Pointing Performance Evaluation and Analysis

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20 December 2006

GBT Archive: PR066

File: Projects

Keys: Pointing

Abstract

This document is a presentation that compares several pointing models performance against available astronomical pointing runs, illustrates some remaining pointing error phenomena, discusses possible mechanisms for the azimuth pointing "hysteresis" between azimuth forward and backward scans, and briefly discusses the possibility of damping structural vibrations.

History

54.1 20 December 2006. Original Version (KTC)

Pointing Evaluation

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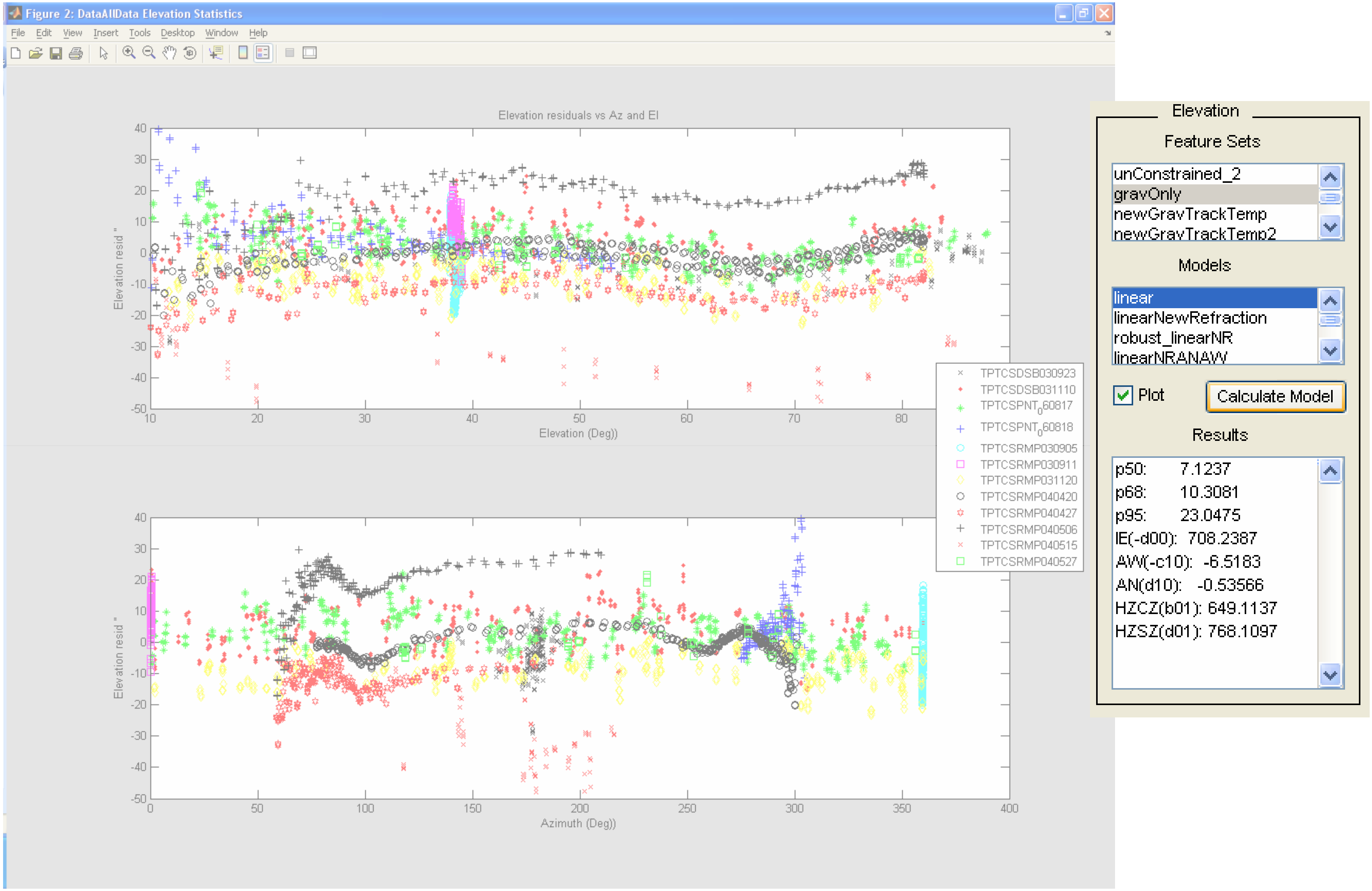
Summary

