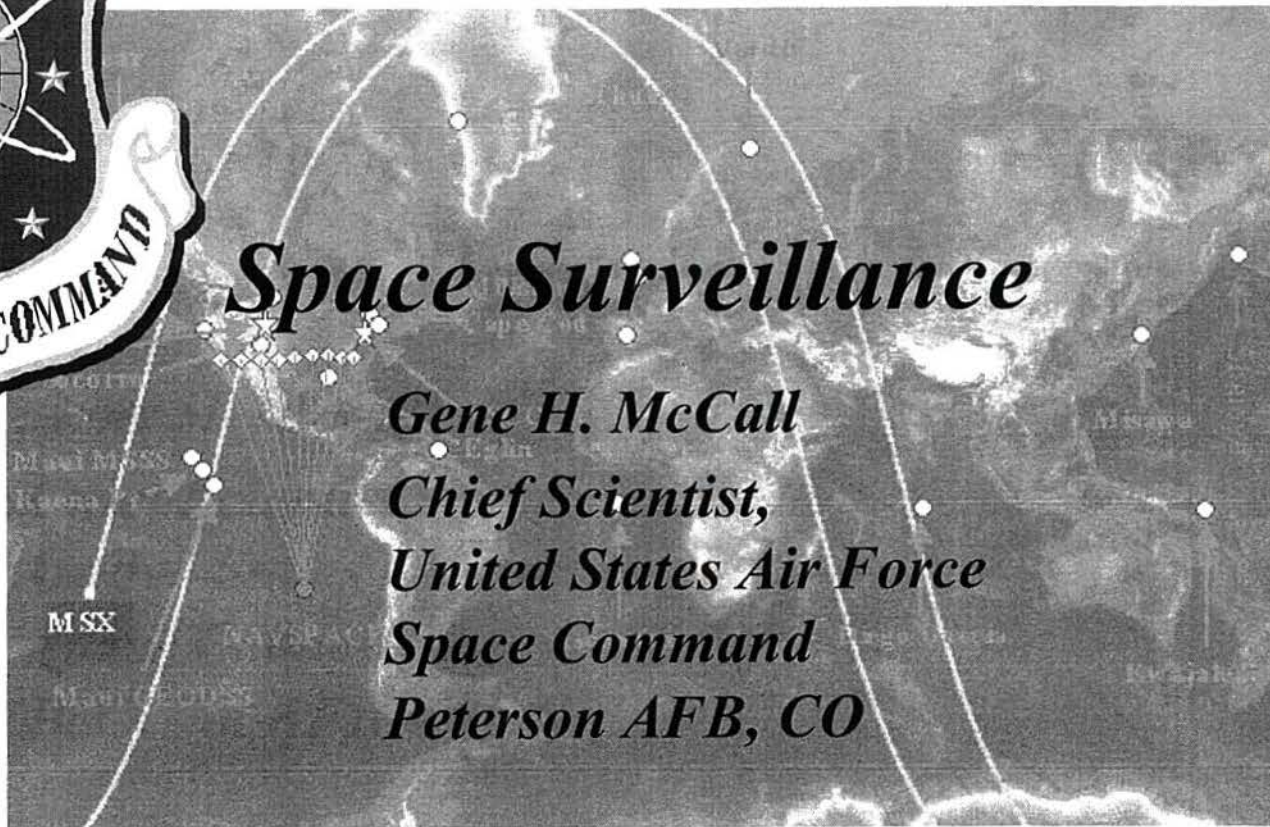# This Briefing Is Unclassified

Space Surveillance

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

AIR FORCE SPACE COMMAND

Space Surveillance

- **Surveillance and cataloging of space objects is a high priority mission for Air Force Space Command.**
  - **Both civil and military applications**
  - **Collision warnings are an important output**
- **Includes cataloging and orbit predictions**
  - **Regularly published element sets**
- **Modern space conditions demand ever increasing accuracy of both measurement and prediction.**
- **Current standards are in need of revision**

Sensors and Command and Control (C²)

- **Three types of sensors that support the SSN**
  - **Dedicated. Space Surveillance is primary mission**
  - **Collateral. Space Surveillance is secondary or tertiary mission**
  - **Contributing. Non USSPACECOM sensors under contract to support space surveillance**
- **There are two major C² centers that manage the SSN**
  - **Air Force Space Control Center (AFSSC), in CMAS, CO**
    - **Primary C² center**
  - **Naval Space Control Center (NSCC), in Dahlgren, VA**
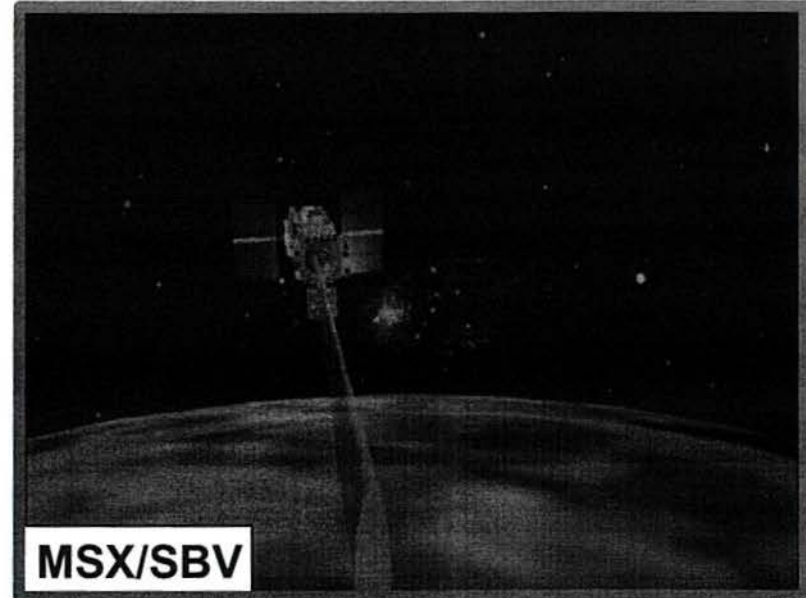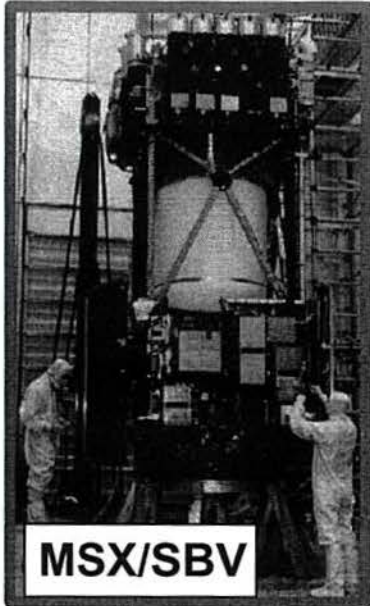   - **Equivalent backup to the AFSSC**

SSN Sensors and C² Center Locations

Space Surveillance Network
Western Hemisphere

Space Surveillance Network
Eastern Hemisphere
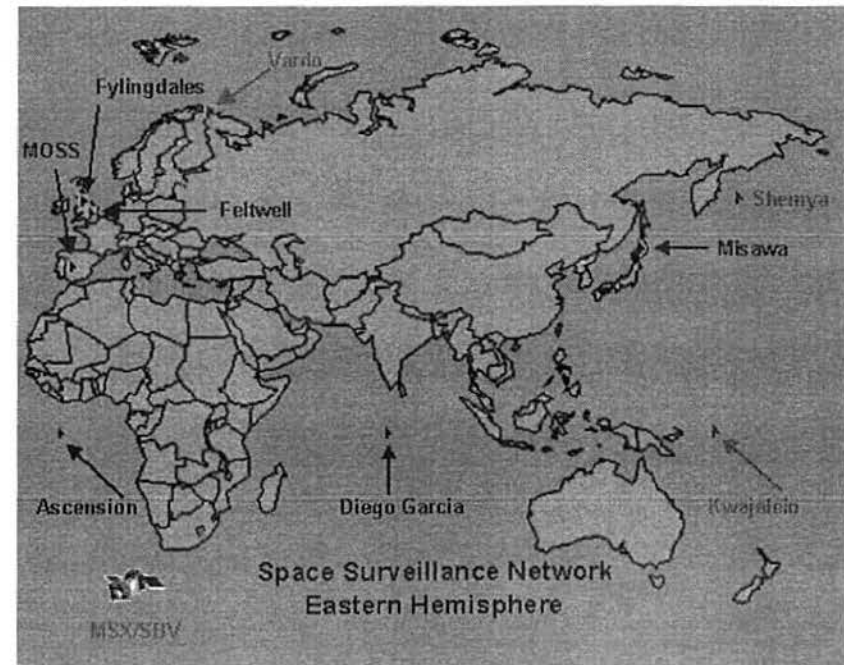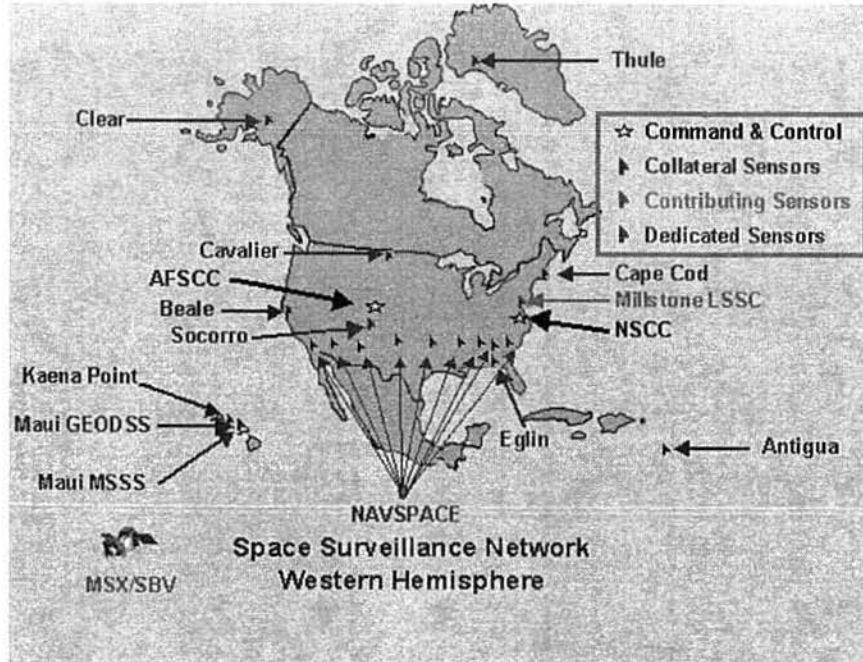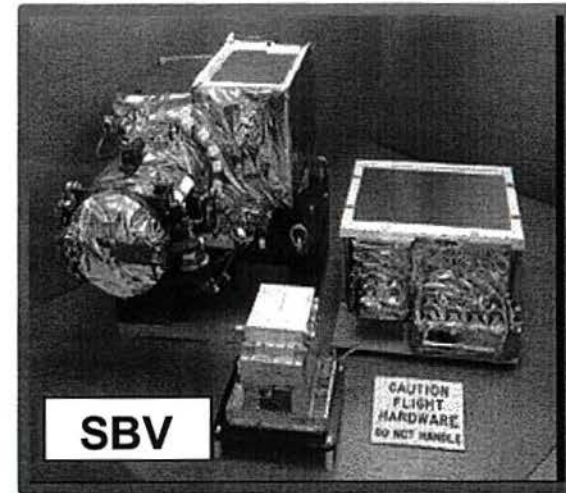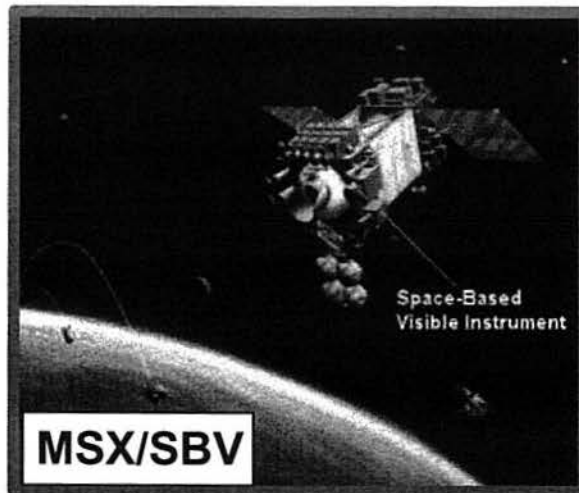
MSX/SBV Mission

