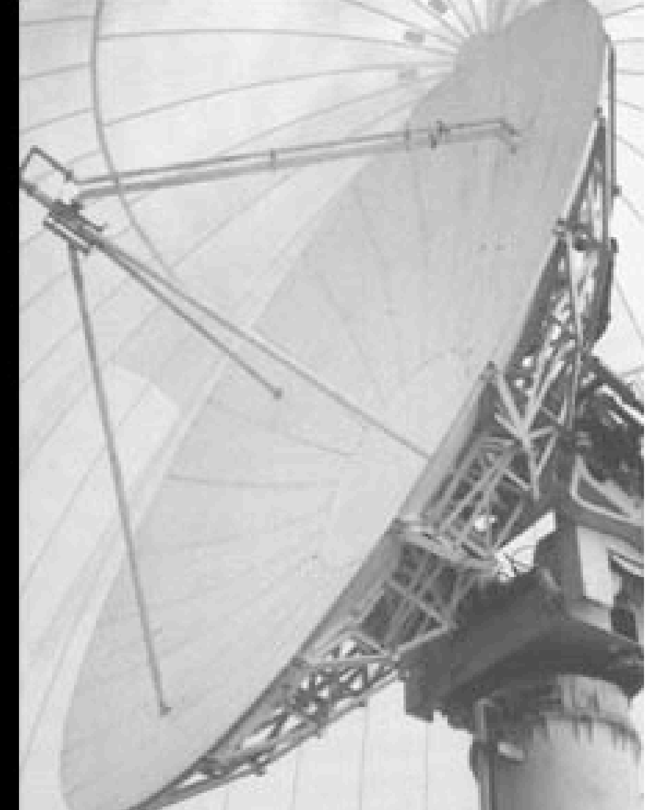
Implementation of a Dish Radar Bias Model for Conjunction Assessment Simulation



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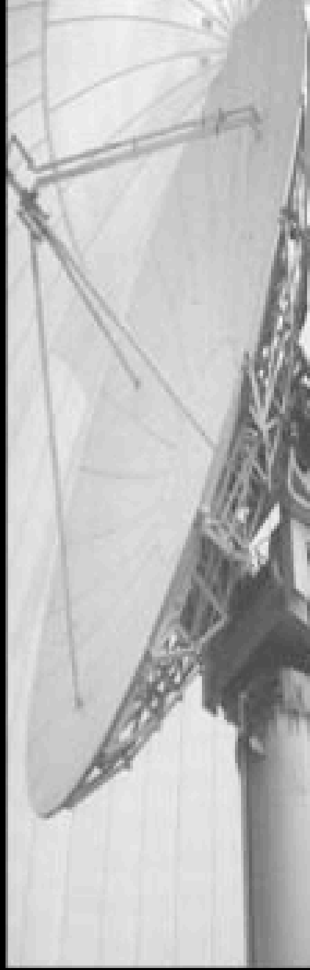
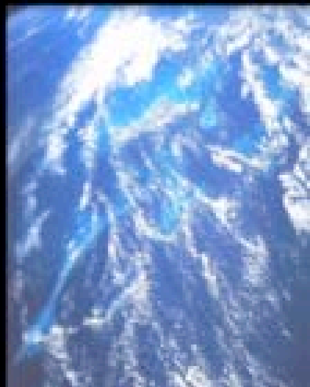
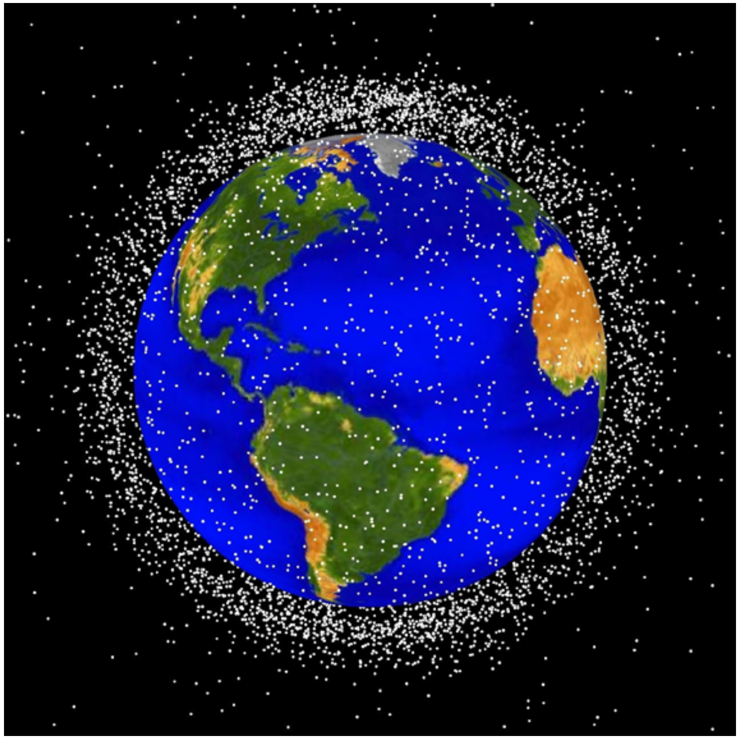


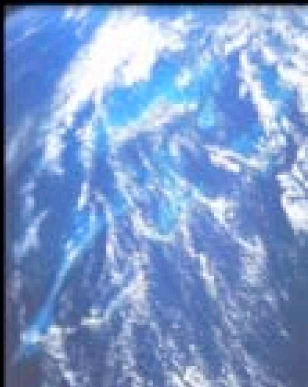


Introduction

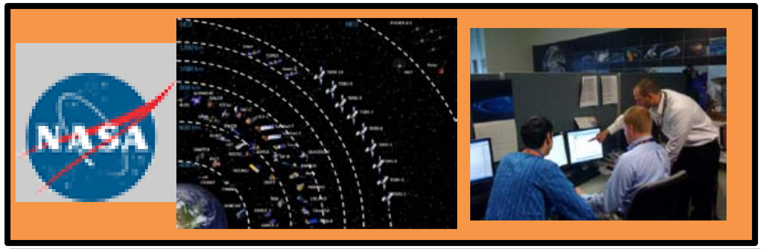


- Orbital debris poses threat to long term sustainability of space operations.