- Comparison of current and enhanced model
- Catalog of defects
- Data for new models
- Experiments for new models
  - Model development is now data limited
  - Several defects of similar magnitude: All must be addressed

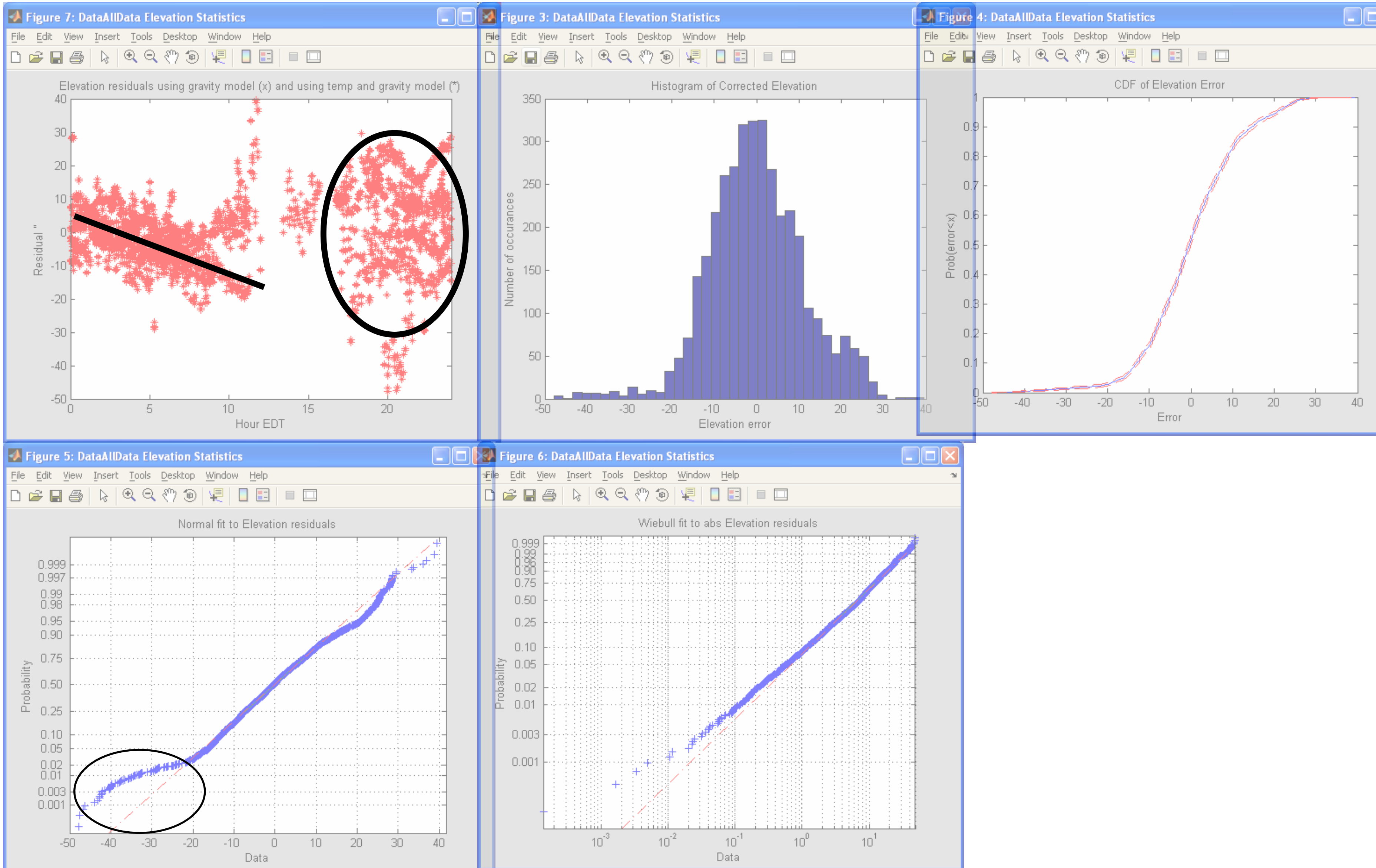
Enhanced vs Current Model Performance

- Compare static pointing performance:
  - Geometry and gravity
    - linear regression, exclude twist
  - Geometry, gravity, temperature
    - robust linear regression, exclude twist ($\beta_{2,a}$, $\beta_{3,a}$ in PTCS PN draft on pointing model, Table 3) differential expansion only
    - New refraction model
  - Geometry, gravity, temperature, track
    - robust linear regression, exclude twist, differential expansion and temperature dependent modulus of elasticity
    - New refraction model
  - Fits using all data unless otherwise noted (12 datasets including NCP, AllSky, SSTrack- 2003 to 2006)

