhances the amount of sky that LINEAR can search by 10% to 20%, and captures second-night data on 100 to 200 objects each night. The L3 system consists of a 30-inch telescope with a 1024 × 1024 Lincoln Laboratory CCD sensor in a camera system similar to the one in the Moron Optical Space Surveillance satellite tracking system.

http://www.fas.org/spp/military/program/track/geodss_poster.pdf



Relocatable Optical Sensors


37.170 N , 5.609 w

Pointer lat 37.170868° lon -5.609213° elev 84 m

Streaming |||||||||| 100%

Eye alt 6.14 km

Morón Air Base, Spain
37.170 N, 5.609 W

http://www.fas.org/spp/military/program/track/mccall.pdf

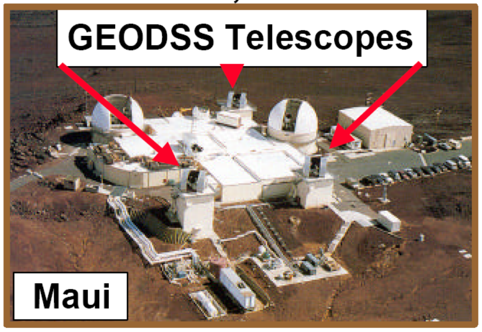
UNCLASSIFED

GEODSS Mission

Det 2, 18 SPSS

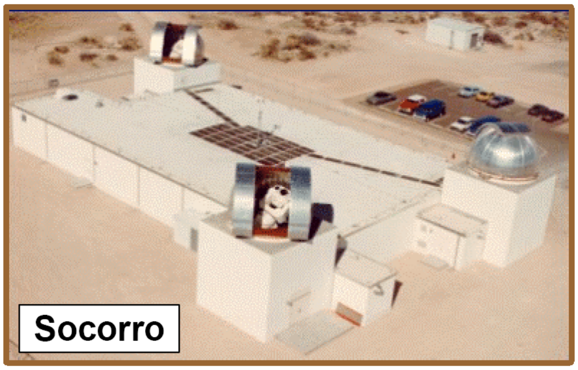

Diego Garcia

Det 3, 18 SPSS


GEODSS Telescopes

Maui

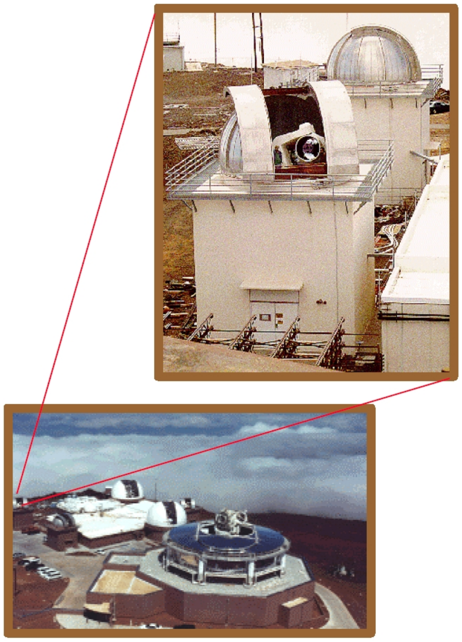
Det 1, 18 SPSS


Socorro

- Primary: Space Surveillance
- Supports AFSPC as a dedicate Deep Space (DS) sensor
- GEODSS brings together the telescope, low-light-level television cameras, and computers -- three proven technologies

http://www.fas.org/spp/military/program/track/mccall.pdf

GEODSS Description



- Each site has three telescopes, two main and one auxiliary
  - Diego Garcia is exception with three mains
  - Maui will have 3 mains, Oct 00
  - Socorro will have 3 mains, Oct 01
- Main Telescopes have 40-inch aperture and 2° field of view
- Auxiliary Telescopes have 15-inch aperture and 6° FOV
- Operates at night
  - Cloud cover inhibits operation
    - Not a severe problem at Socorro or Diego Garcia

http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4733

DET 1, 21st OPERATIONS GROUP

Commander: Capt. Charles Holland

Detachment 1, 21st Operations Group is a dedicated space surveillance unit in the northwest corner of the U.S. Army's White Sands Missile Range, approximately 30 miles southeast of the town of Socorro, New Mexico. The detachment was the first operational site in the Ground-based Electro-Optical Deep Space Surveillance system.

MISSION

The primary mission of the detachment is to detect, track, and identify all tasked space objects within its area of coverage. The unit usually provides data on deep space objects in the orbits from 3,000 to 22,000 miles, although it has a limited near earth detection capability. Satellite information is provided to the Space Control Center at Cheyenne Mountain Air Force Station, Colorado.

TELESCOPES

The detachment is one of three worldwide Ground-based Electro-Optical Deep Space Surveillance sites.

The GEODSS site performs its mission using three powerful telescopes; low light level, electro-optical cameras; and high speed computers. Detachment 1 uses two 40-inch "main" telescopes with a 2-degree field of view, and one "auxiliary" telescope with a 6-degree field of view.

Because the site is an optical sensor, mission operations are limited to relatively clear sky conditions at night. The isolated high desert of central New Mexico provides an excellent location for such operations.

HISTORY

The detachment was activated as Detachment 1, 1st Strategic Aerospace Division, Strategic Air Command in April 1981 and became operational on 30 July 1982. The detachment became part of the 1st Space Wing, Air Force Space Command on 1 May 1983.

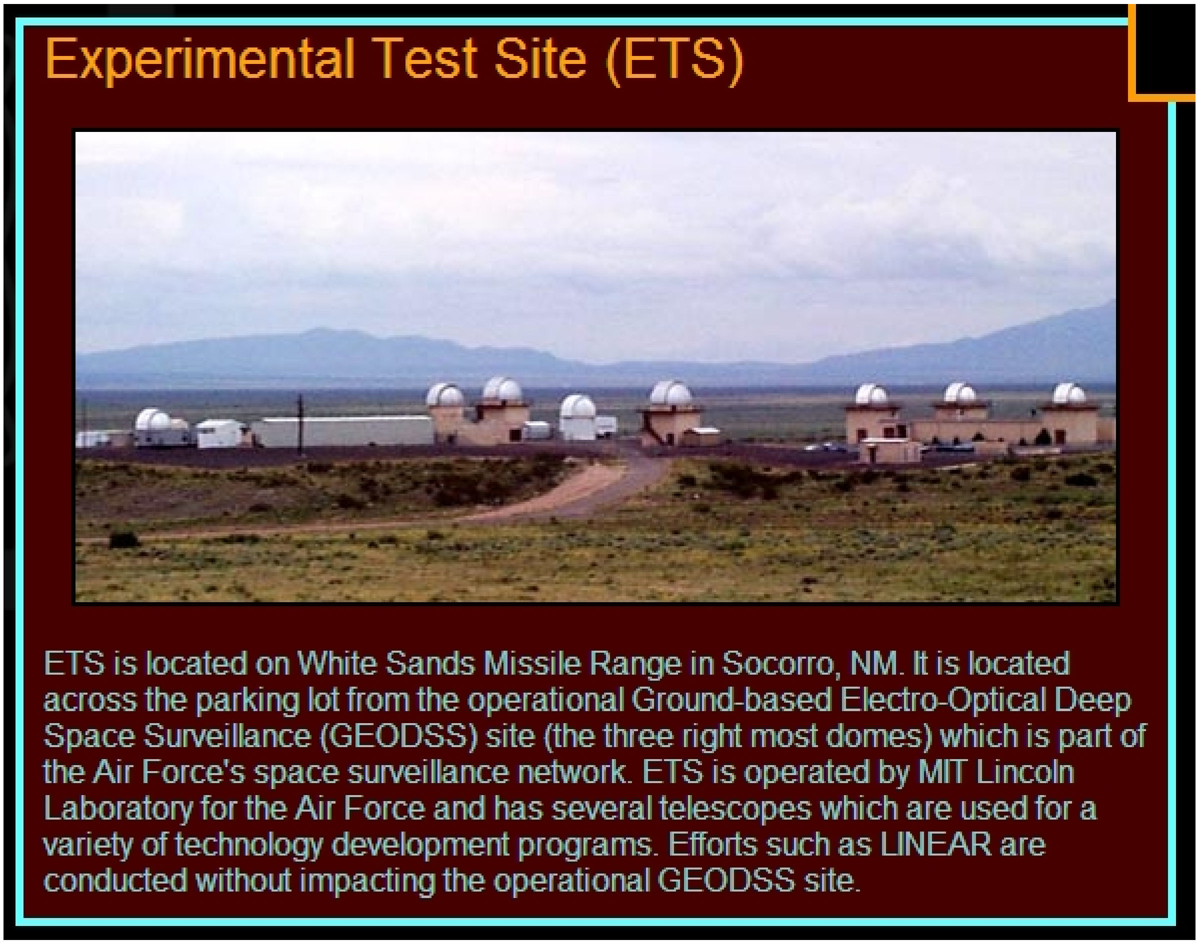
On 1 February 1990, it was reassigned to the 18th Space Surveillance Squadron at Peterson Air Force Base upon activation of the squadron. Both the detachment and its parent squadron were reassigned to the wing from the 73d Space Group on 15 May 1992, when the 21st Space Wing assumed responsibility for all space surveillance units. The unit was redesignated as the 18th Space Control Squadron in February, 2003.

The site is operated and maintained by 19 contract workers. The single Air Force captain assigned is responsible for ensuring that the mission is accomplished and the contractor's work performance is satisfactory. The current contractor is Northrop Grumman Information Technology.

LOCATION

The detachment sits on the northwest corner of the White Sands Missile Range on Route 525, 30 miles southeast of the town of Socorro. The terrain is dry and sandy, and the area's desert climate is hot and dry in summer, cool and dry in winter.

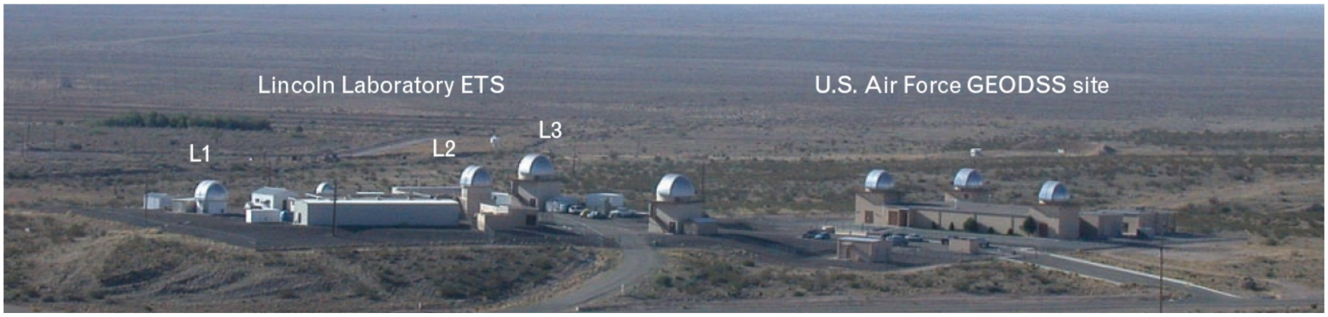
http://www.ll.mit.edu/LINEAR/ets.html



Experimental Test Site (ETS)

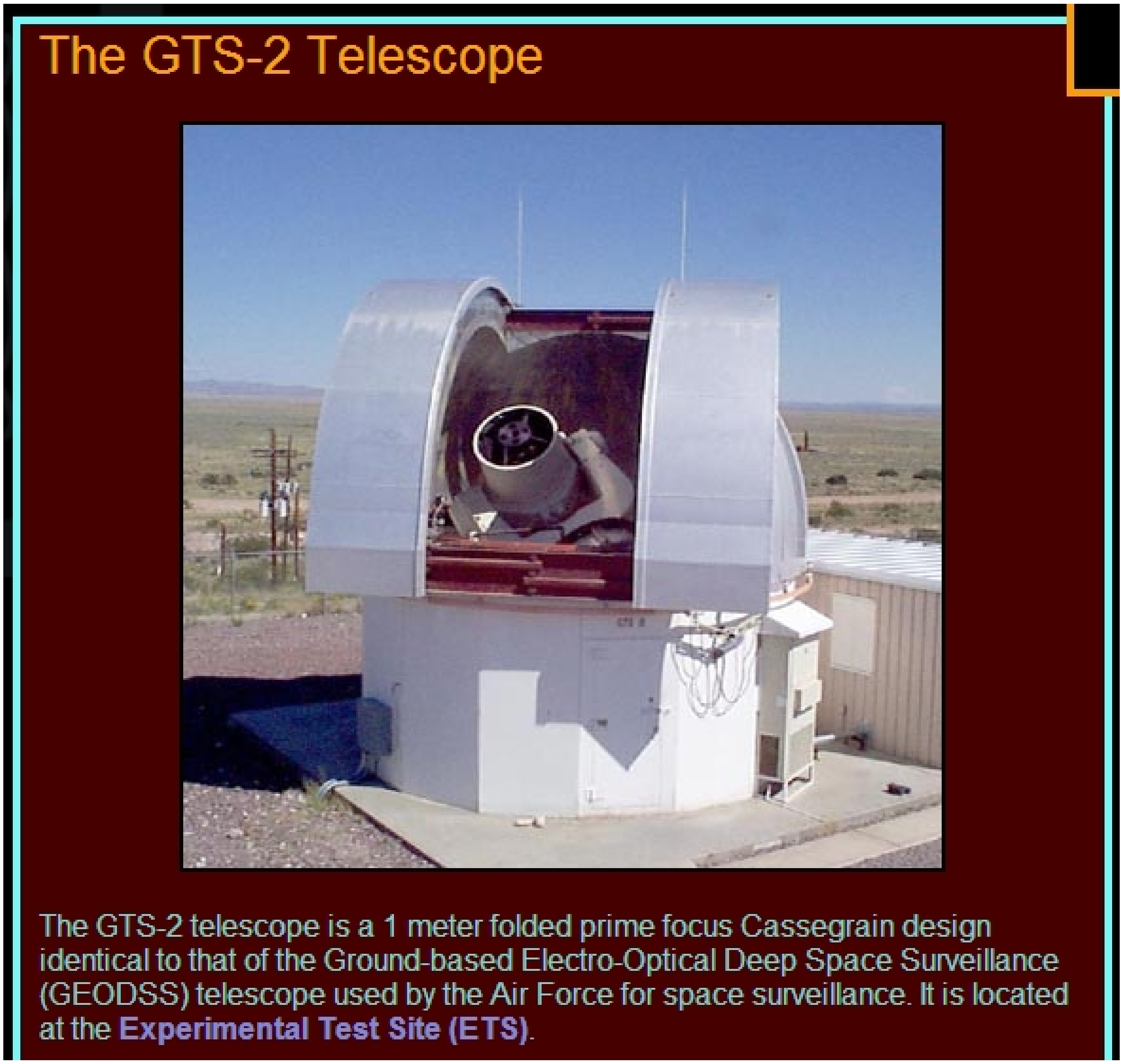
ETS is located on White Sands Missile Range in Socorro, NM. It is located across the parking lot from the operational Ground-based Electro-Optical Deep Space Surveillance (GEODSS) site (the three right most domes) which is part of the Air Force's space surveillance network. ETS is operated by MIT Lincoln Laboratory for the Air Force and has several telescopes which are used for a variety of technology development programs. Efforts such as LINEAR are conducted without impacting the operational GEODSS site.

http://www.ll.mit.edu/news/journal/pdf/vol14_no2/14_2linear.pdf



The ETS at White Sands Missile Range, near Socorro, New Mexico, adjacent to the U.S. Air Force GEODSS site. The LINEAR program operates two search telescopes, called L1 and L2, and one follow-up telescope, called L3.

http://www.ll.mit.edu/LINEAR/gts2.html



The GTS-2 Telescope

The GTS-2 telescope is a 1 meter folded prime focus Cassegrain design identical to that of the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) telescope used by the Air Force for space surveillance. It is located at the **Experimental Test Site (ETS)**.

http://www.ll.mit.edu/news/journal/pdf/vol14_no2/14_2linear.pdf

One of two one-meter Ground-Based Electro-Optical Deep-Space Surveillance (GEODSS) search telescopes at the Lincoln Laboratory Experimental Test System (ETS) at White Sands Missile Range, New Mexico. This telescope, which previously was used for space surveillance, is now a component of the Lincoln Near-Earth Asteroid Research (LINEAR) asteroid search program.

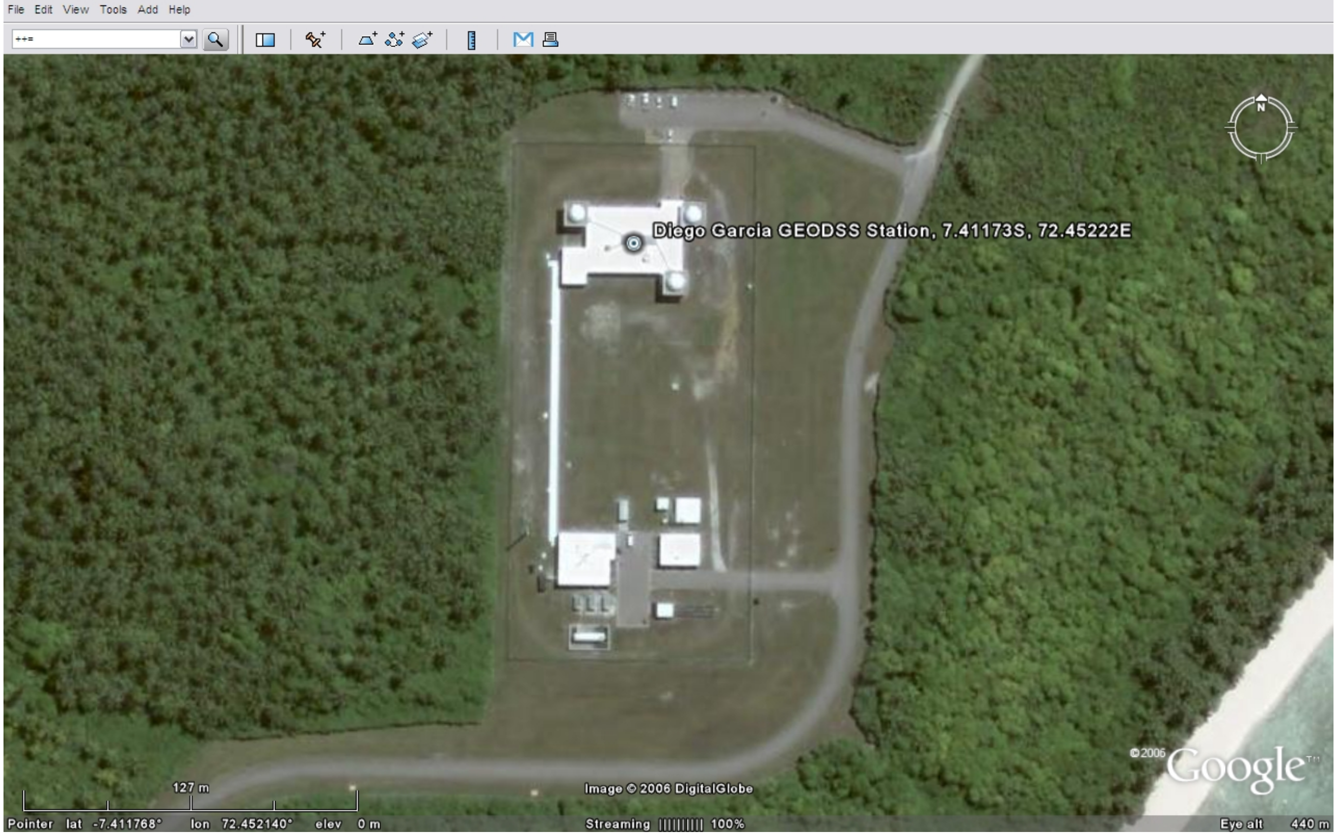
http://www.wsmr.army.mil/bd/visitors/doc/whitesands.pdf

View of GEODSS Detachment 1 at Stallion Range Center.

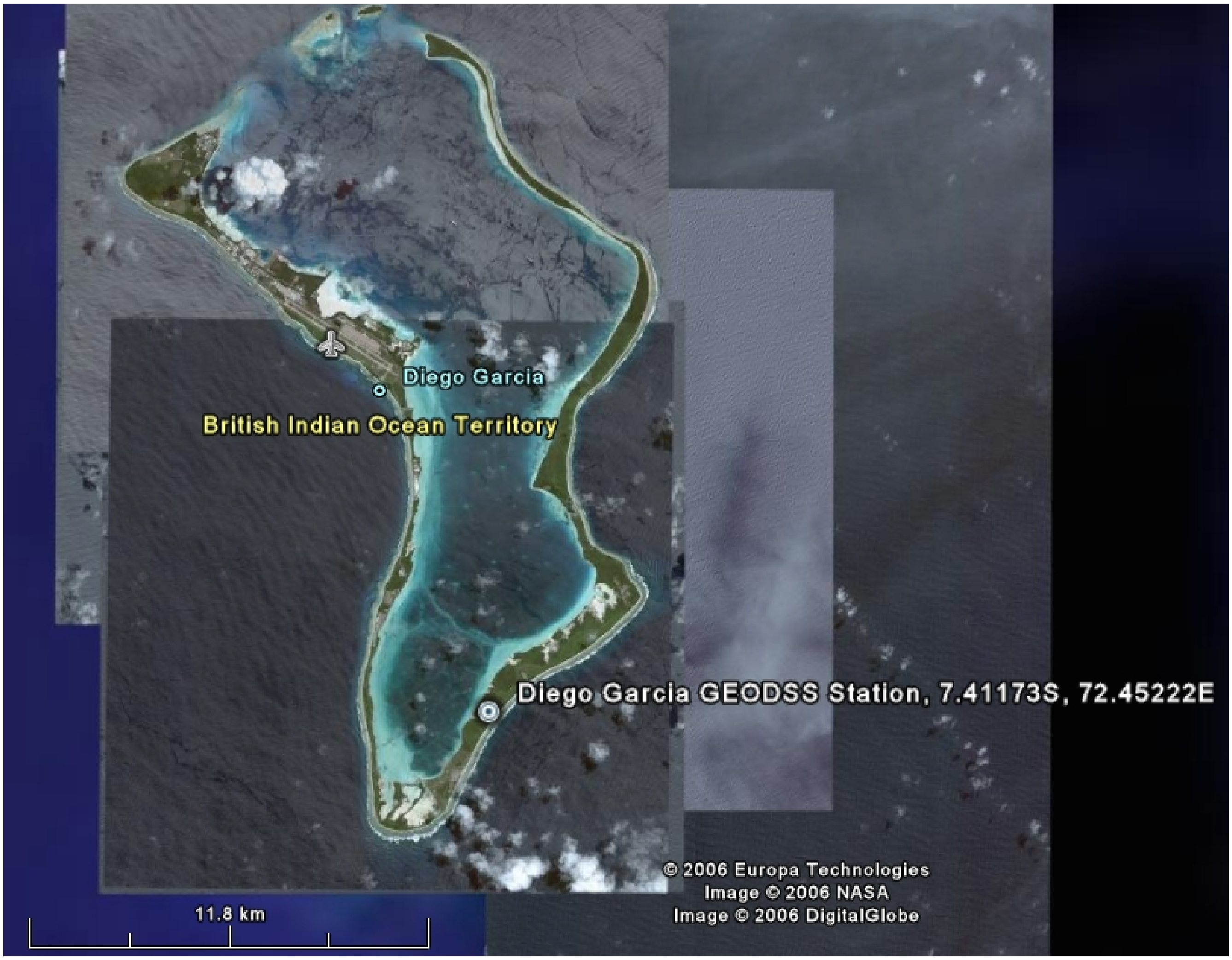
http://www.fas.org/spp/military/program/track/geodss_poster.pdf

Google Earth Image of Socorro GEODSS Station
33.8172 N, 106.6599 W

Location of Socorro GEODSS Station relative to Socorro, NM



Diego Garcia GEODSS Station
7.41173 S, 72.45222 E



Diego Garcia GEODSS Station

http://www.fas.org/spp/military/program/track/geodss_poster.pdf

Diego Garcia, BIOT

http://home.earthlink.net/~telawson/sitebuildercontent/sitebuilderpictures/geodss.jpg

Diego Garcia GEODSS Station

hhttp://www.tycho.dk/article/view/844/1/50

Diego Garcia GEODSS

Diego Garcia GEODSS

http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4740

DET 2, 21st OPERATIONS GROUP DIEGO GARCIA, BRITISH INDIAN OCEAN TERRITORIES

Detachment Commander: Maj. Gary Benton

Detachment 2, 21st Operations Group is a dedicated space surveillance unit on the island of Diego Garcia, in the British Indian Ocean Territories.

MISSION

The primary mission of the detachment is to detect, track, and identify all tasked space objects within its area of coverage. The unit provides data on deep space objects in the orbits from 3,000 to 22,000 miles, although it has a limited near earth detection capability. Satellite information is provided to the Space Control Center at Cheyenne Mountain Air Force Base, Colo.

TELESCOPES

The detachment is one of three worldwide Ground-based Electro-Optical Deep Space Surveillance sites. It performs its mission using three main telescopes. Each telescope has a 40-inch aperture and a 2-degree field of view. All telescopes at Diego Garcia are sealed against the environment and each observatory dome has a forced air system to keep out the salt-laden air of the Indian Ocean. It is the only site south of the equator.

HISTORY

The detachment was activated on 18 June 1986 as Detachment 4, 1st Space Wing, Air Force Space Command. It was reassigned to the 18th Space Surveillance Squadron at Peterson AFB in February 1990. It was reassigned to the 73rd Space Group on 15 May 1992, and then reassigned again to the 21st Space Wing in May 1995. The detachment became Detachment 2 of the 18th Space Surveillance Squadron on 1 August 1994. On 1 June 2004, the detachment was reassigned to the 21st Operations Group, 21st Space Wing due to the deactivation of the 18th Space Control Squadron.

The site is operated and maintained by contract workers. The single Air Force officer assigned has the primary responsibility for ensuring that the mission is accomplished and the contractor's work performance is satisfactory. The current contractor is Northrop Grumman Information Technology.

LOCATION

The detachment is situated near the center of the Indian Ocean between Africa and the Indonesian Archipelago. The island is remote, with the nearest commercial port being Colombo, Sri Lanka, some 960 nautical miles away. Diego Garcia is classified as a coral atoll and is among a number of islands forming a cluster known as the Chagos Archipelago. Diego Garcia is part of the British Indian Ocean Territories and is administered by the British government.

http://www.af.mil/news/story.asp?storyID=123019807&page=2

Trackers watch for dangerous 'space junk'

by Master Sgt. Scott King
40th Air Expeditionary Group Public Affairs

5/2/2006 - SOUTHWEST ASIA (AFPN) -- Roughly 15,000 miles above the Earth's surface a communications satellite provides vital information to all branches of the U.S. military.

It joins more than 9,000 other items in space that are tracked by the Ground-Based Electro-Optical Deep Space Surveillance System, known as GEODSS.

There are three operational GEODSS sites that report to the 21st Space Wing at Peterson Air Force Base, Colo. They are Detachment 1 in Socorro, N.M.; Detachment 2 in Southwest Asia; and Detachment 3 in Maui, Hawaii.

Each site is responsible for tracking thousands of known man-made deep-space objects in orbit around the Earth at an altitude of 10,000 to 45,000 kilometers. These objects range from active payloads such as satellites to "space junk" such as debris from launch vehicles and satellite breakups.

"As various on-orbit satellites perform their military, civilian or scientific functions, we monitor the relative presence of every man-made deep-space object in earth orbit," said Bruce Bookout, GEODSS site manager with Northrop Grumman Technical Services.

"Those (who) utilize space to fight the (war on terrorism) need to ensure those assets are available and are under no threat," Mr. Bookout said. "We act as a passive police force, watching for natural or artificial interference."

Each GEODSS site transmits its orbital data to U.S. Strategic Command's Joint Space Operations Center located at Cheyenne Mountain Air Force Station in Colorado Springs, Colo. The center maintains a satellite catalog of every man-made object in Earth's orbit.

GEODSS performs its mission using a one-meter telescope equipped with highly sensitive digital camera technology, known as Deep STARE. Each detachment has three of these telescopes that can be used in conjunction with each other or separately. These telescopes are able to "see" objects 10,000 times dimmer than the human eye can detect.

The Deep STARE system is able to track multiple satellites in the field of view. As the satellites cross the sky, the telescopes take rapid electronic snapshots, showing up on the operator's console as tiny streaks. Computers then measure these streaks and use the data to figure the current position of a satellite in its orbit. Star images, which remain fixed, are used as references or calibration points for each of the three telescopes.

"Space is the ultimate high ground, giving us the ability to communicate over long distances and determine exact locations through the Global Positioning System," said Maj. Jay Fulmer, Det. 2 commander.

“Many of our (servicemembers) serving on the front lines use technology that is greatly enhanced through the use of space," Major Fulmer said. "(Our detachments, which are) part of a global space surveillance network, ensure the U.S. and our allies have the ability to operate unencumbered in the medium of space, allowing our troops direct access to space-derived force enhancements.”

Thinking “big” is what these guys do.

“As mankind continues to explore and exploit the realm of space there needs to be some accounting and understanding of the medium,” Mr. Bookout said.