- Orbital debris mitigation efforts are in place
  - U.S. Space Policy
  - NASA policy
    - CARA



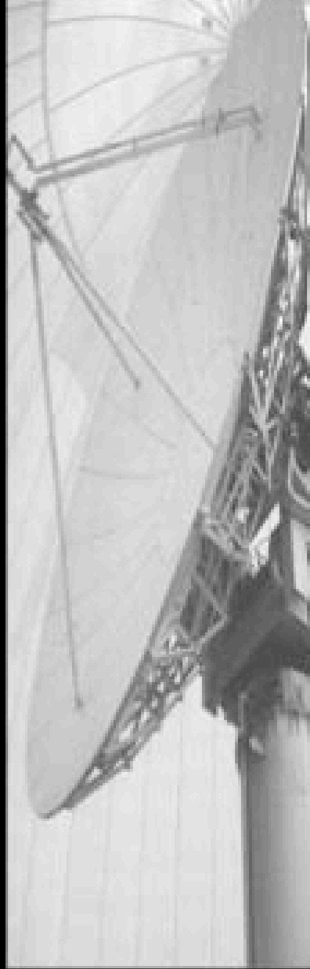
NASA CARA Process

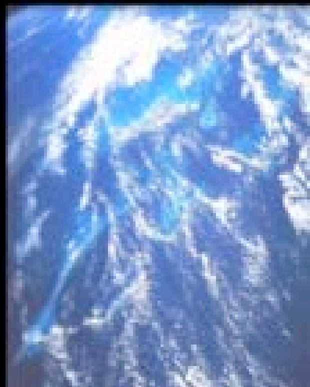


	JSpOC (VAFB)	NASA Robotic CARA Team (NASA GSFC)	Mission Operations Teams (Global)
Area of Responsibility	• Maintain High Accuracy Space Object Catalog • Interface with Space Surveillance Network • Request Increase Tracking Data Collects	•Perform CA Risk Analysis •Quantify Collision Risk •Compute Pc •Interface with JSpOC analysts to ensure data product delivery •Assist Mission Operations Teams with avoidance maneuver strategy	• Provide ephemeris (state & covariance) to NASA Robotic CARA Team for evaluation • Weigh CA event risk against other mission risks
Products	• Generate daily close approach predictions • Provide state and state uncertainty information for primary and secondary objects • Provide miss distance Summaries • Provide object tracking information	• Conjunction event trending • Qualitative assessment of orbit determination solutions • Conjunction geometry examination • Recommendations to Mission Operations Team	• Avoidance maneuver planning • Maneuver execution

Problem Definition

A simulation that accounts for all the data items affecting the trajectory as the TCA nears is needed to improve event characterization





CA TCA Characterization Simulation

Modules:

Tracking simulation

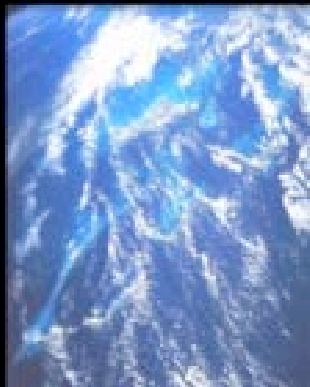
Observation noise

Sensor detectability

Orbit determination

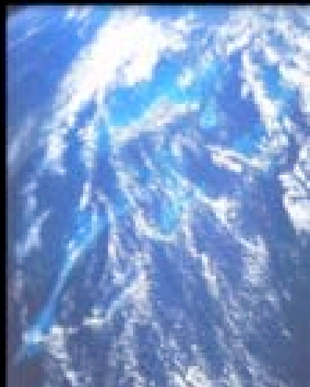
Pc calculation

Monte Carlo framework



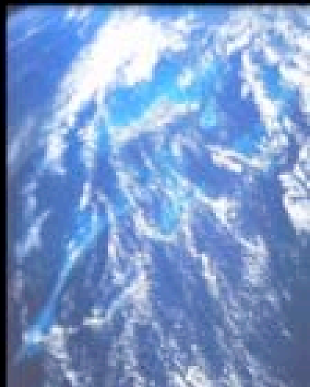
Research Objective

To describe the implementation of the model used for the calibration of equipment-induced systematic biases found in dish radars.