MSX/SBV

MSX/SBV

- **Primary Mission - Space Surveillance**
  - Conduct space surveillance from space
  - Surveillance of entire geosynchronous belt
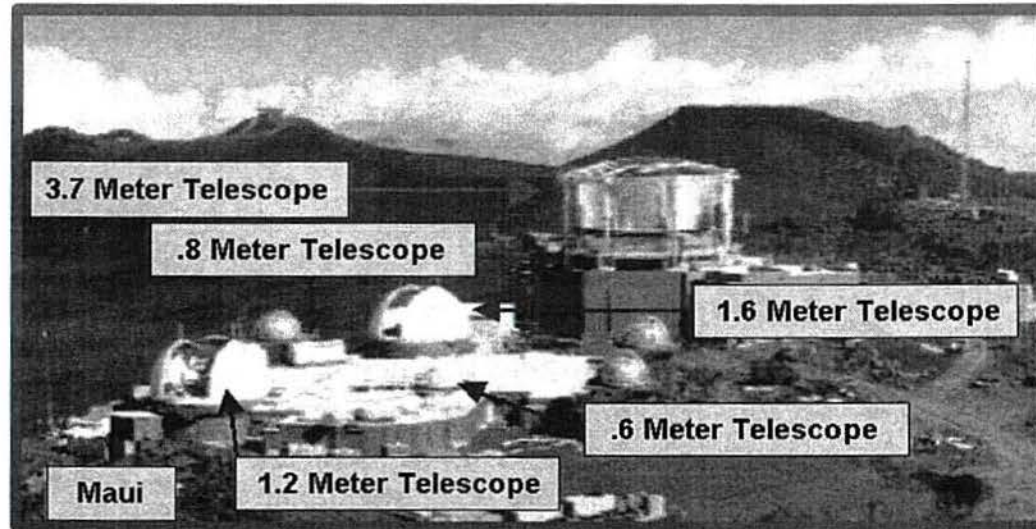 - Assured access to objects of military interest

MSX/SBV Description

MSX/SBV — Space-Based Visible Instrument

SBV

- **Strengths of space-based sensors**
  - **Access to all space**
  - **No weather outages**
  - **Reduced dependence on foreign-based sites**

- **Advanced Concept Technology Demonstration (ACTD)**
  - **Oct 1997 to Sep 00**
  - **Now making ~400 observations/day**
  - **Contributing sensor to Space Surveillance Network (SSN)**
 - **Significant impact on SSN Deep Space (DS) performance**

Maui(Haleakala) Description

3.7 Meter Telescope
.8 Meter Telescope
1.6 Meter Telescope
.6 Meter Telescope
Maui
1.2 Meter Telescope

- **Located on Maui, Hawaii - Consists of the 3.7, 1.6, 1.2, .8 and .6 meter telescopes**
  - **Part of the Maui Space Surveillance Complex (MSSC) which includes Maui GEODSS**
  - **MSSS host and mission responsibilities to be transferred from AFSPC to Air Force Research Laboratory (AFRL), Oct 00**

3.7 Meter Mission and Description
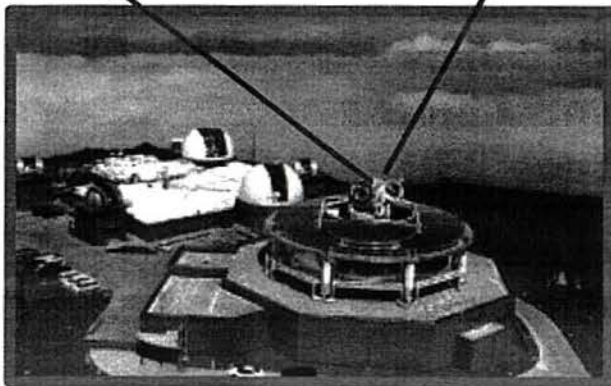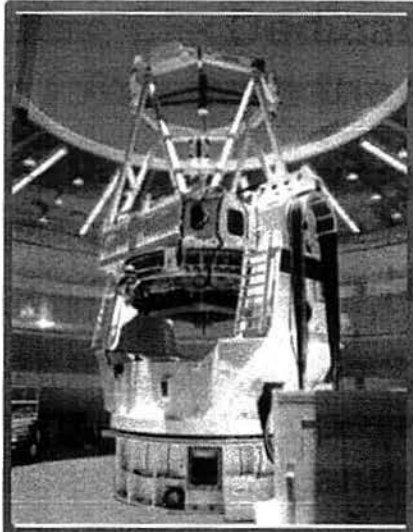
- **Dedicated Electro-Optical (E-O) telescope with the following major features**

  - **Adaptive Optics Imaging System provides high resolution imaging and metric data on Near Earth (NE) objects**

  - **Longwave Infrared (LWIR) sensor provides LWIR images / temperature maps and metric data on NE objects**

  - **Radiometric/photometric sensor provides visible Midwave Infrared (MWIR), LWIR and signature/temperature data on NE/Deep Space (DS) objects**

  - **System supports Space Intelligence through high resolution E-O SOI data**
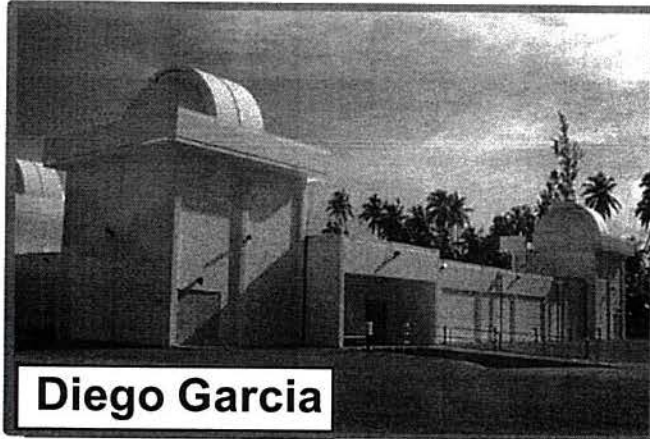
MOSS Description
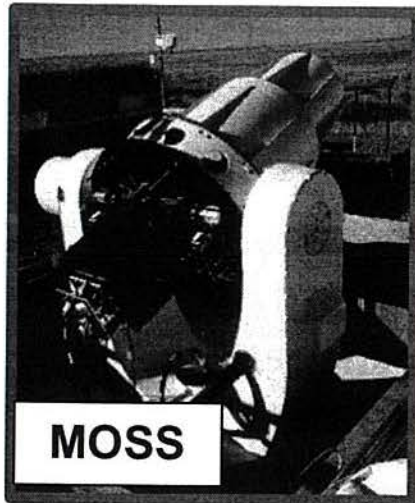
MOSS

- **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**
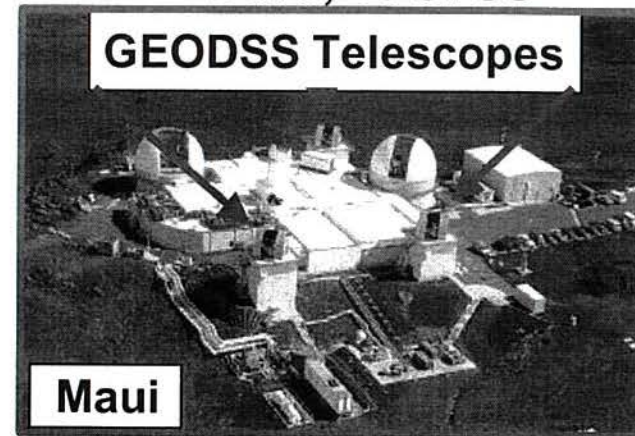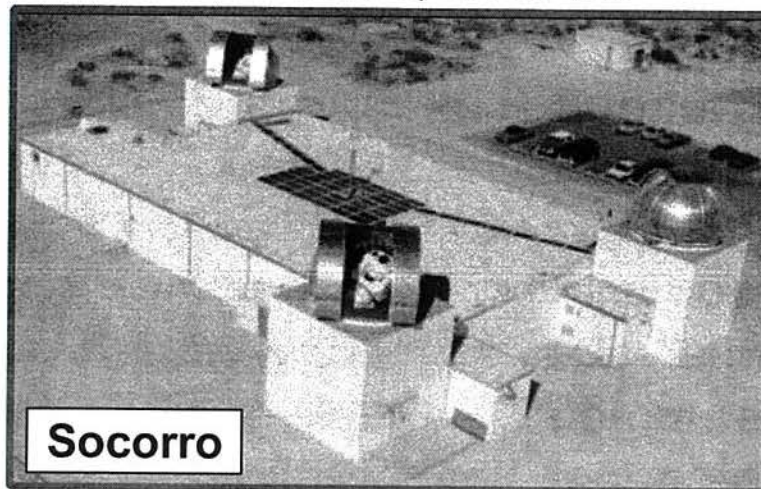
GEODSS Mission

Det 2, 18 SPSS

Diego Garcia

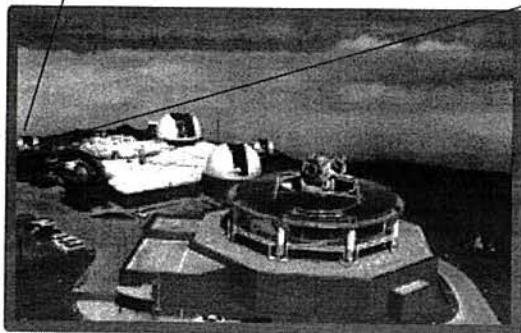## Det 3, 18 SPSS

GEODSS Telescopes

Maui

Det 1, 18 SPSS

Socorro

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

1/23/01

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**

GLOBUS II Mission
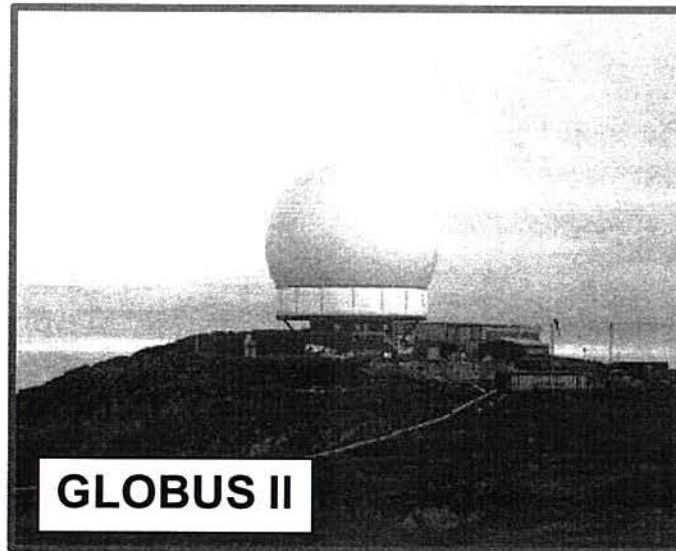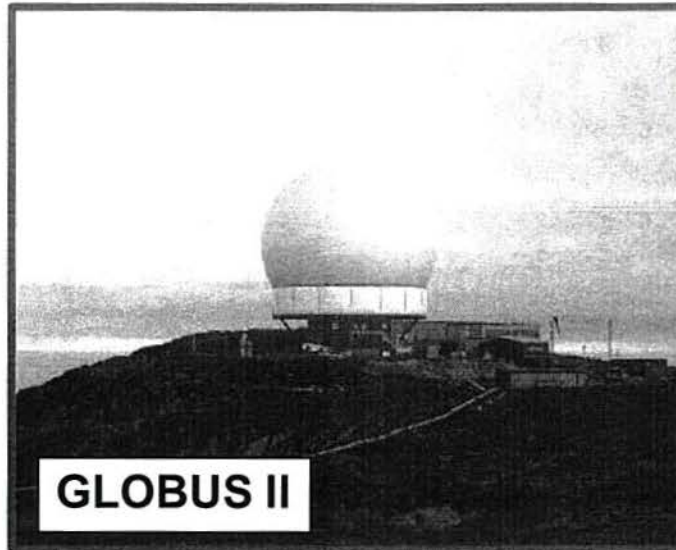