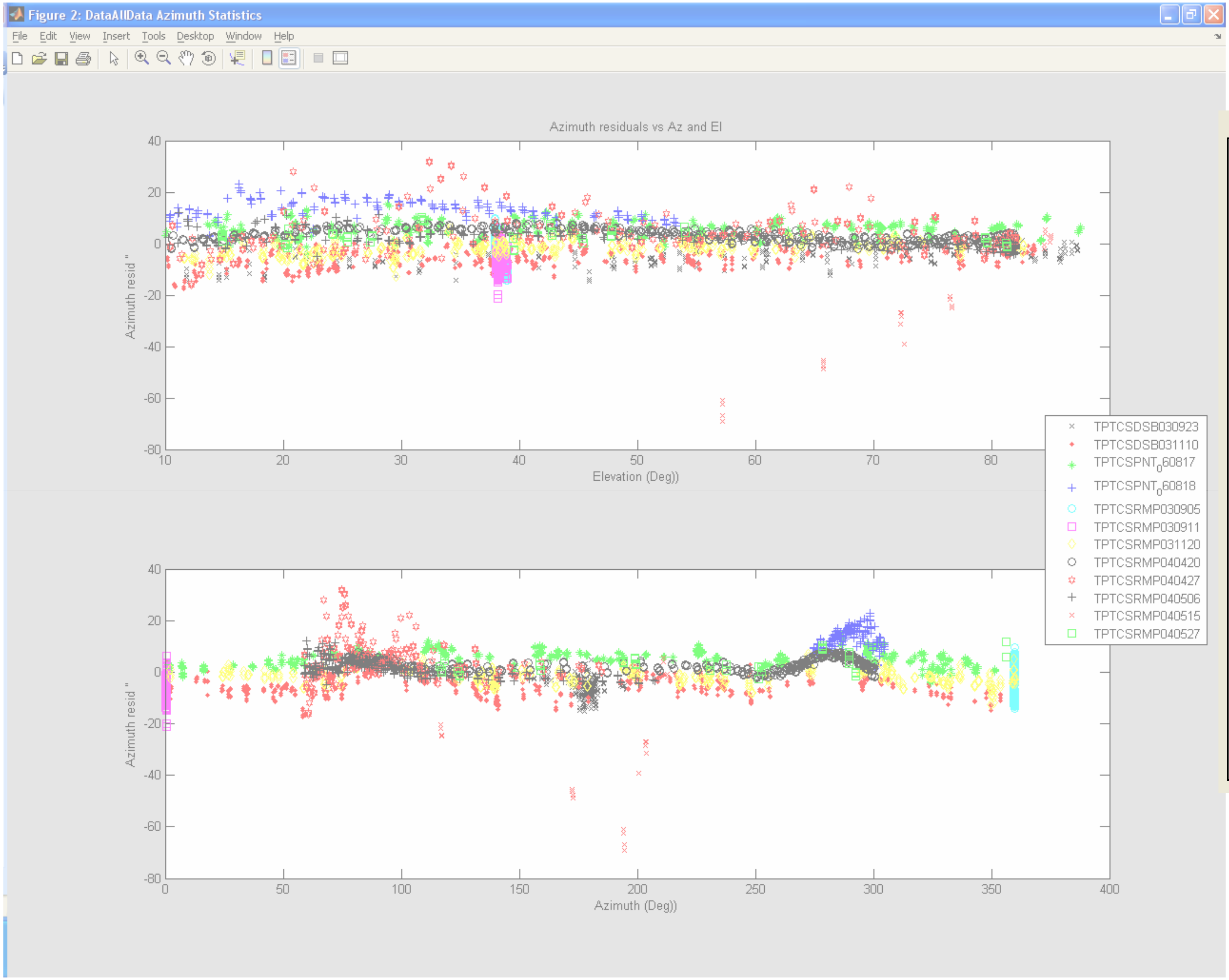
Geometry and Grav Only, Elevation

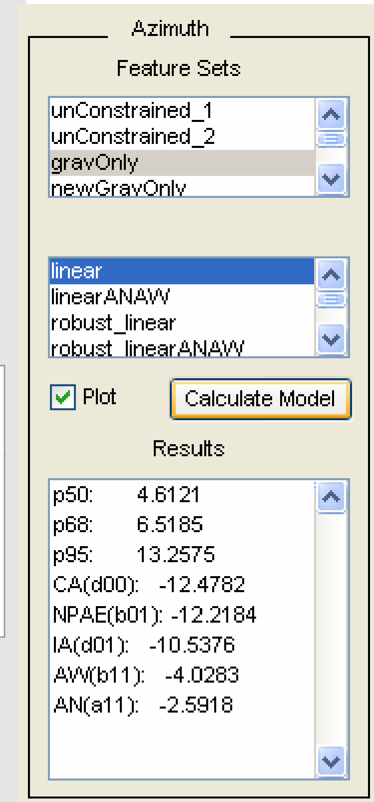