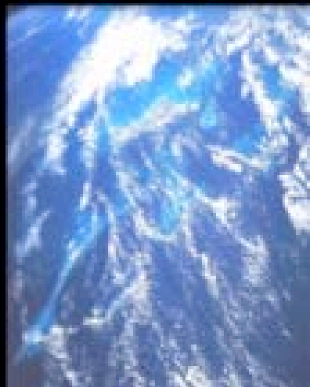
Background: SSN

Dish Radars in the Space Surveillance Network (SSN)Table 1	
Sensor name	**Year fielded**
Haystack Radar	1963
Haystack Auxiliary Radar	1993
Millstone Hill Radar	1957
Advanced Research Projects Agency (ARPA) Lincoln C-Band Observables Radar (ALCOR)	1970
ARPA Long Range Tracking and Instrumentation Radar (ALTAIR)	1970
Target Resolution and Discrimination Experiment (TRADEX)	1963
Millimeter Wave (MMW) Radar	1983
Globus II	1999
Ascension radar	1971

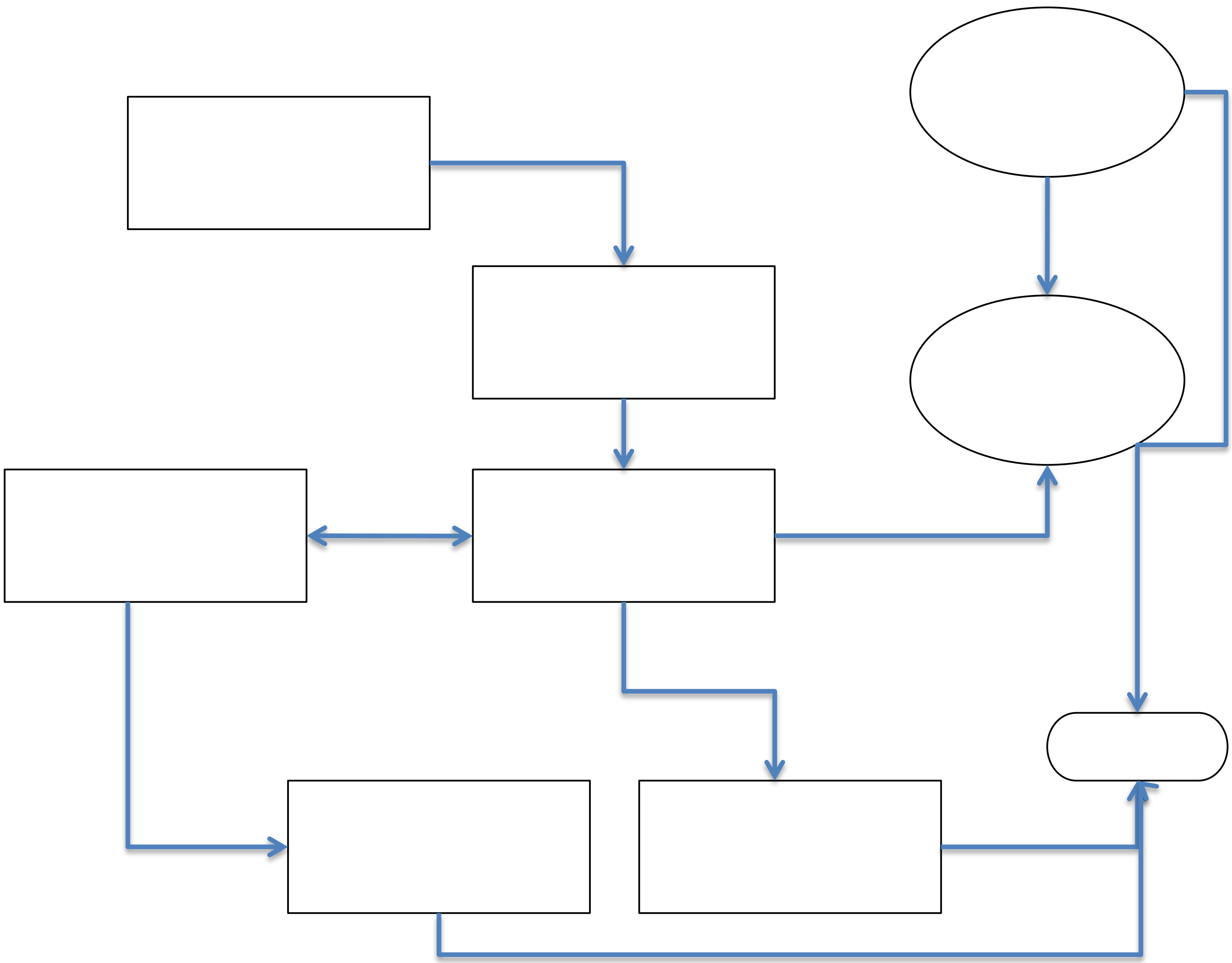


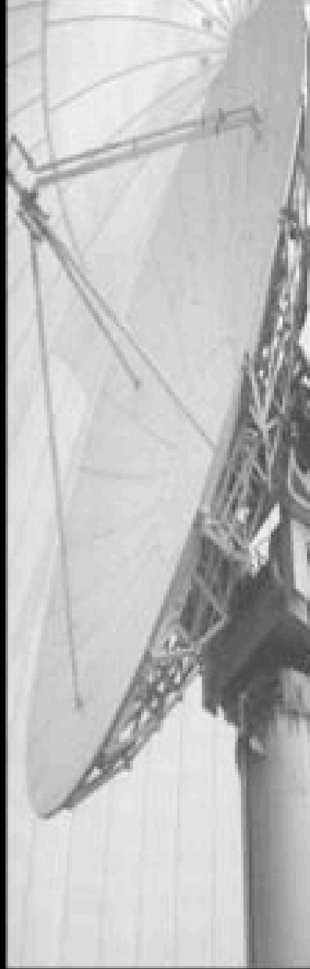
Background (cont'd)

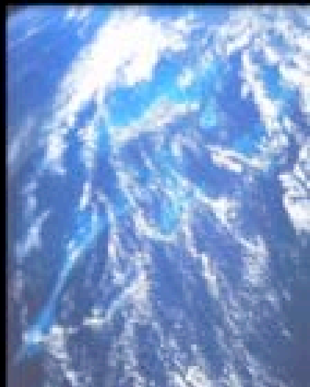
- In 1979, the MITRE Corporation performed an investigation on satellite-referenced calibration techniques.
- Derived an analytical model of the equipment-induced systematic biases in a generic tracking dish radar.