GLOBUS II

- **Primary: Space Surveillance**
- **GLOBUS II is expected to track 100 Deep Space (DS) objects per day**
    - **Expected to provide wideband Space Object Identification (SOI) imagery data on 3 DS objects per day**
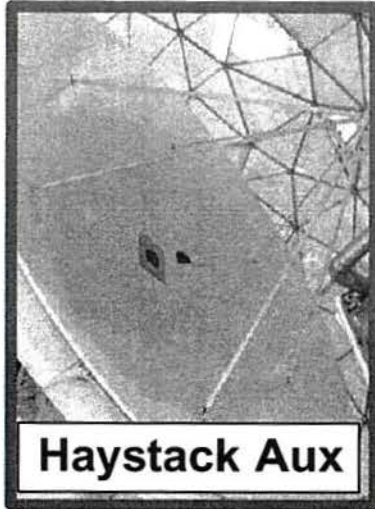   - **Numbers are based on studies, not actual data**

GLOBUS II Description

GLOBUS II

- **Globus II is a 27 meter mechanical tracker radar**
  - **Covers 0-360° in azimuth, 0-90° in elevation, and out to geostationary orbit in range**
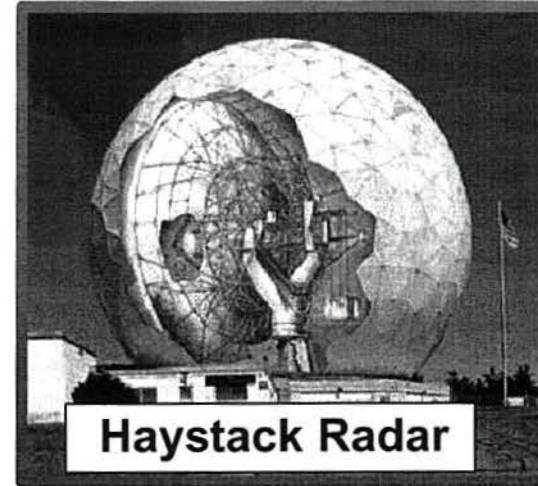
Haystack Aux

Haystack Radar

Millstone Hill Radar

- **Primary: Research and Development (R&D) of Space Surveillance techniques**
- **Secondary: Supports AFSPC as a contributing sensors**
    - **Millstone Hill Radar -- Near Earth (NE)/Deep Space (DS)**
    - **Haystack Radar -- NE/DS**
    - **Haystack Auxiliary (HAX) -- NE**

Haystack Radar Description
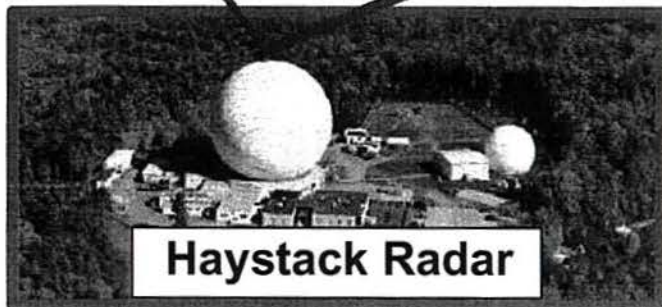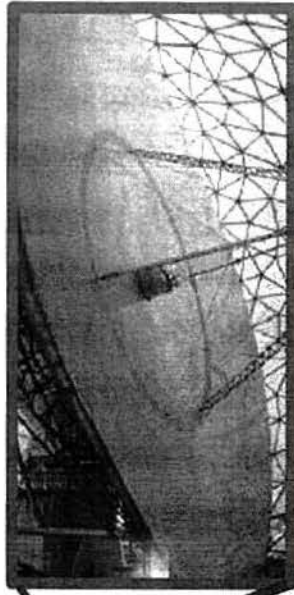

Haystack Radar

- **Haystack is a mechanical tracker**
- **Only sensor in the SSN capable of imaging NE and DS objects**
- **Provides images for Mission Payload Assessment (MPA) and satellite status determination**
  - **High resolution in NE (25 cm)**
  - **All weather day/night capability**
- **Conducts measurements of space debris to sizes of 1 cm (NASA)**
  - **NASA debris campaign**
- **Provides unique support for satellite anomaly resolution**

Millstone Hill Radar (MHR) Description
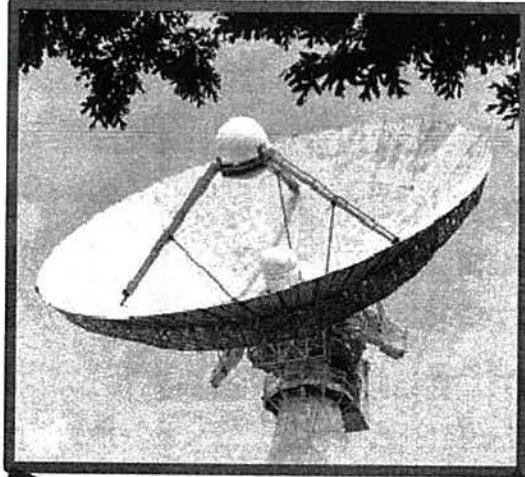
- **MHR is a mechanical tracker**
- **Built as a BMEWS prototype**
  - **First radar to track Sputnik 1957**
- **High power sensitive radar that routinely tracks DS satellites, rocket bodies and debris in the Geo belt**
- **High precision radar generates highly accurate orbital data**
  - **Provides Geo collision avoidance data to some commercial entities via Cooperative Research & Development Agreement (CRDA)**

Millstone Hill Radar

BMEWS Mission

Clear AFS, Alaska

Clear
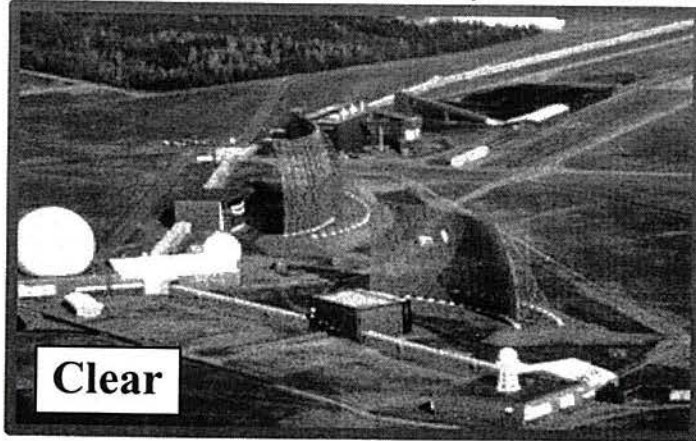
RAF Station Fylingdales, UK

Fylingdales

Thule AB, Greenland

Thule
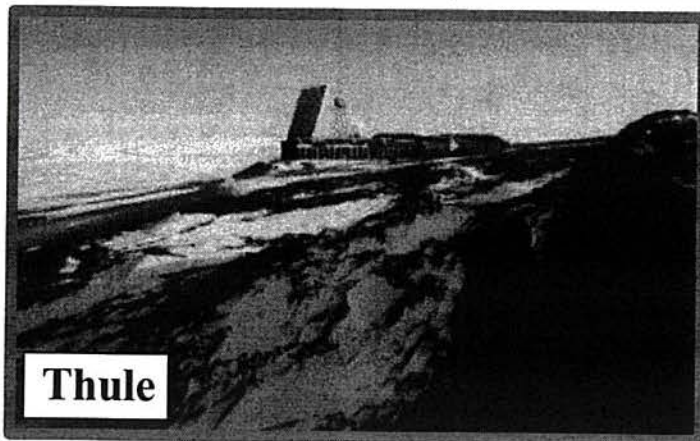
- **Primary: Missile Warning**
  - Provides ballistic missile warning and attack assessment of a ballistic missile raid against CONUS, Alaska and Southern Canada

- **Secondary: Space Surveillance**
  - Supports SSN as collateral sensors

Clear Mission

Clear

Clear Upgrade
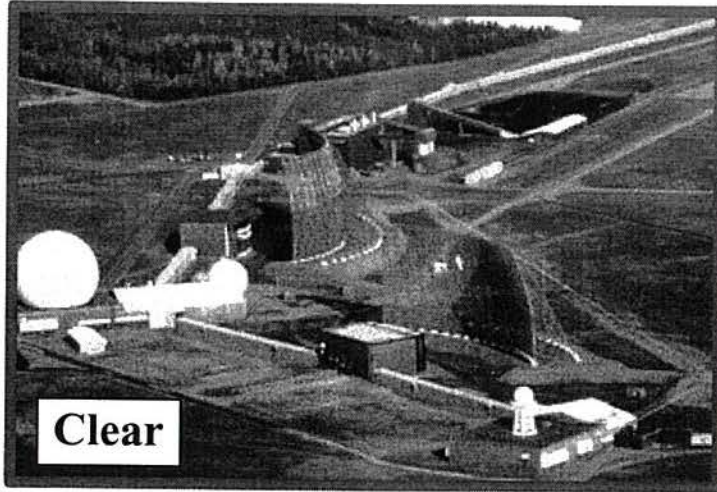
- **Primary Mission: Provide tactical warning and attack assessment of a ballistic missile attack against CONUS and southern Canada**

- **Secondary Mission: Support Space Surveillance as collateral mission**

Fylingdales Mission

Fylingdales

- **Primary Mission: Provides warning of an IRBM, MRBM, or SLBM against UK and Western Europe**
- **Secondary Mission: Provides warning of an ICBM/SLBM attack against CONUS**
- **Tertiary Mission: Space Surveillance as collateral mission**

Thule Mission

Thule

- **Primary Mission: Provides tactical warning and attack assessment of SLBM and ICBM attacks against CONUS and Canada**

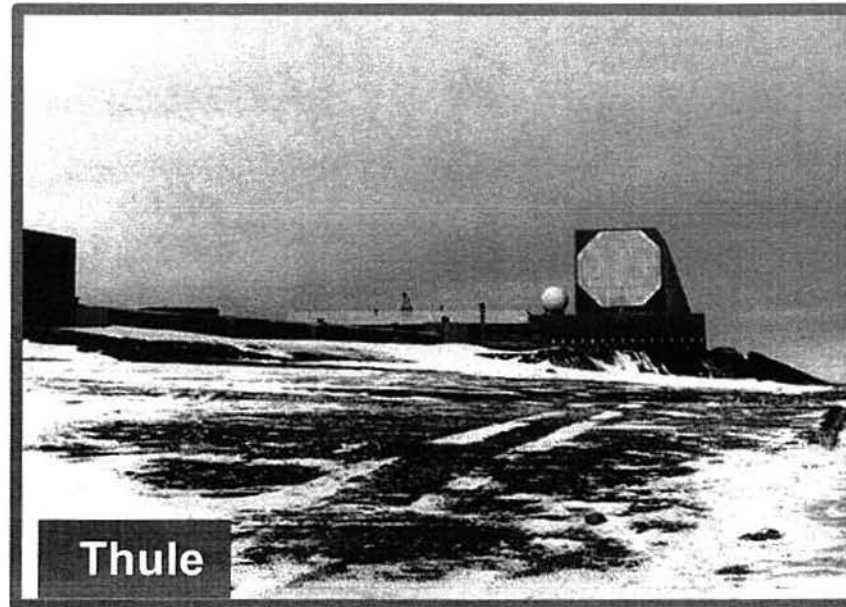- **Secondary Mission: Supports Space Surveillance as collateral mission**

Cavalier Mission

Cavalier
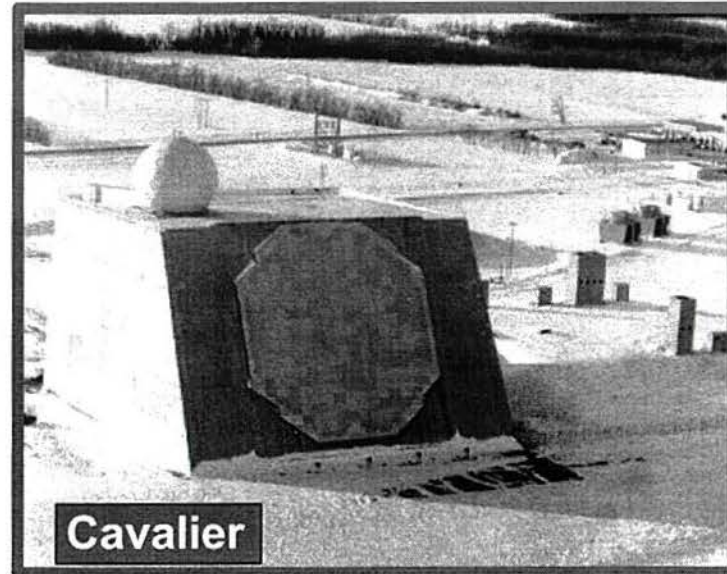
- **Primary: Missile Warning**
  - Provides Warning and Attack Characterization of ICBM/SLBM attack against the CONUS and Southern Canada
- **Secondary: Space Surveillance**
  - Supports SSN as a collateral sensor