Geometry and Grav Only, Elevation

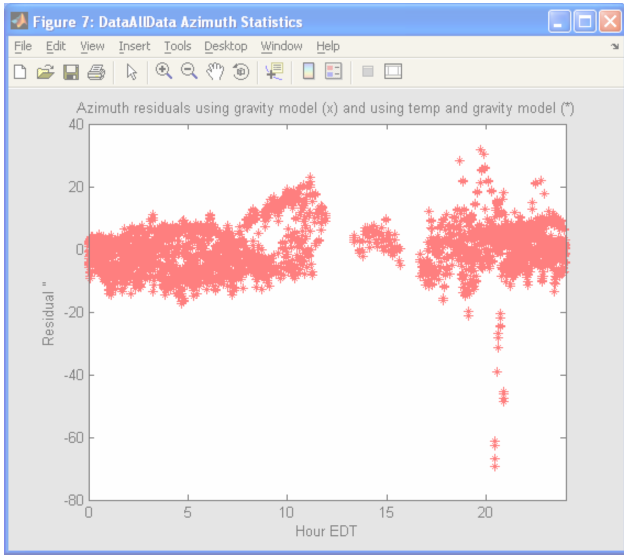


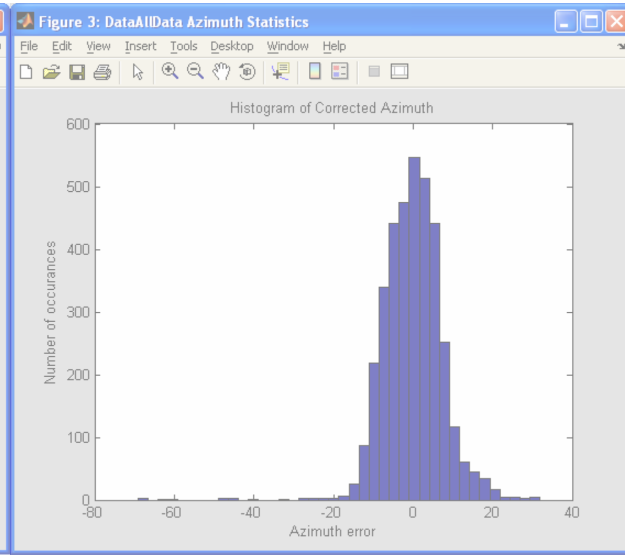