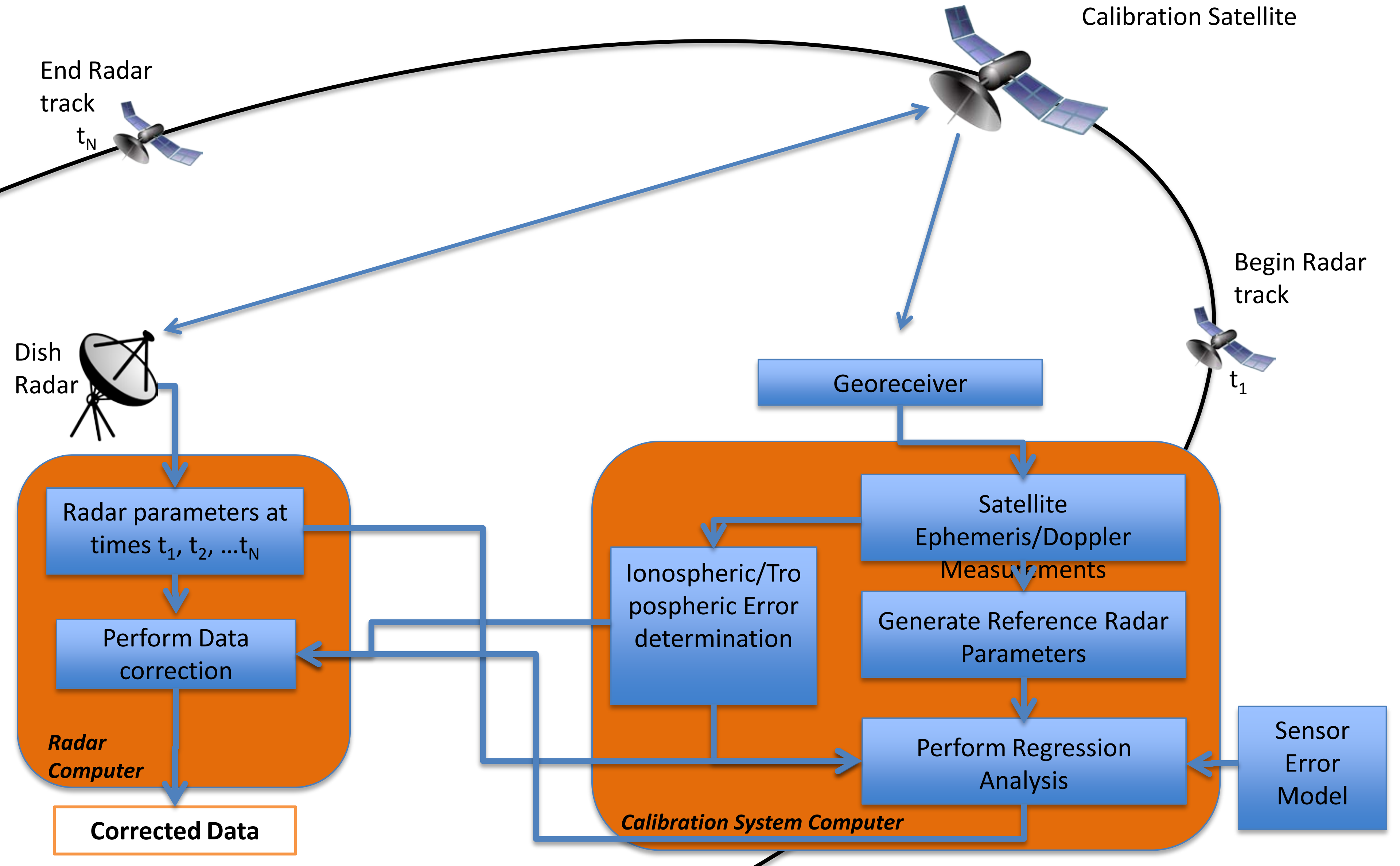
Methodology



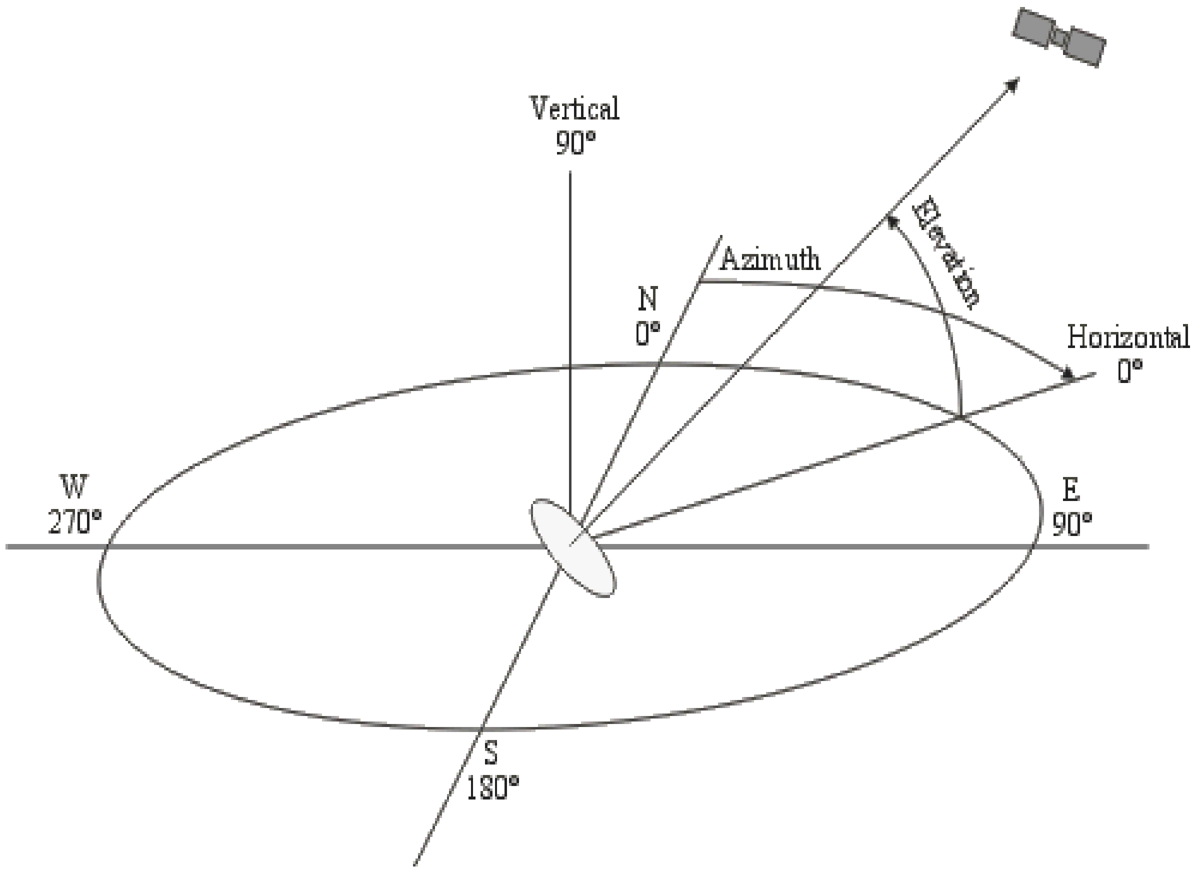




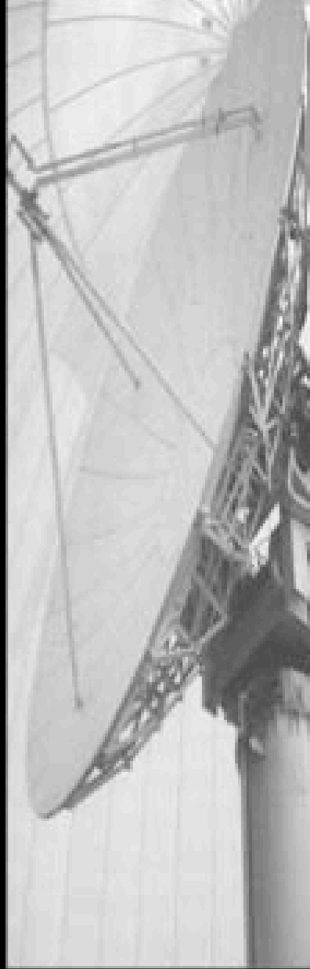
Sensor Calibration

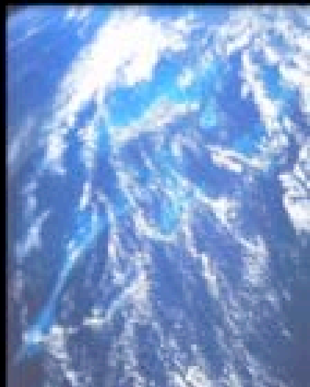


Error Model



Vertical
90°
Azimuth
Elevation
N
0°
Horizontal
0°
W
270°
E
90°
S
180°

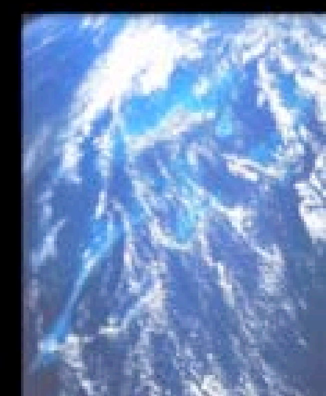




Range Bias Correction, ΔR

$$\Delta R = C_1 + C_3(R) + C_4(\dot{R}) + C_5(\ddot{R}) + C_7(\sin(Az)\cos(El)) + C_8(\cos(Az)\cos(El)) + C_9(\sin(El))$$

C_1 = Range bias [km]
C_3 = Range bias proportional to range [km/km]
C_4 = Range timing error [km/(km/s)]
C_5 = Range acceleration error [km/(km/s^2)]
C_7 = Site position error (east) [km]