Eglin Mission

Eglin

- **Primary Mission: Spacetrack as dedicated sensor**
  - Tracks 4,257 NE and 357 DS objects per day per Jan 00 Space Surveillance Analysis Tool (SSPAT)

Eglin

Transmitter   Receiver
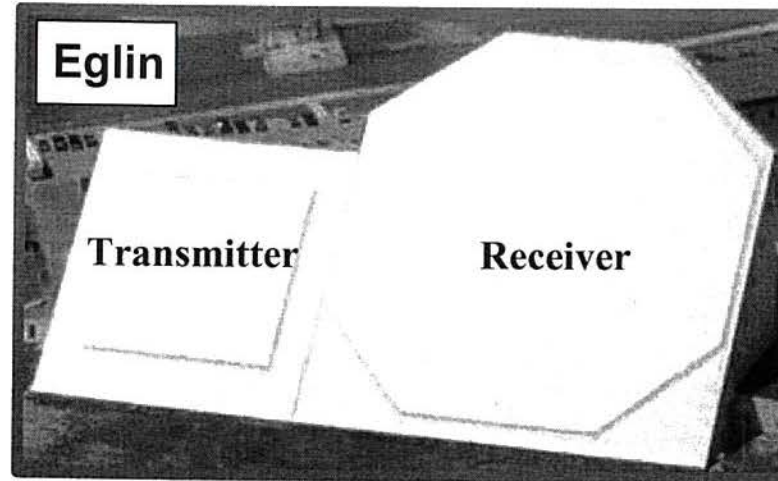
- **One of a kind phased array radar with a separate transmitter and receiver face**
  - **Covers 120^0 in azimuth and in excess of 22,000 NM in range**
  - **Has capability to track small objects**
  - **Only dedicated space surveillance phased array radar**

MMW Description

MMW

MMW
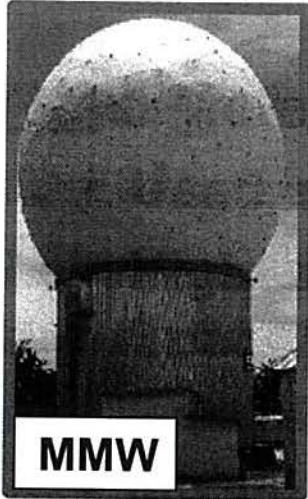
- **MilliMeter Wave (MMW) Radar**
  - **Used exclusively for SOI collection**
  - **Highest Resolution Imaging radar in Space Surveillance Network (SSN)**
    - **12-25 cm resolution**
  - **Missions supported**
    - **Imaging of new launches**
    - **Satellite anomaly resolution**

NAVSPACE Fence Mission
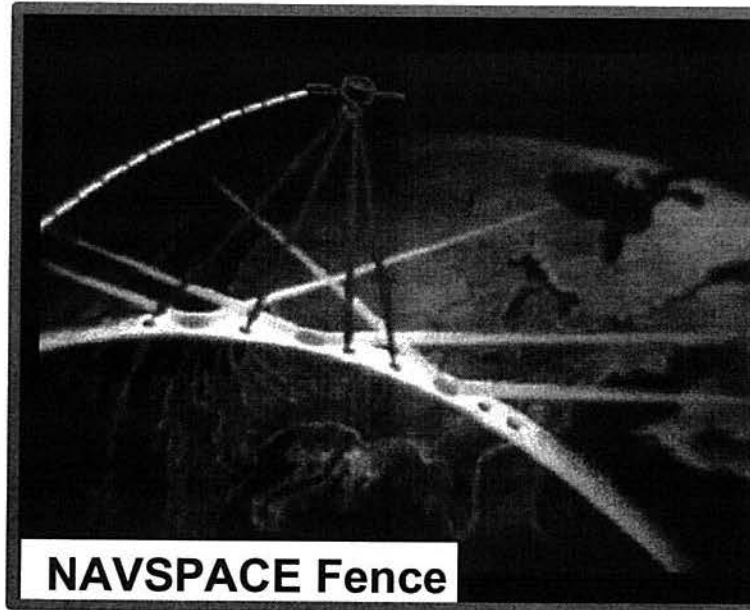
NAVSPACE Fence

- **Primary: Space Surveillance**
  - Provides up to date satellite orbital elements to Fleet and Fleet Marine forces
  - Supports US Space Command as part of nation's worldwide Space Surveillance Network

NAVSPACE Fence Description

NAVSPACE Fence Sensor Locations
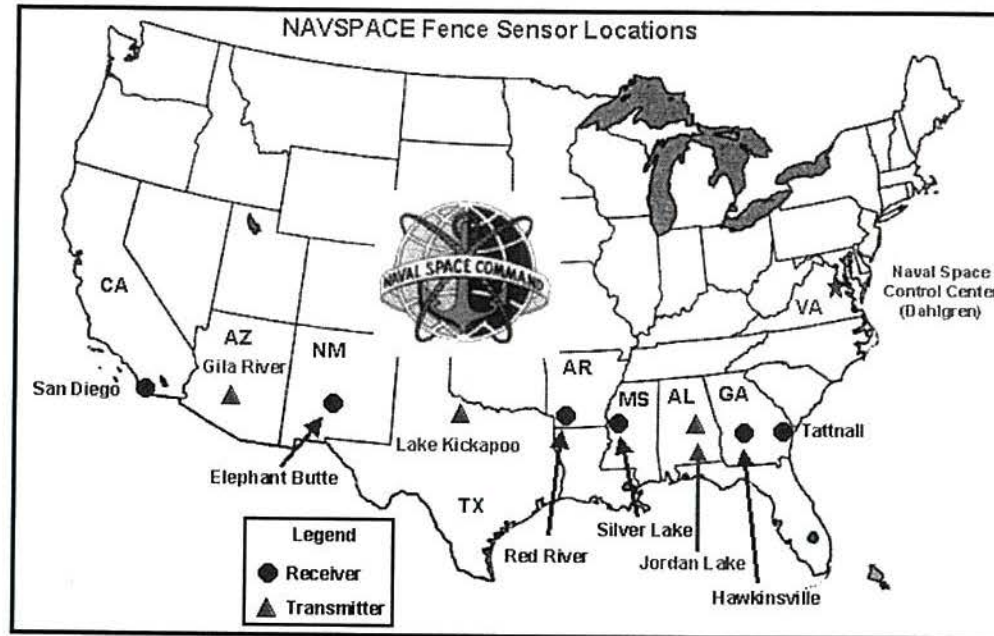
- **Comprised of three transmitters and six receivers located along the 33rd parallel**
- **Transmits a continuous electronic fence straight up into space**
- **Relays unknown detections to Eglin Phased Array for further refined processing**

PAVE PAWS Description

6 SWS, Cape Cod AFS, MA

Cape Cod

7 SWS, Beale AFB, CA

Beale

- **Both Beale and Cape Cod are dual face Solid State Phased Array Radars (SSPAR)**
  - **Both radars cover 240⁰ in azimuth and in excess of   2,800 NM in range**
  - **At extreme range, both radars can detect objects the size of an automobile - smaller at closer ranges**

Range Radar Mission
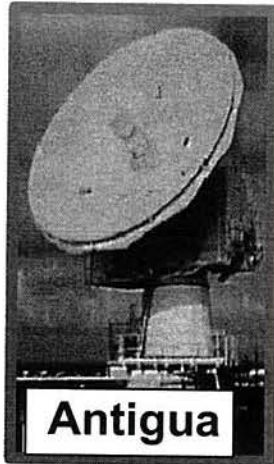
Antigua
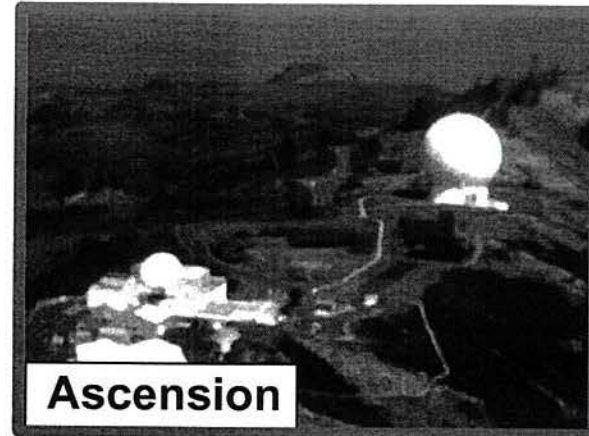
Ascension
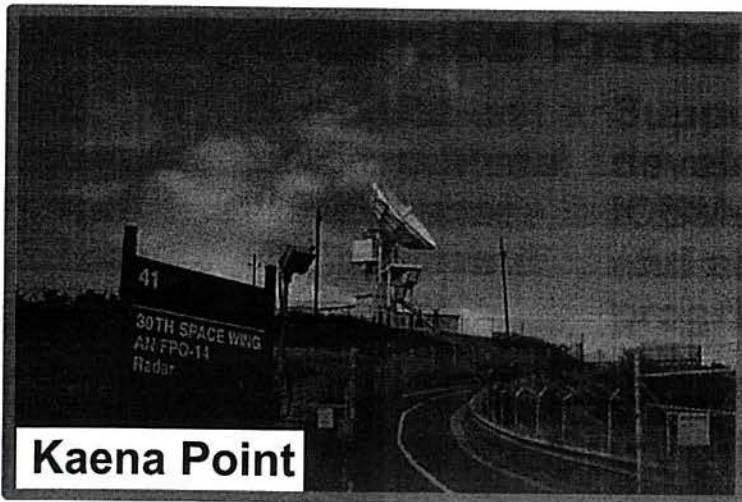
Kaena Point

- **Primary: Range Support**
  - **Supports test and evaluation of developmental and operational ICBMs, space launch vehicles and aeronautical development programs**

- **Secondary: Space Surveillance**
  - **Support of SSN as collateral Near Earth (NE) sensors**

Cobra Dane Radar
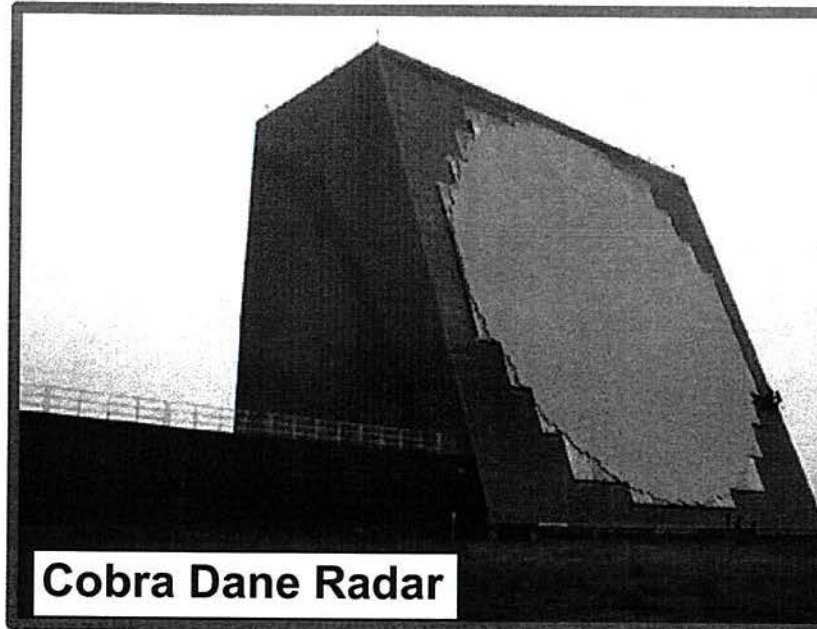
- **Primary: Intelligence**