“Space is a new realm to the human experience. We’ve learned much during the last 50 years, but we still have much more to learn," Mr. Bookout said. "Space surveillance provides critical information on the location of every man-made object in space. (It ensures) our space-based assets are protected from potential on-orbit collisions or from adversaries who might try to take away our abilities to operate in space. This guarantees the warfighter access to space-derived tools they need to execute their mission.”

http://www.af.mil/shared/media/photodb/photos/060501-F-0000S-003.jpg

Diego Garcia GEODSS

http://www.af.mil/shared/media/photodb/photos/060501-F-0000S-002.jpg

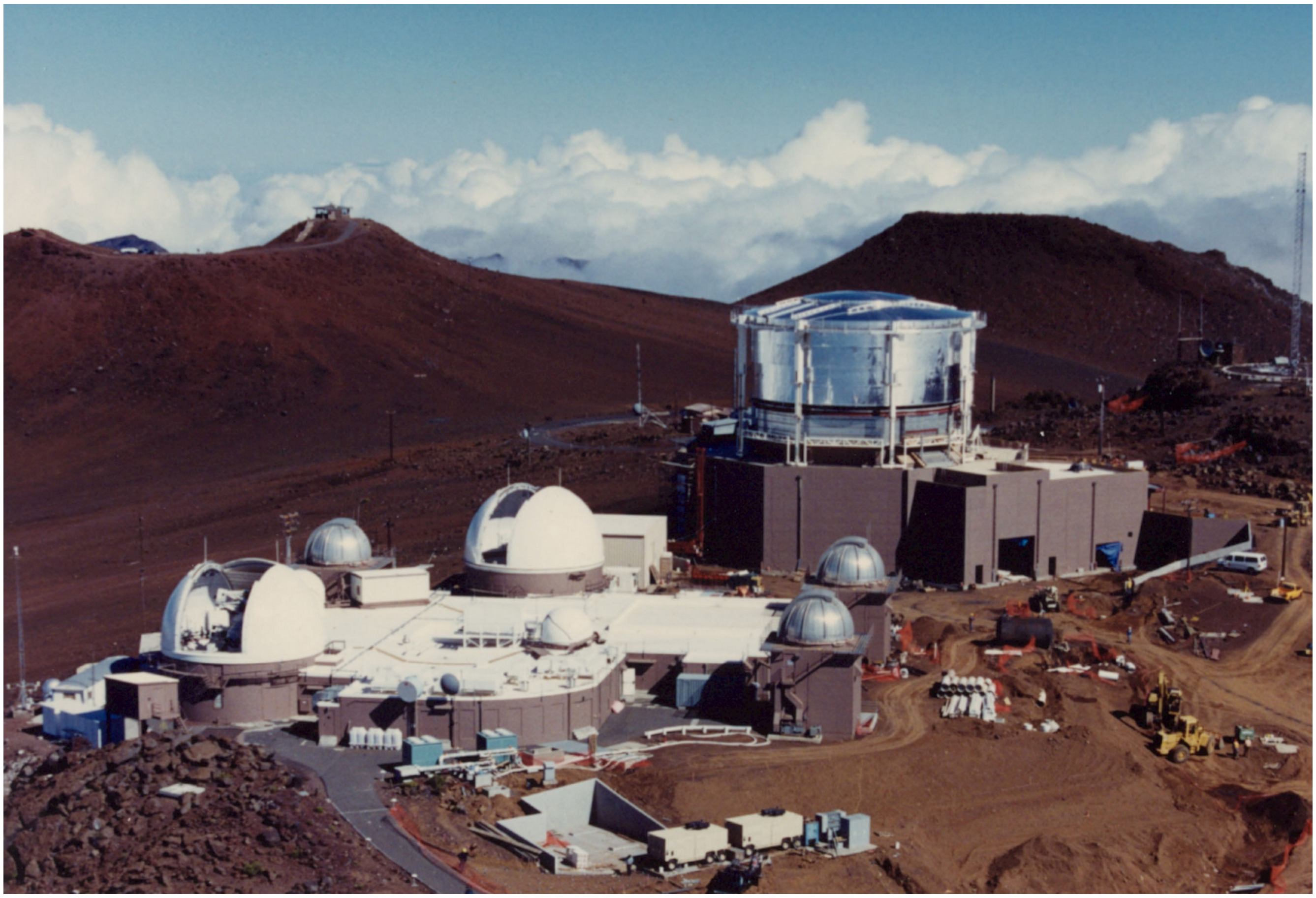
Inside Diego Garcia GEODSS Station

Maj. Jay Fulmer uses space and missile analysis software to track known man-made deep space objects in orbit around Earth. Major Fulmer is commander of Detachment 2 of the Ground-Based Electro-Optical Deep Space Surveillance System in Southwest Asia. (U.S. Air Force photo/Senior Master Sgt. John Rohrer)

http://www.fas.org/spp/military/program/track/geodss_poster.pdf

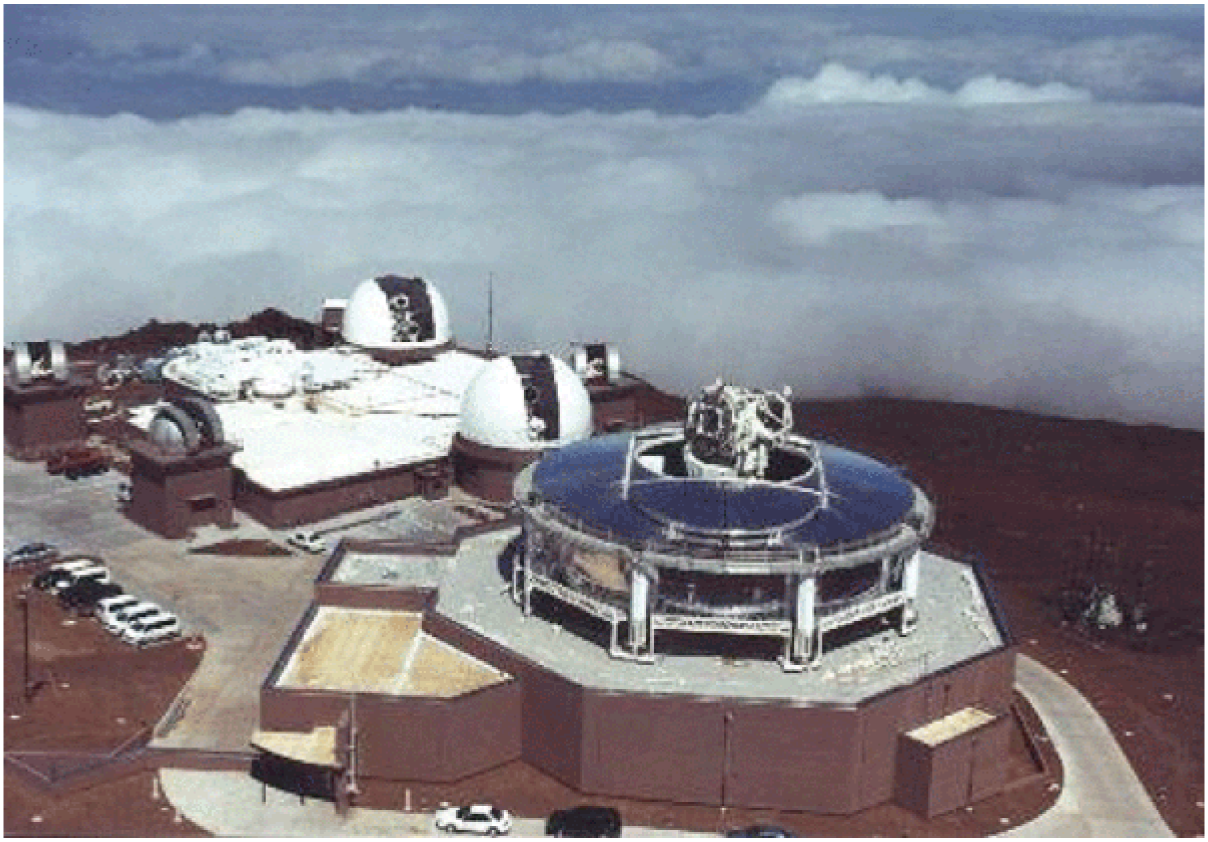
GEODSS & Maui Opticals, HI

www.orbitaldebris.jsc.nasa.gov/photogallery/gallarypage/amos.jpg



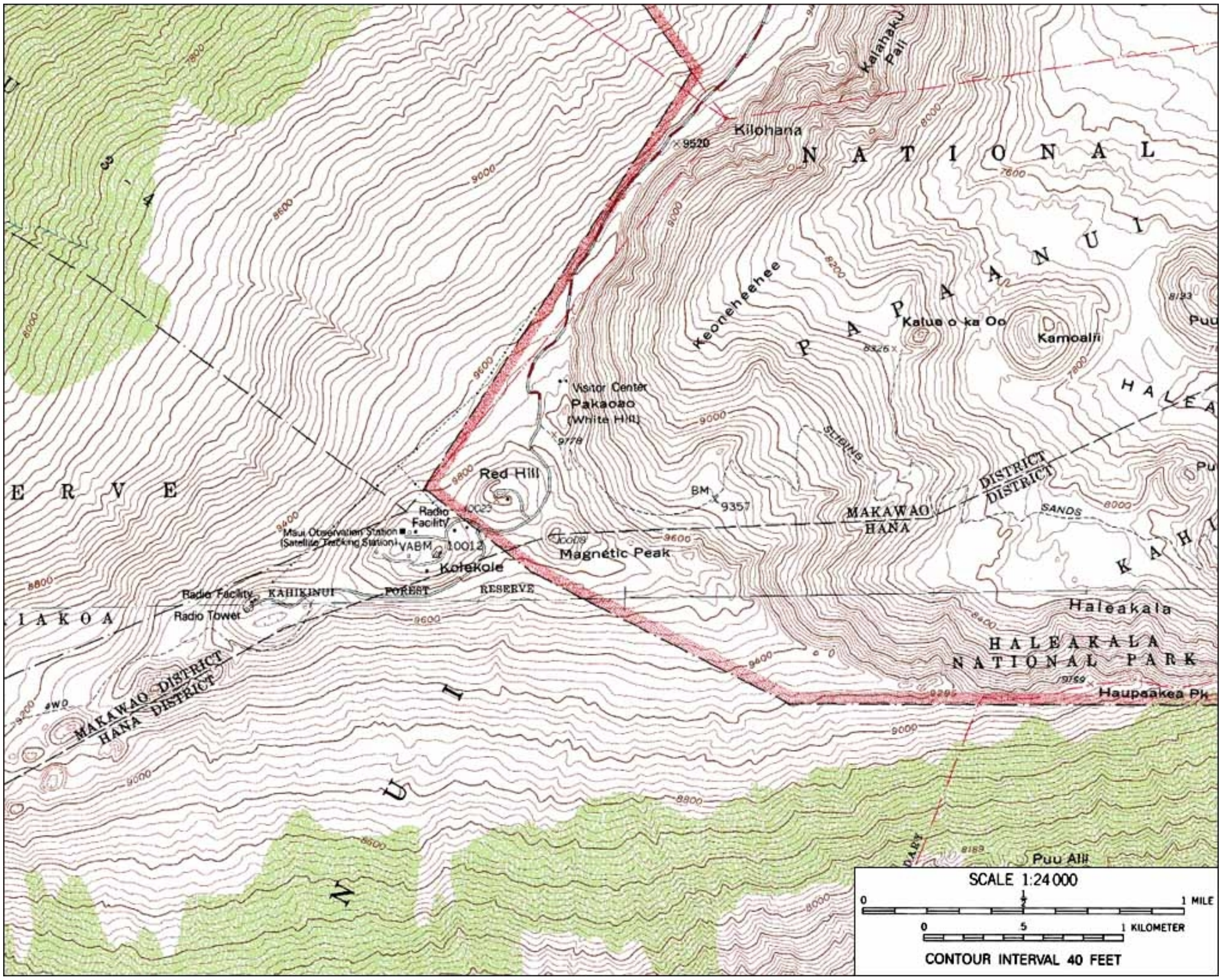
AMOS/GEODSS on Maui

www.afrl.af.mil/accomprpt/jun03/accompjun03.asp



MSSS/GEODSS on Maui

www.skimountaineer.com/ROF/OcAnt/Haleakala/HaleakalaMap2.jpg



www.skimountaineer.com/ROF/OcAnt/Haleakala/HaleakalaMap2.jpg
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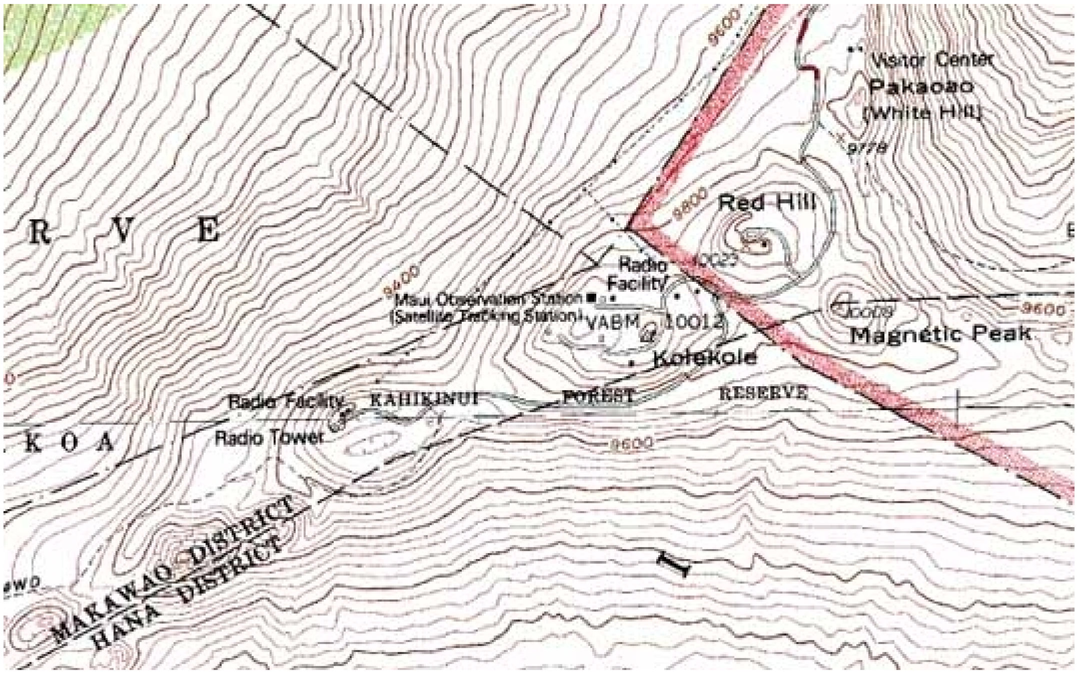
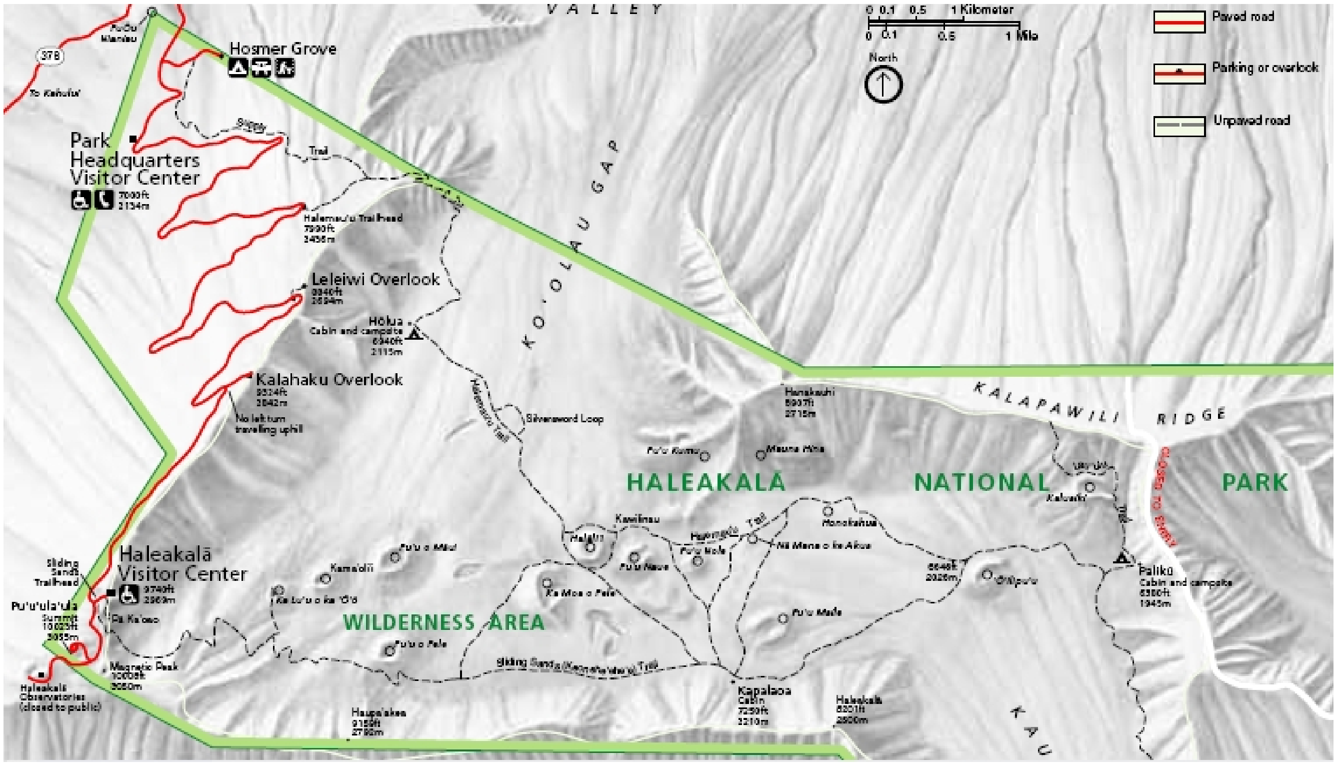


http://www.nps.gov/archive/hale/graphics/maps/topo_map.pdf



Maui GEODSS Site
20.7088 N , 156.2578 W

http://www.maui.afmc.af.mil/about.html

Situated at the crest of the dormant volcano Haleakala, the observatory stands at an altitude of 3058 meters, latitude 20.7 degrees N, and longitude 156.3 degrees W.

http://newton.dm.unipi.it/cgi-bin/neodys/neoibo?sites:566;main

Haleakala-NEAT/GEODSS - 566

Parallax information

Distance from rotation axis and height above equatorial plane (in Earth radii):
0.93623 +0.35156

Longitude (degrees East):
203.7424 *[156.2576 W]*

http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4741

DET 3, 21st OPERATIONS GROUP

Detachment Commander: Maj. David T. Isue

Detachment 3, 21st Operations Group is a dedicated and shared use space surveillance unit in the state of Hawaii, on the island of Maui, approximately 90 air miles east of Hickam Air Force Base. The detachment operates the Maui Space Surveillance System, located atop the 10,023 foot summit of Haleakala, a dormant volcano.

MISSION

The primary mission of the detachment is to detect, track and identify all tasked space objects within its area of coverage using the Ground-based Electro-Optical Deep Space Surveillance system. GEODSS provides metric data to the Space Control Center operated by the 1st Space Control Squadron at Cheyenne Mountain Air Force Station, Colo. Additionally, GEODDSS provides Space Object Identification to the USSTRATCOM Joint Intelligence Center at Offutt AFB, Neb.

TELESCOPES

The GEODSS system performs its mission using three optical telescopes, low light level, electro-optical cameras, and support computers. The three telescopes are main telescopes with 40-inch apertures and a 2-degree field of view. GEODDSS telescopes primarily operate between nautical sunset and nautical sunrise, when all ambient light is out of the atmosphere.

HISTORY

The detachment was activated on 1 June 1979 as Operating Location AA of the 46th Aerospace Defense Wing to aid in the, then named, Maui Optical Tracking and Identification Facility transition into the North American Aerospace Defense Command/Aerospace Defense Command spacetrack network. On 1 October 1981, the unit became Detachment 3, 1st Strategic Aerospace Division, Strategic Air Command. Maui's GEODSS system achieved Initial Operating Capability on 1 October 1982.

The detachment became part of the 1st Space Wing, Air Force Space Command, on 1 May 1983. On 1 February 1990, it was assigned to the 18th Space Surveillance Squadron at Peterson Air Force Base, Colo. Both the detachment and its parent squadron were reassigned from the wing to the 73rd Space Group on 15 May 1992, when the group was activated and assumed responsibility for all space surveillance units. In July 1995, the 18th SPSS relocated to Edwards Air Force Base, Calif. The group was deactivated in May 1995 and all units, including the 18th SPSS, were assigned to the 21st Space Wing. In February 2003, the unit was redesignated as the 18th Space Control Squadron. However, the squadron was deactivated at Edwards AFB in June 2004. Subsequently, the detachment, along with it's two sister sites located at Socorro, New Mexico (Det. 1) and Diego Garcia, B.I.O.T. in the Indian Ocean (Det. 2), and a fourth optical detachment (Moron Optical Space Surveillance -- MOSS) located at Moron AB, Spain, were realigned directly under the 21st Operations Group.

In June 2004, the GEODDSS system underwent a major technology upgrade. The antiquated and difficult-to-sustain Silicon Intensified Target (STT) tubes were replaced by the digital Charged Cathode Device (CCD) chips. With this upgrade, known as Deep STARE, came a phenomenal increase in the accuracy and throughput of observations, resulting in many more objects tracked with much better positional data flowing to the Space Control Center. Another upgrade to the system involved the ability to automatically detect the sky visibility with the addition of an Infra-Red Cloud-monitoring instrument. Sensor tasking is now much more efficient as the GEODDSS telescopes execute tasking in 'clear' zones rather than attempting to track through the cloud layers.

The site is operated and maintained entirely by a contract work force. The assigned Air Force Space Command officer has the responsibility for ensuring that the operational mission is accomplished and that work required by the contracts are performed satisfactorily. The current GEODDSS O&M contractor s Northrop-Grumman IT, which has held the contract since 1 October 1983.

In addition to the Mt. Haleakala observatory, where the operational mission is performed and applicable quality assurance evaluations are accomplished, the detachment maintains an office in Kihei, where detachment administration and contract management functions are conducted.

HOST: Det. 3, 21st OG is a tenant at the Maui Space Surveillance Complex (MSSC) hosted by Det. 15, AFRL (AFMC). The transition of host responsibilities from AFSPC to AFMC took place October 1, 2000. While Det 3, 21st OG retains responsibility for conducting and maintaining the GEODSS mission, the facilities as well as the Maui Space Surveillance System (MSSS) and Advanced Electro-Optical System (AEOS) missions, comprising the remainder of the MSSC, are the responsibility of the commander, Det. 15, AFRL.

LOCATION

The detachment sits atop of Mt. Haleakala on the island of Maui, HI. Maui is 90 miles east of Honolulu and Hickam AFB, Oahu, HI.

TRANSPORTATION: Kahului is the major airport on Maui. All commercial traffic comes into this airport. Visitor's who arrive at Honolulu International Airport should change to one of the inter-island shuttles. Auto rental booths are located across from the baggage claim area at Kahului Airport. Government ground transportation and housing is not available.

http://www.journals.uchicago.edu/AJ/journal/issues/v117n3/980386/980386.web.pdf

THE ASTRONOMICAL JOURNAL, 117:1616-1633, 1999 March

THE NEAR-EARTH ASTEROID TRACKING (NEAT) PROGRAM: AN AUTOMATED SYSTEM FOR TELESCOPE CONTROL, WIDE-FIELD IMAGING, AND OBJECT DETECTION

STEVEN H. PRAVDO,1,2 DAVID L. RABINOWITZ,1 ELEANOR F. HELIN,1 KENNETH J. LAWRENCE,1 RAYMOND J. BAMBERY,1 CHRISTOPHER C. CLARK,1 STEVEN L. GROOM,1 STEVEN LEVIN,1 JEAN LORRE,1 STUART B. SHAKLAN,1 PAUL KERVIN,3 JOHN A. AFRICANO,3 PAUL SYDNEY,3 AND VICKI SOOHOO3

Received 1998 September 2; accepted 1998 November 20

ABSTRACT

The Near-Earth Asteroid Tracking (NEAT) system operates autonomously at the Maui Space Surveillance Site on the summit of the extinct Haleakala Volcano Crater, Hawaii.

[deletia]

5.3. Satellite Tracking Potential

The results of the satellite observations discussed in § 4.8 show that the NEAT system has a satellite tracking performance that exceeds the dynamic range, precision, and throughput of the current USAF operational system, a high-voltage video-tube-based instrument. The limiting magnitude for the operational instrument is about V = 15, while NEAT is able to detect satellites at least 3 mag fainter. With one satellite per image, the throughput of NEAT is 2-3 times faster than the current GEODSS system. Another advantage of the NEAT system is the capability of observing several satellites per exposure. Typical GEODSS procedures generate track data on only one satellite in the field of view at any one time, regardless of how many satellites are visible in the image. Processing of NEAT data, however, allows multiple tracks to be obtained per image.

http://www.maui.afmc.af.mil/Newsletter_spring01.pdf

GEODSS Gets A Facelift

C-5 aircraft landing in Maui? If you were on the island back in November that's exactly what you would have seen as members of the 439th AW from Westover Air Reserve Base in Springfield, Massachusetts delivered three new Ground-based Electro-Optical Deep Space Surveillance (GEODDS) telescopes to Detachment 3 of the 18th Space Surveillance Squadron. These $1.1M Contraves-built telescopes were installed over a period of 45 days with final integration completed on 15 December 2000.

The GEODSS system, a dedicated sensor of the Space Surveillance Network (SSN), consists of passive telescopes used to observe deep space artificial satellites. Deep space satellites are defined as satellites whose orbital periods are greater than 225 minutes. The telescopes are connected to very sensitive low-light television cameras and are remotely tasked and scheduled by the GEODSS Optical Command, Control, and Communications Facility (OC3F) at Edwards Air Force Base, California. They are able to track more than 500 satellites daily.

"The positional data we gather on satellites is critical," said Maj. Sam McNiel, Det. 3, 18th Space Surveillance Squadron commander. "It helps the Air Force keep track of the location of almost all of the nearly 9,000 satellites in orbit. That helps governments and private companies keep their satellites from colliding with one another. It also helps NASA ensure the safety of the space shuttle or the international space station. Our Hawaii location is very important because it allows us to provide data for a large part of sky over the Pacific Ocean."

The telescope replacement project, called the GEODSS Telescope Refurbishment program, replaces the existing GEODSS telescopes with completely rebuilt ones. The existing GEODSS telescopes were installed in 1983 and have not been refurbished since then. “The new optics and mirrors in these refurbished telescopes should allow us to detect even smaller objects,” said McNiel. “With the old telescopes we could see a basketball 22,000 miles away. Hopefully, we can substantially improve on that. It’s important we be able to track as small an object as possible because things in orbit are going about 17,000 miles per hour, so a collision with even a small object can cause a catastrophic failure for a spacecraft.”

Based on how it is tasked, GEODSS will generate either metrics or space object identification (SOI) data. Metric data consists of very accurate measurements of the satellite position and the time the measurements were taken. The metric observations are usually generated in sidereal track mode, moving the telescope to keep the stars fixed in the field of view. A series of frames are recorded and processed using a maximum value projection method for background subtraction, and cluster/moment processing for streak detection. The pointing angle data is derived from the mount angular encoders, while the time comes from the global positioning system (GPS) satellites. SOI data consists of recording the satellite brightness as a function of time, typically at 100 Hz. SOI data is collected in rate track mode, moving the telescope to keep the image of the satellite on a single pixel.

The Deep-space Surveillance Technology Advancement & Replacement for Ebsicons (Deep STARE) upgrade, presently in acquisition, will introduce in-frame metrics. In-frame metrics utilizes the well-known position of the stars present in the field of view to accurately determine the location of the target objects. Implementation of in-frame metrics, performed only in sidereal tracking mode, will eliminate the now-stringent dependence on the mount model and the mount encoders in the development of metric observations. In-frame metrics, also know as astrometry, has been used for several years at AMOS by both the Raven and NEAT programs.

Appendix A
COSTS

U.S. AIR FORCE AWARDS NORTHROP GRUMMAN SPACE SURVEILLANCE CONTRACT

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HERNDON, Va. -- Sept. 9, 2003 -- Northrop Grumman Corporation (NYSE: NOC) has been awarded a contract to continue supporting the U.S. Air Force Space Command's Ground-Based Electro-Optical Deep-Space Surveillance System (GEODSS). Northrop Grumman will implement new performance improvement and cost saving approaches for GEODSS by introducing greater use of web-based technology in training and information management, and implementing quality program improvements.

The contract value is $5.7 million over one year with four one-year options to Northrop Grumman's Information Technology (IT) sector.

"Our outstanding past performance delivering service excellence on the GEODSS contract coupled with our commitment and innovations to reduce costs exemplified the best value solution to the Air Force Space Command," said Gregg Donley, president, Technical Services, Northrop Grumman IT. "We are gratified that we continue to be considered a valued member of 21st Space Wing team, even after two decades, and look forward to serving our client with the same level of commitment in the future."