Geometry and Grav Only, Azimuth

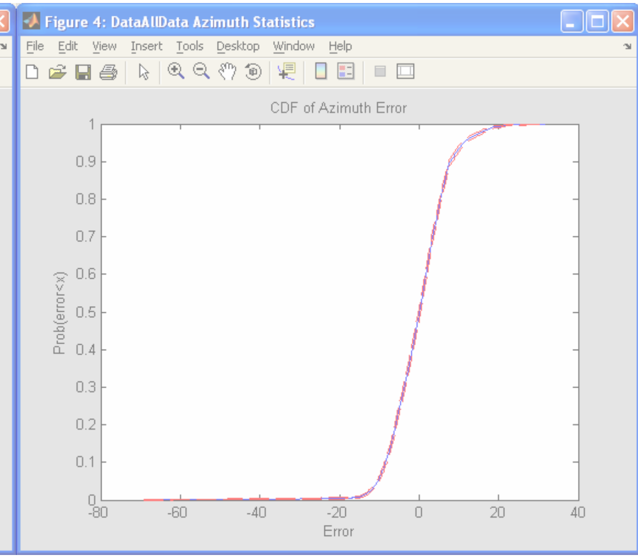


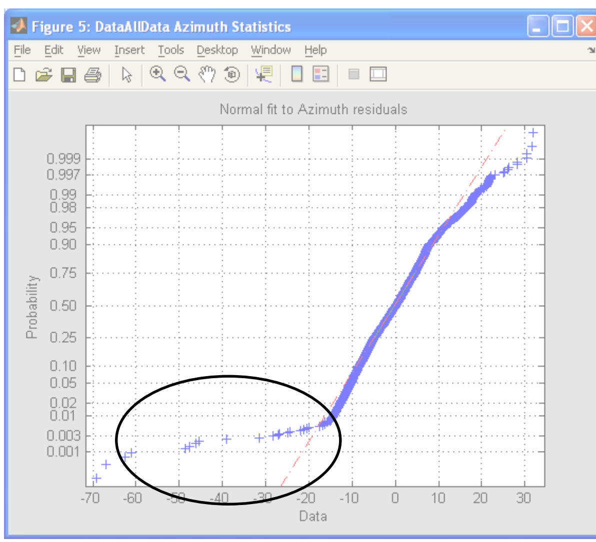