  - **Supports Treaty Verification of Soviet ICBM & SLBMs**

- **Secondary: Space Surveillance**

  - **Supports SSN on limited basis**

  - **Highly valuable for tracking priority events**

1/23/01

Shemya Description
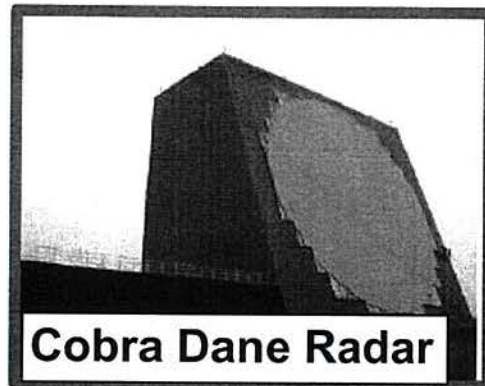
Eareckson AS
Shemya Island, Alaska

Cobra Dane Radar

- **Located on Shemya Island, Alaska**

- **Cobra Dane is a single face Phased Array radar originally designed to monitor Soviet ICBM & SLBM tests**

- **Discontinued MW and Space Surveillance in 1994**

- **Recommissioned as a Space Surveillance asset in 1999**

Near Earth Tracking Percentages
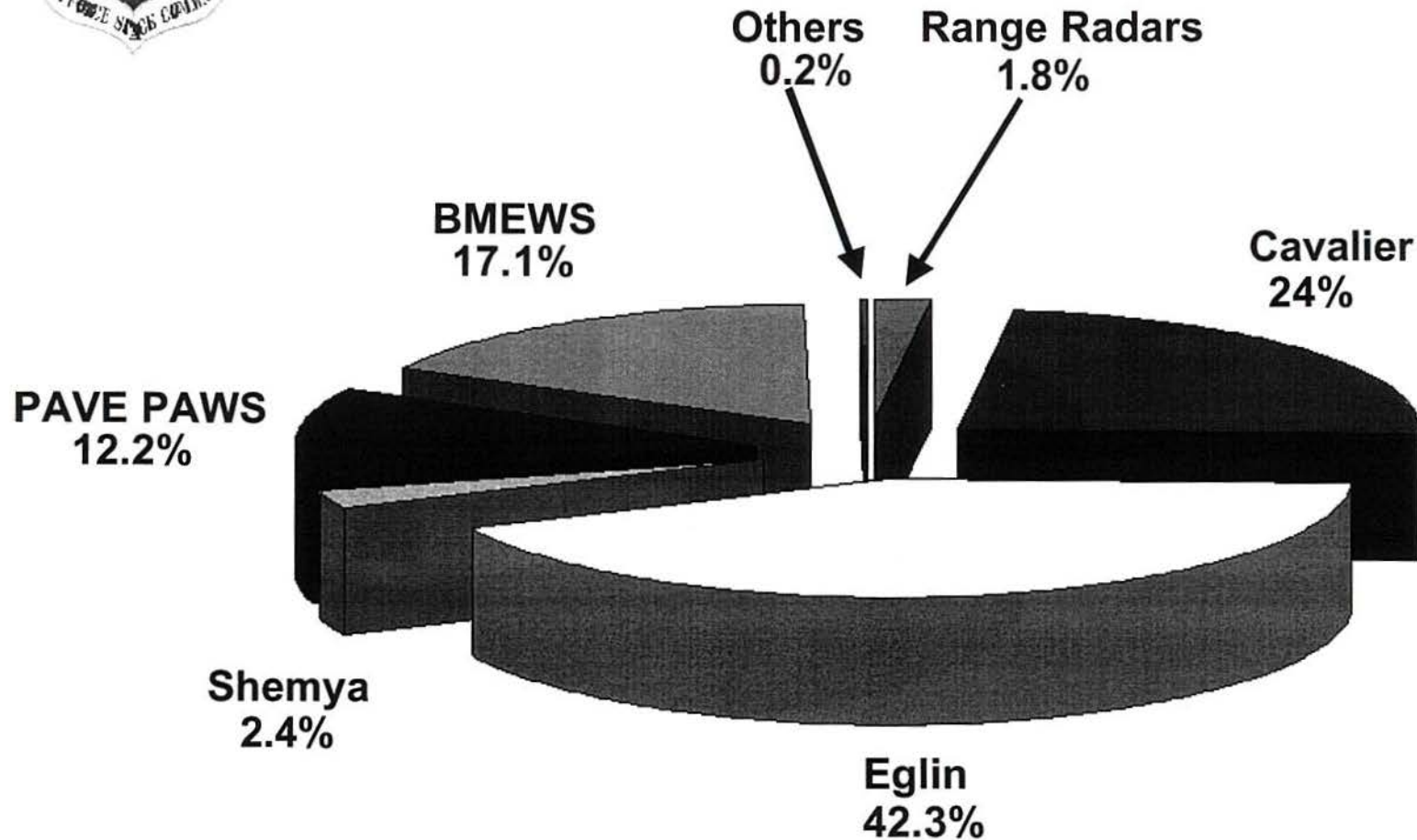
Others
0.2%

Range Radars
1.8%

BMEWS
17.1%

Cavalier
24%

PAVE PAWS
12.2%

Shemya
2.4%

Eglin
42.3%

Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

Deep Space Tracking Percentages
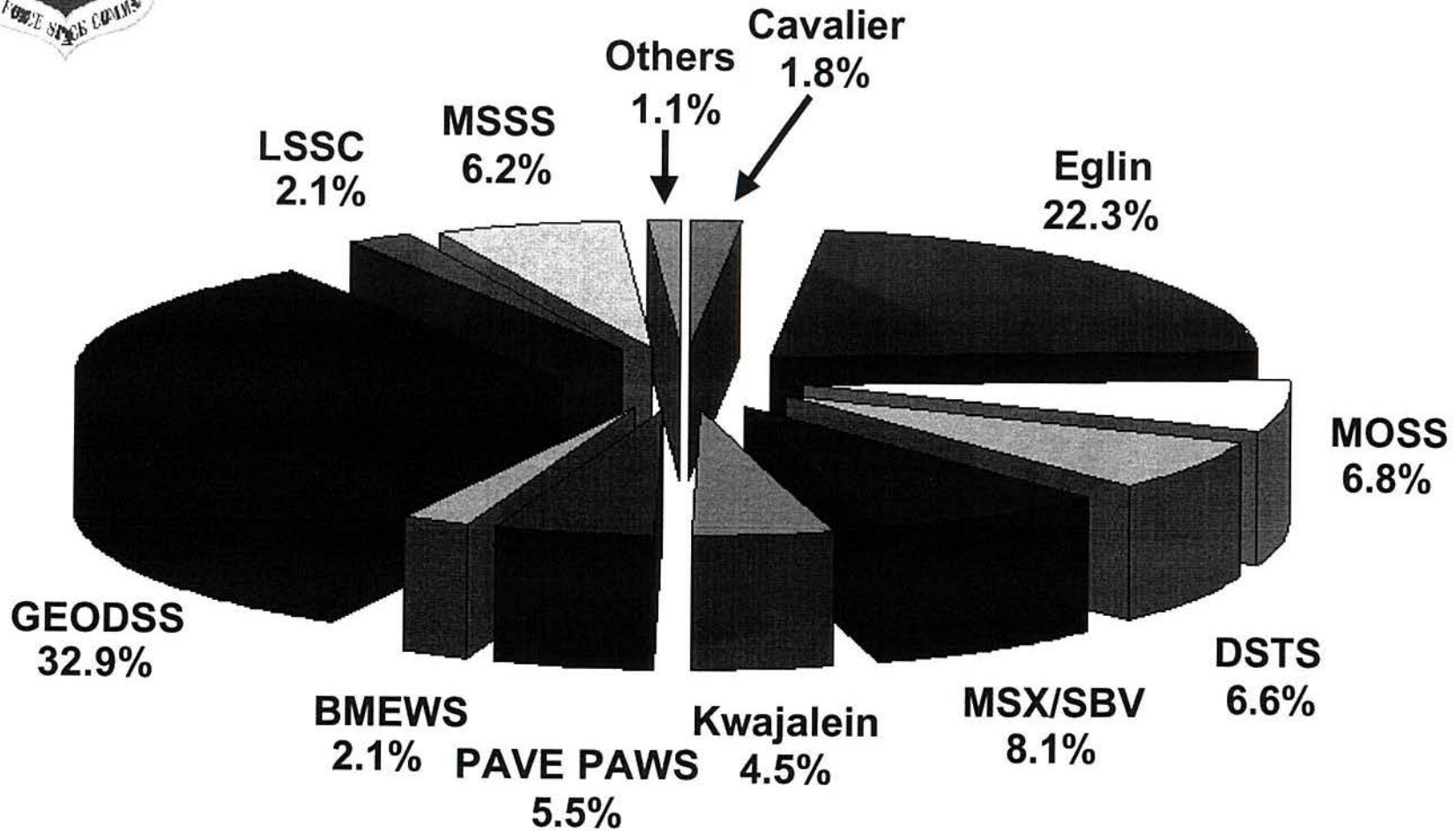
Others 1.1%

Cavalier 1.8%

MSSS 6.2%

LSSC 2.1%

Eglin 22.3%

MOSS 6.8%

GEODSS 32.9%

DSTS 6.6%

BMEWS 2.1%

Kwajalein 4.5%

MSX/SBV 8.1%

PAVE PAWS 5.5%

Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

1/23/01

Geosynchronous Tracking Percentages
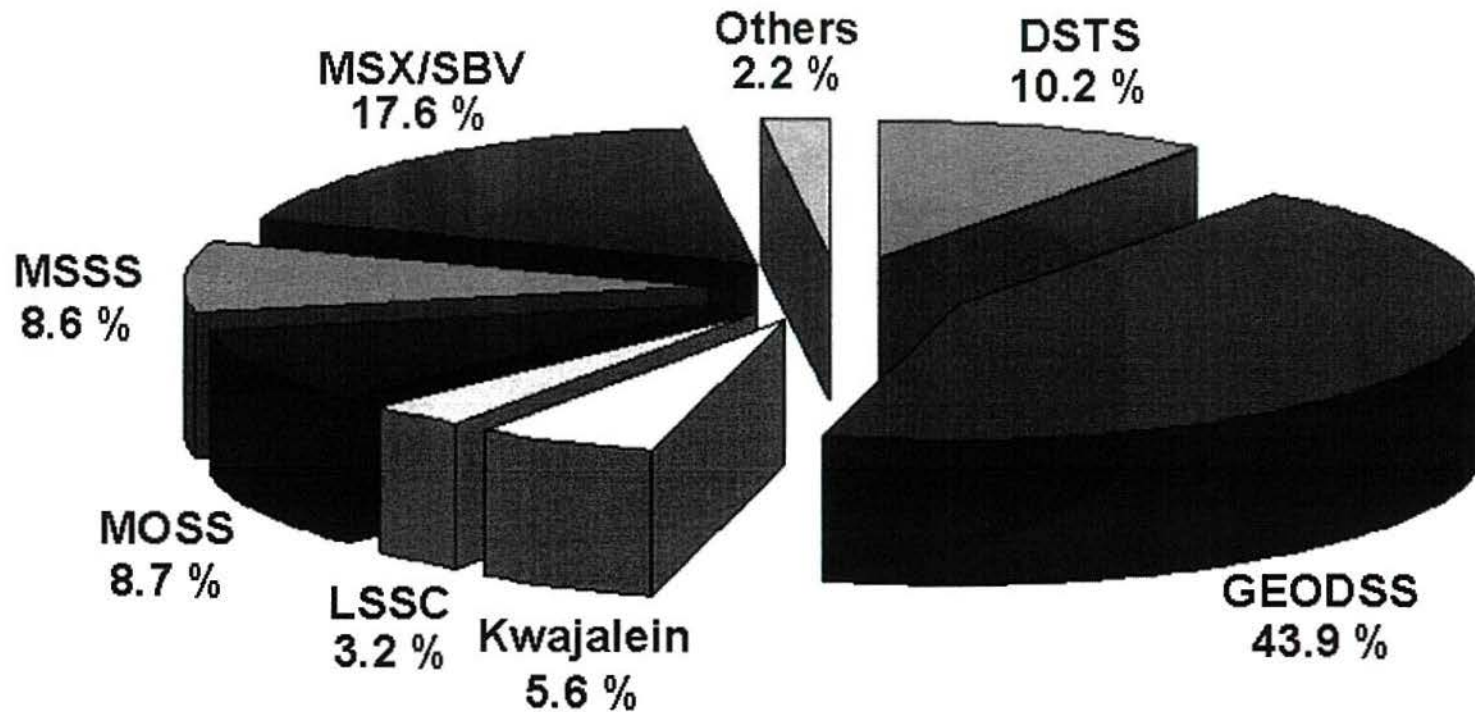
Others
2.2 %