C_8 = Site position error (north) [km]
C_9 = Site position error (up) [km]

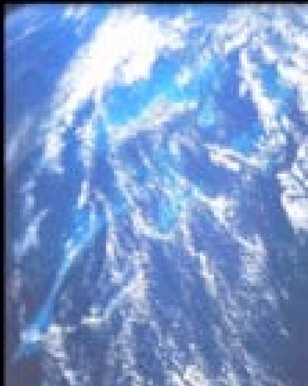


Azimuth Bias Correction, ΔAz

$$\Delta Az = \left[\left(\frac{C_{7}}{DTRA}\right)\left(\frac{\cos(Az)}{(R)\cos(El)}\right)\right] + \left[\left(\frac{C_{8}}{DTRA}\right)\left(\frac{-\sin(Az)}{(R)\cos(El)}\right)\right] + C_{10} + C_{11}(\ddot{A}z) +$$
$$C_{12}\left((P)\tan(El)\right) + C_{13}\left(\frac{P}{\cos(El)}\right) + C_{14}\left((\tan(El))(\sin(Az))\right) +$$
$$C_{15}\left((-\tan(El))(\cos(Az))\right) + C_{16}(\dot{A}z) + C_{17}\left((P)(\sin(Az))\right) +$$
$$C_{18}\left((P)(\cos(Az))\right) + C_{25}(CAHI) + C_{34}(CENC)$$