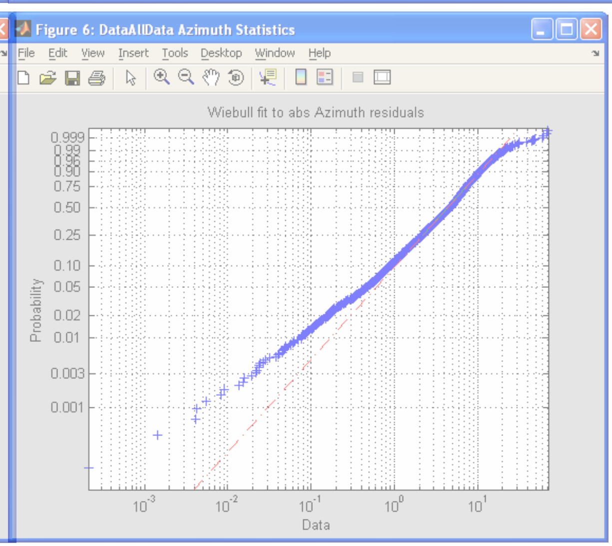
Geometry and Grav Only, Azimuth



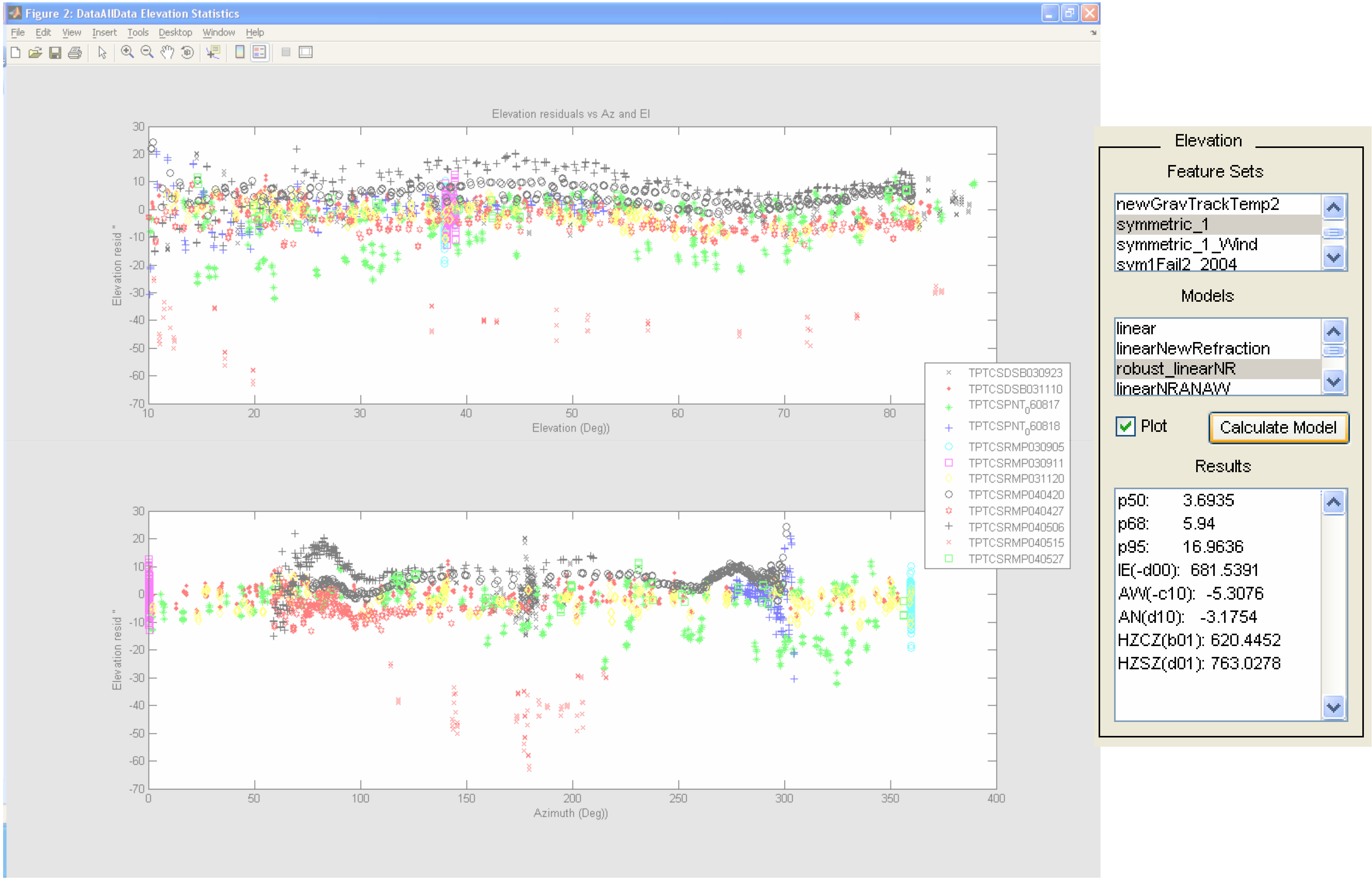