Northrop Grumman IT will provide operations, maintenance and support services to the Air Force Space Command, 21st Space Wing for the three geographically dispersed GEODSS sites: Site 1, at White Sands Missile Range, N.M.; Site 2, on Diego Garcia, British Indian Ocean Territory; and Site 3, Maui, Hawaii. These sites are part of Air Force Space Command's optical space surveillance network and conduct deep space surveillance of orbiting space objects in support of U.S. Strategic Command and Air Force Space Command's space control mission. Every night, telescopes operating at these sites search for, track and identify man-made objects that are orbiting the earth – most more than 22,000 miles away. The Air Force anticipates adding a fourth site in Moron, Spain, by the contract's first option year.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)

DATE
February 2002

BUDGET ACTIVITY
07 - Operational System Development

PE NUMBER AND TITLE
0305910F SPACETRACK

	COST ($ in Thousands)	FY 2001 Actual	FY 2002 Estimate	FY 2003 Estimate	FY 2004 Estimate	FY 2005 Estimate	FY 2006 Estimate	FY 2007 Estimate	Cost to Complete	Total Cost
	Total Program Element (PE) Cost	10,829	23,289	21,917	66,632	119,115	159,062	221,380	Continuing	TBD
4279	Have Stare Radar	9,674	5,970	0	0	0	0	0	0	128,773
4791	GEODSS Sustainment	1,155	5,649	0	0	0	0	0	0	12,531
4930	Space Based Space Surveillance	0	2,290	9,959	21,464	47,336	61,030	113,011	Continuing	TBD
5011	Space Situational Awareness Initiatives	0	9,380	11,958	45,168	71,779	98,032	108,369	Continuing	TBD
	Quantity of RDT&E Articles	0	0	0	0	0	0	0	Continuing	TBD

Note: In FY 2003, Project 5011, Space Situational Awareness Initiatives, was changed from Project 5010 (same name) to correct an administrative error. This action did not change program content.

(U) A. Mission Description

The SPACETRACK program element represents a worldwide Space Surveillance Network (SSN) of dedicated, collateral, and contributing electro-optical, passive radio frequency (RF) and radar sensors. The SSN is tasked to provide space object identification and cataloging, satellite attack warning, timely notification to U.S. forces of satellite fly-over, space treaty monitoring, and scientific and technical intelligence gathering. The continued increase in satellite and orbital debris populations, as well as the increasing diversity in launch trajectories, non-standard orbits, and geosynchronous altitudes, necessitates continued modernization of the SSN to meet existing and future requirements and ensure their cost-effective supportability. The resources and responsibility for completing the HAVE STARE Radar System development were transferred to SPACETRACK from an intelligence program per Congressional direction in FY93.

The GEODSS Sustainment project develops and fields ten Charge-Coupled Device (CCD) cameras for the Ground-Based Electro Optical Deep Space Surveillance (GEODSS) System, located at Socorro, NM; Diego Garcia, Indian Ocean; and Maui, Hawaii. In addition, this project funds the purchase and integration of ten Modular Precision Absolute Control Systems (MPACS), as well as sensor controller hardware and associated software.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2A Exhibit)

DATE
February 2002

BUDGET ACTIVITY	PE NUMBER AND TITLE	PROJECT
07 - Operational System Development	**0305910F SPACETRACK**	**4791**

COST ($ in Thousands)	FY 2001 Actual	FY 2002 Estimate	FY 2003 Estimate	FY 2004 Estimate	FY 2005 Estimate	FY 2006 Estimate	FY 2007 Estimate	Cost to Complete	Total Cost
4791 GEODSS Sustainment	1,155	5,649	0	0	0	0	0	0	12,531

(U) A. Mission Description

The GEODSS Sustainment project began in FY00 to develop and field ten Charge-Coupled Device (CCD) Cameras for the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) System, located at Socorro, NM; Diego Garcia, Indian Ocean; and Maui, Hawaii. The project includes associated software changes to the Optical, Command, Control & Communications (OC3F) at Edwards AFB, CA. In addition, this project purchases and integrates ten replacement Modular Precision Absolute Control Systems (MPACS), and funds associated logistics requirements, technical data and training. The project develops the first components and installs them at the test unit at Yoder, CO. Follow-on CCD cameras and MPACS will be produced and installed using Space Track Modification funds (BP83). This project, with the recently completed GEODSS Modification Program, will result in more than double the throughput and search rate of the legacy system. Without CCD camera replacement, the entire GEODSS system will be unusable in the FY05 time-frame, as mission critical Ebsicon tubes are no longer manufactured or supported by any vendor and the current supply of spares will run out by the end of 2004. This would result in loss of geosynchronous space situational awareness and less ability to assess the space order of battle of a potential aggressor.

(U) FY 2001 ($ in Thousands)

(U)	$155	Began operational use of Test Bed at Yoder, Colorado
(U)	$500	Completed camera design
(U)	$500	Tested prototype camera /MPACS
(U)	$1,155	Total

(U) FY 2002 ($ in Thousands)

(U)	$549	Contingency & closeout efforts on development contractor
(U)	$1,500	Complete prototype camera and testing
(U)	$3,600	Initial spares (require OPAF vice RDT&E)
(U)	$5,649	Total

(U) FY 2003 ($ in Thousands)

(U)	$0	No Activity - RDT&E efforts completed in FY02
(U)	$0	Total

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2A Exhibit)		DATE February 2002
BUDGET ACTIVITY 07 - Operational System Development	PE NUMBER AND TITLE 0305910F SPACETRACK	PROJECT 4791

(U) B. Project Change Summary

$3.6M in FY02 3600 to purchase initial spares was inadvertently placed in the wrong appropriation due to a database error, convert to OPAF.

(U) C. Other Program Funding Summary ($ in Thousands)

	FY 2001 Actual	FY 2002 Estimate	FY 2003 Estimate	FY 2004 Estimate	FY 2005 Estimate	FY 2006 Estimate	FY 2007 Estimate	Cost to Complete	Total Cost
(U) Other APPN								0	0
(U) OPAF (PE 0305910F, Space Mods Space, P-1 Line Item #66, BA 3)*	8,537	8,724	2,406	0	0				19,667
(U) OPAF (PE 0305910F, Spares and Repair Parts,P-1 Line Item #104, BA 5)*	509	27	4,159	588	212			0	5,495

* For the GEODSS Sustainment project only

(U) D. Acquisition Strategy

The contract for the GEODSS Sustainment project was awarded after full and open competition

(U) E. Schedule Profile

	FY 2001				FY 2002				FY 2003			
	1	2	3	4	1	2	3	4	1	2	3	4
(U) Prototype Mod Kit Test				*								
(U) Detail Design Technical Interchange Mtg				*								
(U) Ops Acceptance of 1st Software Release							X					
(U) Operational Acceptance at Site 1 (Socorro, NM)									X			
(U) Mod Kit Production Completed											X	

* = Complete event
X = Planned event

RDT&E PROGRAM ELEMENT/PROJECT COST BREAKDOWN (R-3)

DATE
February 2002

BUDGET ACTIVITY
07 - Operational System Development

PE NUMBER AND TITLE
0305910F SPACETRACK

PROJECT
4791

(U) A. Project Cost Breakdown ($ in Thousands)

		FY 2001	FY 2002	FY 2003
(U)	System Engineering	250	80	0
(U)	Hardware Development	600	1,900	0
(U)	Software Development	300	0	0
(U)	Program Office Support	5	69	0
(U)	Need OPAF for Initial Spares	0	3,600	0
(U)	Total	1,155	5,649	0

(U) B. Budget Acquisition History and Planning Information ($ in Thousands)

(U) Performing Organizations:

Contractor or Government Performing Activity	Contract Method/Type or Funding Vehicle	Award or Obligation Date	Performing Activity EAC	Project Office EAC	Total Prior to FY 2001	Budget FY 2001	Budget FY 2002	Budget FY 2003	Budget to Complete	Total Program
Product Development Organizations										
TRW, Inc.	SS/CPAF/PR	Mar 00	7,230	7,230	4,100	1,150	1,980	0	0	7,230
Support and Management Organizations										
MITRE	SS/PR	Jan 00	716	716	700	0	16	0	0	716
MIT/Lincoln Lab	SS/PR	Feb 00	365	365	365	0	0	0	0	365
A&AS	C/PR	Mar 00	445	445	400	0	45	0	0	445
SPO	Various	Jan 00	175	175	162	5	8	0	0	175
Test and Evaluation Organizations										
None										

(U) Government Furnished Property:

Item Description	Contract Method/Type or Funding Vehicle	Award or Obligation Date	Delivery Date	Total Prior to FY 2001	Budget FY 2001	Budget FY 2002	Budget FY 2003	Budget to Complete	Total Program

RDT&E PROGRAM ELEMENT/PROJECT COST BREAKDOWN (R-3)		DATE February 2002
BUDGET ACTIVITY 07 - Operational System Development	PE NUMBER AND TITLE 0305910F SPACETRACK	PROJECT 4791

(U) Government Furnished Property Continued:

Item Description	Contract Method/Type or Funding Vehicle	Award or Obligation Date	Delivery Date	Total Prior to FY 2001	Budget FY 2001	Budget FY 2002	Budget FY 2003	Budget to Complete	Total Program
Product Development Property									
None									
Support and Management Property									
None									
Test and Evaluation Property									
None									

Subtotals	Total Prior to FY 2001	Budget FY 2001	Budget FY 2002	Budget FY 2003	Budget to Complete	Total Program
Subtotal Product Development	4,100	1,150	1,980	0	0	7,230
Subtotal Support and Management	1,627	5	69	0	0	1,701
Subtotal Test and Evaluation						
Total Project	5,727	1,155	2,049	0	0	8,931

Appendix B

http://www.mitre.org/work/tech_papers/tech_papers_00/faccenda_geodss/geodss_faccenda.pdf

GEODSS: PAST AND FUTURE IMPROVEMENTS

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GEODSS: PAST AND FUTURE IMPROVEMENTS

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ABSTRACT

The Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system, a passive electro-optical visible wavelength sensor in the Space Surveillance Network (SSN), has been and continues to be upgraded. Introduction of the Optical Command, Control, and Communications Facility (OC^3F) improved efficiency. The accuracy of its metric observation data of artificial deep space satellites, greatly improved just recently, will again be substantially improved. Improvements in sensitivity in both its metric and photometric (Space Object Identification, SOI) missions will also be achieved in the present acquisition phase.

INTRODUCTION

The Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system, an asset of the Space Surveillance Network (SSN), is a passive sensor used to observe individually tasked ‘deep space’ artificial satellites, those having periods greater than 225 minutes. The GEODSS generated data is used by the US Space Command’s Space Control Center (SCC) and the Combined Intelligence Center (CIC), both in Cheyenne Mountain, Colorado Spring, CO. The telescopes are remotely tasked and scheduled by the GEODSS Optical Command, Control, and Communications Facility (OC^3F) at Edwards Air Force Base, CA.

ASSETS

GEODSS is composed of one-meter aperture f /2.15 telescopes of basically Ritchey-Chretien design. There are three passive electro-optical visible wavelength telescopes at each of three geographically dispersed sites; Socorro, NM on White Sands Missile Range (WSMR), Diego Garcia, British Indian Ocean Territory, and Mt. Haleakala on the island of Maui, HI. Presently Ebsicon (Electron-Bombarded Silicon) vacuum tubes fill the 80 mm diameter circular focal plane, with 832 pixels of horizontal and vertical resolution across the center of the focal plane. A portion of the energy, within ~ 20 arc-sec of the boresight, can be directed to a photo-multiplier tube for photometric brightness measurements, i.e., SOI.

HISTORY

In the summer of 1999 GEODSS operationally introduced the GEODSS Modification Program (GMP) components. The GMP contractor, PRC (Colorado Springs, CO), was responsible for the introduction of the OC^3F into the GEODSS system along with its Optical Dynamic Scheduler (ODS), based on a prototype developed by the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL). PRC also developed the hardware and software for the Data Processing Group (DPG), the high level GEODSS controller of tasks. The core sensor functionality of the metrics and SOI missions resides in the Sensor Controller (SC), developed by TRW (Colorado Springs, CO). This component, developed in the GEODSS Technology Insertion Program (GTIP), was introduced at the same time, and was largely responsible for the improvement in GEODSS metric accuracy.

GEODSS Data Accuracy

The metric observations (obs) data are principally generated by sidereal track mode; recording a series of frames, which are processed using a maximum value projection method for background rejection, and cluster/moment processed for streak detection. Based on how it was tasked, GEODSS will generate either orbital metrics of time and pointing angle (sent to the SCC) or Space Object Identification (SOI) data (sent to CIC), tracking of object brightness, typically at 100 Hz. SOI data is collected in a rate-track like mode.

Rate-track, i.e., continuously moving the telescope to keep the object's image on one pixel, for SOI – within the photo-multiplier tube (PMT) aperture, is also used to develop metric obs, in the observation of dimmer objects.

Metric obs data contain time and the pointing angle. Being a passive sensor, there are no range data. The GEODSS sites maintain their time stamp from the Global Positioning System (GPS) satellites. Metric obs are reported within an accuracy of 0.001 seconds. The pointing angle data are derived from the mount angular encoders. All positional accuracy ultimately is derived from the robustness of the mount model. The Deep-space Surveillance Technology Advancement & Replacement for Ebsicons (Deep STARE) upgrade, presently in acquisition, will introduce in-frame metrics. In-frame metrics utilizes the 'well-known' position of the stars present in the field-of-view to accurately determine the location of the target objects. 'Well-known' is, of course, only as good as the star catalog used. Implementation of in-frame metrics, performed only in sidereal tracking mode, will eliminate the now-stringent dependence on the mount model and the mount encoders in the development of metric observations.

At a top level in the processing are algorithms to select and process the stars, and to locate their centers. In the present implementation the GEODSS custom star catalogs are comprised of stars from the Smithsonian Astrophysical Observatory (SAO) Catalog and the Astrographic Catalog Reference Stars (ACRS). These star catalogs are utilized within the mount calibration catalog and the SOI calibration catalog. Because the metric accuracy requirements remained the same in going to GMP, there was no need to change the star fields already in use. There was an effort made to incorporate the most recent positional data. The SOI star catalog was created using a subset of the Hubble Guide Star Photometric Catalog from which 600 to 800 solar (G2) type stars have been identified.

The mount model incorporates five high level algorithms in its execution: Calibration Data Collection, Correction (including for atmospheric refraction), Control, Read-out Interpolation, and the Mount Model Solution. The mount calibration uses an assembled grouping of 54 stars, which are evenly distributed over the field-of-regard. Each mount calibration uses the previously assembled mount model, the known star location, and the mount encoder read-out, in a least squares fit algorithm and thus improves on the residual error. Acceptable performance is achieved when, at the end of the 54 star survey, the residual error, as reported by the Mount Model Solution, is less than 6 arc-sec rms.

Accuracy in the focal plane is achieved through the implementation of Camera Geometry Models including: Ebsicon Camera Alignment and Calibration and Ebsicon Plate Model. For the camera alignment, i.e., rotation and centration, about 25 pre-identified sets of star fields, typically identifying about 10 stars each, are used. There are a sufficient number of star fields identified such that those used for the calibration are located close to zenith so as minimize the variable refractive atmospheric effects. The Ebsicon Plate Model Calibration Algorithm is used to determine 10 calibration constants used for transforming the focal plane coordinates to the pixel coordinates. This algorithm does not use stars in the present implementation in consideration of the Ebsicon vacuum tube's non-linearities. The instabilities cause a fixed-point image on the focal plane to not always get read-out in the same pixel. It does use fixed reseau points on the faceplate. These are mapped to the pixels and thus achieve a fixed focal plane dimensional reference. To ensure consistent metric accuracy the present system is limited to reporting observations centered in the field-of-view (fov).

The SSN system tracks metric accuracy by having each of the space surveillance sensors report obs on a set of calibration satellites (CalSats). The Space Surveillance Performance Analysis Tool (SSPAT) uses the reported positional data to characterize the system and sensor performance against data supplied by the NASA laser ranging office, specifically from their Crustal Dynamics Data Information System. The analysis against CalSats (Lageos 1 and 2, Etalons 1 and 2, and GPS satellites 34, 35, and 36, SATNOs 08820, 22195, 19751, 20026, 22779, 22877, and 23027, respectively) of the sensor raw data is presented in Figure 1. Prior to inclusion of GMP, the metric accuracy, as analyzed, bias plus sigma, can be seen to be roughly 40 arc-seconds. Following GMP's acceptance in the late summer of 1999 the three GEODSS sites have consistent accuracy in the vicinity of 4 arc-seconds. The improvements were accepted at face value. Insufficient effort has been made to identify and evaluate the contributing errors either in the legacy or the GMP improved GEODSS. Expanded detail of the data in Figure 1 can be found in the same web site within the PowerPoint presentation accompanying this paper.

With the introduction of GMP metric accuracy of the reported GEODSS data did improve noticeably. This change was driven by real and purposeful improvements but may be partially attributable to a serendipitous set of events associated with the treatment of annual aberration. Components and methodologies changed within the GMP installation included improvements to the mount model, a rigorous treatment of coordinate systems, a better plate model, a change in the spacing between obs, and the replacement of the streak detection algorithm. Corrections for annual aberration were included in both generations of GEODSS.

The mount model, unless the base of the mount has been moved, is used to point the telescope in the collection of the data for use in developing the subsequent model. The legacy mount model used a Kalman filter. It was replaced by a least squares fit algorithm. Unlike the Kalman filter mount model, which weights the most recent measurements heavily in achieving the model, the least squares fit mount model simultaneously fits data from all 54 observed star locations.

For the implementation of the SC processing a great deal of attention was given to the formulation of what, when, where, and how to apply coordinate transformations. TRW worked the details with the Space Warfare Center. SPAce Defense Operations Center (SPADOC) uses mean equinox coordinates (true equator, mean equinox).

The plate model incorporated a least squares fit registering reseau points to render angles off-boresight accurately.

The manner in which the SC recorded metrics observational data was changed at this time. Specifically the temporal and spatial distances between obs, was lengthened. Previously, a set of 5 obs was executed, each ob having temporal spacing of 10 seconds. Post GMP two sets, each containing 3 obs, are executed. But the two sets of three obs are temporally and, more importantly, spatially separated. Again, the three obs within each set are separated by at least 10 seconds. This improvement, the greater obs separation in true anomaly, contributed to the SPADOC and its orbit determination capability, which in turn drove an accuracy improvement in the resident space object catalog maintained by SPADOC.

The sidereal track streak detection algorithm in the legacy system recorded a series of frames, as does the GMP enhanced system. In the legacy system, the streak was generated by subtracting the first frame from each of the subsequent images. Summing the residual images generated the streaked image of the satellite. GMP introduced the maximum value projection to identify signals above a certain threshold. Each method thus affected background rejection. In both implementations a second algorithm filters for clustering and determines the moment of the identified streaks. The new algorithms likely achieve more of an improvement in detection sensitivity than in metric accuracy.

Just prior to the incorporation of the GMP there were biases, principally in right ascension (RA), evident in the GEODSS data. A component of the improvement has been credited to the incorporation of treating annual aberration within the Sensor Controller (SC). Annual aberration does manifest dominantly in RA. However, the legacy system also treated annual aberration. Changes in the processing of the calibration laser ranging data, which may have occurred at about the same time as the GMP installation, may have played a role in the quality improvement of the GEODSS data. Although this is not clearly evidenced in data accuracy changes of the other optical sensors (see Figure 1). Annual aberration is caused by the earth's motion around the sun. The positional correction is applied against non-earth-orbiting objects. The objects of interest, artificial satellites, are traveling with the earth. Thus the apparent positions of the stars are aberrated, i.e., displaced, in the same manner as the apparent location from which rain originates while one is observing it from a moving vehicle. Annual aberration in and of itself can contribute errors up to ~20 arc-sec.

Figure 1 shows the enhancement in the quality of the data when GMP came on-line in August of 1999.

The SOI data processing did not change in the implementation of GMP. The instrument calibration portion surveils a set of G2 solar type stars to estimate the device's zero value coefficient and current sky extinction value. To correct the measured data the bias and dead-time coefficients of the PMT are also determined. The present device, the PMT, is effectively a single pixel device staring at a circular portion of the sky ~40 arc-sec in diameter. It also measures the sky background brightness. The background sky correction is also applied to the SOI data.

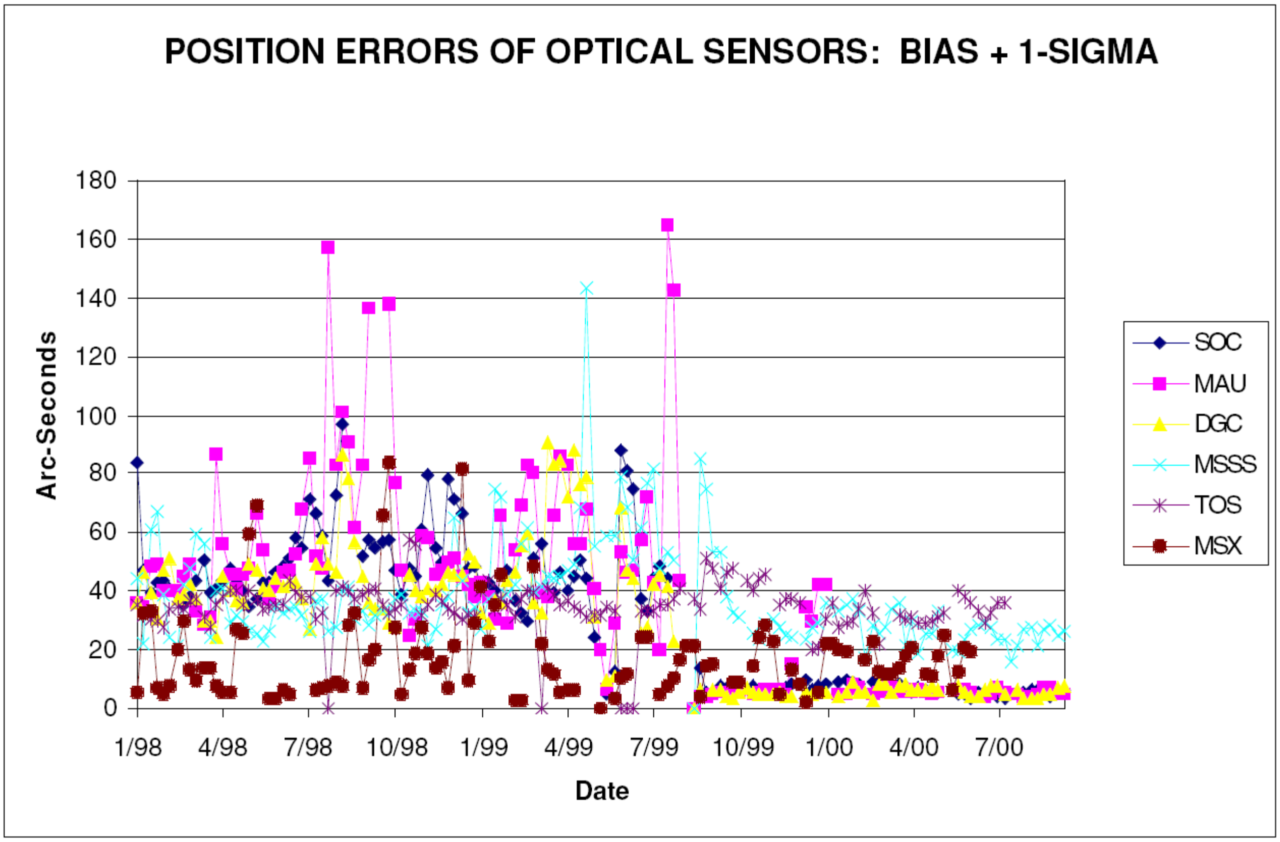

Figure 1: Geosynchronous object positional accuracy

Figure 1 shows the position errors for a number of optical sensors, which contribute to the Space Surveillance Network (SSN). Defining the legend:

SOC	GEODSS Site 1	Socorro, NM
MAU	GEODSS Site 3	Mt. Haleakelaa, Maui, HI
DGC	GEODSS Site 2	Diego Garcia, BIOT
MSSS	Maui Space Surveillance Site	Mt. Haleakelaa, Maui, HI
TOS	Transportable Optical System	Moron, Spain
MSX	Midcourse Experiment satellite	Space Based Visible (SBV)

Table 1: Figure 1 Legend

GEODSS FUTURE

TRW (Colorado Springs, CO) is presently on contract for the Deep STARE program. They are responsible for the development and installation of a charge-coupled device (CCD), the CCD camera, a replacement mount control system, and among other capability improvements, the introduction of in-frame metrics and enhanced streak detection (ESD) algorithms.

The CCD, modeled on the MIT/LL CCID-16 device, presently in the design stage at Sarnoff, will have a monolithic array of 1960 by 2560 24 μm square pixels, with 100% active area. It will cover just under 60% of the 80 mm GEODSS telescope circular focal plane. This back-illuminated device will have 8 channel outputs enabling approximately a 3 frame per second read-out rate. The chip will also have a 32 X 32 array of the same pixel architecture to be used for obtaining the photometric SOI signatures.

Sensitivity improvements for objects tracked are expected to be on the order of 2 to 2.5 m_v.

Accuracy improvements are expected to be about a factor of 2. Presently for obtaining metric observations the Ebsicons are run in Zoom mode. This affects an Ebsicon pixel of about 4.5 μm square versus 2.3μm square for the CCD.

In today's system only metric observations of objects tracked at, or across, the center of the fov are reported, due to the sum of unpredictable non-linearities, dominated by that of the Ebsicon tube. With the elimination of the Ebsicon's free electron path, the introduction of fixed location focal plane array, namely the CCD, off-axis obs positional corrections can be achieved by modeling the telescope optics' non-linearities through the introduction of an enhanced plate model. With the addition of in-frame metrics, real-time plate models should achieve metric accuracy within two arc-sec for all objects detected within the fov. Thus, enhancements to the number of objects tracked per unit time can be achieved by reporting on all objects within the telescope's fov. With multiple objects within a fov being reportable, alternate tasking methods to maximize the number of objects expected within the tasked fov, are being considered.

With the introduction of Deep STARE, GEODSS is again hoping to achieve an incremental improvement in its contribution to SPADOC and to its ability to perform orbit determination. As was done in GMP, Deep STARE is proposing to further separate the obs in true anomaly. As proposed, each sidereally generated streak will in-turn generate two obs, one from each end of the streak. Streaks of the same object will be separated by at least tens of minutes with three streaks needed to suffice a typical object's tasking. Each pair of obs intrinsically contains data on position and topocentric angular velocity.

Presently SOI data are obtained by beam-splitting the collected energy, part to the Ebsicon, to maintain closed-loop tracking, with the principle portion of the energy directed to the PMT for the object brightness signature. There is appreciable loss in the process. The Ebsicon is the limiting factor in this design. Receiving only a muted signal induces an all-too-soon loss in the ability to maintain track. With the introduction of the Deep STARE CCD camera, the photometric measurement will be performed in the telescope's focal plane, rather than having only some of the energy relayed to the PMT. This will achieve approximately a 35% improvement in the energy to the detector for a given object thus improving the signal-to-noise ratio (snr). The SOI CCD array will function as both the collector of energy for the SOI mission and will supply the signal to maintain tracking. This eliminates the limitation of closed loop tracking induced by the Ebsicon. SOI sensitivity improvements in going from the PMT (quantum efficiency $\cong 0.10$) to the CCD ($Q_e \cong 0.70$) are expected to be about 2 visual magnitudes improvement. Assuming, both the improved sensitivity and the 35% improvement in energy throughput, our ability to track dim objects should improve by about 2.5 visual magnitude. The improvement in signal strength, the resulting improvement in SOI data quality for objects already being tracked, and the ability to track far dimmer objects beg for an improvement in the accuracy of brightness calibration. Data will be accessible over a greater useful range of visual magnitudes. An improved photometric star catalog will greatly enhance the accuracy of the generated data.

The introduction of in-frame metrics gives rise for the need for an improved star catalog, which will enable positional accuracy to be achieved across the focal plane array (FPA). To improve SOI accuracy, better photometric calibration stars are required. Improvements to the existing GEODSS star catalogs will likely engender a greater benefit to the SOI photometric accuracy than that of positional metric accuracy.

Toward this goal the Deep STARE program is presently formulating sets of requirements for the customized star catalogs. The metric needs are for three sets of star ‘catalogs’ for performing 1) the mount calibration 2) the camera rotation calibration, as well as 3) for the in-frame metrics. Sets one and two will likely be a subset of 3 whose to-date requirements are listed.

For the astrometric catalogs;
- Single isolated stars, outside of galactic plane
- Positional accuracy ≤ 0.3 arc-sec rms
- 5 to 10 stars per square degree – uniformly distributed
- Stars of 12 to 15 m_v, color corrected for the Sarnoff supplied CCD

The SOI star catalogs will be used for the instrument calibration (zero point coefficient) and the atmospheric extinction estimation.

For the photometric catalogs;
- Single isolated stars, outside of galactic plane
- Stars of 9 to 12 m_v, color corrected for the Sarnoff supplied CCD
- Photometric accuracy ≤ 0.05 m_v
- ~1000 stars – uniformly distributed.

Conversations with the USNO indicate their ability and eagerness to provide a custom catalog by using existing tools to identify a sub-set of B1.0 of B2.0. Discussions included supplying updates to maintain positional accuracy correcting for proper motion. Through use of USNO CCD Astrograph Catalog (UCAC) star positional accuracy down to 0.1 arc-sec could be achieved.

The replacement to the present mount control system, the Modular Precision Angular Control System (MPACS), is the Telescope and Dome Control (TDC) system. The TDC is being supplied by Raytheon of Albuquerque, NM. It’s pointing accuracy performance will not dramatically differ from that of the original MPACS. Nor does it really have to. With the introduction of in-frame metrics, getting the telescope to point-and-report to sub-arc-sec accuracy for the sidereal tracking mission is not a requisite to improved accuracy. However, because of the smaller pixels, the mount’s drift and jitter performance will be of greater concern.