C_7 = Site position error (east) [km]
C_8 = Site position error (north) [km]
C_{10} = Azimuth bias [deg]
C_{11} = Azimuth acceleration error [deg/(deg/s^2)]
C_{12} = Non-orthogonality between azimuth and elevation axes [deg]
C_{13} = Non-orthogonality between RF and elevation axes [deg]

C_{14} = Azimuth axis tilt toward north [deg]
C_{15} = Azimuth axis tilt toward east [deg]
C_{16} = Azimuth timing error [deg/(deg/s)]
C_{17} = Azimuth encoder error (#1) [deg]
C_{18} = Azimuth encoder error (#2) [deg]
C_{25} = Azimuth hysteresis error [deg]
C_{34} = Azimuth square wave error [deg]



Elevation Bias Correction, ΔEl

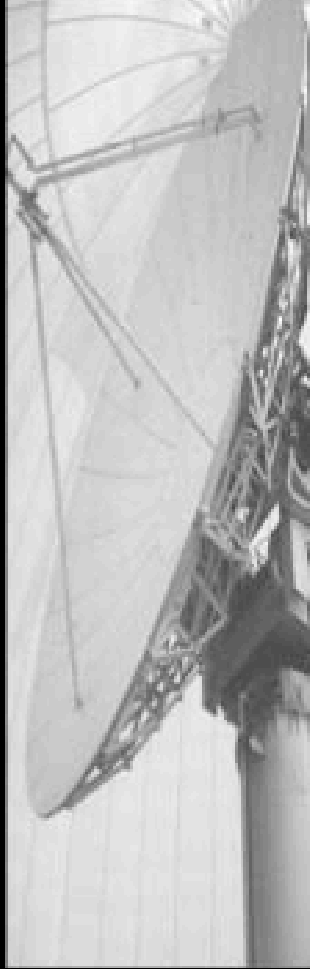
$$\Delta El = C_{19} - C_{7}\left(\frac{\sin(Az)\sin(El)}{R}\right) - C_{8}\left(\frac{\cos(Az)\sin(El)}{R}\right) + C_{9}\left(\frac{\cos(El)}{R}\right) +$$

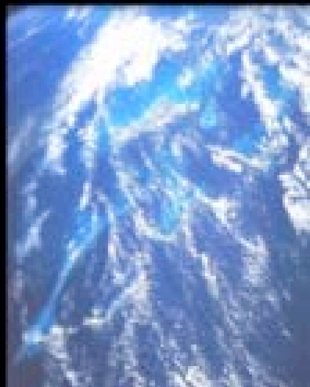
$$C_{14}(\cos(Az)) + C_{15}(\sin(Az)) + C_{21}\left(\dot{El}\right) +$$

$$C_{20}\left(El + \cos(El) + \ddot{\sin}(El) + \sqrt{\cos(El)}\right) + C_{27}\left((S)(\dot{El})\right)$$

C_{19} = Elevation bias [deg]
C_{7} = Site position error (east) [km]
C_{8} = Site position error (north) [km]
C_{9} = Site position error (up) [km]
C_{14} = Azimuth axis tilt toward north [deg]

C_{15} = Azimuth axis tilt toward east [deg]
C_{21} = Elevation timing error [deg/(deg/s^2)]
C_{20} = Elevation acceleration error [deg/(deg/s^2)]
C_{27} = Elevation hysteresis error [deg]



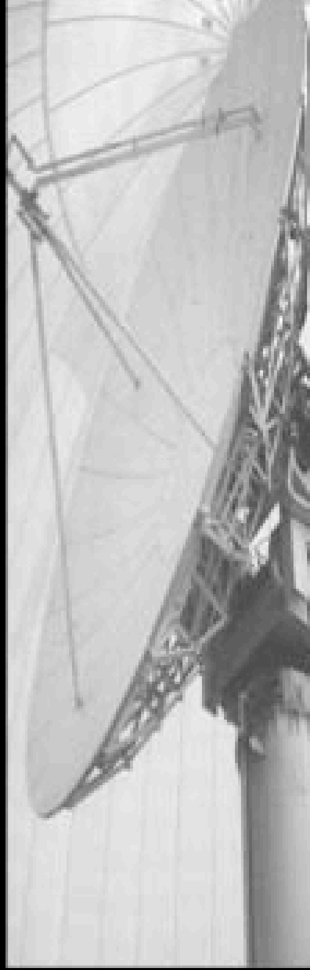


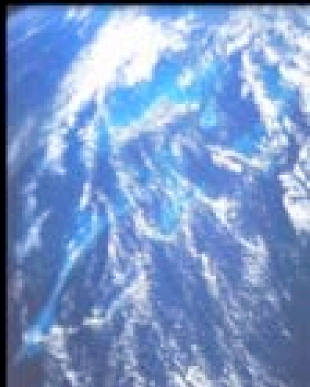
Regression Analysis

Akaike Information Criterion (AIC):

$$AIC = (N)\ln\left(\frac{SSres}{N}\right) + 2(K)$$

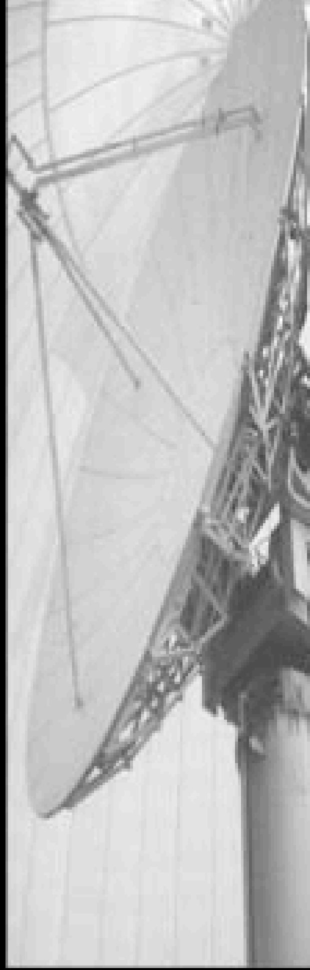
N = Number of data points
SSres = Sum-of-squares residual
K = Number of fitted coefficients plus one