DSTS
10.2 %

MSX/SBV
17.6 %

MSSS
8.6 %

MOSS
8.7 %

LSSC
3.2 %

Kwajalein
5.6 %

GEODSS
43.9 %

Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

Current Catalog

Satellites - 2671

Space
Probes - 90

Debris - 6096

Total - 8927

Position estimates

- **Positions are calculated from a model of orbital motion.**

- **Orbital perturbations are included.**
  - **General perturbations**
    - **average atmosphere , 3-body, gravity models**
      - **J2 and J3 components of gravity model**
  - **Special perturbations**
    - **General + detailed atmosphere, better solar**

- **Element sets are generated to predict future motion**
  - **Include average motion and time derivatives**
  - **Production delay may be 3-4 days**
  - **Format based on 80 column IBM card**

Element sets and accuracy

- ## Useful in calculating positions to ~1km accuracy
- ## Not all parameters are explicit
  - ### Major axis is calculated from other parameters
    - e.g. revs per day and eccentricity
  - ### Least squares analysis sometimes replaces physics
  - ### Parameters frequently derived from measurements on other satellites
    - Some quantities, such as atmosphere and solar effects are not directly measured
      - Results are based on analysis
  - ### Some sensors have systematic errors

- **Satellites with known mass, area, etc. are used to calibrate the system.**

- **Laser ranging is employed for satellites with corner cubes.**

- **Ajisai(EGP), Starlette, ERS-1, ERS-2, Topex/Poseidon**
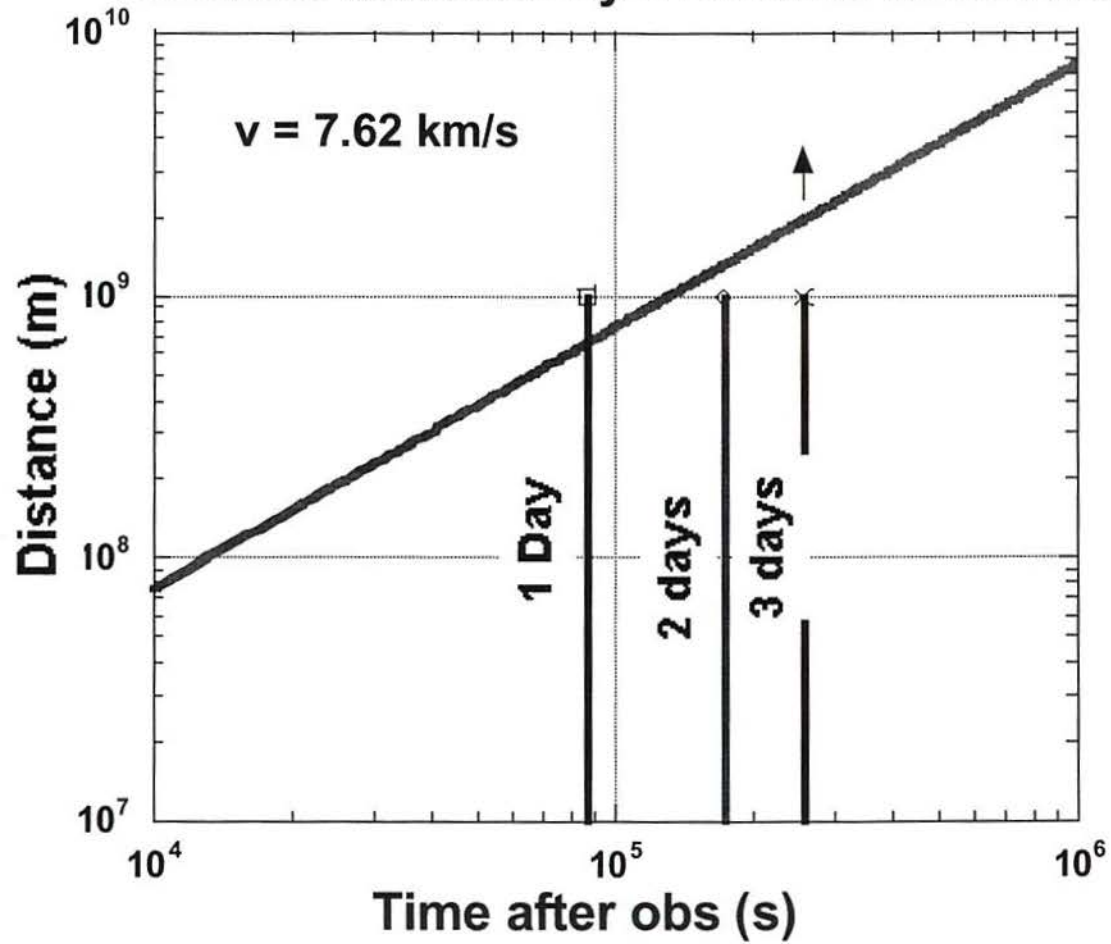 - **SLR measurements to cm accuracy**

Requirements for measurement accuracy

- **Consider quantities, such as velocity, based on radius measurement**

- **Derive required accuracy from simple orbital considerations**

- **Major errors are in sensors and in atmosphere**

- **Errors in calculated positions should be ~1 meter for future applications**
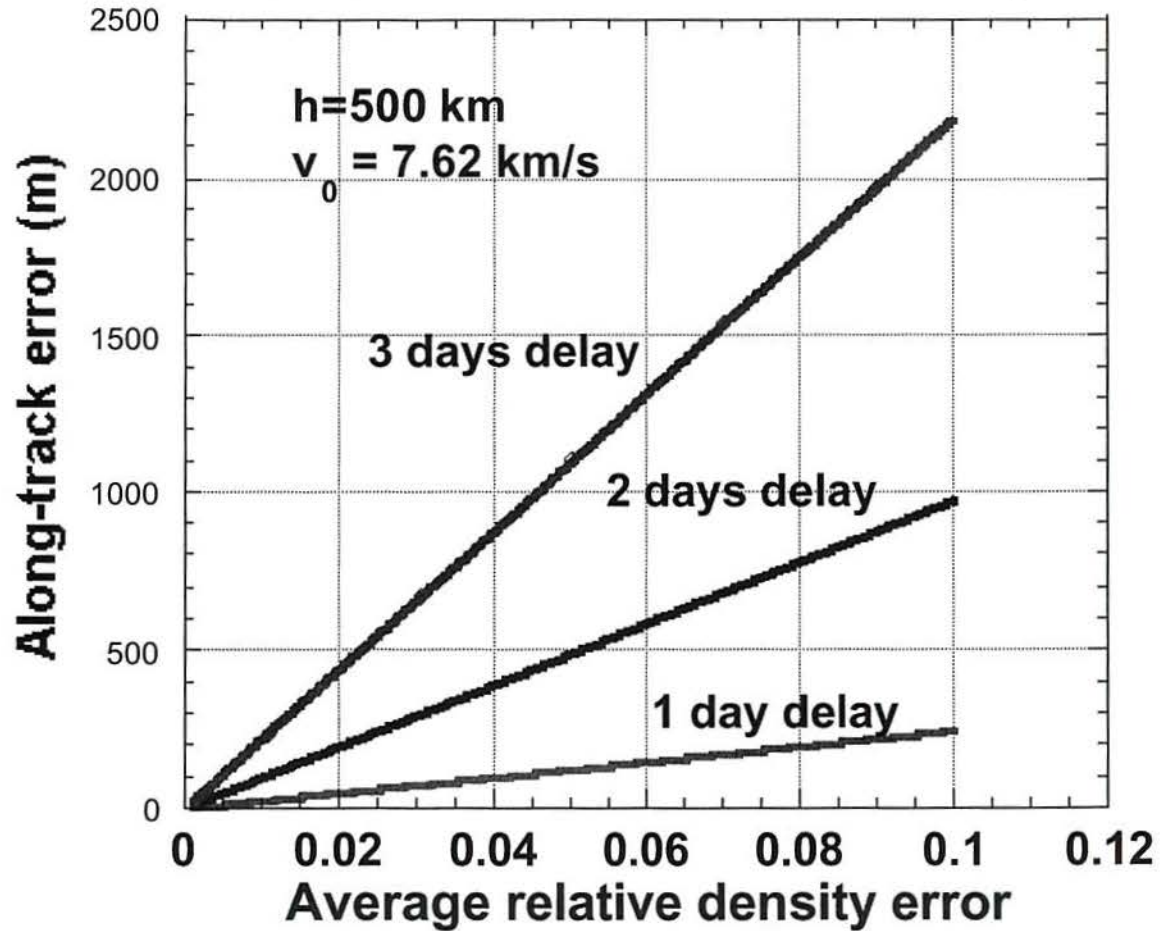
Distance travelled by a satellite at 500 km

$v = 7.62$ km/s

Distance (m) vs Time after obs (s)

1 Day
2 days
3 days

Air density contributes to error

Position error as a function of density error

h=500 km
$v_0 = 7.62$ km/s

3 days delay

2 days delay

1 day delay

Along-track error (m) — Average relative density error

Position error after a given delay time

Data 3

Along-track position error (m) vs radius measurement error (m)