SUMMARY

GEODSS metric accuracy improved substantially late in the summer of 1999. GEODSS will hopefully continue that trend with an estimated 2 times improvement in metric accuracy with the introduction of Deep STARE. The sensitivity of the main focal plane arrays will enable tracking objects 7 to 10 times dimmer than the Ebsicon based GEODSS. SOI will also achieve an improvement in sensitivity and will likely sustain a substantial improvement in the quality of its SOI data.

Table 2 summarizes the principal components, events(?), and algorithm introductions associated with the legacy GEODSS, GMP, and the future Deep STARE.

	GEODSS	**GMP**	**Deep STARE**
Metric Accuracy		Annual aberration correction?	In-frame metrics
			ESD
Sensor	Ebsicon	Ebsicon	CCD
Pixel Size	4.4 arc-sec	4.4 arc-sec	2.2 arc-sec
Star Cat	SAO	SAO	USNO UCAC?
SOI Photometric Accuracy			
Sensor	PMT	PMT	CCD
Star Cats	?	Hbl GS Phtmtrc	USNO?

Table 2: Principal contributors to metric and SOI accuracy improvements.

ACKNOWLEDGEMENTS

I would like to thank Dr. Max Williams of TRW, Colorado Springs, CO, Dr. Jerry Yos of SenCom, Bedford, MA, and Dr. Eric Pearce of MIT/LL at the Experimental Test Site in Socorro, NM for their time and efforts in reviewing this paper.

Appendix C

http://www.mitre.org/work/tech_papers/tech_papers_00/miller_geodss/miller_geodss.pdf

Contributions of the GEODSS System to Catalog Maintenance

J. G. Miller (The MITRE Corporation),
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Contributions of the GEODSS System to Catalog Maintenance

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The Electronic Systems Center completed the Ground-based Electro-Optical Deep-Space Surveillance (GEODSS) Modification Program (GMP) in 1999 with new mission critical computer resources, including sensor controllers at the GEODSS sensor sites and an Optical Command, Control, and Communications Facility (OC3F) at Edwards AFB. The GEODSS system with the GMP configuration became operational on 3 August 1999, with the OC3F dynamically scheduling the three GEODSS sites in response to tasking from the Space Defense Operations Center (SPADOC). SPADOC still tasks the individual GEODSS sites, Socorro, Maui, and Diego Garcia, based on site visibility and capacity, but the site tasking messages are transmitted to the OC3F instead of the individual sites. The OC3F combines the individual site tasking messages into a single database and dynamically schedules the individual sites in near real-time, independent of which site SPADOC tasked. For example, a high-priority satellite may be tasked by SPADOC to Socorro and not Maui, even though it has visibility, but the dynamic scheduler may schedule Maui to track the satellite because Socorro is clouded over during the satellite pass. SPADOC tasks the optical sites hours before their shooting periods begin, assuming clear skies, because it cannot predict the weather in advance.

The OC3F also converts track requests from SPADOC into several tracklets of three obs each, separated in time by at least ten minutes, to achieve better orbit distribution of the observations. This benefits catalog maintenance by producing more accurate element sets. In accordance with U. S. Space Command Instruction UI 10-40, SPADOC tasks satellites to sensors at a category 1 through 5 (category 1 has the highest priority) and a suffix A through Z, indicating the number of tasked tracks and the number of observations per track. As a hypothetical example, consider a semi-synchronous satellite that is visible to all three GEODSS sites. Suppose SPADOC determines that the satellite only needs to be tasked to two sensors, which could be any combination of radar and optical sensors with visibility. Suppose SPADOC tasks Socorro at 2K and Diego Garcia at 2K, i.e. category 2 and suffix K, indicating one track of five observations. K is the most frequently used suffix by SPADOC for ground-based optical sensors. When the OC3F receives Socorro s tasking message from SPADOC, it converts the suffix for each satellite into the number of 3-ob tracklets necessary to provide at least as many observations in SPADOC s track request. For the K suffix, this would be two tracklets, providing SPADOC one more observation than requested but in two tracks or tracklets. When the OC3F receives Diego Garcia s tasking message, it does the same conversion to tracklets. So the hypothetical satellite would have a requirement of four tracklets in the dynamic scheduler s database. The OC3F would attempt to obtain the four tracklets for this satellite from any site that has visibility, based on the real-time optimization and prioritization of all other requests. It is possible that Socorro could be scheduled to provide one of the tracklets, Maui two of the tracklets, and Diego Garcia one of the tracklets to satisfy SPADOC s tasking request. This would result in a total of 12 observations in four tracklets, two more observations than SPADOC requested.

GEODSS with the GMP configuration now produces more tracks, on more objects, and provides more observations per day, on average, than the legacy GEODSS system. The purpose of this paper is to show the effect of this increased throughput on catalog maintenance.

The throughput of GEODSS under GMP from August 1999 through December 1999 is compared with the throughput of the GEODSS legacy system from August 1998 through December 1998, so that the time intervals cover the same months of the year. Figure 1 shows the track response for these two time intervals from all deep-space sensors. The other deep-space sensors include the Maui Space Surveillance System (MSSS), the Space Based Visible (SBV) sensor on board the MSX satellite, the Moron Optical Space Surveillance (MOSS) system, the ALTAIR and Millstone (MIL) radars, and the passive RF sites, Feltwell (FLT) and Misawa (MSW). The post-processing software that reconstructs tracks from SPADOC observation files defines a track to be a contiguous collection of observations on a satellite from a sensor over a short time interval. Thus, GEODSS tracklets are counted as tracks by this software.

Given that the OC3F converts SPADOC 5-ob track requests into two 3-ob tracklets, one would expect GEODSS under GMP to produce twice as many tracks as legacy GEODSS, based on this post-processing software. It is evident from Figure 1 that the GEODSS track throughput has more than doubled (legacy GEODSS provided 40,658 tracks and GMP provided 116,052 tracks for a 185 percent increase). The legacy GEODSS system did have red time from August through December 1998 due to GMP testing. However, the third cameras, both on auxiliary telescopes at Socorro and Maui, were available for spacetrack under the legacy GEODSS system, but are not available under GMP. These auxiliary telescopes will be replaced with main telescopes in the future and scheduled by the OC3F. This will further increase the GEODSS throughput under GMP. The SBV track throughput essentially remained the same for these two time intervals, 26519 and 27563, respectively. It is also evident from Figure 1 that the MSSS track throughput has decreased (from 29577 to 18534 for a 37 percent decrease), and the MOSS track throughput has increased (from 15376 to 25532 for a 66 percent increase). The decrease from MSSS is due to the refurbishment of the 1.2 meter telescope to support Near Earth Asteroid Tracking (NEAT) during the latter part of 1999. In 2000, the 1.2 meter telescope will be used three weeks per month supporting NEAT and only available one week per month for spacetrack. The spacetrack throughput from MSSS will only decrease further in 2000. The increase from MOSS is due to two factors. The site was exhausting its tasking list before the end of its shooting period and just revisiting previously attempted satellites with no success. On 7 February 1999, the daily number of tracks tasked by SPADOC was increased from 250 to 400 at the site s request. On 13 April 1999, operational changes were made at the site to improve the scheduling efficiency by adjusting the miss weight so that satellites would not continue to be scheduled after several missed acquisitions.

Figure 2 shows the object response from the deep-space sensors. The GEODSS object throughput went from 35454 to 51289 for a 45 percent increase. The SBV object throughput essentially remained the same for these two time intervals, 22372 and 21363, respectively. The MSSS object throughput went from 28738 to 17866 for a 38 percent decrease. The MOSS object throughput went from 12445 to 22237 for a 79 percent increase.

Figure 3 shows the observation response from the deep-space sensors. The GEODSS observation throughput went from 202545 to 385753 for a 90 percent increase. The SBV observation throughput essentially remained the same, 81734 and 83454, respectively. The MSSS observation throughput went from 157221 to 97994 for a 38 percent decrease. The MOSS observation throughput went from 80668 to 126669 for a 57 percent increase.

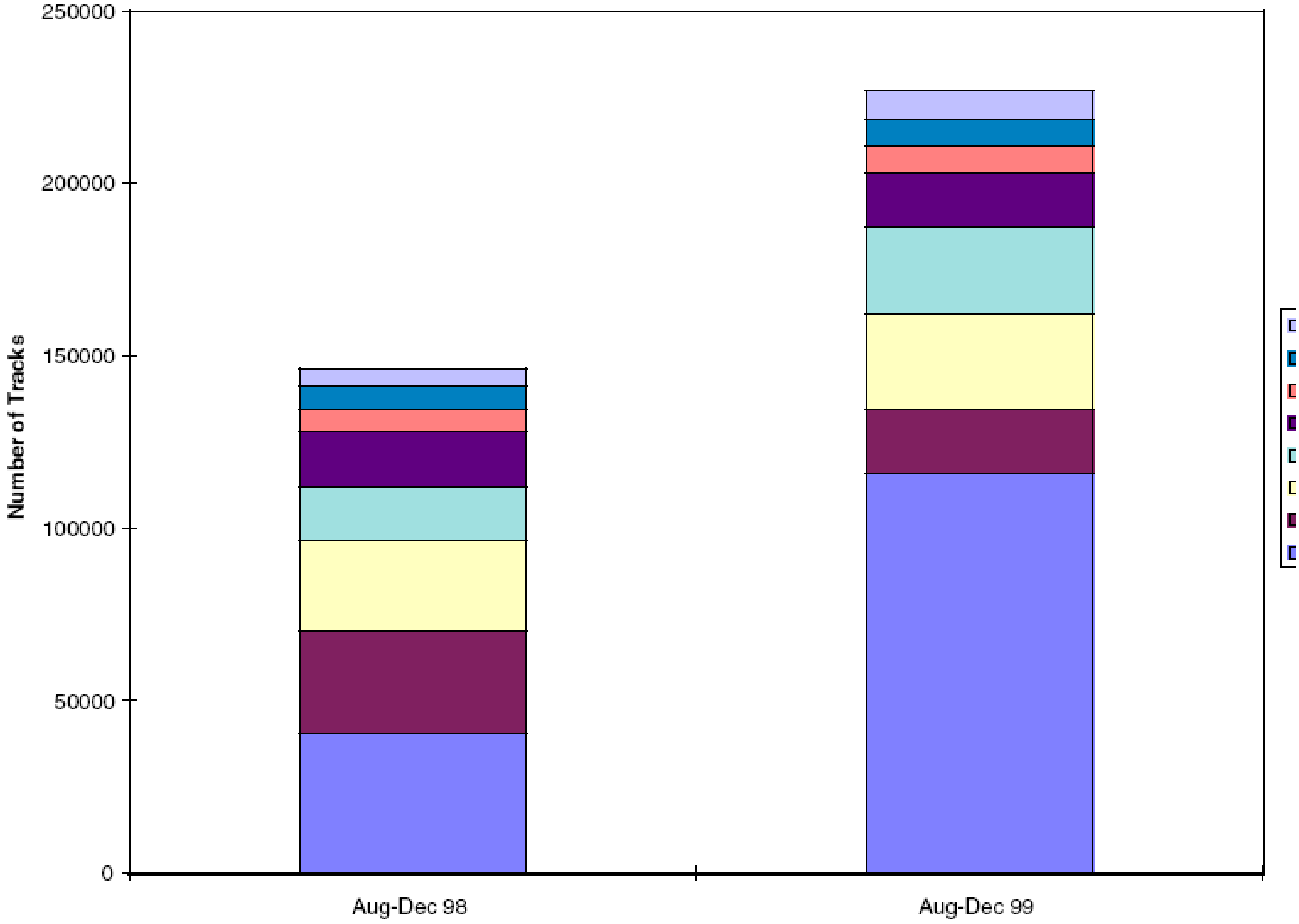


Figure 1. Track Response from the Deep-Space Sensors

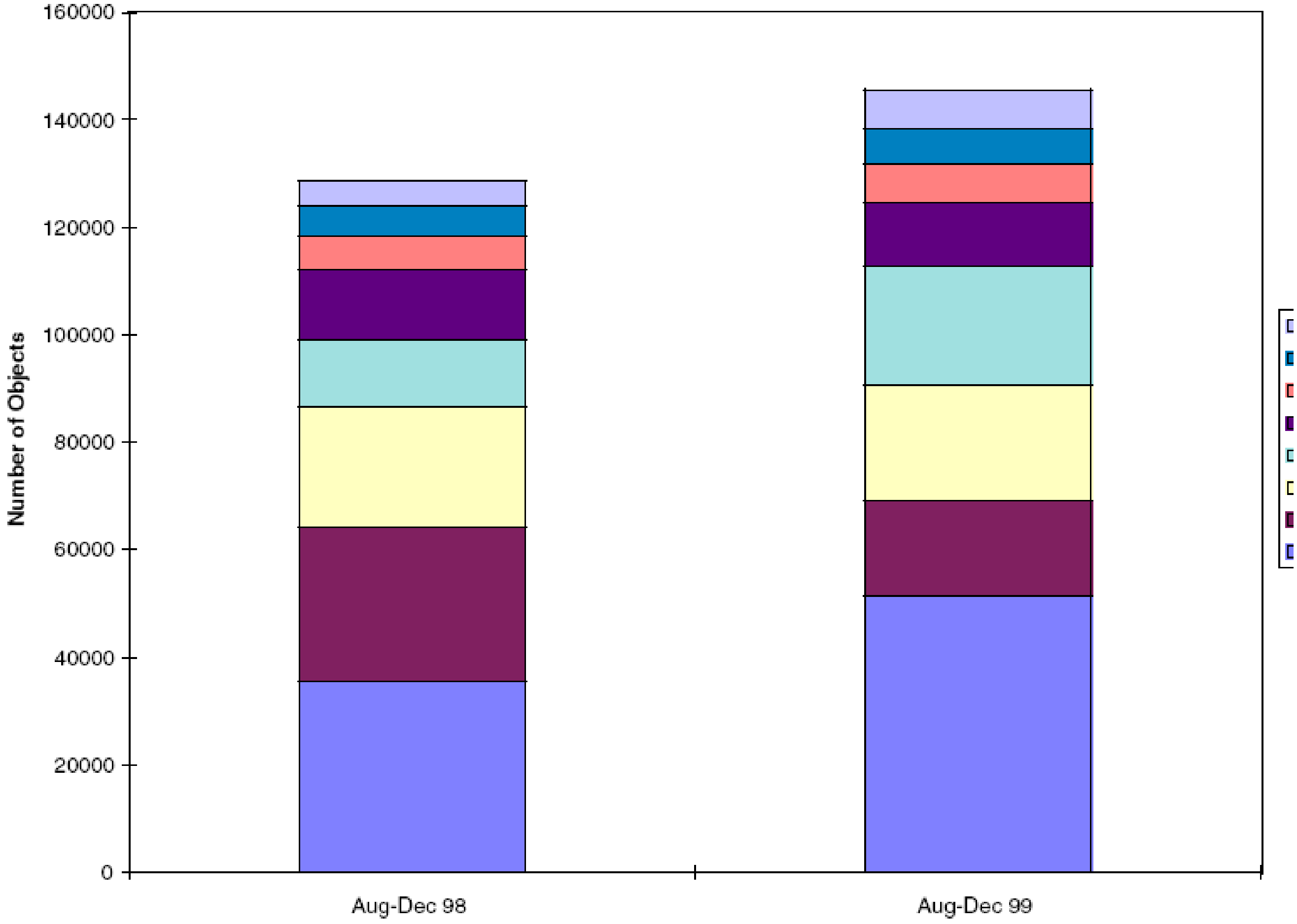


Figure 2. Object Response from the Deep-Space Sensors

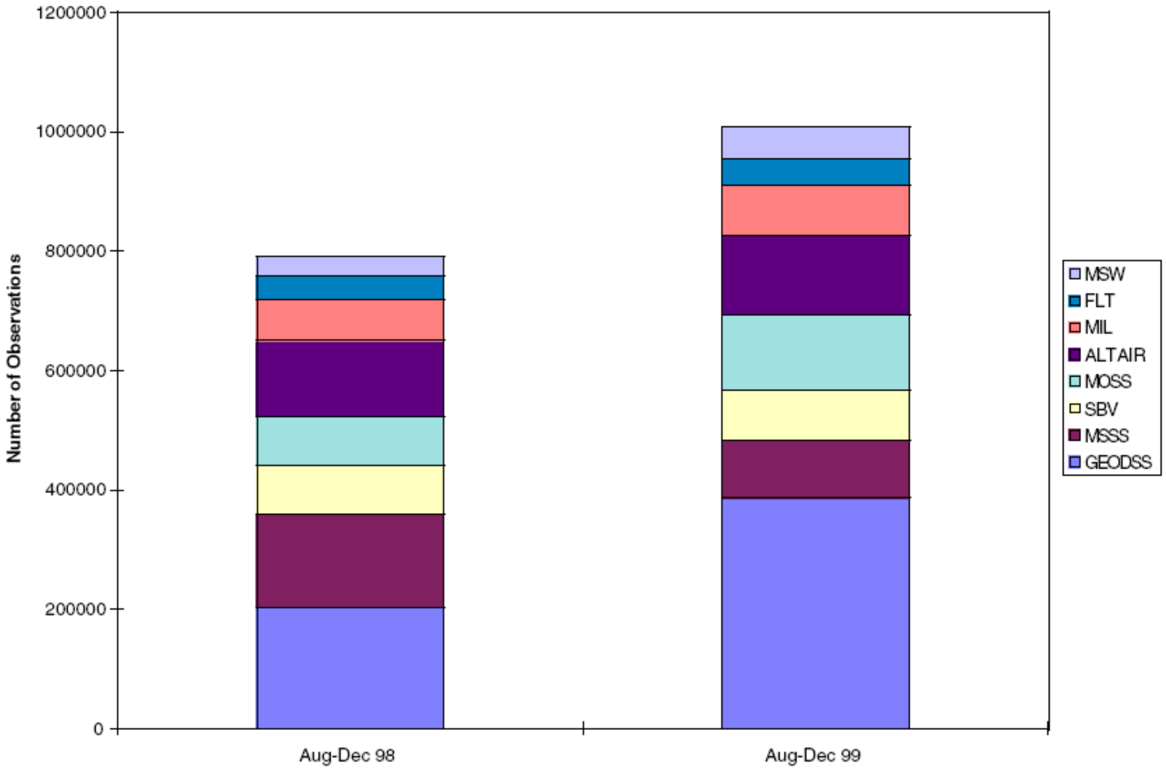


Figure 3. Observation Response from the Deep-Space Sensors

From August 1998 through December 1998, the average number of observations per track from the legacy GEODSS system was 5.0. From August 1999 through December 1999, the average number of observations per track from GEODSS under GMP was 3.3, agreeing with the 3-ob tracklet scheduling by the OC3F for most of the objects. For SBV, the average number of observations per track was 3.0 for both time intervals. The most frequently used tasking suffix for SBV by SPADOC is C, which specifies one track of four observations. The frame processing from SBV s signal processor produces two observations from the endpoints of a streak on the focal plane array. It takes two streaks on the same satellite to produce the four observations requested by SPADOC. For half of the satellites tracked by SBV, a second streak is not obtained, thus explaining the average 3.0 observations per track. For MSSS, the average number of observations per track was 5.3 for both time intervals. For MOSS, the average number of observations per track for these two time intervals was 5.2 and 5.0, respectively.

The GEODSS track response over time is shown in Figure 4. An operational assessment of GMP was done in May 1999. The OC3F s conversion of SPADOC tasked tracks to 3-ob tracklets is clearly seen in the increased track throughput. The increased track throughput is seen again in the beginning of August 1999 when GMP became operational. The GEODSS object response over time is shown in Figure 5. The upper curve in Figure 5 is the number of unique objects tasked to the GEODSS system, which has remained fairly constant except for the fall of 1998. The same object may be tasked by SPADOC to multiple GEODSS sites on a given day, and these objects are counted only once. The bottom curve is the number of unique objects tracked by the GEODSS system. If more than one GEODSS site tracks the same object or the same site tracks an object multiple times on a given day, the object is counted only once. The increase in May 1999 and again in August 1999 is evident in Figure 5, but it is not as significant as the increase in track throughput. Many of the additional tracks (or tracklets) are on the same object in order to satisfy SPADOC s total observation request. The GEODSS observation response over time is shown in Figure 6 with increased throughput under GMP.

The MOSS track response over time is shown in Figure 7. The increase from 250 to 400 tasked tracks by SPADOC on 7 February 1999 is clearly seen in the upper curve with a corresponding increase in track throughput. Since the sensor tasking function in SPADOC uses a maximum track limit as a measure of a site s capacity, the upper curve is a step function that changes when the track limit for a site is updated in the SPADOC database. The site requested an increase from 400 to 600 tasked tracks per day on 23 April 1999. There seems to be no immediate change in the MOSS track response after 23 April 1999. The only effect is to reduce MOSS percentage track response (number of tracks acquired divided by the number of tasked tracks times 100). A site s percentage response can be very misleading without looking at the absolute response numbers. There is an increase in track throughput beginning in August 1999, which cannot be explained. It appears that MOSS is over tasked at 600 tracks per day and that 500 tracks per day would be more appropriate. There needs to be a balance between providing an optical site with enough tasking so that it does not run out of objects to schedule during its shooting period and not over tasking the site, in which case the percentage response will decrease. In the latter case, objects will not get tracked that could have been tasked by SPADOC to other sites.

The MOSS object response over time is shown in Figure 8. An increase in object throughput is noticeable beginning in February 1999, with a further increase beginning in August 1999. The number of tasked objects per day by SPADOC is not constant because some objects are tasked to a site for multiple tracks. The number of tasked objects will always be less than or equal to the number of tasked tracks.

The MOSS observation response over time is shown in Figure 9. An increase in observation throughput is noticeable beginning in February 1999, with a further increase beginning in August 1999.