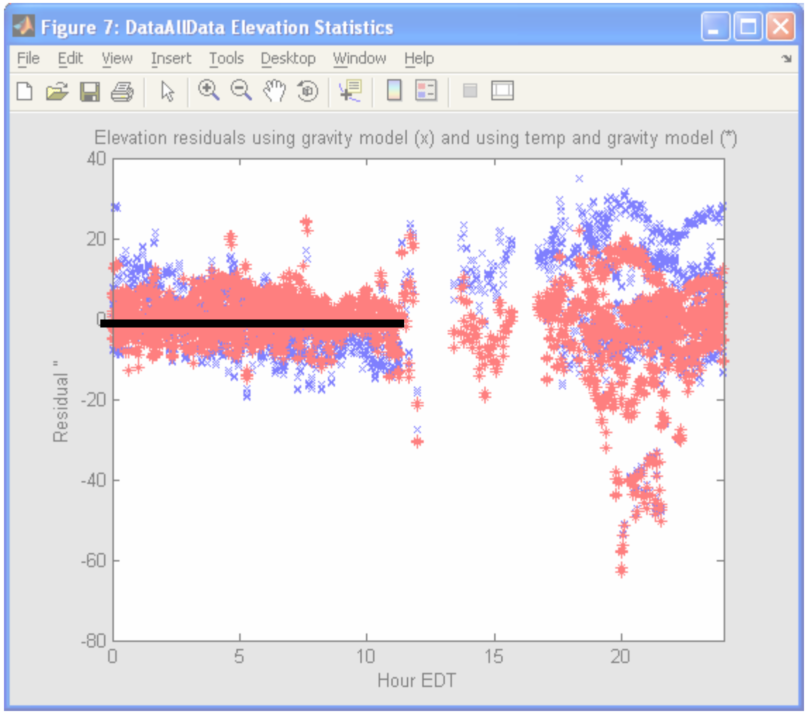


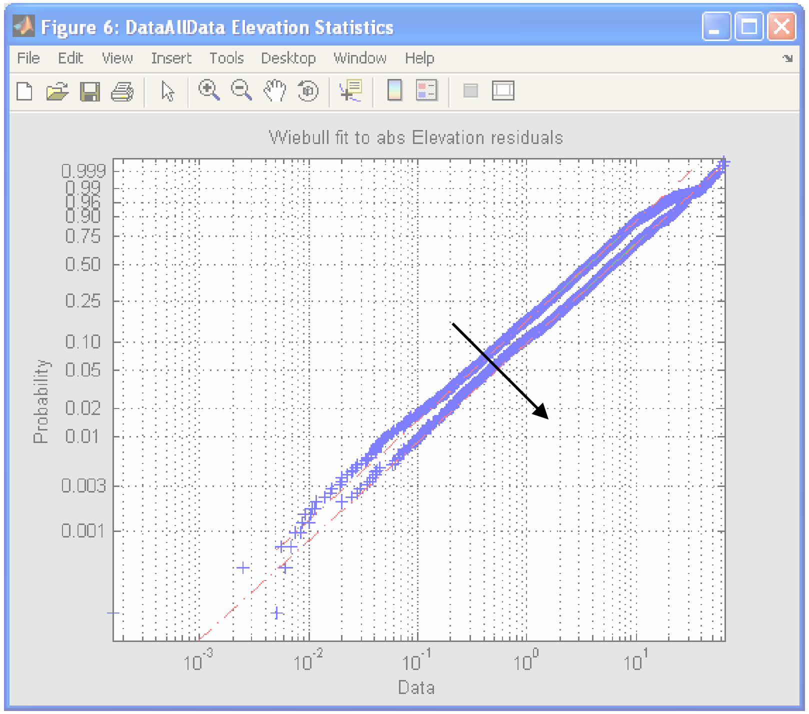


Geometry,Grav, and