- 3 day delay
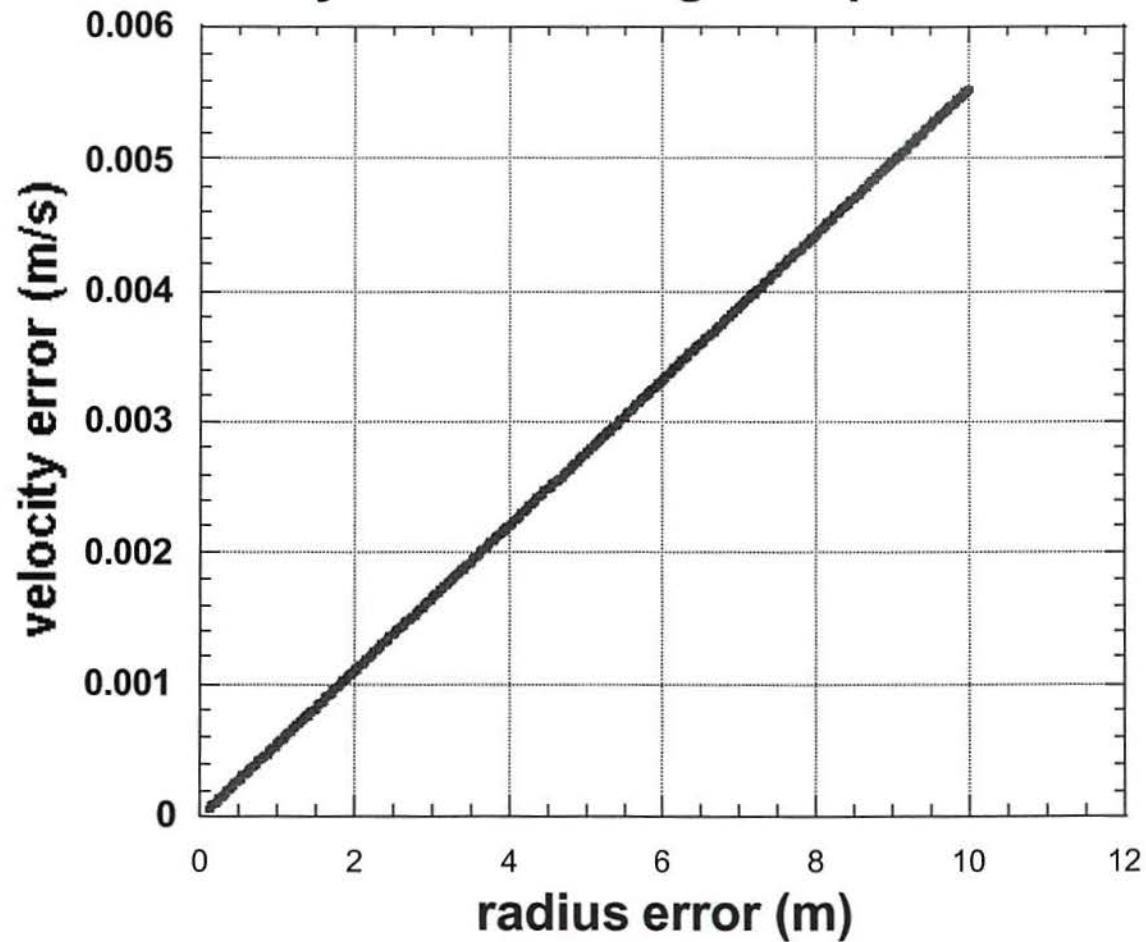- 2 day delay
- 1 day delay
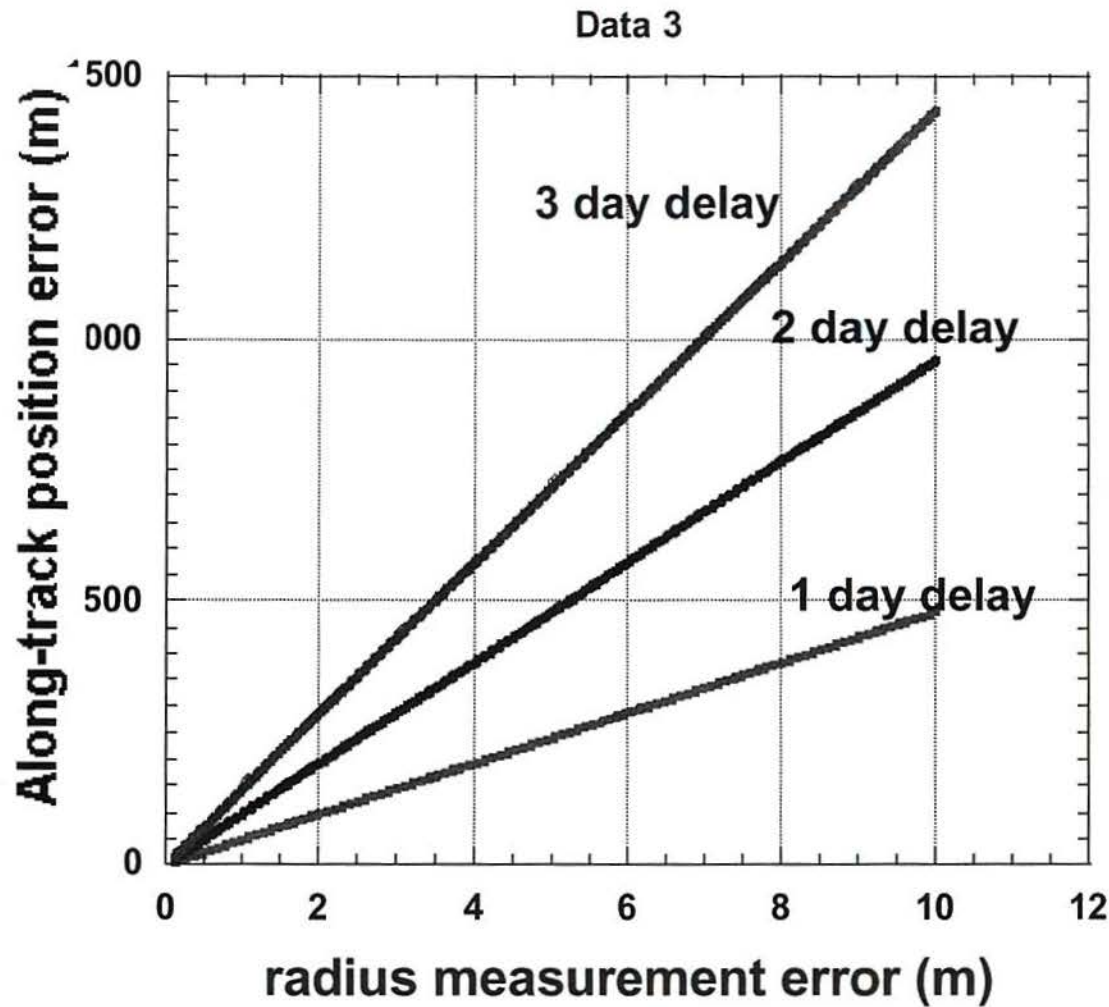
Error grows rapidly as a function of measurement error

Data 3
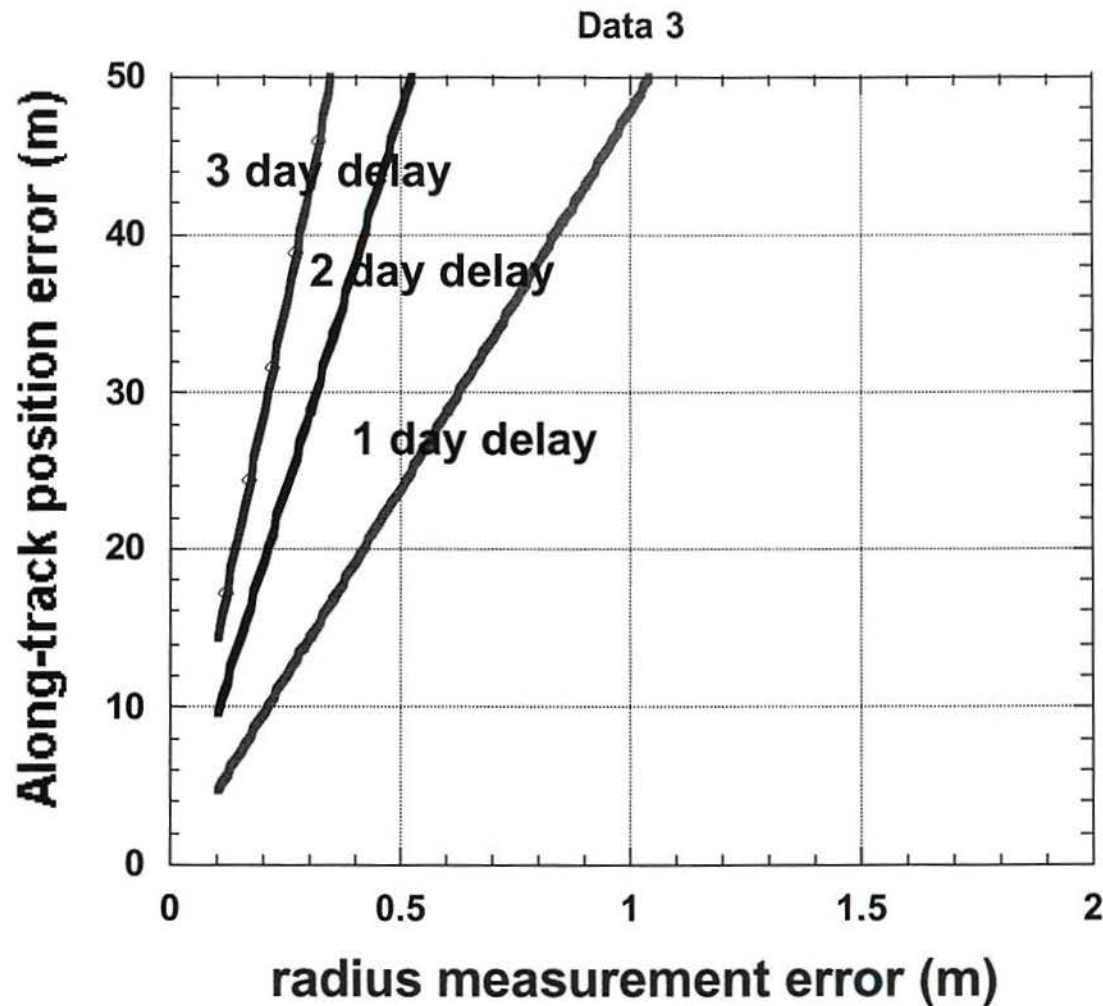
Error in range measurement is important

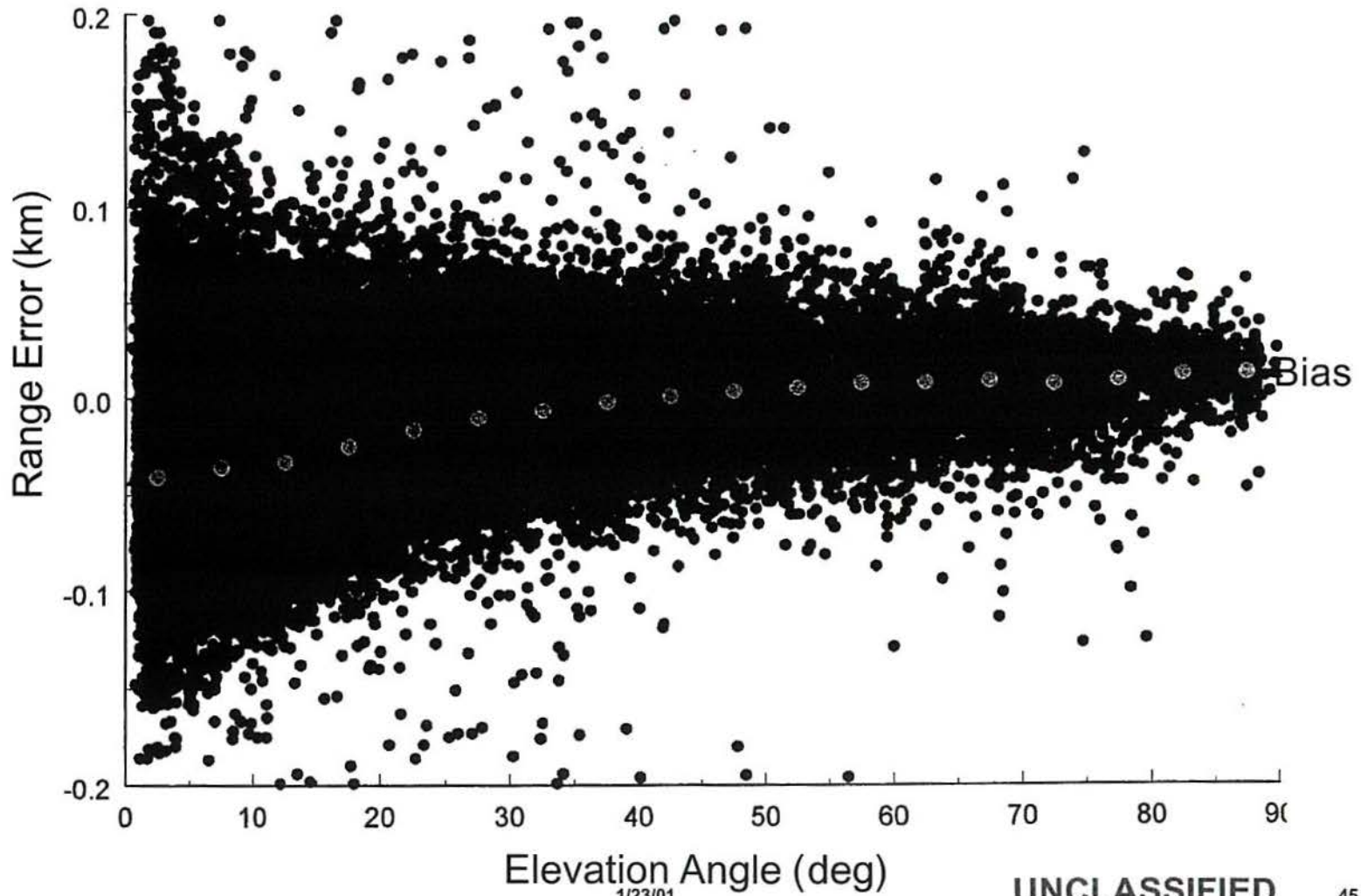## Velocity error resulting from position error

Some errors decrease with successive measurements

- **Element sets also include first and second derivatives of mean motion**

- **Drag coefficient is determined, but atmosphere is still an issue.**

- **How inaccurate are the initial measurements?**
  - **SLR range error is insignificant**
  - **Radar measurements may have significant error**
    - **Systematic range**
    - **Ionosphere and troposphere**
    - **Elevation**