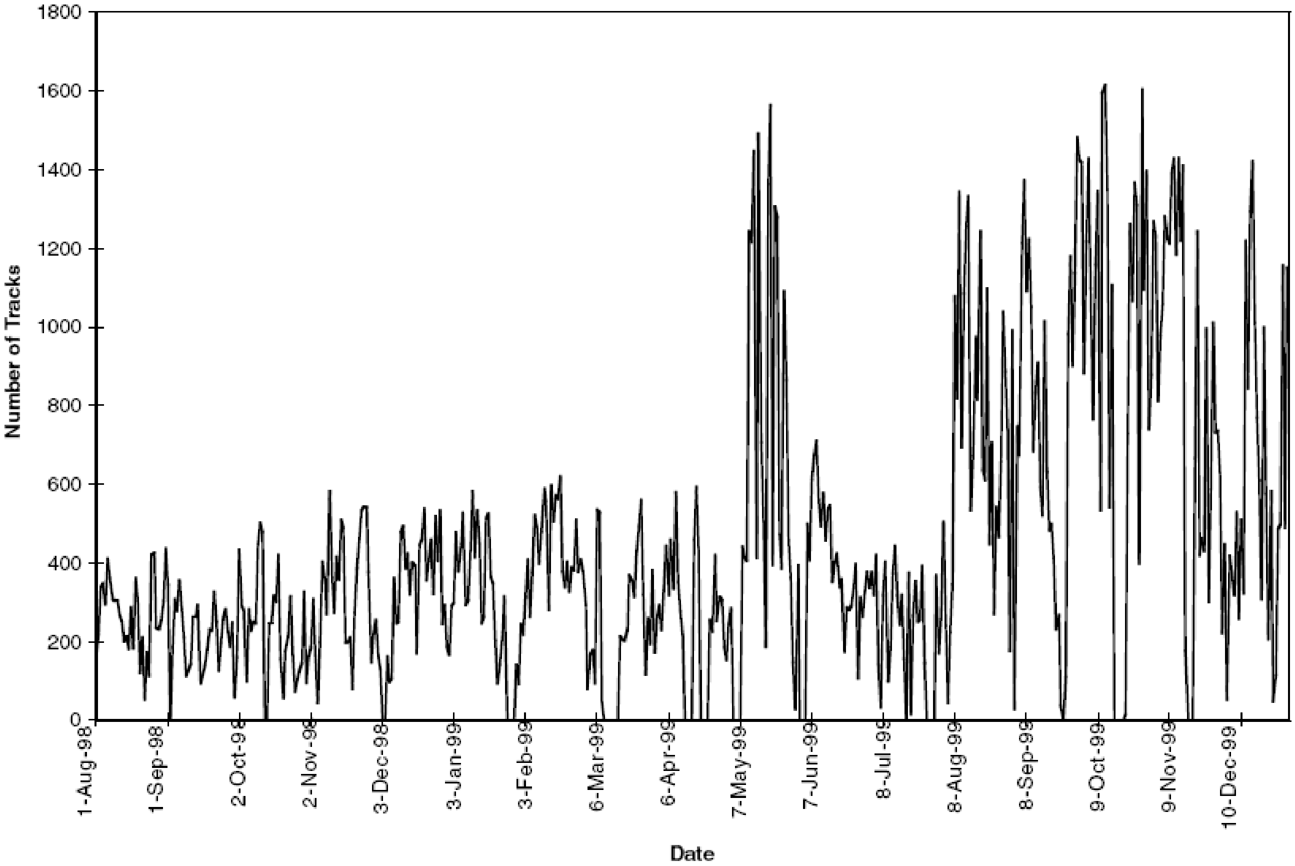


Figure 4. GEODSS Track Response

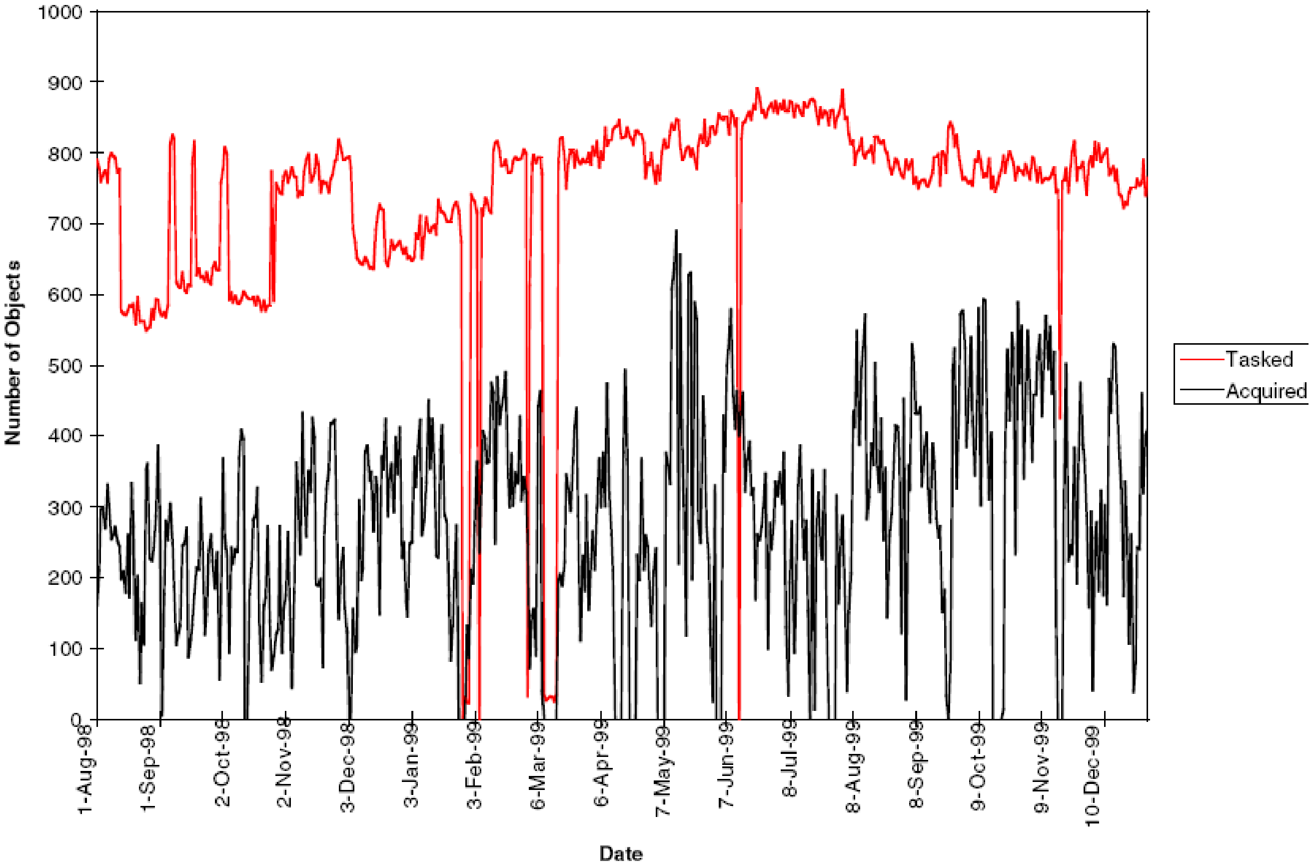


Figure 5. GEODSS Object Response

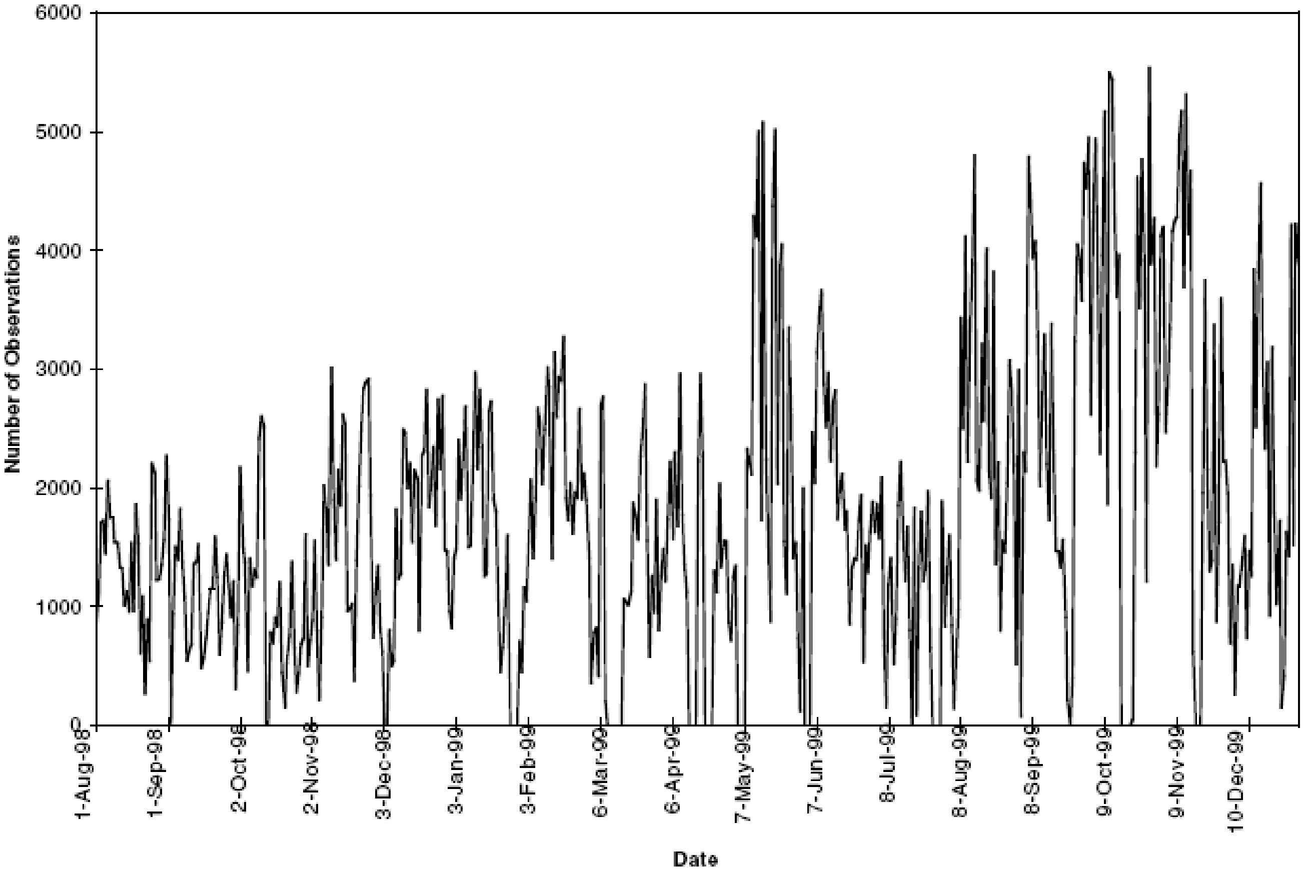


Figure 6. GEODSS Observation Response

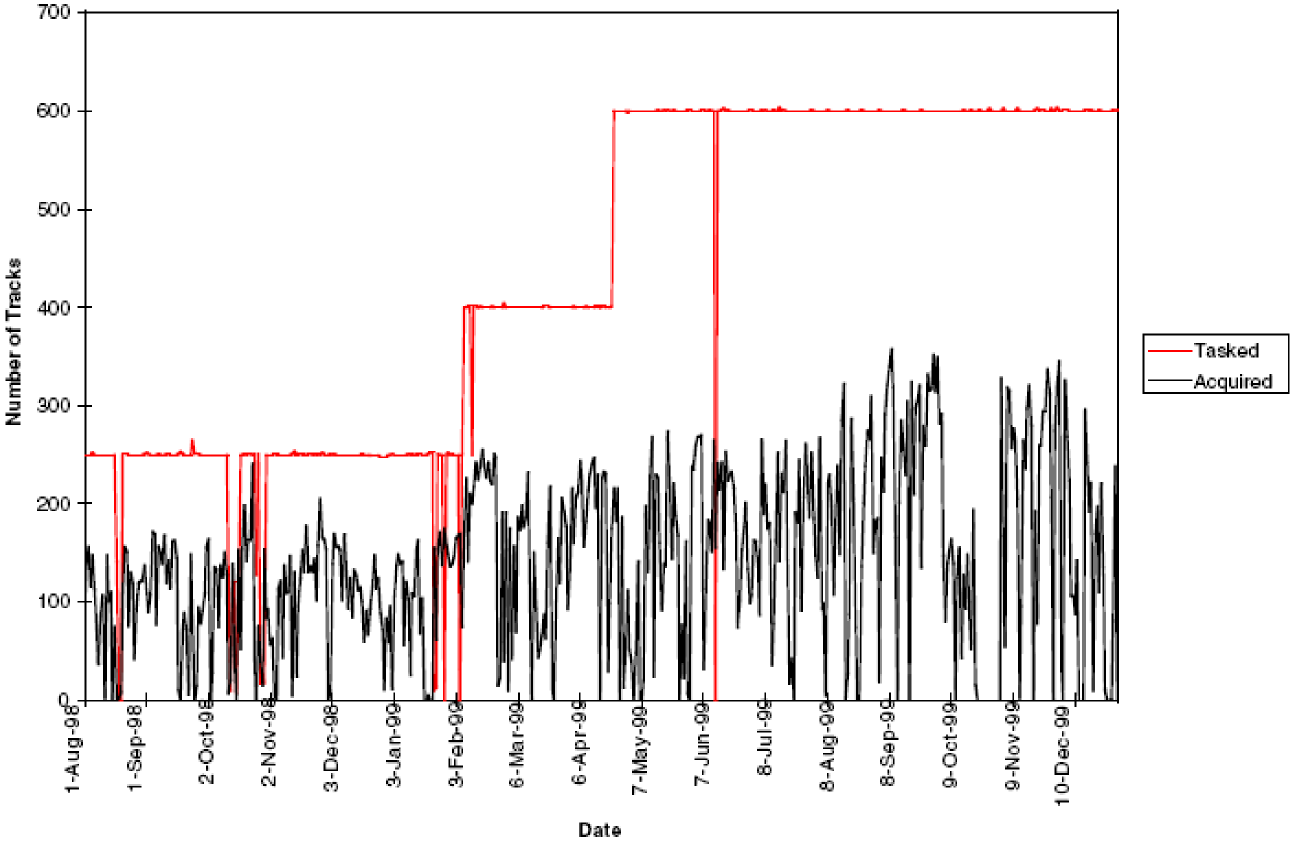


Figure 7. MOSS Track Response

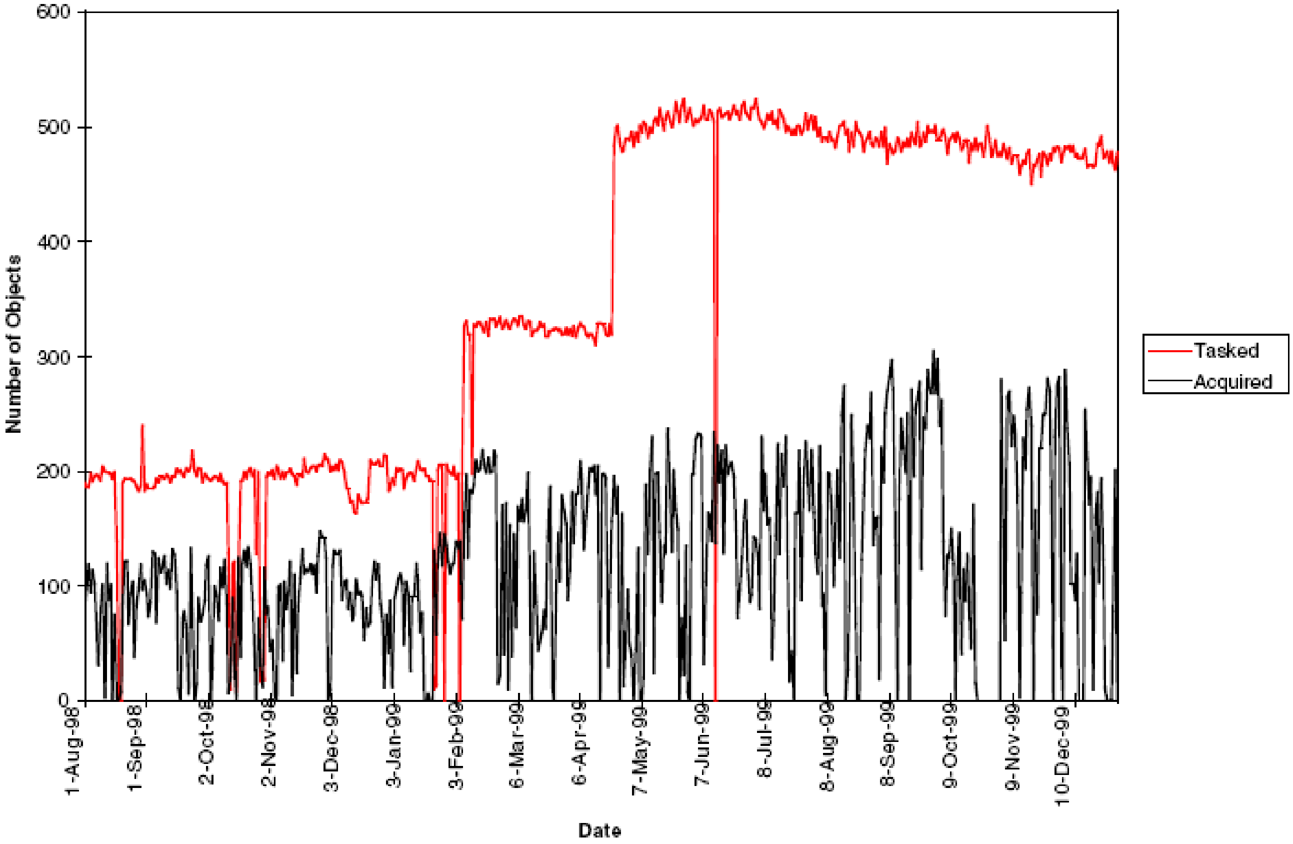


Figure 8. MOSS Object Response

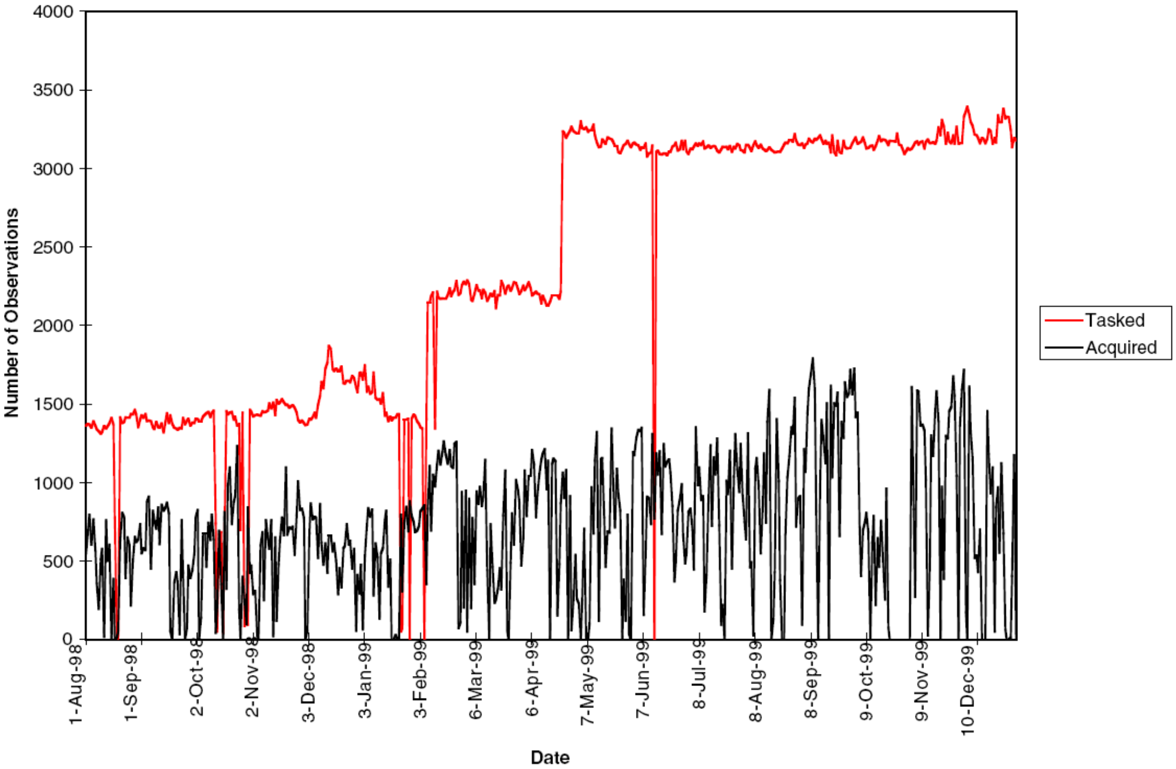


Figure 9. MOSS Observation Response

The impact of the increased throughput from GEODSS under GMP and from MOSS on the deep-space satellite catalog is now investigated. Table 1 shows the number of deep-space satellites (period greater than 225 minutes) on 31 December 1999, broken down by cataloged and analyst satellites and by orbit type. The Naval Space Command Fence and the Eglin radar contribute by far the most tracks on deep-space satellites, even though they are near-earth sensors. Most of these deep-space tracks from the Fence and Eglin are on satellites in highly eccentric orbits and are obtained near perigee. The impact of GMP and MOSS on the subset of the catalog consisting of all deep-space satellites will be minimal because their tracking data constitutes such a small percentage of the total data.

Table 1. Number of Deep-Space Satellites on 31 December 1999

	Deep-Space	Geosynchronous	Deep-Space Other
Cataloged Satellites	1812	736	1076
Analyst Satellites	674	98	576
Total	2486	834	1652

GEODSS provides the most tracking data on geosynchronous satellites. It might be expected that a significant improvement in the GEODSS throughput by GMP would be reflected in the statistics of the geosynchronous satellites. The number of analyst satellites fluctuates daily due to uncorrelated track (UCT) processing. Statistics on the geosynchronous cataloged satellites will be shown because this subset of the catalog represents known objects and is rather stable over time.

The long-term average epoch age of the geosynchronous cataloged satellites dropped from 5.0 days to 4.2 days after SBV became operational in April 1998 as a contributing sensor to the Space Surveillance Network. Figure 10 shows the daily average epoch age of geosynchronous cataloged satellites, which is around 4.0 days in August 1998. However, the daily average epoch age increased the latter part of 1998 even with the observations from SBV. This increase in average epoch age is strongly correlated with the increase in the geosynchronous work list. The work list consists of satellites whose element set has failed an automatic differential correction (DC) on SPADOC. The epoch age of these satellites is not current, yet there are recent observations in the database that have not been used to update the element set. If human resources are not applied to manually update the element sets of satellites on the work list, the age of the element sets continue to grow older and the work list increases from new failures from the automatic DC process on SPADOC.

The daily average epoch age did drop in early 1999, which is correlated with the drop in the number of satellites on the work list. The increased MOSS throughput beginning in February 1999 may have also contributed to the decrease in average epoch age. The decrease in average epoch age in May 1999 correlates with the operation assessment of GMP. However, there is no decrease in average epoch age beginning in August 1999 when GMP became operational. In fact, there is an increase in average epoch age in November and December 1999, but this appears to be correlated with an increase in the number of satellites on the work list. The impact of the increased throughput of GEODSS under GMP and from MOSS appears to be minimal and can be offset by increases in the work list.

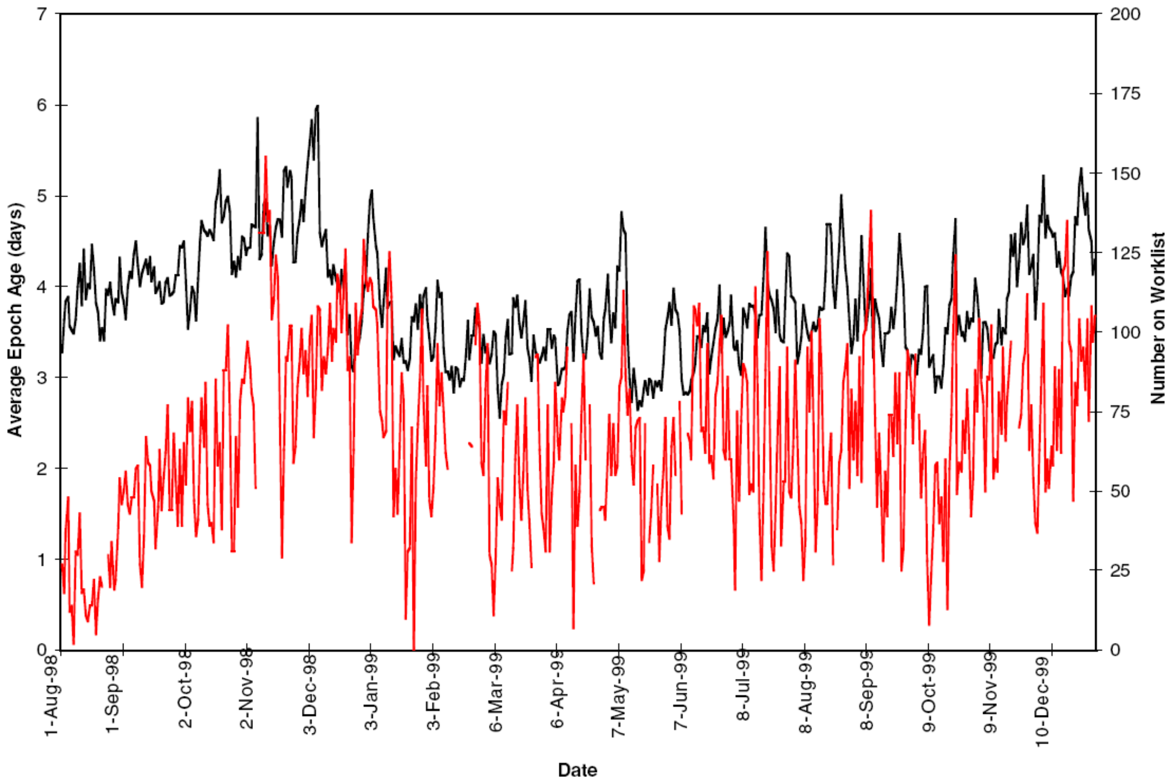


Figure 10. Average Epoch Age of Geosynchronous Cataloged Satellites

The increase in object throughput of GEODSS under GMP is not as nearly as large as the increase in the track and observation throughput. An increase in object throughput will have a greater impact on the average epoch age than an increase in track or observation throughput because more satellites will be updated with a current epoch. If all the GEODSS 3-ob tracklets were taken on different satellites, the average epoch age would probably decrease but the SPADOC observation request would not be satisfied as well. More satellites can always be tracked at the expense of providing fewer observations per satellite. SBV has taken the approac of maximizing the object throughput at the expense of not always getting a second streak on the same satellite. GMP maximizes observation throughput by scheduling enough tracklets for eac satellite to satisfy SPADOC s request.

The long-term average error growth rate of the geosynchronous cataloged element sets dropped from 10.6 km/day to 9.6 km/day after SBV became operational in April 1998. Figure 11 shows the daily average error growth rate and long-term average of the geosynchronous cataloged satellites. The long-term average dropped from 9.6 km/day to 8.9 km/day after GEODSS with the GMP configuration became operational in August 1999.

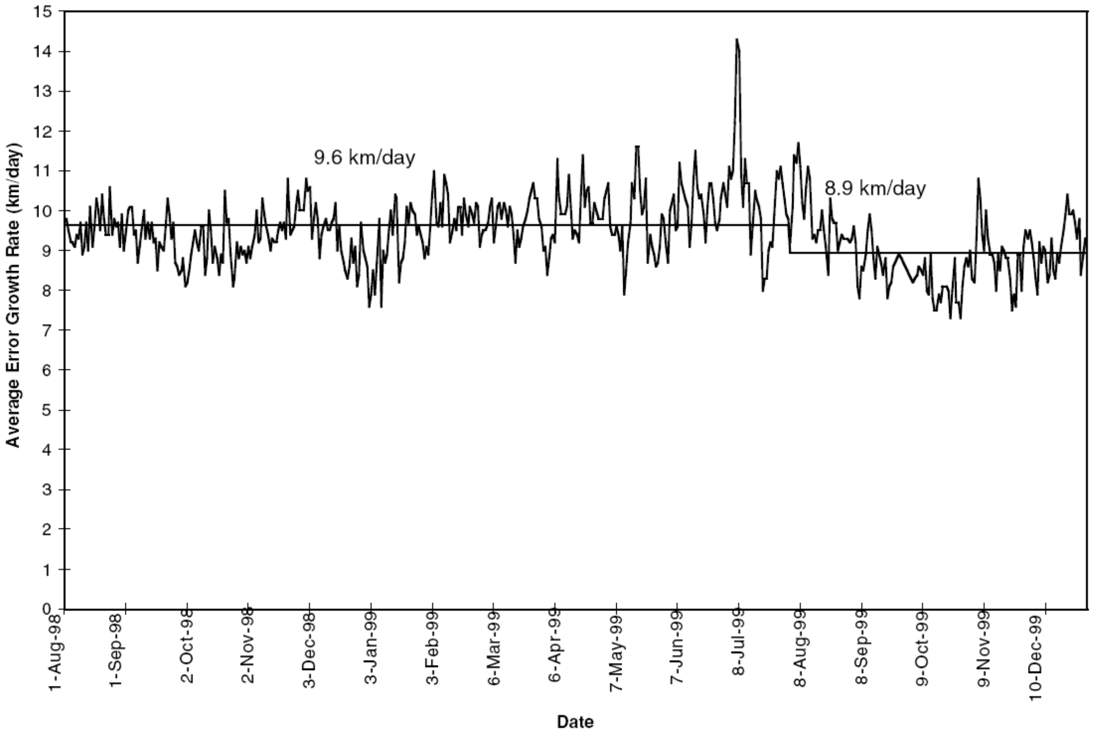


Figure 11. Average Error Growth Rate of Geosynchronous Cataloged Satellites

Two reasons may account for this drop in error growth rate. Two 3-ob tracklets spread over time provide better orbit distribution of the observations and should provide a more accurate element set than a 5-ob track taken at one point in the orbit. Also, an observational coordinate system mismatch between GEODSS and SPADOC was corrected in GMP. SPADOC was expecting right ascension and declination to be in topocentric coordinates, and legacy GEODSS was using a heliocentric coordinate system. The computation of aberration is coordinate system dependent, and this coordinate system mismatch for the observational data caused SPADOC to compute a significant bias in right ascension, which was not really present in the site data but an artifact of the coordinate system. Average biases and sigmas for right ascension and declination for each sensor before and after GMP are displayed in Figures 12 and 13, respectively. Note that MOSS and MSX were not changed by GMP, but their biases before and after GMP (3 August 1999) have been included for comparison sake.

Reference orbits for the calibration of the optical deep-space sensors are generated using laser-ranging observations obtained from NASA s Crustal Dynamics Data Information System. Reference orbit fits of centimeter-level root mean square (RMS) are generated for Lageos 1 (SATNO 08820), Lageos 2 (SATNO 22195), Etalon 1 (SATNO 19751), and Etalon 2 (SATNO 20026). Additionally, declassified GPS precise ephemeris files are obtained from the National Imagery and Mapping Agency (NIMA) for GPS satellites 34, 35, and 36 (SATNOs 22779, 22877, and 23027). The deep-space sensors are routinely tasked to track these satellites, and then those observations are compared against the reference orbits. Calibrations are performed using two weeks of sensor observations and calculating the residuals against the reference orbits.

The mean, one sigma standard deviation, and RMS of all the individual observables are computed from the residuals. Where sufficient observational data are available, the results (biases and sigmas) were very consistent.

Note that prior to GMP, the three GEODSS sites display a noticeable bias in right ascension. After GMP the bias has become negligible. Even more significant is the improvement in the right ascension and declination sigmas after GMP. In some cases there is a 400 percent improvement. The third cameras, both on auxiliary GEODSS telescopes at Socorro and Maui, have yet to be replaced by main telescopes and therefore have yet to produce post-GMP data. MOSS has not yet corrected the reference frame in which it provides its data to SPADOC, and thus has not shown the improvement that the post-GMP GEODSS sensors have. A software release at MOSS in the spring of 2000 will correct this problem. MSX has always provided its data in the correct reference frame and thus does not show any biases. Its average sigmas appear to be higher than that of the GEODSS sensors, but this could be due to its low response to calibration tasking. MSX only provides about 10 to 12 observations on the calibration satellites in any two-week period.