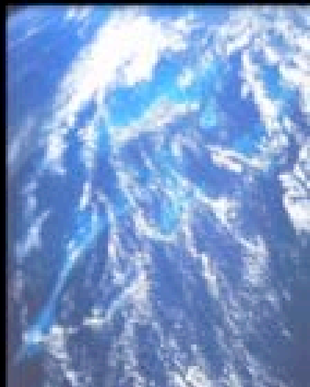




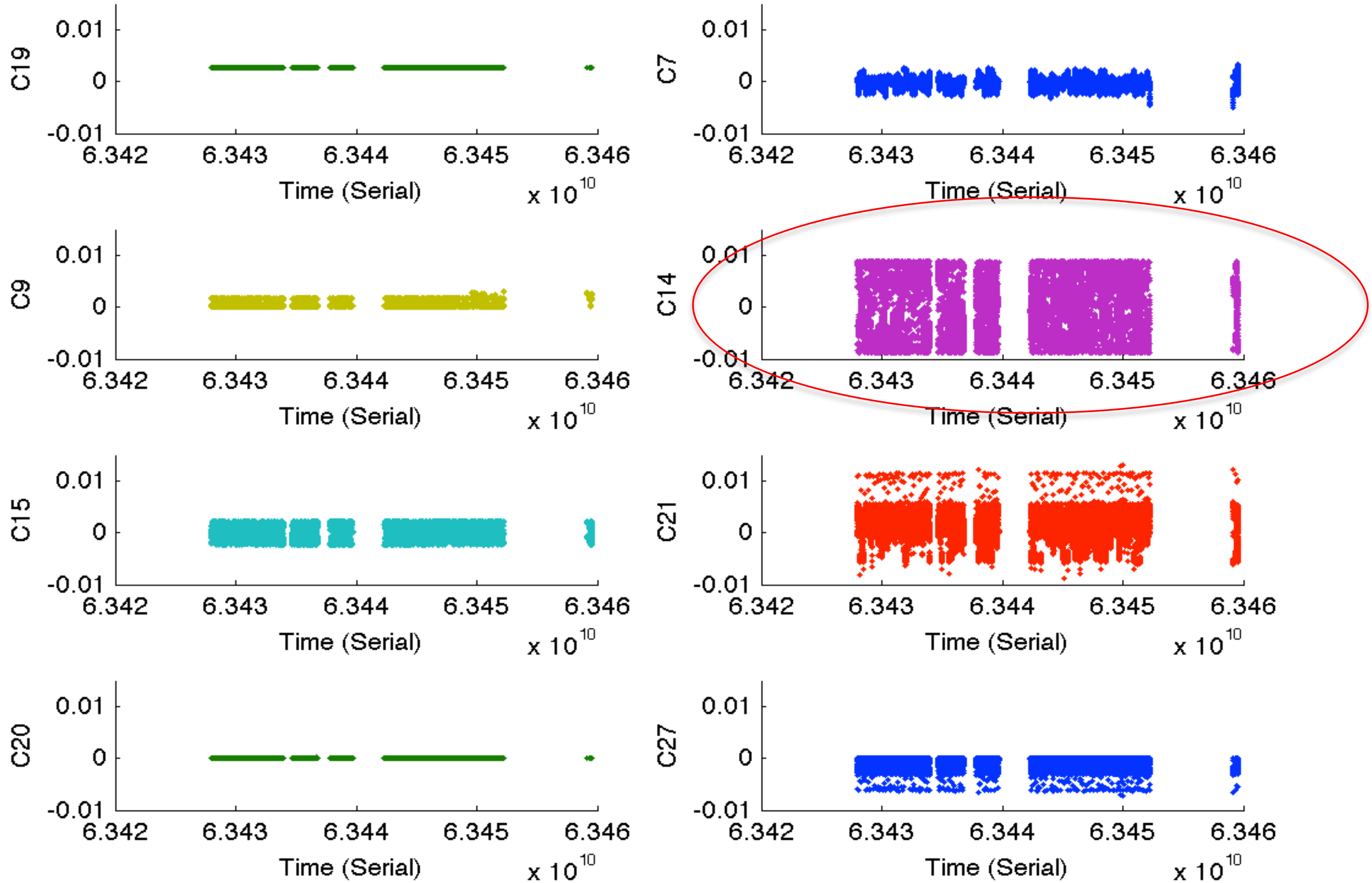
Results

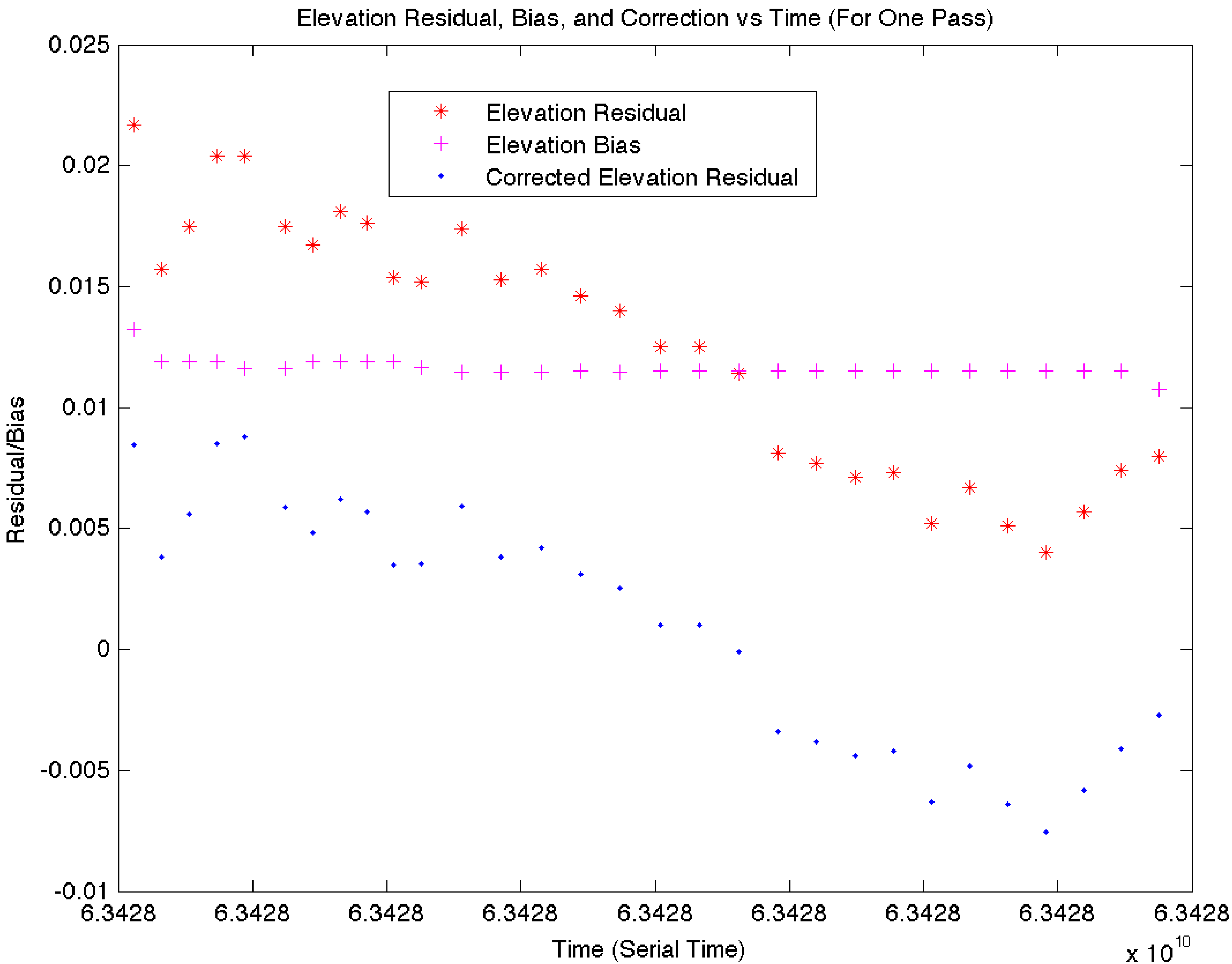
- ALTAIR L-band Calibration results will be discussed
  - Contained the largest amount of observations
- Original range, azimuth, and elevation residuals, biases, and corrected residuals were plotted against serial time.





Elevation Bias Coefficients vs. Time

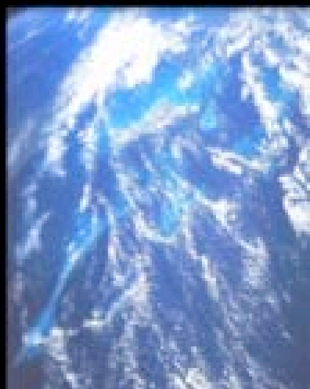




Elevation Residual, Bias, and Correction vs Time (For One Pass)
Elevation Residual
Elevation Bias
Corrected Elevation Residual
Residual/Bias
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
6.3428
Time (Serial Time)
x 10^10

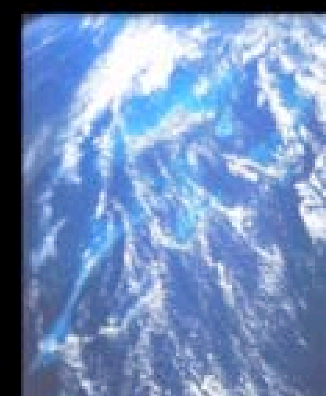
Summary

- Analytical error model was implemented and regression analysis performed
  - Best-fit model of systematic biases was determined
- Best-fit model was used to remove systematic biases
- Validity of best-fit model and regression analysis was implied
- Model is fit for observation noise module



Future Work

- Similar sensor calibration technique to be used for phased-array radars and optical sensor systems
- Implement ionospheric and tropospheric error model(s)
- Include all models in observation noise module



Acknowledgements

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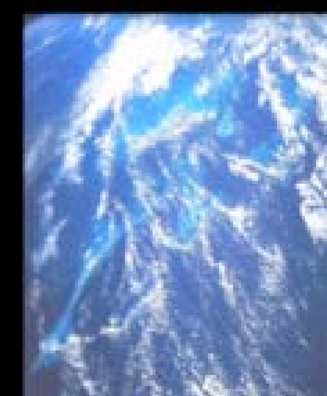
- Mark Beckman
- Navigation and Mission Design Branch



Any Questions?