Range residuals from Eglin Observations

Range residuals plot: Range Error (km) vs Elevation Angle (deg), with a "Bias" curve labeled near 0.0 km.
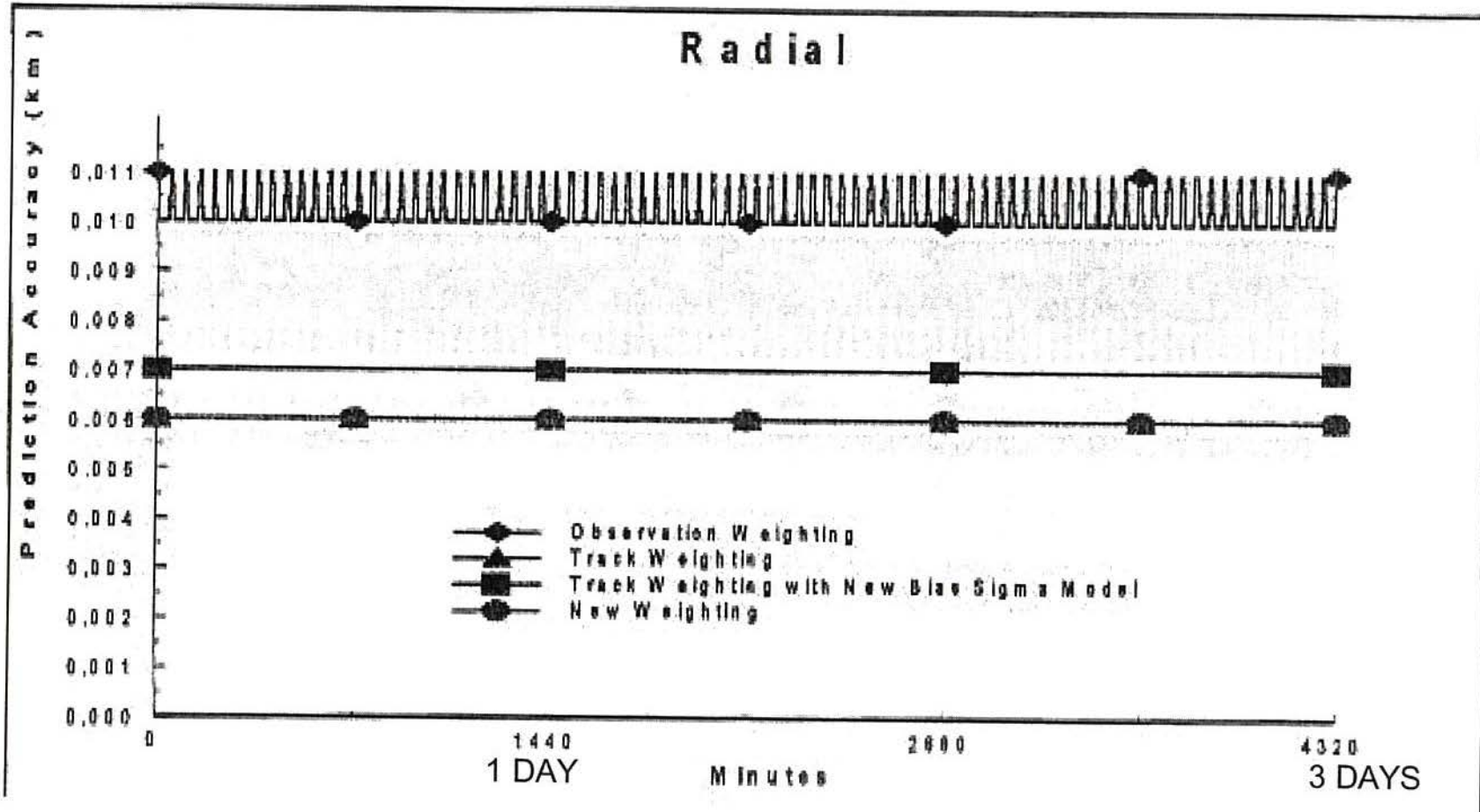
Special perturbation results

- **Calculate errors as a function of time**

New methods improve accuracy

Starlette - Calibration Tasking

R a d i a l

Prediction Accuracy (km)

0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000

Observation Weighting
Track Weighting
Track Weighting with New Bias Sigma Model
New Weighting

0   1440   2880   4320

1 DAY   Minutes   3 DAYS

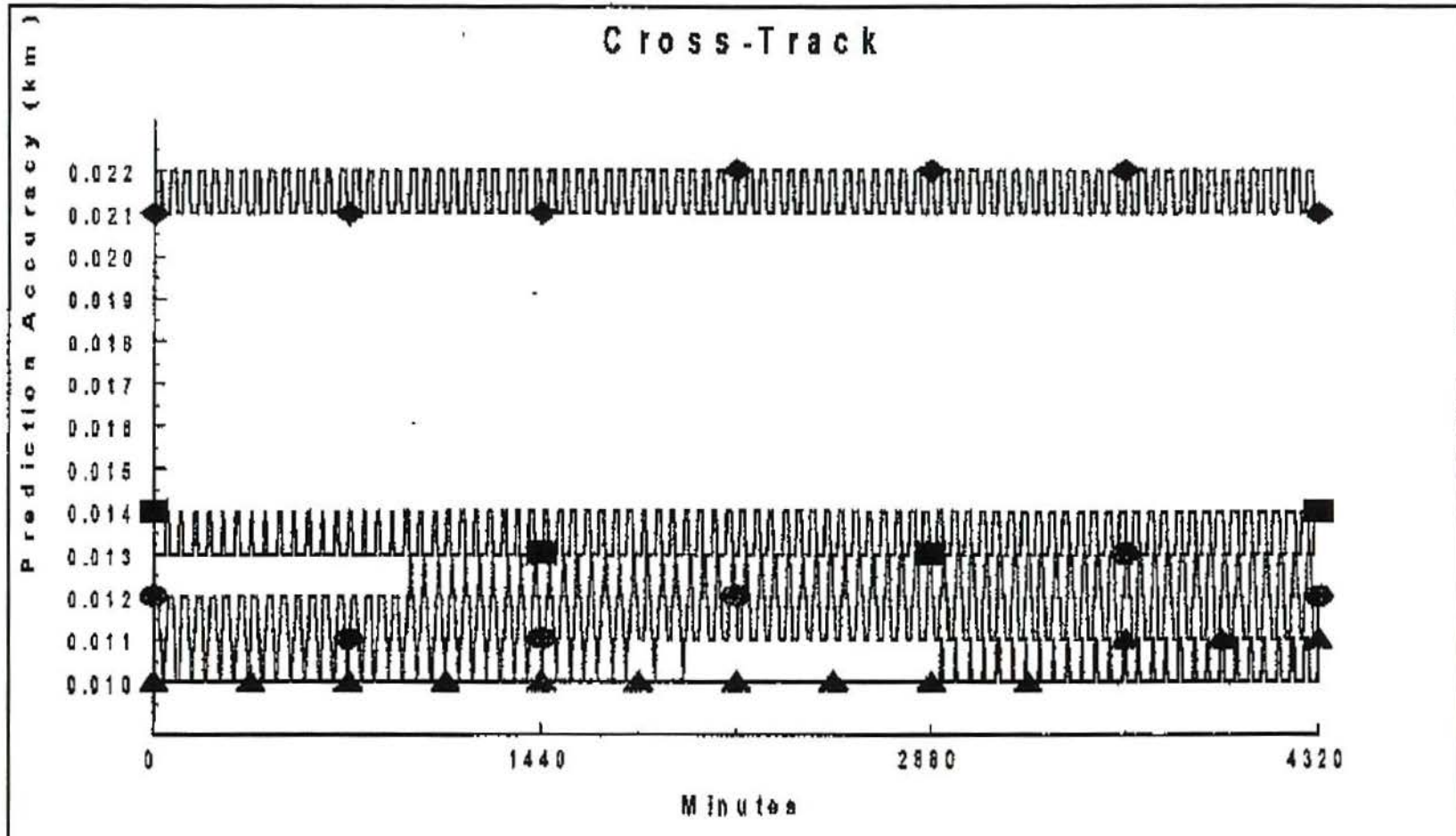# *Improved, but not yet adequate*

In-Track
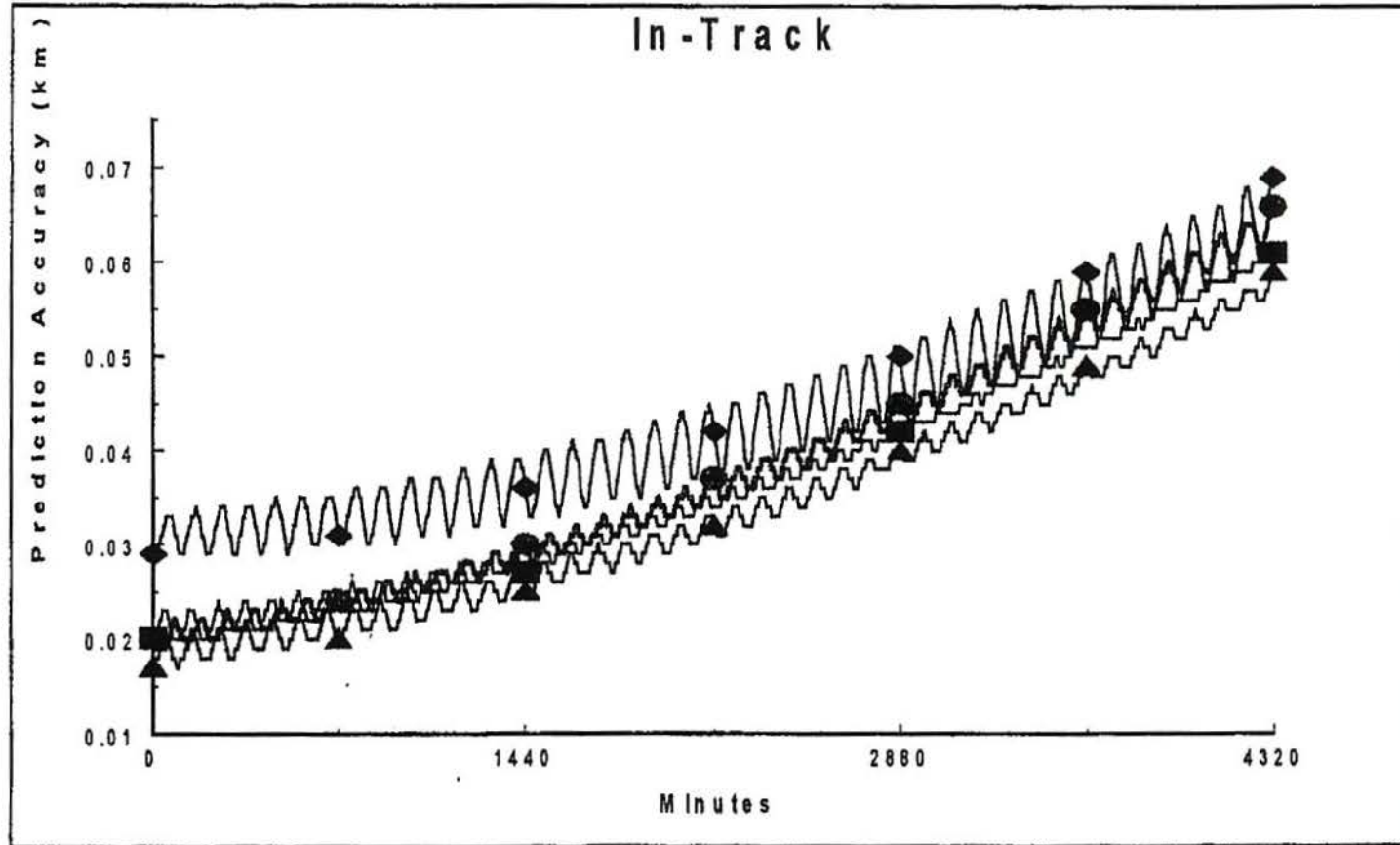
Crosstrack accuracy improved

Cross-Track

- **Improved calculational techniques have improved accuracy significantly.**

- **Accuracy is still inadequate for 21st century applications.**
  - **E.g. autonomous docking and servicing**
  - **Collision avoidance for robotic vehicles**
- **SLR measurements improve ranging accuracy**

Suggestions(personal, not official)

- **Add laser ranging measurements at selected sites**
  - **SLR sites are inexpensive**
  - **Enough real estate exists at many sites for two SLR systems.**
    - **Eglin**
    - **Clear**
    - **Thule**
    - **Socorro**
- **Increase element set update rate**
- **Set goal of 1 meter prediction accuracy at end of 24 hours.**

- **Improvements in orbit predictive capability since 1997 are striking.**

- **Work is ongoing**

- **Reentry point and time are still issues.**

- **Number of observations is adequate.**

- **Accuracy should be improved.**