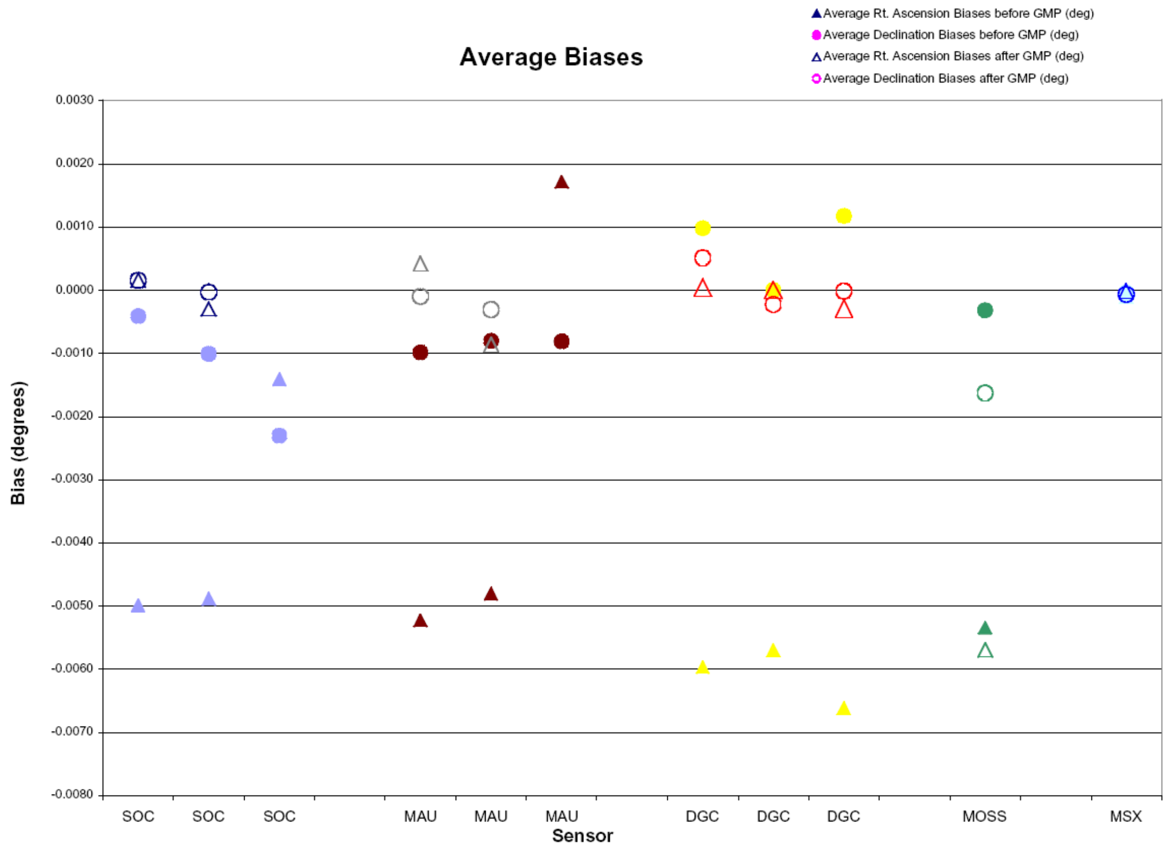


Figure 12. Average Biases of Optical Sensors

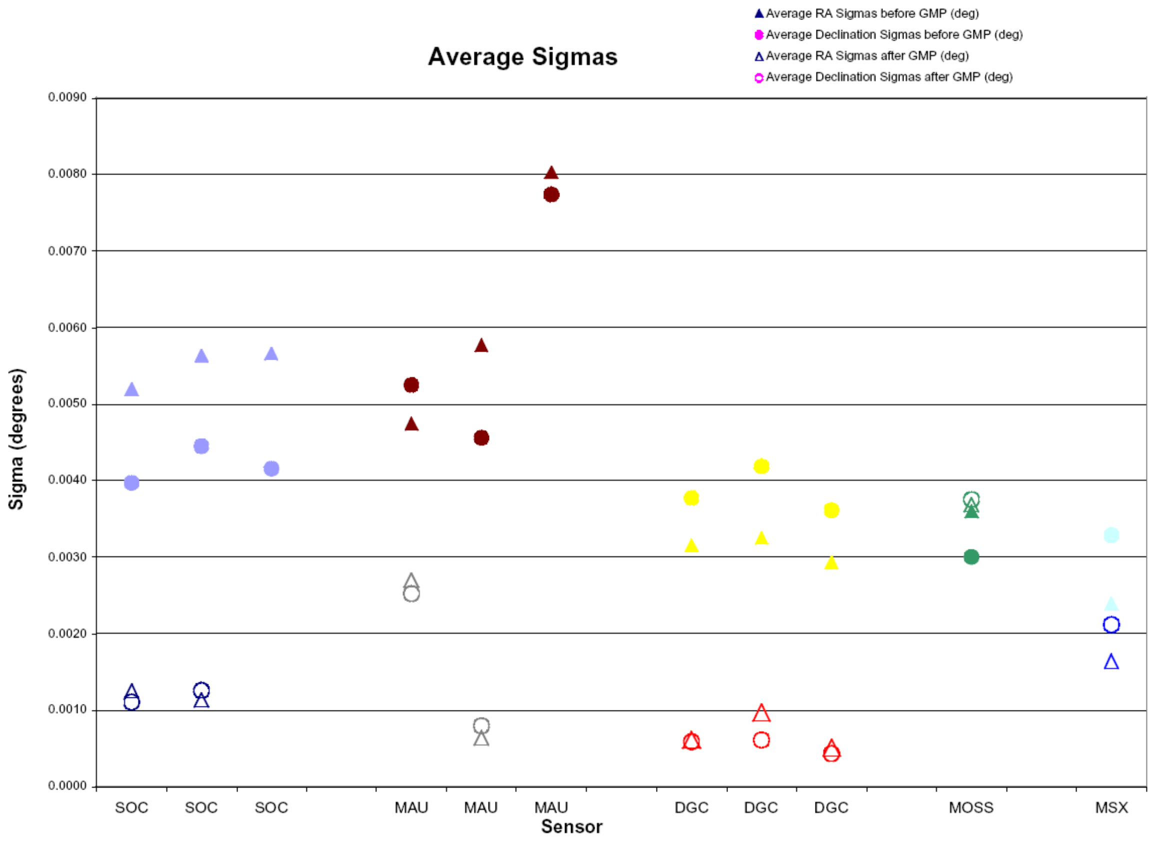
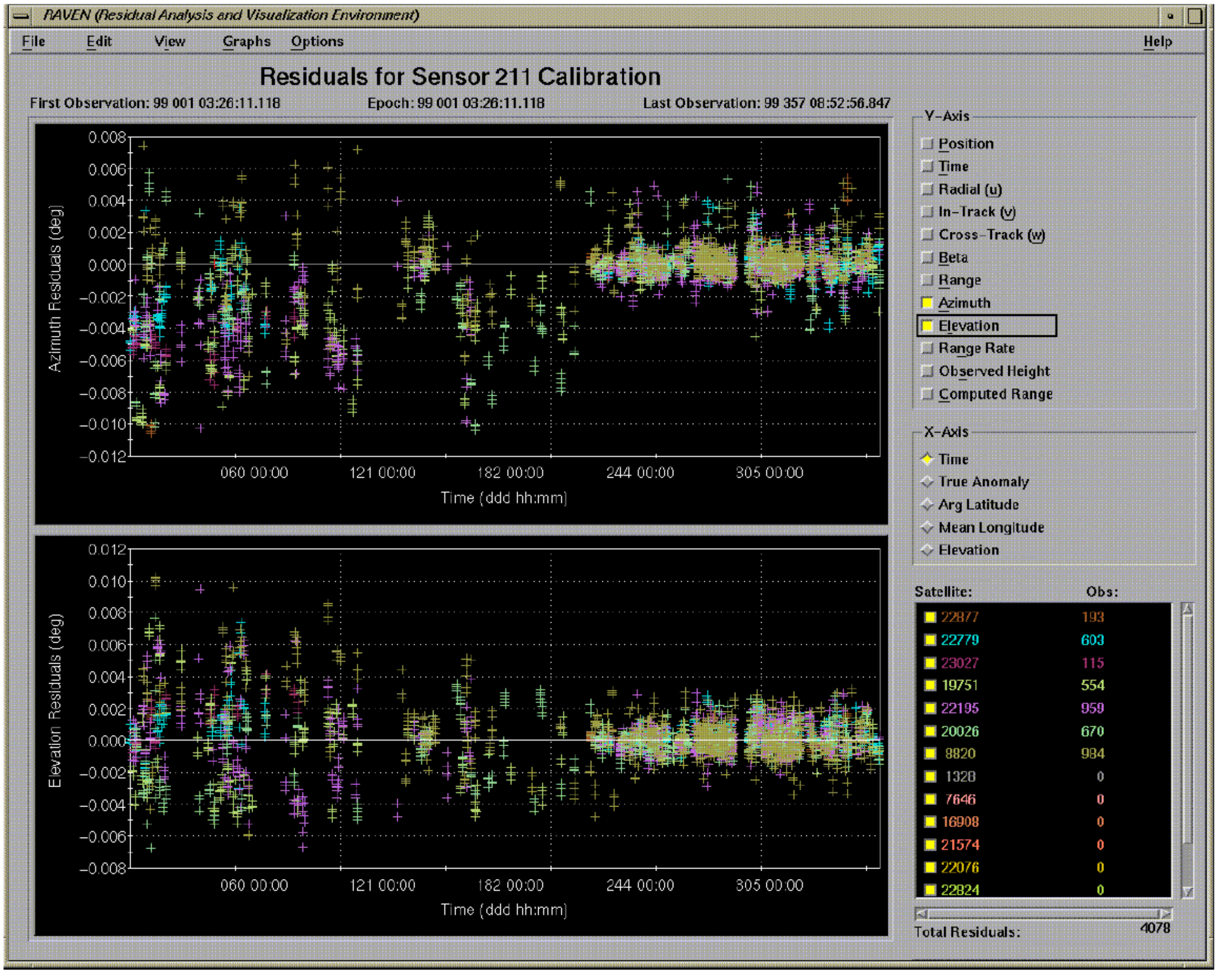


Figure 13. Average Sigmas of Optical Sensors

Figure 14 shows the first pass residuals for Camera 1 at Socorro. This is typical of a standard calibration run except that the time scale has been greatly extended beyond the usual 14 days of observations. Notice the drastic improvement in the right ascension and declination residuals after the post-GMP changes beginning 3 August 1999 (day 215).

Although sensor bias can be corrected in satellite orbit determinations, the larger sigmas generally result in a less accurate orbit fit. Thus, the smaller right ascension and declination sigmas of the post-GMP GEODSS are also contributing to a more accurate deep-space satellite catalog.



Residuals for Sensor 211 Calibration

First Observation: 99 001 03:26:11.118
Epoch: 99 001 03:26:11.118
Last Observation: 99 357 08:52:56.847

Y-Axis
☐ Position
☐ Time
☐ Radial (u)
☐ In-Track (v)
☐ Cross-Track (w)
☐ Beta
☐ Range
☑ Azimuth
☑ Elevation
☐ Range Rate
☐ Observed Height
☐ Computed Range

X-Axis
◆ Time
◇ True Anomaly
◇ Arg Latitude
◇ Mean Longitude
◇ Elevation

Satellite:	Obs:
22877	193
22779	603
23027	115
19751	554
22195	959
20026	670
8820	984
1328	0
7646	0
16908	0
21574	0
22076	0
22824	0

Total Residuals: 4078

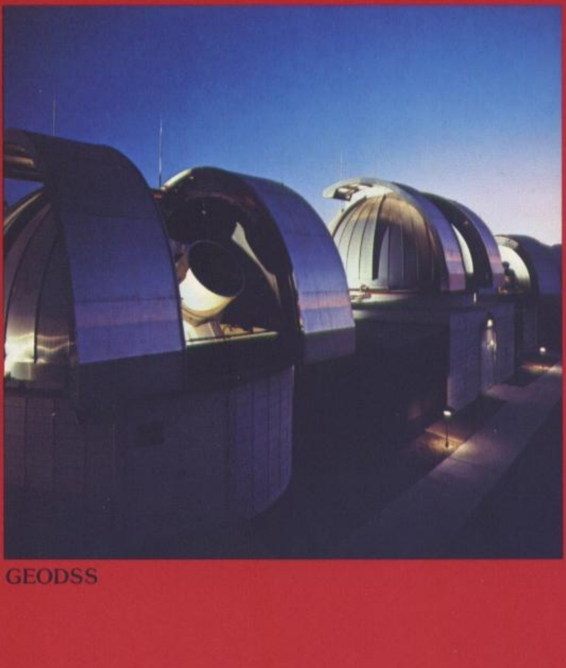
Figure 14. First Pass Residuals for Camera 1 at Socorro

Appendix D

Origins

Quest

NEW TECHNOLOGY AT TRW DEFENSE AND SPACE SYSTEMS GROUP



GEODSS

AUTUMN 1980

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COVER PHOTO: TELESCOPES FOR THE GROUND-BASED ELECTRO-OPTICAL DEEP SPACE SURVEILLANCE SYSTEM (GEODSS) AT TRW'S FACILITY IN NEWBURY PARK, CALIFORNIA. THE STORY OF GEODSS, DESIGNED TO TRACK SATELLITES IN THE NIGHT SKY, BEGINS ON PAGE 2. (168171-80-4)

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GEODSS: HEAVENLY CHRONICLER

A CAREFULLY ENGINEERED MATING OF PRECISION OPTICS, SOPHISTICATED ELECTRONICS, AND ADVANCED SOFTWARE TECHNIQUES GIVES OUR AIR FORCE A NEW KIND OF "EYE ON THE SKY."

The number of satellites launched each year keeps increasing, and so does their commercial and military value. And as these orbiting assets increase in number and altitude, so does the difficulty of keeping track of them. Within just a few years some 1,500 satellites will be orbiting in "deep space" (altitudes defined as 3,000 nautical miles and beyond), and there will be a need to detect and identify all of them regularly. This need cannot be filled by present optical and radar systems. One example of the inadequacy of existing systems was the loss of all trace of the relatively large RCA COMSAT last year.

As the potential military uses of space become more sophisticated and deadly, the need for surveillance becomes even more urgent. In dealing with this problem, the U.S. Air Force realized that to appropriately upgrade our ground radars or to develop suitable space-based radar, optical, or infrared systems would require an extraordinary investment, and such systems could not be operational for many years. What was needed was some way to get this job done in a short time and at relatively low cost.

The Air Force for the past decade has put several contractors, including TRW, to work studying this problem. The questions addressed included: what existing components could be brought together and adapted to a deep space surveillance system? What new items would have to be developed? What performance was possible for a system to be designed and deployed in a short time and at low cost?

The result, designed by TRW for the Air Force Electronic Systems Division, is the Ground-Based Electro-Optical Deep Space Surveillance System (GEODSS), which is capable of finding and identifying extremely faint objects in the night sky, in real time, at search rates that are more than 100 times faster than present systems. Reflected sunlight from its surface makes a satellite visible to the system at night, just as the moon and planets are visible to the naked eye. Satellites, however, are much more difficult to detect because of the very small amount of available reflected light.

At this writing, the design, development and integration of the GEODSS system is nearing completion. This article provides a general overview of how the system works and some of the major factors that influenced its development.

GEODSS BASIC PRINCIPLES

GEODSS is a complex system of wide-field telescopes, extremely sensitive television cameras and radiometers coupled with modern signal processors and digital computers, and some very sophisticated software. It will take over where current systems leave off, gathering orbital and optical signature data on all man-made objects in deep space. Five sites are planned to provide worldwide coverage. The first site will be installed in White Sands, New Mexico early in 1981. The second will be located in Korea, the third in Maui, Hawaii. Two additional sites, one in the Middle East and another in the Atlantic region, have yet to be selected. TRW has proposed that the last two facilities be totally relocatable so they can be easily moved if necessary.

GEODSS detects reflected sunlight from satellites by using specially designed telescopes, very sensitive, high-resolution television cameras, signal processing electronics, computers, and some sophisticated computer software. A simplified block diagram is shown in Figure 1 and general specifications in Table 1.

Each telescope focuses light on a television camera tube face and the camera in turn converts the light signals to electrical signals. The camera is computer-controlled to adapt it to varying sky conditions, and both camera and telescope are mounted on a sidereal drive mechanism. This rotates the telescope on an axis parallel to the earth's axis, at precisely the same rate and in the opposite direction to the earth's rotation. The result is that stars appear motionless to the system and satellites appear as streaks of light.

The signal processing circuits filter the analog signal output from the camera, digitize the data for computer analysis, and remove as many as 20,000 stars plus a substantial amount of noise from the data. The process of finding all the satellites in a single field of view takes just five to 20 seconds.

The system can detect objects as dim as a 16-1/2 visual magnitude star (about 10,000 times dimmer than what the naked eye can see). In graphic terms, GEODSS can detect a reflective object the size of a soccer ball 20,000 miles from earth. Even dimmer objects—those at the 19th visual magnitude—can be tracked if the system operator knows approximately where the object is and how fast it is traveling.

To find the dimmest object at the highest search speed, the camera zoom ratio, camera gain, as well as the time per data frame and the total number of frames, are varied in accordance with the ambient sky brightness and the number of stars in the field of view.

An important requirement of the development program was to put together a reliable surveillance system that could be brought on line by 1981. It was essential, therefore, to select existing technology and off-the-shelf components whenever possible.

Computer software was a substantial development challenge, and without it, GEODSS as it stands now would not be workable. Another extension of the state of the art with high leverage was the silicon intensified target (SIT) Vidicon tube. This tube with its 80 mm photocathode, high responsivity, high resolution, and low noise was fundamental to the development of a low-cost GEODSS system. A new high performance telescope and mount design were also required to meet system performance specifications.

Although many of the system elements were to be "off the shelf," GEODSS nonetheless presented a difficult systems engineering task in several respects. For example, a highly complex systems analysis and synthesis was needed for the process of selecting the number of telescopes required at each site, as well as their size and *f* number (the ratio of lens focal length to aperture diameter). The result of this analysis was the selection of two 40-inch "main" telescopes and one 15-inch "auxiliary" telescope per site.

An important system engineering effort was also required for those elements which did in fact come "off the shelf." The issues of whose shelf and at what price were critical to the development of a high performance system on time and at a firm fixed price. Their resolution required an integrated effort of the engineering, subcontracts, materiel, and product assurance organizations at TRW to handle vendor search, make-or-buy analysis, and competitive procurement for all items.

GEODSS' stringent specifications required detailed reliability, maintainability, and logistics analysis—another major systems engineering effort. Finally, detailed interface specifications had to be written for all hardware and software elements of the system.

SYSTEM ELEMENTS

Despite the requirement to use existing hardware wherever possible in GEODSS, modifications were generally needed to adapt the various components of the system to their unique function and integrate them properly. Two major considerations in this process were that the system was required to search at rates which were much faster than ever before and to handle much heavier work loads. It was therefore necessary

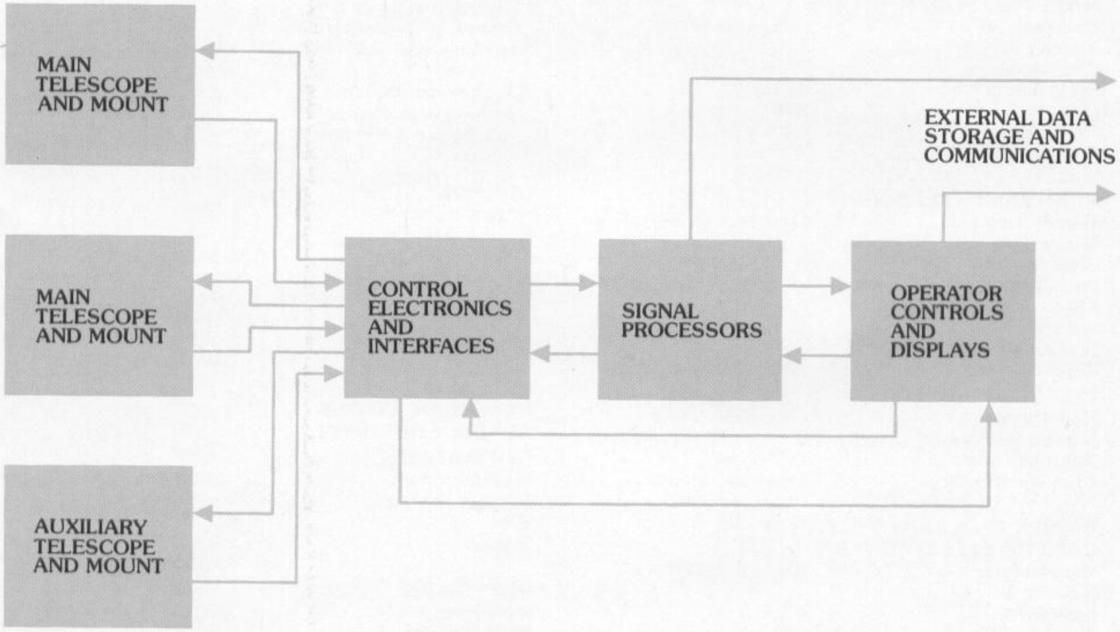


FIGURE 1

SIMPLIFIED BLOCK DIAGRAM OF GEODSS SYSTEM. Each installation includes two main telescopes and an auxiliary telescope with identical mount, sidereal drive, and video camera. Control electronics and interface units provide manual or automatic control of telescope and camera operations and also convert the analog video signals from the telescope cameras to digital form for processing by computer. Signal processing eliminates stationary images (stars) and identifies moving objects (satellites) as small as a soccer ball at distances up to 20,000 miles from earth. Operator controls and displays are designed to simplify the tasks of daily system calibration and visual identification of new satellites.

DETECTION PERFORMANCE	
Probability of detection	0.95
False alarm rate	1 per 20 fields of view
Maximum detections	>10 per field of view
TRACKING PERFORMANCE	
Angle accuracy	±10 arcsec, 3σ
Timing accuracy	±1 millisec
Time per track	1 minute
SPACE OBJECT IDENTIFICATION (SOI) PERFORMANCE	
Signal-to-noise ratio	7.72 (1 sec intergration)
Classifies object as payload, tank or fragment	
Classifies object as stable, spinning or tumbling	
Determines basic periods	
Visual magnitude calculation	±0.125
SEARCH PERFORMANCE	
All telescopes	35,000 sq deg/hour max.
Main telescopes (all speed search)	2,400 sq deg/hour
Aux. telescope (all speed search)	5,000, 15,000 sq deg/hour
OBSERVATORY DOME	
Manufacturer	Observadome
Number per site	3
Diameter	20 ft
Weight	5,000 lb
MAIN TELESCOPE	
Manufacturer	Contraves Goerz
Number per site	2
Clear aperture	40 in.
Focal length	86 in.
f-No.	2.15
Field of view	2.1 deg
Blur circle	2 arcsec
Weight	3,200 lb
AUXILIARY TELESCOPE	
Manufacturer	Contraves Goerz
Number per site	1
Clear aperture	15 in.
Focal length	30 in.
f-No.	2.0
Field of view	6 deg
Blur circle	6 arcsec
Weight	2,400 lb
TELESCOPE MOUNT	
Manufacturer	Contraves Goerz
Number per site	3
Max. slew rate	15 deg/sec
Tracking accuracy	1.5 arcsec (main) 10 arcsec (aux.)
Weight	12,000 lb
CAMERA ELECTRONICS	
Manufacturer	Itek
Number per site	3
Scan rate	0.3, 0.6 sec
Scan lines	832 (slow scan)
Bandwidth	7.5, 1.5, 0.75 MHz
CAMERA TUBE	
Manufacturer	RCA, Westinghouse
Number per site	3
Type	Vidicon
Photocathode	Type S-20
Photocathode diameter	80 mm
Target diameter	32 mm
Responsivity	160 μamp/lumen (2,854°K light)
Average resolution	625 elements per diagonal
Electronic zoom range	2:1
RADIOMETER ELECTRONICS	
Manufacturer	Itek
Number per site	3
Mode	Photon counting
Timing interval	1 millisec
RADIOMETER TUBE	
Manufacturer	RCA
Number per site	3
Type	Photomultiplier
Photocathode area	4x10 mm
Tube diameter	2 in.
Responsivity	1,025 μamp/lumen
Current gain	10^6
VIDEO PROCESSOR	
Manufacturer	Itek
Number per site	3
Converts analog camera output to digital format	
Sampling rate	832 samples per camera line
Adaptive thresholding responds to changes in background and noise levels	
CONSOLE	
Manufacturer	TRW
Number per site	2
CRT	2 per operator
Function keys	48 per operator
Other input/output devices	A-scope, strip chart recorder, joysticks, alphanumeric terminals
Size	160x48x56 in.
COMMUNICATIONS	
AUTODIN, AUTOVON	
COMPUTERS	
Manufacturer	Digital Equipment Corp.
Number per site	4
Type	PDP 11/70
Memory	256k-384k words per computer
SOFTWARE	
Developer	TRW
Machine language instructions	400,000

TABLE 1
GEODSS GENERAL SPECIFICATIONS

for TRW systems engineers to work very closely with the individual manufacturers to ensure that the specifications for each component were met.

Telescope and Mount—Every GEODSS site will contain two main telescopes and an auxiliary. The main telescope (Figure 2) has a 40-inch aperture, a two degree field of view, and weighs 3,200 pounds. It is a new "folded optics" design with two reflectors and a field group of refracting lenses. Light enters the aperture, reflects off a hyperbolic mirror to a flat secondary mirror, and from there to a field group for imaging at the camera focal plane. The field correcting group and primary mirror are mounted in a single assembly located at the center of rotation to keep deforming forces to a minimum. A beam splitter is inserted when radiometric data is taken.

The auxiliary telescope (Figure 3) is also a new design, based on a folded "Schmidt" configuration selected to provide the required

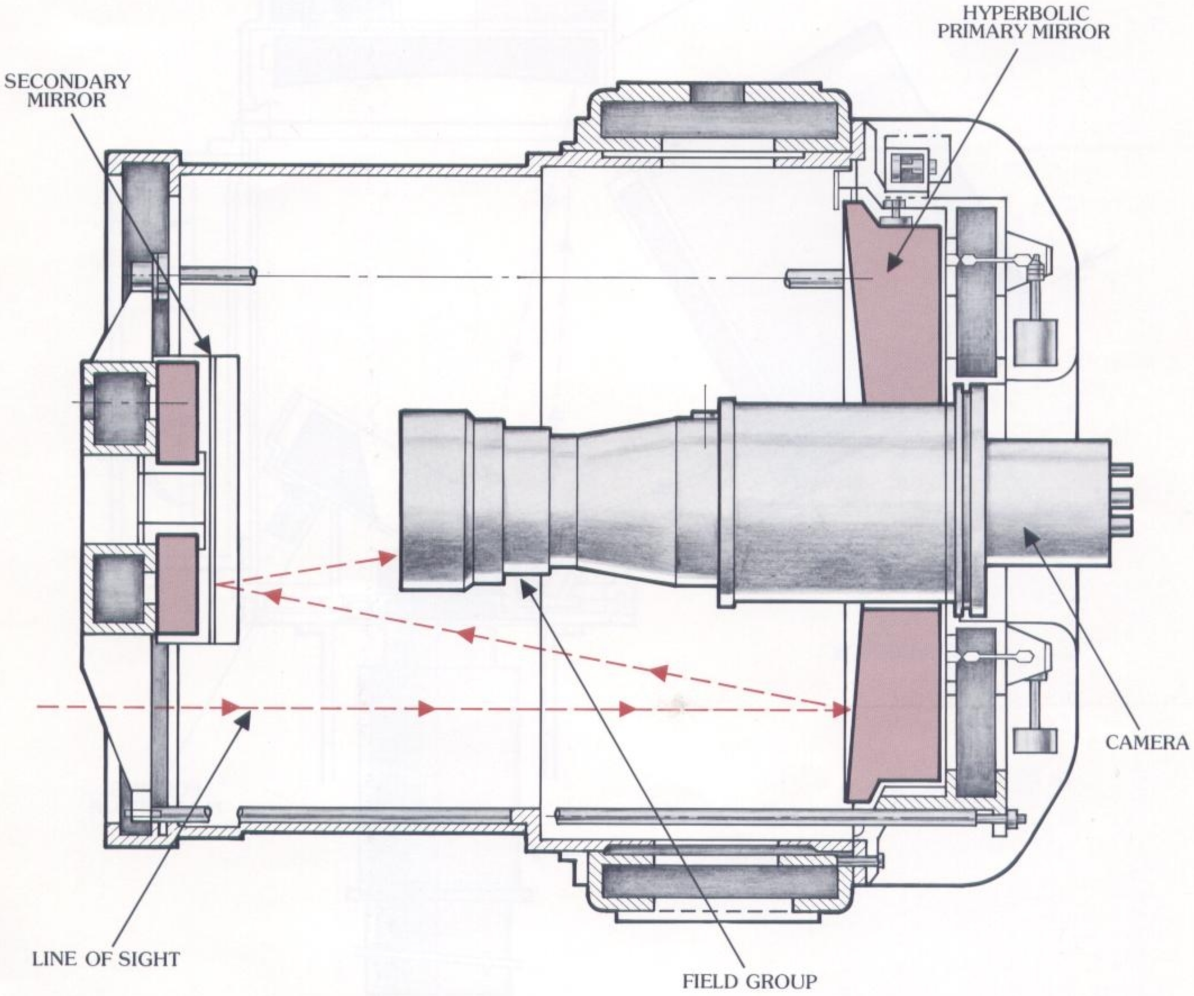


FIGURE 2

MAIN TELESCOPE FOR GEODSS has 40-inch aperture, two degree field of view, 86-inch focal length, and weighs 3,200 pounds. Two main telescopes at each site comprise an integral part of the system to search, track, and discriminate moving objects in deep space. A precision mount and control system makes it possible to change the telescope's pointing angle two degrees in one second, and position it to within 1.5 arc seconds of the desired angle. Both the main and auxiliary telescopes were designed and built by Contraves Goerz of Pittsburgh.

six degree field of view in a stiff, compact structure. Designed for extremely high search rates, it will detect, track, and discriminate brighter objects. The auxiliary has an aperture of 15 inches, a focal length of 30 inches, and a six degree field of view.

Although the smaller auxiliary telescope could have used a smaller mount, the cost-effective approach dictated the use of the same 12,000-pound mount for both telescopes. Despite its bulk, this mount smoothly and accurately positions the telescope within the specified time frame to give GEODSS its unique search capability. The mount is able to move the telescope through two degrees of rotation and stop within 1.5 arc seconds of the desired pointing angle in one second.

The mount incorporates two orthogonal gimbals with one axis parallel to the earth's rotational axis. This "polar" configuration is

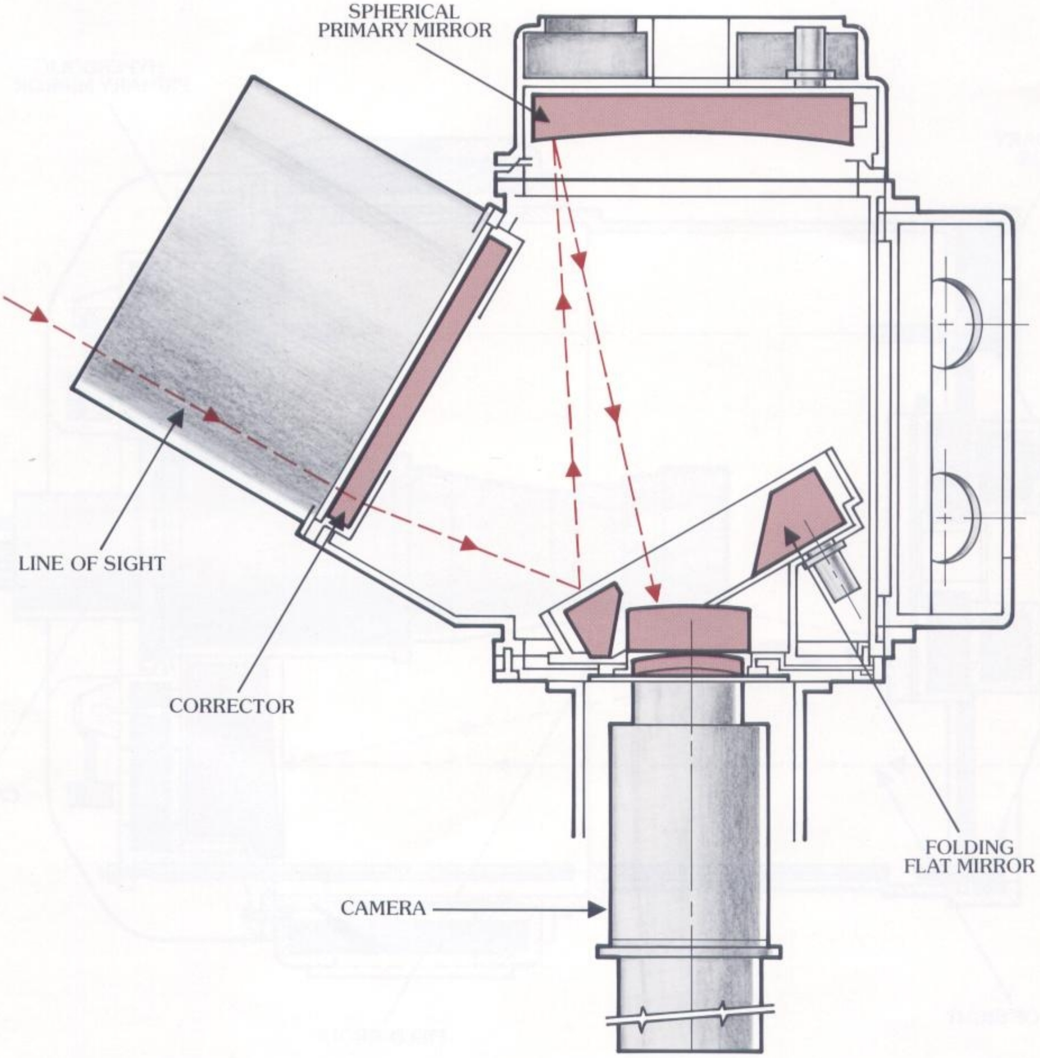


FIGURE 3

AUXILIARY TELESCOPE is designed to complement the two main telescopes at each GEODSS site, searching at very high rates for bright objects (generally satellites orbiting at lower altitudes). The auxiliary telescope has a 15-inch aperture, six degree field of view, and 30-inch focal length. It is a folded Schmidt optical system to provide the large field of view in a relatively compact structure. The mount and drive control system are the same as for the main telescopes.

conventional in astronomy because of its convenience for sidereal drive. The accuracy and quick response of the mount are achieved by means of a very stiff structure, powerful direct drive DC torque motors, and an excellent servo design.

The telescopes, mounts, and drive electronics were all designed and manufactured by Contraves Goerz of Pittsburgh, Pennsylvania.

Camera and Tube—The camera for the GEODSS system (Figure 4) and its 80 mm state-of-the-art SIT Vidicon imaging tube are the culmination of years of development and test. The camera itself was fabricated by Itek Corporation; the Vidicon tube was first developed by RCA and later by Westinghouse.

The camera automatically adapts to varying sky brightness and is computer-driven to permit different exposure lengths and zoom ratios. For example, bright,

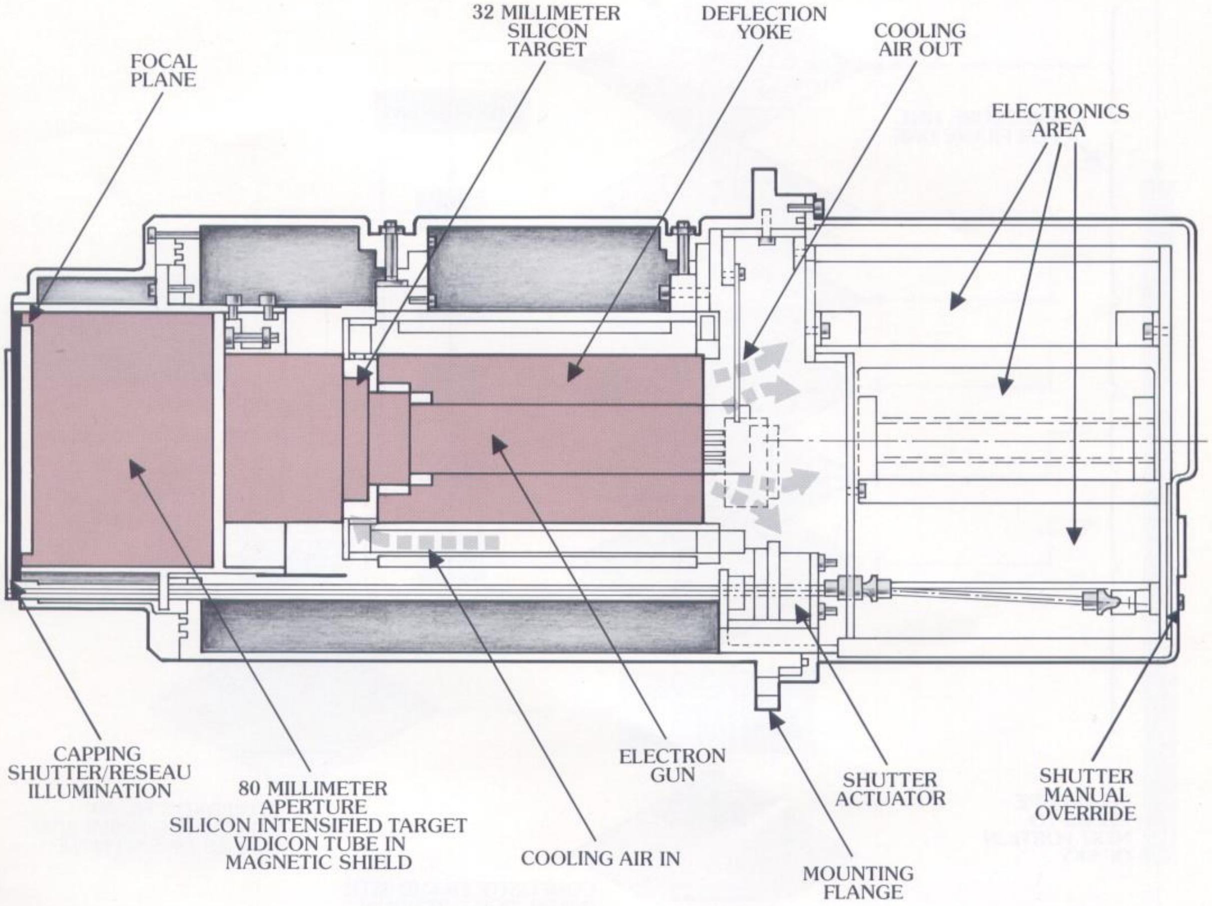


FIGURE 4

GEODSS VIDEO CAMERA AND VIDICON TUBE are the result of a five year development and test program by TRW and the Itek Corporation. The state-of-the-art Vidicon was developed originally by RCA and later by Westinghouse. The camera characteristics and design features were tailored specifically for operation with TRW's automated moving target indicator (AMTI) software. The camera is computer-controlled and designed to accommodate varying conditions of sky brightness, object angular velocity, and system search rate.

fast-moving objects against a dark sky with low star density can be found with no zoom and long integration times, increasing the search rate of the system. Dim, slow-moving objects, on the other hand, require full zoom and minimum integration time.

The frame rate for a standard television camera is 30 frames per second, which at appropriate brightness levels appears continuous to the human eye, with no flicker. The GEODSS camera can also scan at that rate, but operation at 30 frames per second would require off-tube integration of 10 to 20 frames to obtain the required detection. To reduce system costs, we chose to use a much slower scan rate for GEODSS of 0.3 and 0.6 seconds per frame. These relatively slow scan rates are suitable for the signal processing electronics and computers, but are much too slow for people, so a converter was designed to display the information to the operators at normal TV rates. The all-solid-state scan converter

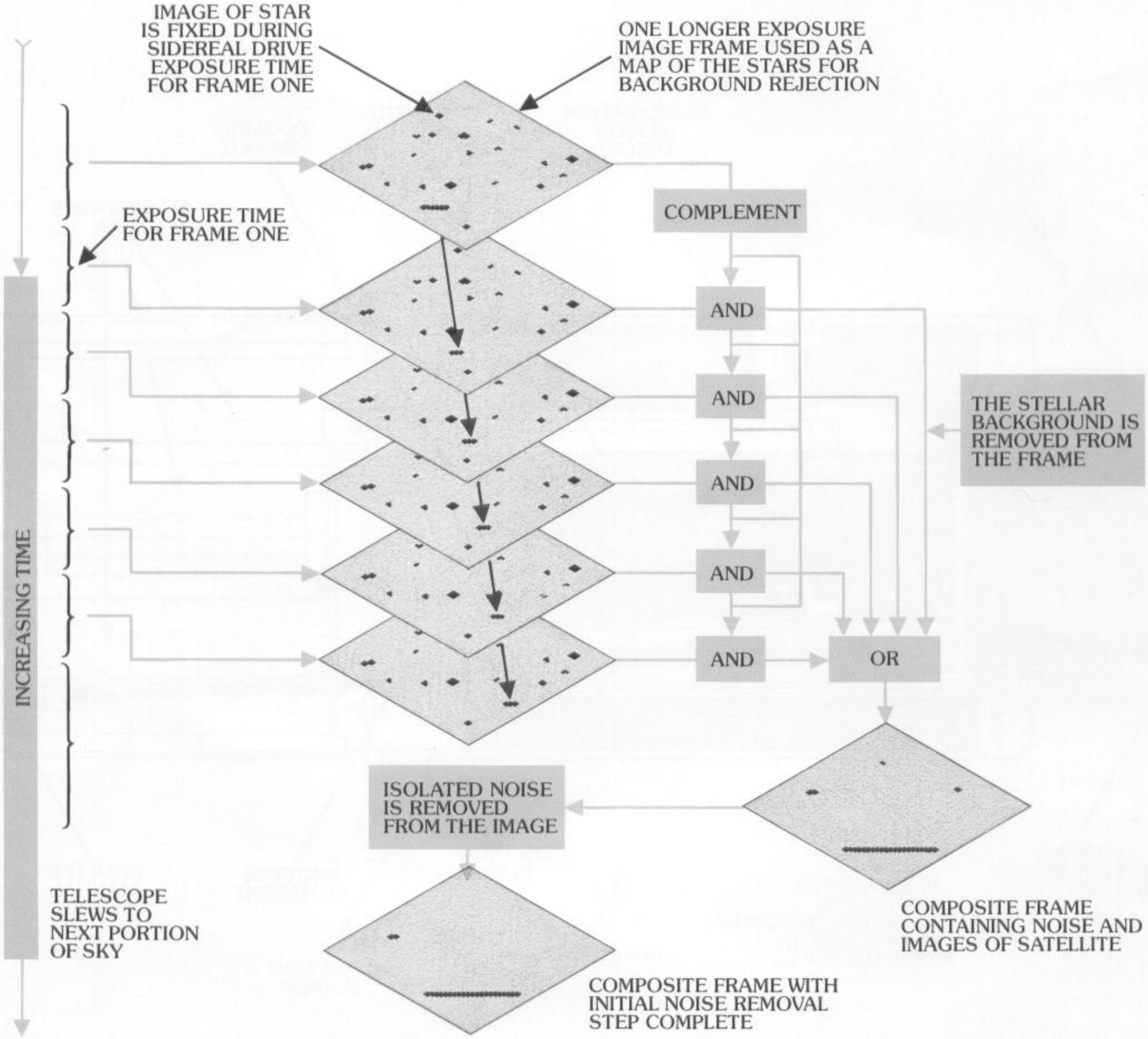


FIGURE 5

TRW ADAPTIVE SOFTWARE TO RECOGNIZE ORBITING SPACE OBJECTS (ASTROSO) performs the automated moving target indicator (AMTI) function in GEODSS. ASTROSO cancels the star background and signal noise from the field of view by creating a composite frame from a series of individual frames. The first frame in the series is used to reject stars from subsequent frames by removing detected points of light that appear in the same place. Moving objects leave a "signature" in the form of a "streak" on the composite frame, and data which fits that pattern is retained for further analysis. Noise signals that do not fit the streak pattern are also removed from the composite frame.

was designed and built by Vidco, of Portland, Oregon.

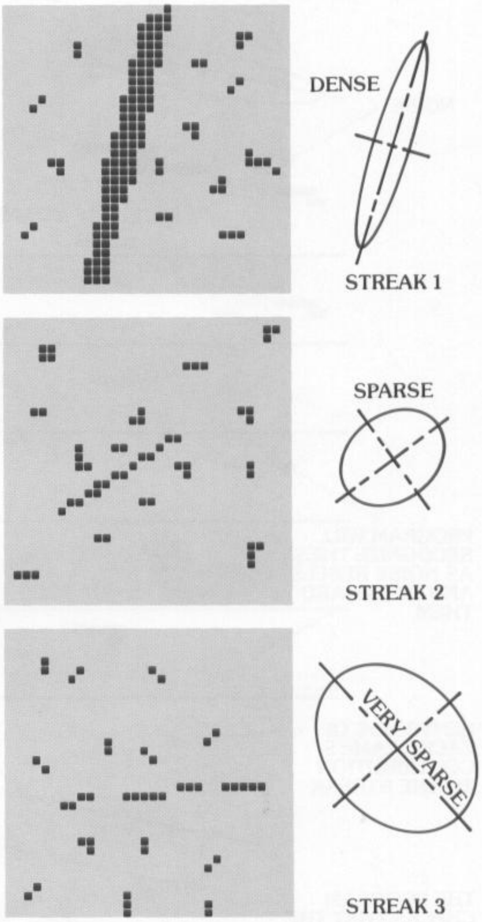
The electro-optical subsystem performance is dominated by the sensitivity, resolution, and noise parameters of the SIT Vidicon tube. The camera's sensor format uses the full circular active target area uniquely specified by TRW for GEODSS. The field of view can be reduced by selecting one of two discrete electronic magnifications, and focus is maintained by special purpose circuitry. Thus, the system has an inherent "electronic zoom" feature very important to GEODSS and very difficult to achieve optically.

Radiometer—GEODSS also uses an off-the-shelf radiometer to provide extended amplitude and frequency response in a very narrow field of view. A gallium arsenide tube manufactured by RCA is the basic sensing element for the radiometer.

Automated Moving Target Indicator (AMTI)—An automated system to detect satellites was essential to the GEODSS concept, since it would increase the search rate by a factor of about 100 over an unaided human observer. Some time prior to the GEODSS procurement, TRW had developed a computer program called Adaptive Software to Recognize Orbiting Space Objects (ASTROSO), and this program was specified by the Air Force for the GEODSS system.

Before the data is fed to ASTROSO for analysis, automatic light control sets the best gain and the signals from the camera are appropriately filtered. The filtered video output is zero referenced, compensated for nonuniformities in the tube, and adaptively thresholded. (That is, the threshold is set at a predetermined level which allows a fixed number of stars and noise pulses to be detected.) This activity is equivalent to a constant false alarm detector threshold in a radar system and is necessary for maximum sensitivity. This output is digitized and fed into a special purpose "background rejection" processor. This hardware drastically reduces the quantity of data that must be sent to the computer. Even so, two Digital Equipment Corporation (DEC) 11/70 computers are required to further process the information from the three cameras.

In the background rejection processor, a composite frame of a given field of view is created by combining five to 20 individual frames (the number is determined as a function of sky conditions), as shown in Figure 5. This is done by performing a logical "OR" function on each image element. The first frame of the selected



1. BRIGHT FAST SATELLITE PLUS NOISE. IMMEDIATE RECOGNITION BECAUSE BEST FIT ELLIPSE PARAMETERS PASS.

2. SPARSE STREAK PLUS NOISE INITIALLY PRODUCES ELLIPSE THAT FAILS TEST. STEP 2 LOOPS ON ALL DATA CONSTELLATIONS WITH 6 OR MORE RESELS AND SUCCESSIVELY DISCARDS ELEMENTS WITH LARGE RESIDUALS. THIS TEST PULLS DIM TARGETS OUT OF NOISE.

3. SPARSE, INTERMITTENT STREAK NOT FOUND IN STEP 1 OR 2. STEP 3 TREATS ALL SMALL FEATURES OF 3 TO 6 RESELS THAT HAVE THE SAME DIRECTIONAL TREND. THE SMALL FEATURES ARE COMBINED AND THEN THE STREAK IS DETECTED. THIS IS A POWERFUL FEATURE FOR DETECTING SCINTILLATING TARGETS.

FIGURE 6

STREAK DETECTION OCCURS IN THE SECOND PHASE OF AMTI processing in GEODSS. The composite frame with the stationary star signals removed (Figure 5) is displayed for the operator and also fed to the computer. Data elements that are elliptical in shape, or streak-like, are considered to be moving objects. Because noise is always present, it may obscure small, dim signatures; for this reason, the data is processed or "looked at" three different times to determine whether or not it should be identified as a streak. Conversely, some noise signals may create a streak-like pattern; a "bad data" rejection feature is incorporated in the software to minimize these false alarms (Figure 7).

series is used as a "map" of the star field, and each stationary element (point of light) that appears in the map frame is erased from subsequent frames. Since moving objects will not leave a signature in the same place in successive frames, ideally only the star field is removed from the composite frame. Isolated noise elements are also removed in this process. With the stars and much noise removed, the composite is then reasonably "clean" as viewed by the operator.

The data is then sent to the computer where the "streak detector" software acts on the cleaned-up composite frame, examining each dense area as a possible streak, as shown in Figure 6. Following streak identification, a description of each noted streak (which includes the image coordinates of the streak's centroid, the number of image elements composing it, and its slope, length, and other decision parameters) is passed on to the "false alarm reject" software. This software examines all data passed to it, checking to see if the images are contributed to individual frames in a logical streak-like manner (Figure 7). If this is not the case, the image is dismissed as noise. If it is not directional, it is not a satellite.

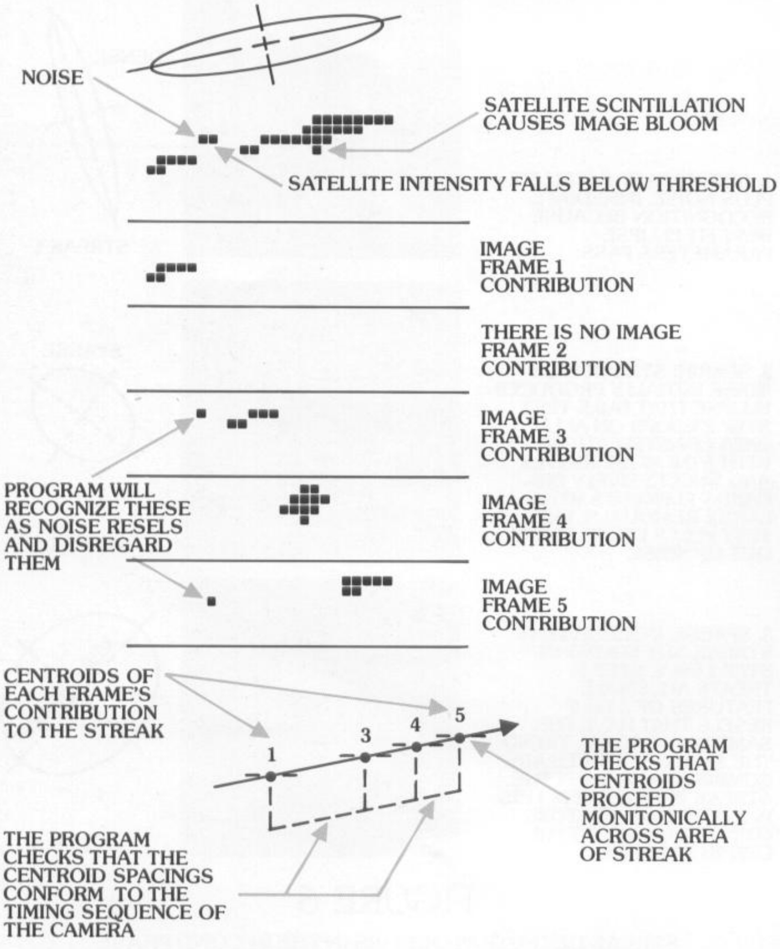


FIGURE 7

FALSE ALARM IDENTIFICATION AND REJECTION occurs in the third phase of the AMTI process. An ASTROSO program function checks the centroid spacings of each frame's contribution to the streak. If the spacings do not conform to the timing of the camera, the data is rejected as a false alarm. The data is also rejected if the centroids do not proceed monitonically across the area of the streak in successive frames.

Other Key Software Features—In addition to locating and identifying satellite streaks, GEODSS software performs other searching and tracking tasks. Space object identification (SOI) is a primary one. Radiometric data is collected by pointing the telescope so that the object in question is on boresight of the photometer. The photometer then collects optical signature data which is fed to the computer in digital form and stored. The operator can also measure sky brightness near the object to compute background illumination and atmospheric extinction. Once the data is collected, it can be displayed on the CRT for the operator to examine, format for transmission, and measure the object's intensity and periodicity.

Maneuver query (MQ) is another important software function. This is the process of looking for an object to determine if it is in its expected orbit or if it has moved. Air Force specifications require that this task be accomplished in one minute, but GEODSS can do it in less than half the time. The telescope is pointed to the position in the sky where the object is expected to appear and an automatic moving target indication (AMTI) is performed. The detected targets are compared with the Resident Space Object (RSO) catalog and if the object is in its expected position, the maneuver query is negative. If the object position or velocity differs from the expected value by more than a specified tolerance, the object is assumed to have maneuvered. The outcomes of these queries are reported to the Air Defense Command in Colorado Springs.

Precision position measurement (PPM) is another feature. Accurate line-of-sight measurements are taken to update or establish an object's orbit. The telescope is aimed at the location where the object (satellite) is expected, and an AMTI is performed to determine the location of the object within a fraction of an arc minute. The telescope is then slewed to place the object on boresight and a second AMTI is performed. The exact detection coordinates in the field of view are recorded and corrected by telescope and camera calibration. The measurement is accurate to better than three arc seconds (1σ) and is accomplished in less than one minute.

The control and display subsystem, Figure 8, designed and built by TRW, is the principal point of interaction between the operator and the system. To simplify this interaction, we designed unique software to translate complex data to easy-to-read operator displays. Using these visual "tools," an operator can work quickly and efficiently with the various elements of the system with minimum training. Every software function was designed with this


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FIGURE 8

GEODSS CONTROL AND DISPLAY SUBSYSTEM is one of TRW's major hardware contributions to the project and the principal point of interaction between man and machine. Unique software was designed by TRW to simplify this interaction and provide easy-to-read displays of complex functions and data, minimizing the amount of operator training required. Details of some of the displays are shown in the following figures.

critical man/machine interface in mind.

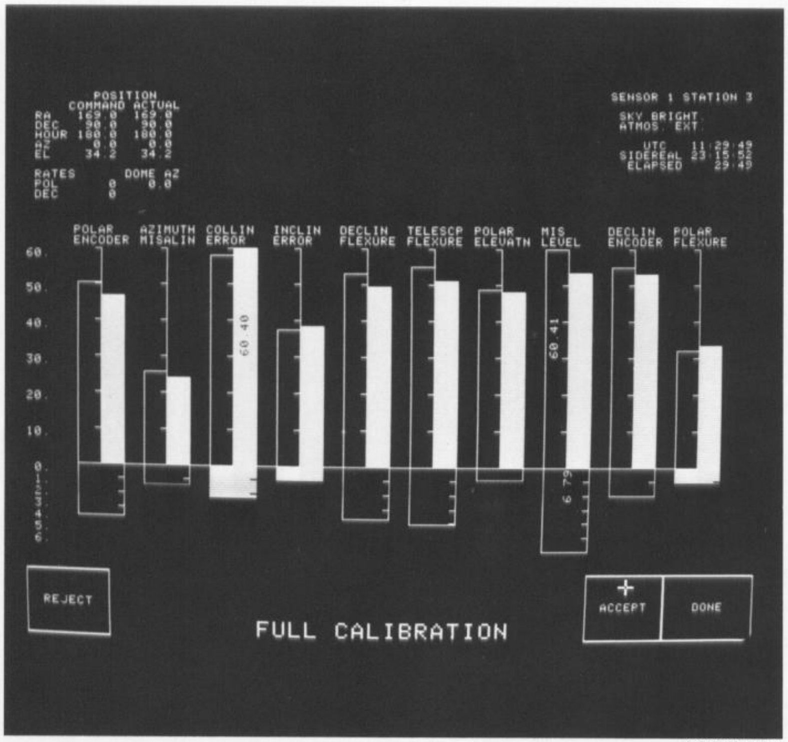
One example of this simplicity is system calibration, a task that must be done every evening. The computer automatically selects stars to observe, and using a Kalman filter, recursively corrects the effects of telescope mount and camera errors. These include common types of alignment errors as well as structural flexure of the telescope tube and mount axes, which are gravity-dependent. To estimate these errors, the system selects stars from a stored catalog, and automatically positions the telescope to observe each star. When the estimation is completed, the 10 correction terms are stored and used to correct the pointing commands to the telescope and the telescope readout.

Instead of dealing with the complex mathematics of the Kalman filtering, the operator works with the simple CRT display shown in Figure 9. The accumulated calibration errors and the error contribution from the current star observation are represented by a series of bars displayed side by side. The operator monitors the computer's calibration activities by keeping an eye on the bar chart. When the new and previous bar displays are approximately equal and remain so for several star observations, the operator can conclude that the system has successfully estimated the telescope mount errors. A potentially tedious and burdensome process is thus automated.

Another unique operator display was designed for calibration of the offset between the SIT Vidicon and the radiometer (Figure 10). The radiometer boresight relative to the camera cannot be determined by direct observation, but the operator can determine where it is pointing by referring to a known star viewed by the SIT Vidicon and displayed on the CRT. The software remembers light intensities as measured by the photometer on trial boresights, and as the operator "hunts" around the displayed star, the intensity measurements for each trial boresight appear on the screen. The area that is shown to have the maximum light intensity is where the radiometer is pointing.

Another example of how GEODSS software simplifies the operator's task is the search mission. The definition of how a particular search must be performed involves such parameters as what is being looked for, how big is the area in question, and what type of search is required. Again, the software aids the operator, as shown in Figure 11. The operator is given a search "menu" at the touch of a button from which a tailored search may be defined. As each option is selected, it is backlighted and when the operator is satisfied with the definition, the search is initiated. (Displays for various tasks are similar in that menus for selecting options are displayed in the lower portion of the CRT screen.)

As the search progresses, the operator is kept informed as to the duration of the search and what objects have been found. When something of interest



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HOUR  180.0  180.0
AZ      0.0    0.0
EL     34.2   34.2

RATES       DOME AZ
POL      0     0.0
DEC      0
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 SKY BRIGHT.
 ATMOS. EXT.

    UTC    11:29:49
 SIDEREAL  23:15:52
  ELAPSED     29:49
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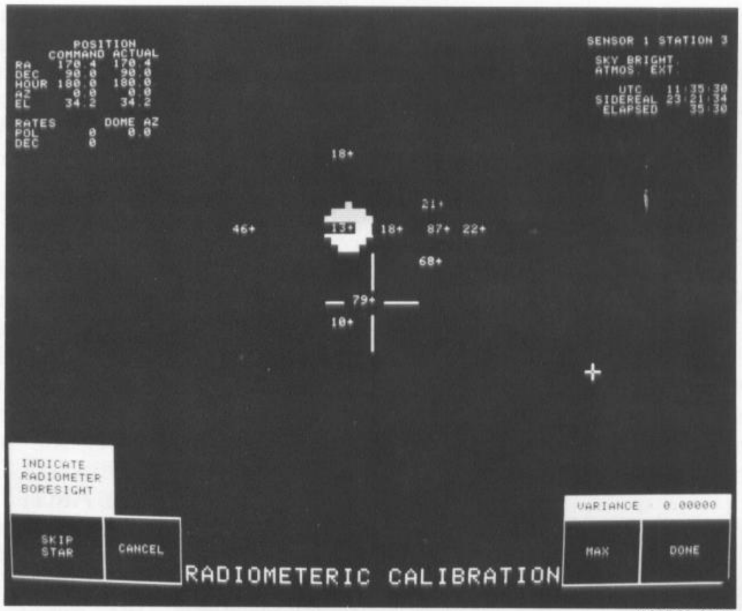
FIGURE 9

GRAPHIC DISPLAY USED FOR SYSTEM CALIBRATION, which must be performed each night. Instead of dealing with complicated mathematics, the operator checks a series of bars of varying lengths as the computer corrects the effects of alignment errors. When the differences in length are minimized, the computer has completed its estimate of the telescope and mount errors and the calibration process is complete. (The designer of this display got the idea from an episode of the TV science fiction series "Star Trek.")



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DEC      0
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SENSOR 1 STATION 3

 SKY BRIGHT.
 ATMOS. EXT.

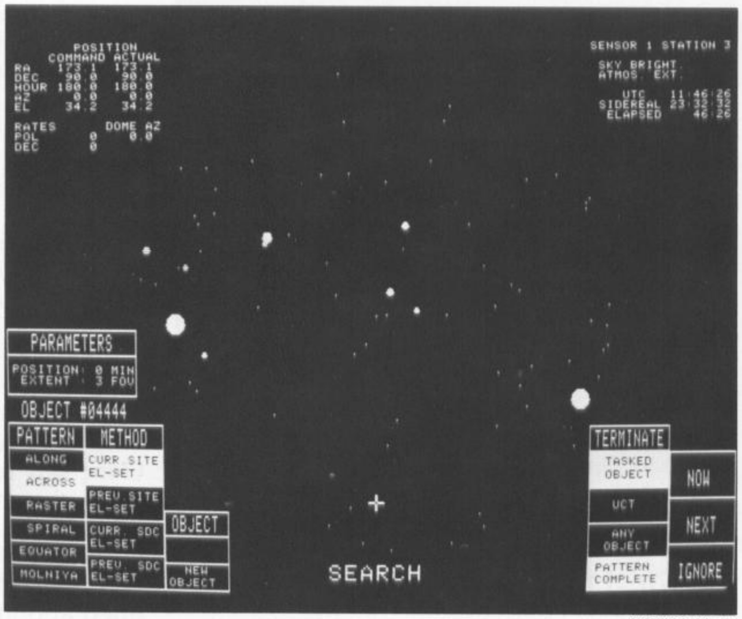
    UTC     11:35:30
 SIDEREAL  23:21:34
  ELAPSED     35:30
```

```
VARIANCE : 0.00000
```

(167562-80-7)

FIGURE 10

RADIOMETRIC CALIBRATION DISPLAY simplifies the process of calibrating offsets between the radiometer and the SIT Vidicon. The radiometer boresight cannot be determined by direct observation; therefore, the software determines where the radiometer is pointing by remembering the previously measured light intensity of a known star. The operator "hunts" around the known star until an area of maximum intensity is found, as represented by an area of high light readings provided by the software. This is identified as the area where the radiometer is pointing.



```
       POSITION
    COMMAND ACTUAL
RA     173.1  173.1
DEC     90.0   90.0
HOUR   180.0  180.0
AZ       0.0    0.0
EL      34.2   34.2

RATES       DOME AZ
POL      0      0.0
DEC      0
```

```
SENSOR 1 STATION 3

 SKY BRIGHT.
 ATMOS. EXT.

    UTC     11:46:26
 SIDEREAL  23:32:32
  ELAPSED     46:26
```

```
POSITION: 0 MIN
 EXTENT : 3 FOV
OBJECT #04444
```

(167562-80-10)

FIGURE 11

GEODSS SOFTWARE PROVIDES A "SEARCH MENU" DISPLAY which allows the operator to choose a tailored set of search options at the touch of a button. As each option is selected, it is backlighted and when the operator is satisfied with the definition of the function to be performed, the search is initiated. The definition involves such parameters as what is being looked for, how big the search area is, and the type of search required.

appears, the search may be temporarily stopped (see Figure 12), allowing that area of the sky to be carefully examined.

HISTORY OF GEODSS

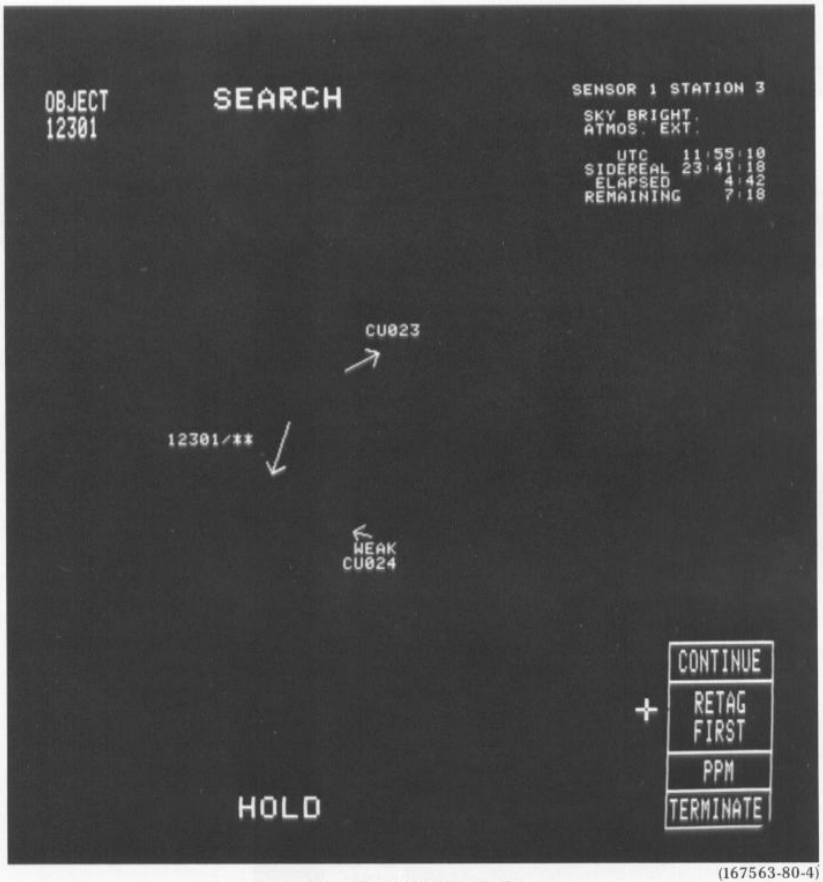
The forerunner of the GEODSS system, still in use at this writing, is the Air Force's Baker-Nunn system. Like GEODSS, the system includes a telescope on a sidereally driven mount, so that star fields remain stationary and moving objects appear as streaks, but the camera uses film instead of electronic imaging. Hundreds of feet of film are run through the camera system each day, and processing it can take up to 90 minutes. This long delay represents a serious disadvantage in the detection of potential military threats; also, any "unknowns" will have moved by the time the film has been processed and analyzed. For today's requirements, the system falls short in terms of sensitivity, real-time imaging, and high speed, sophisticated data processing.

Early AMTI Work—The GEODSS project had its beginning in the early 1970s when the Air Force recognized the growing need for a new space surveillance system. TRW teamed with the Itek Corporation and won the competitive bidding to define a system concept and devise a technology plan. As a result of that early effort, the AMTI software and the SIT Vidicon imaging tube were identified as the highest risk elements in the development program. If the SIT Vidicon could not be built to specifications, the search rate might be cut in half. On the other hand, if the AMTI fell short, the search rate could be reduced by orders of magnitude.

In 1974, TRW began work on the initial development of an automated moving target indicator, to be called ASTROSO, as mentioned earlier. Two computer programs were written, the AMTI itself and a simulation with which to test it. The simulation included a star field background, complete with noise, scintillating stars, and moving objects. Early test results with these two programs showed a detection probability of about 50 percent, which of course was far short of requirements.

ASTROSO was refined and tested once more, this time with a detection probability of 85 percent. By 1975, we were ready to test the software on the real data. A primitive field test took place at Patrick Air Force Base in Florida. The data collected there was stored on tape and brought back to Space Park for analysis. Once fed to the computer, the data showed that ASTROSO had found everything that crossed its field of view during the tests.

The system was further refined and in 1976 was tested at a site developed by Lincoln Laboratory in White Sands, New Mexico. This Experimental Test Site (ETS) became the proving ground for TRW's ASTROSO and



```
OBJECT          SEARCH                SENSOR 1 STATION 3
12301
                                        SKY BRIGHT.
                                        ATMOS. EXT.

                                           UTC    11:55:10
                                        SIDEREAL  23:41:18
                                         ELAPSED      4:42
                                        REMAINING     7:18

                HOLD
```

(167563-80-4)

FIGURE 12

A SEARCH "HOLD" PATTERN CAN BE INITIATED BY THE OPERATOR at any time, allowing the display to be examined carefully when something of interest occurs. Numbered streaks are those that have already been identified by the system. The "unknowns" are those preceded by a "CU" designator. At any time after initiating the hold, the operator may either terminate or continue the search.

certain other GEODSS elements.

The TRW/Itek tests at the ETS demonstrated that ASTROSO was a viable component for GEODSS. It had changed remarkably little since 1974 when it was tested with synthetic data.

SYSTEM DEVELOPMENT AT TRW

By 1977, TRW was developing a baseline system design to satisfy a draft GEODSS specification prepared by the Air Force. TRW's ASTROSO had proven itself to be the only practical alternative software for a deep space surveillance system (see Table 2); the Air Force stipulated that it be used and made our work available to all competitors.

The basic questions still to be answered included: How many telescopes should each GEODSS site have? How big should each one be? What type of camera tube should be used? What computer resources would each site need?

Systems Analysis—The system proposed had to satisfy hundreds of performance requirements and use proven technology where possible. And it had to fit extremely tight budget constraints.

Initially there were many key design drivers and conflicting requirements. It was important to reduce the problem to a manageable set of design parameters. A systems analysis (see box) established the relationship among many parameters that would optimize system performance. The camera exposure time that would result in the minimum size telescope was determined. The optimal telescope field of view was related to telescope aperture, camera sensitivity, and ASTROSO performance. Specialists identified cost/performance breakpoints in hardware subsystems and this data was integrated with the mathematical analysis.

During the early design effort that followed, it first looked as if GEODSS would need four telescopes per site, two main and two auxiliary. With only one auxiliary telescope, the ASTROSO streak logic as previously tested could not detect the slowest satellites. Unfortunately, the four telescope solution was too costly. Each telescope also required sensor and signal processing hardware, more computing power, an extra console position, and an operator. Our systems analysts solved the problem by adding a "slow, bright" logic algorithm to the software. The added algorithm works properly at a different threshold setting than the correct one for the streak logic, so we designed a dual threshold capability into the system. The streak logic threshold was now set to detect the dimmest objects, and the slow, bright threshold was set higher to detect the slowest objects. This added some complexity to the signal processing hardware, but achieved an overall program cost reduction on the order of $10 million.

Data Processing Hardware and Software Selection—In 1977, while we were defining all the system software requirements and taking a fresh look at ASTROSO, we also studied every available type and model of computer to handle the heavy system data processing load and also to provide a backup capability in the event of a computer failure.

Three basic types of computer

MISSION	BAKER-NUNN	EXPERIMENTAL TEST SITE	GEODSS WITH ASTROSO
SEARCH (DEG^2/HR)	50-200	50-200	7,400-35,000
TRACKS/NIGHT	100-400	100-300	1,200
SPACE OBJECT IDENTIFICATION	NONE	MANUAL	COMPUTER AIDED

TABLE 2
OPTICAL SURVEILLANCE SYSTEMS PERFORMANCE

SAMPLE GEODSS SYSTEM ANALYSIS

This simplified analysis determines the camera exposure time, number of camera exposures per field of view, and telescope "clear effective aperture" (the diameter of an ideal telescope that has equivalent light collecting power) necessary to satisfy conflicting sensitivity and scan rate requirements. It is an example of the analysis used in the development of the GEODSS top level design.

Successful detection requires that two conditions be satisfied:

(1) That the signal-to-noise ratio in a single camera exposure be above a given threshold

(2) That the satellite move at least a given minimum amount over all the exposures in a field of view.

The first condition is required for the satellite to be distinguishable from noise. The second condition is required for the satellite to be distinguishable from stars.

The signal-to-noise ratio in a single camera exposure for the dimmest satellites to be detected must satisfy

$$S/N = \frac{C_1 D}{\sqrt{t}} \geqslant S/N^* \qquad (1)$$

where
S/N = signal-to-noise ratio
C_1 = constant
D = telescope clear effective aperture
t = camera exposure time
S/N^* = minimum signal-to-noise ratio required for detection.

The minimum satellite motion with respect to the star field must satisfy:

$$\alpha = \frac{N\,V_{min}}{V_C} \geqslant \alpha^* \qquad (2)$$

where
α = satellite motion
N = number of camera exposures
V_{min} = speed of the slowest satellite GEODSS is required to detect
V_C = speed of the dimmest satellite GEODSS is required to detect
α^* = minimum satellite motion required for detection.

It will be assumed that equations (1) and (2) are necessary and sufficient conditions for successful detection. In addition, GEODSS must satisfy a search rate requirement. It can be shown that scan rate must satisfy:

$$S_R = \frac{C_2 t}{N} \geqslant S_R^* \qquad (3)$$

where
S_R = scan rate
C_2 = constant
S_R^* = required scan rate.

Equations (1), (2) and (3) can be solved for the minimum telescope clear effective aperture satisfying detection and scan rate requirements, and for the corresponding values of N and t.

Equation (1) can be solved for D:

$$D \geqslant \frac{S/N^* \sqrt{t}}{C_1} \qquad (4)$$

Combining equations (3) and (4):

$$D \geqslant \left(\frac{S/N^*}{C_1}\right)\sqrt{\frac{S_R^*\,N}{C_2}} \qquad (5)$$

Combining equations (2) and (5):

$$D \geqslant \left(\frac{S/N^*}{C_1}\right)\sqrt{\frac{S_R^*\,\alpha^*\,V_C}{C_2\,V_{min}}} \qquad (6)$$

In general, D cannot achieve the minimum value in (6) because N must be an integer. However, equation (6) provides a useful lower bound for D that is a good approximation for large N:

$$D = \left(\frac{S/N^*}{C_1}\right)\sqrt{\frac{S_R^*\,\alpha^*\,V_C}{C_2\,V_{min}}} \qquad (7)$$

Equation (7) was actually used to quickly evaluate the impact of changes in the GEODSS specification (S_R^*, V_C, and V_{min}) and alternate AMTI systems (S/N^* and α^*) during the preliminary design effort.

More accurate solutions for N, t, and D are:

$$N = \left[\frac{\alpha^*\,V_C}{V_{min}}\right] + 1$$

$$t = \frac{N S_R^*}{C_2} \qquad (8)$$

$$D = \left(\frac{S/N^*}{C_1}\right)\sqrt{t}$$

were evaluated—main frames (large, multi-purpose computers), minicomputers, and special purpose microprocessors. The main frames were eliminated because the need for backup hardware made the overall cost too high. Special purpose microprocessors were not yet available with sufficient capabilities for GEODSS. This narrowed the choice down to a multiple minicomputer system.

The system finally selected consists of four Digital Equipment Corporation (DEC) 11/70 minicomputers and peripherals, chosen on the basis of speed, capability, reliability, hardware/software maturity, and relatively low cost. Two DEC 11/70s are assigned to AMTI functions, one to Executive operations, and the other to Mission Applications.

In addition to the moving target indicator algorithms, software was needed for mission planning, numerous mission applications, and communications. The team first reviewed existing software at TRW, RCA, ADCOM and the Lincoln Laboratory Experimental Test Site to see what could be adapted. Approximately 25 percent of the total GEODSS software was borrowed from these existing programs, including that for orbit propagation, orbit determination, and differential orbit correction. The algorithms were adapted by TRW to the DEC 11/70. Memory reduction techniques, overlay techniques, and some double precision were used to fit the programs designed for larger word length machines to the smaller word length machine chosen for GEODSS.

Mission Planner Software—When the system is operational, the Air Defense Command will issue each day a list of objects to be observed during that night's operations. Tasks such as precision position measurements, space object identification, new launches, and signature data collection will be included. The mission planner will determine the scheduling for all these activities, taking into account when the object will be in view, its priority, and which telescope will look for it. The entire night's work will be scheduled and carried out automatically—barring interruptions.

But interruptions will be typical. Cloud cover may prohibit viewing for several hours. Higher priority tasks may preempt scheduled operations. To that end, two methods have been incorporated into the mission planner software to deal efficiently with interruptions. The first is direct operator intervention. Overriding the mission plan from the console position, the operator can insert a higher priority task at any time. The software first checks to make sure the target is visible at the time of insertion and, if it is, the task is scheduled as the operator requested. If the object is not visible, the operator is alerted and advised to select another time.

The second method is most appropriate in the event of cloud cover or other lengthy interruptions. A computer "bookkeeping" operation checks to see which tasks have been accomplished prior to the holdup, and the mission planner then reschedules those that haven't been completed. Again, the operator can make changes at any time, providing the object sought is visible.

Calibration Software—Two types of calibration are required; one is an overall alignment to achieve the high accuracy required by the system for precision position measurements; the other measures the amplitude response of the photometers (used for space object identification) against known stars.

Gross alignment errors are removed by mechanical means and leveling of the telescope mount assemblies at the time of installation. However, since there are small residual errors, the software is used to estimate these errors in order to correct the observation data.

After a precision position measurement is performed, the precise position of the object of interest on the camera tube is estimated. This is done by estimating the camera tube spatial distortion for the coordinates at which the object was observed. To do this, a shutter is closed and an electroluminescent panel is turned on. This causes tiny translucent dots on the camera tube face, appearing in a grid pattern called a reseau, to be backlit. By reading the reseau pattern and comparing this with the stored reseau dot locations, a distortion correction is obtained.

The software also corrects pointing commands and observations for atmospheric refraction. A stored function that uses the atmospheric pressure, temperature, and altitude of the site estimates the refraction error as a function of the zenith angle. The weather subsystem provides the temperature and pressure information to the data processing system on a routine basis.

The Interface Effort—The more than 400,000 machine language instructions that make up the total GEODSS software package demanded considerable time and attention in the development phase, but the interface problem required the most care. There were literally hundreds of these interfaces—software-to-software and software-to-hardware. The software controls all of the site resources including the three telescopes, three cameras, all video processing hardware, and two two-position operator consoles. It is also required to interface with external weather and communications systems.

To minimize potential interface problems, two sets of data controls were initiated. First, we prepared all interface control documents between various hardware elements. These were then reviewed, coordinated, and signed off jointly by TRW and all affected subcontractors. Secondly, a program called "N-square" was written expressly to keep track of all software interfaces.

The N-square program is based on a chart wherein all inputs and outputs are plotted against software routines. For GEODSS, the chart was computerized so that any error (interface mismatch) would be identified immediately by the program.

N-square proved to be one of our most valuable tools for software development, but there were others. Interactive debugging tools allowed the developers to test software, instrument it, and interactively print out inputs, outputs, and error messages. Tools to automatically recompile changed portions of the code also streamlined and automated much of the development process.

The formal software development was based on military specifications. The strict formality of documentation and design review greatly enhanced configuration control for the complex project.

To ensure that the different GEODSS components (cameras, telescopes, software, electronics) manufactured by different contractors would successfully fit together when the system was assembled, it was necessary to define the required interfaces early in the program. The bolt patterns on the camera, for example, must fit with the holes on the telescope. A button pushed on a computer must send the correct electrical impulse to the correct component at the correct time. This was accomplished by means of interface control documents (ICDs) covering electrical, mechanical, and thermal interfaces between the various components.

INTEGRATING GEODSS ELEMENTS

An important factor in the complex system integration process was the adaptation of the bus interface unit (BIU) developed by TRW previously for the Tracking and Data Relay Satellite System (TDRSS) ground station. The BIU effectively handles the complex electrical interfaces between the computer, the camera, the video processor, and the "background reject" processor, providing serial-to-parallel and parallel-to-serial conversion of data bits. This feature more than paid for itself in wire savings alone.

Another important factor for GEODSS' future was the design and construction of a complete operational site for the system at TRW's Newbury Park facility, which also serves as headquarters for the GEODSS project team. (This facility, located 50 miles northwest of Space Park, provides substantially better nighttime viewing conditions than are available in Redondo Beach.) The system at Newbury Park will eventually be shipped to Korea to become one of the five installations in the worldwide surveillance system. Meanwhile, as each element arrived at Newbury Park it was integrated into the existing system (Figure 13), so that all hardware and software interfaces could be thoroughly tested.

Since GEODSS sites will ultimately be installed around the world by different crews, it is essential that each crew understand what needs to be done. Toward that end, TRW developed a detailed integration "manual" for the system, covering every aspect of system installation. Included in this document are complete details for electrical system grounding, lightning protection, pier height and stability, air conditioning, office facilities, protection against electromagnetic interference (EMI), and instructions for casting the concrete for the observatory structure to assure proper fit and support of the observatory dome.

During the program, the project has had a total of eight DEC 11/70 computers available, giving the software designers an excellent development and integration capability, as well as substantial backup support whenever a computer must be shut down for some reason. Software integration was accomplished on one set of four computers, while the other was used for continual baseline development.

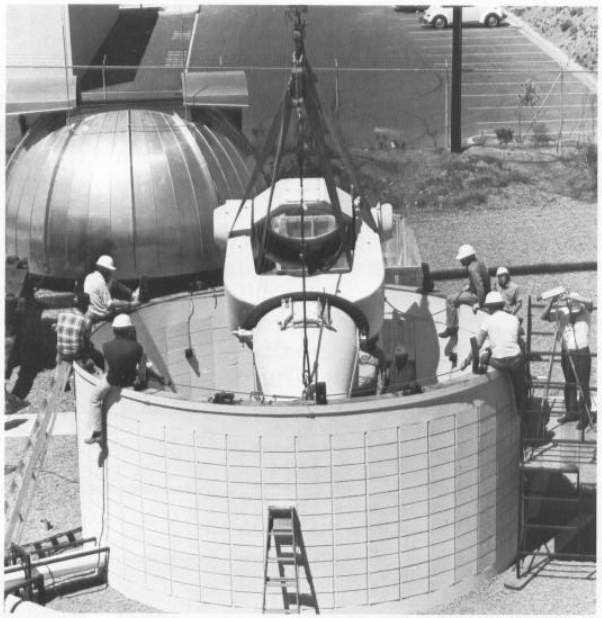
The GEODSS system has a bright future in its intended application of deep space surveillance and identification of satellites. But there is another important potential application.

THE FUTURE FOR GEODSS

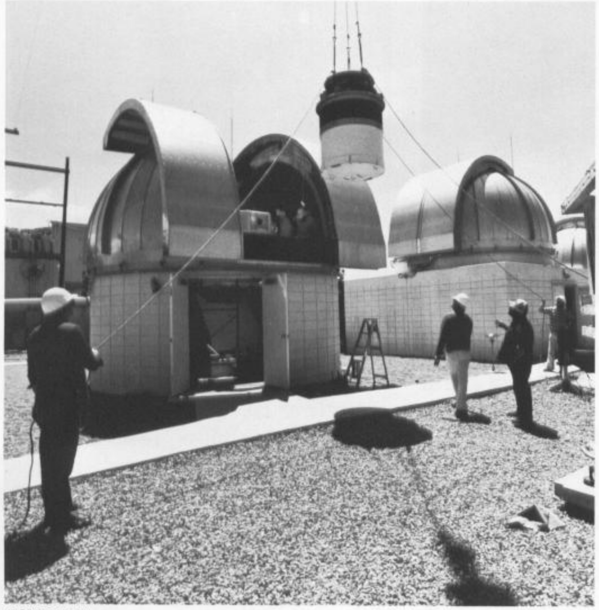
Certain astronomers have closely followed GEODSS development because of its potential use in their work as a resource unmatched by any existing or planned research facility. GEODSS has a unique capability to discover new variable stars, provide a tremendous increase in photometric data, and establish a permanent historical digital base of star data many orders of magnitude larger and more thorough than any in existence today.

At the present time, astronomers have no systematic method to survey many periodic and aperiodic variable stars fainter than the 9th visual magnitude. Usually when one is discovered, it is by accident. Once the star is found, its characteristics (amplitude of intensity variation and time scale of periodic or aperiodic behavior) can be learned only by painstaking observation of the object. GEODSS can provide an unequaled source of discovery for new variable stars. It can also augment fragmentary period and amplitude data for a number of known variable stars.

Photoelectric photometry is currently conducted on one star at a time, and measuring even



(165973-80-11)



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(166618-80-5)

FIGURE 13

INSTALLATION OF A COMPLETE GEODSS OPERATIONAL SITE AT TRW NEWBURY PARK FACILITY was an aid to sequential system integration and the creation of an integration manual to facilitate the construction and equipment installation at other sites around the world. Photo at top shows installation of the first main telescope mount, weighing 12,000 pounds, in its observatory. Bottom left shows installation of one of the main telescopes and bottom right shows the telescope in place.

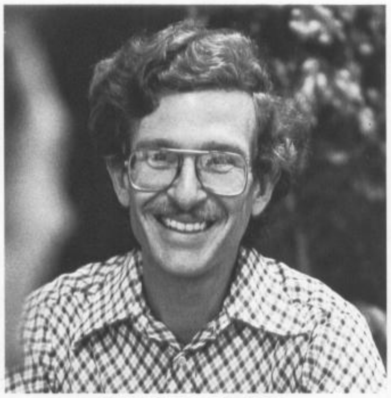
100 stars in one night from a single facility is an arduous task. Astronomical photographic emulsions are slow, and their analog nature impairs extraction of the data and limits its accuracy. The speed and spatial coverage of GEODSS can revolutionize photometric data acquisition. GEODSS will measure an average of 6,000,000 stars per hour, and if the system is coupled with a simple data acquisition hardware interface and a centralized data reduction and storage facility, the quality and volume of this data will quickly surpass the entire current capability of astronomical photoelectric photometry.

As for record keeping, GEODSS will be a giant step forward. The largest star catalogue in the world contains 750,000 stars. Today, permanent records are stored in a very few central banks, the most noteworthy located at Harvard University. The problems with this set of thousands of photographic emulsions—some dating back to the 1890s—are considerable. Time coverage of a given area of the sky is generally sparse. Many of the older glass plates are fading. The material is highly heterogeneous, having been taken with different telescopes by different observers using varying speeds, colors, filters, and exposures. The plates must be manually retrieved and visually examined to find the object in question. They can be analyzed only by eye or manual iris photometer. One can never be sure that all the data on a given object has been found. Yet, this library is highly valued and is the main repository for most historical astronomical data.

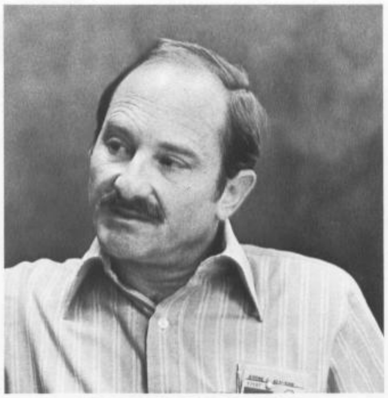
Although GEODSS "sees" all this star data, it is presently designed to discard it and save only streak information. With very minor modifications, the system could serve both military and scientific purposes. If GEODSS were altered to retain the data it otherwise eliminates, astronomers could "ride piggyback" on the data-gathering operation without

THE PEOPLE

DAVID D. OTTEN



ELLIOT I. BAILIS



JERRY G. KLAYMAN

The successful integration of the many GEODSS elements required a carefully coordinated effort both within the project itself and with outside vendors. The Systems Engineering and Integration Division (SEID) proposal effort was led by GEODSS project manager David D. Otten, co-author of the preceding article. Dave has been with TRW for 15 years, starting in Electronic Systems Division (ESD) where he was responsible for systems engineering of the attitude control system for the Orbiting Geophysical Observatory (OGO), and certain strapped-down inertial guidance system studies. Later, in the Space Systems Division (SSD), he served as advanced systems manager responsible for several communications and navigation satellite preliminary designs. He also directed pioneering efforts on the Air Force "NAVSTAR" program. Dave earned his M.S. in Electronics Engineering at the University of Illinois.

Jerry G. Klayman, co-author and assistant project manager for data processing, has been responsible for the GEODSS computer hardware and the software development, test and integration. This was a complex task with tight schedule and budget constraints. During his 19 years with TRW, Jerry has worked extensively on the ballistic missile and manned space programs in trajectory simulation, performance and error analysis, and software development for Atlas, Titan, Minuteman, Gemini and Apollo. Prior to GEODSS, Jerry directed a project responsible for software hampering the system's other activities. The special hardware required would consist of an analog-to-digital converter of eight-bit accuracy and a small mass storage device. A microcomputer would control data acquisition, compression, and storage. Since the stars in each data frame provide their own calibration, it is unnecessary to calibrate for absolute intensity. This method is commonly used in astronomical research and data reduction procedures and algorithms are well established.

Professor Bruce H. Margon, a noted astronomer now with the University of Washington and formerly with UCLA, recently submitted a proposal to the National Science Foundation for a demonstration program to prove the feasibility of this concept. Under the proposed program, TRW would serve as subcontractor to the university, responsible for system engineering and modifications to the existing GEODSS design. If all goes well, the next step would be a program involving instrumentation of most or all GEODSS sites to establish an internationally accessible data bank. As it looks now, this data bank could best be serviced by video disk storage. Estimates of operational-phase central data facility requirements for archival storage of GEODSS astronomical data indicate that one disk, using both sides, could hold 55 days of data. Ten years of data from all 15 GEODSS telescopes could be recorded on less than 1,000 disks, which in turn could be stored in a single four-drawer filing cabinet.

Suggested Additional Reading:

Electro-Optical Systems Analysis, by Khalil Seyrafi, Electro-Optical Research Company, Los Angeles, California, 1973.

"Space Surveillance Deemed Inadequate," *Aviation Week & Space Technology*, June 16, 1980.

"U.S. Upgrading Ground-Based Sensors," *Aviation Week & Space Technology*, June 16, 1980.

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development for SAC Headquarters. He earned the Degree of Aeronautical Engineering from the University of Cincinnati and an M.S. in Engineering from UCLA.

Co-author Elliot I. Bailis is GEODSS subproject manager for system analysis. His mathematical analyses determined many of the specific parameters of GEODSS. Prior to his work on this system, Elliot developed new methods for associating and correlating data from radar and optical sensor systems in SEID. He has been with TRW for 12 years. His B.S. in Mathematics is from Harvard; his M.S., also in Mathematics, is from the University of California, Berkeley.

Systems engineer Larry Mitchler, now retired from TRW, was responsible for systems analysis, interface control, and integration of the various GEODSS components. Dale Foust was responsible for the latter efforts, reporting to Larry. Before joining the GEODSS staff, Dale performed systems engineering tasks for the Minuteman program at Norton Air Force Base. He has a B.S. in Electronics Engineering from California Polytechnic Institute, San Luis Obispo, and an M.E. in Systems Engineering from West Coast College.

John Stone, now assistant project manager for the design and construction of relocatable GEODSS, served originally as deputy program manager for hardware. With TRW since 1966, John first worked on electro-optical and other systems in ESD and then in Subcontracts, where he was responsible for, among other things, the TDRSS antenna subcontract. John attended the University of Kansas and earned a B.S. in Engineering Physics.

Assistant program manager Larry Osborne was responsible for the design, development, and integration of TRW's hardware contributions to the program. Larry has been with TRW since 1966 and has participated in such SEID projects as high speed ground transportation, the Family of Engineering Construction Equipment (FAMECE), and Defense Communications Systems engineering studies. Before joining TRW, Larry was involved in aerospace medicine. He has a B.S. in Bacteriology and an M.S. in Physiology from the University of Colorado.

Martin Robinson, a 20-year TRW veteran, was responsible for direction of the GEODSS telescope and sensor group subcontractors. Working on GEODSS since late 1977, he has been assistant program manager for Electro-Optical Subsystems. Marty's past experience includes work on automatic control systems for satellites in SSD's Control and Sensor Systems Laboratory. He has an M.S. in Aeronautical Engineering from Caltech.

TRW was involved in several GEODSS study programs in the early and mid-1970s; project manager for these studies until 1976 was Roy Schubert. Roy is now working on system definition and analysis in SSD. He was assisted in the early GEODSS work by Hugh Dodge, now with the Systems Development Department of SEID.