Differential Temp: Elevation

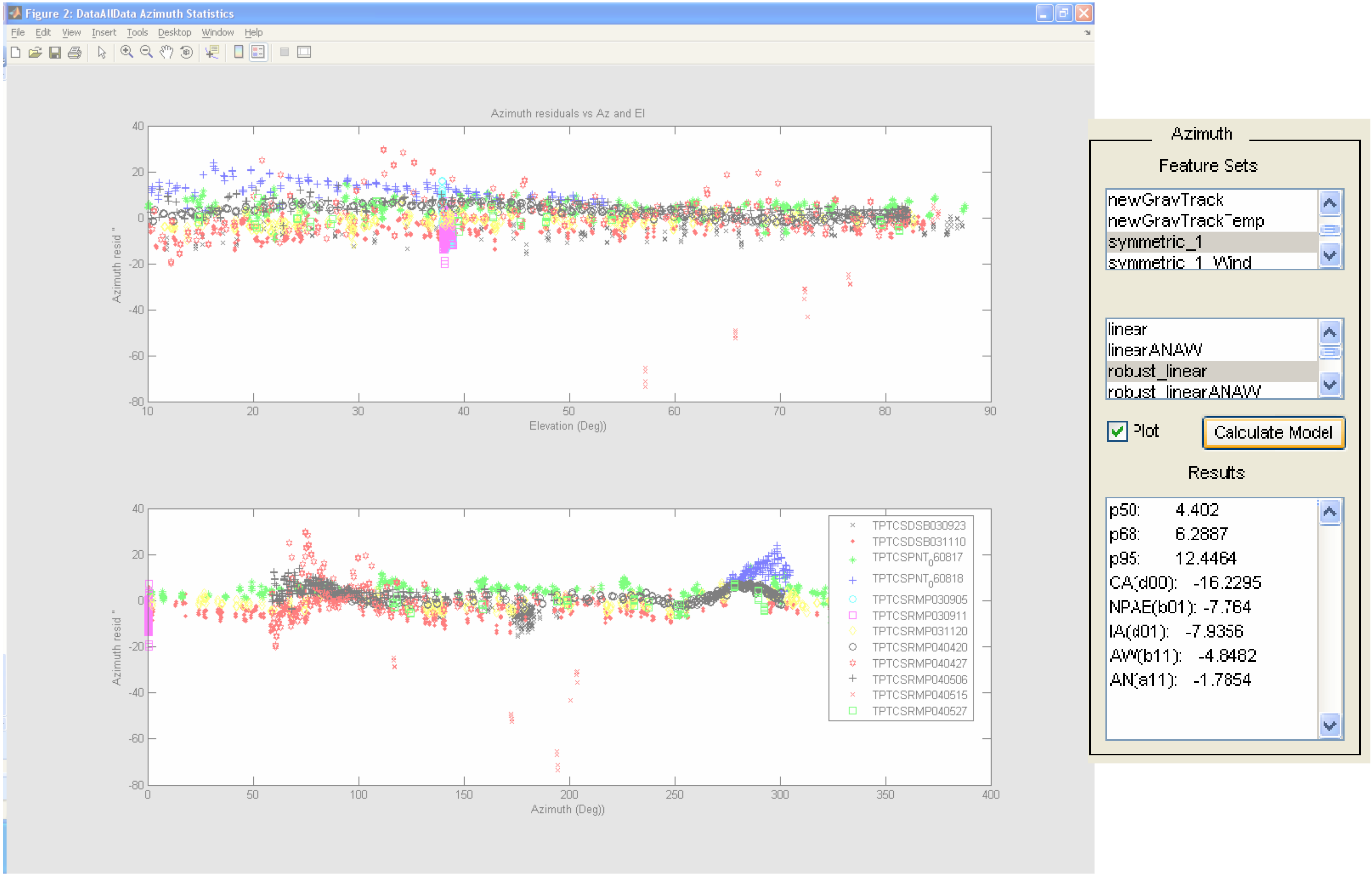


Geometry,Grav, and Differential Temp: Elevation

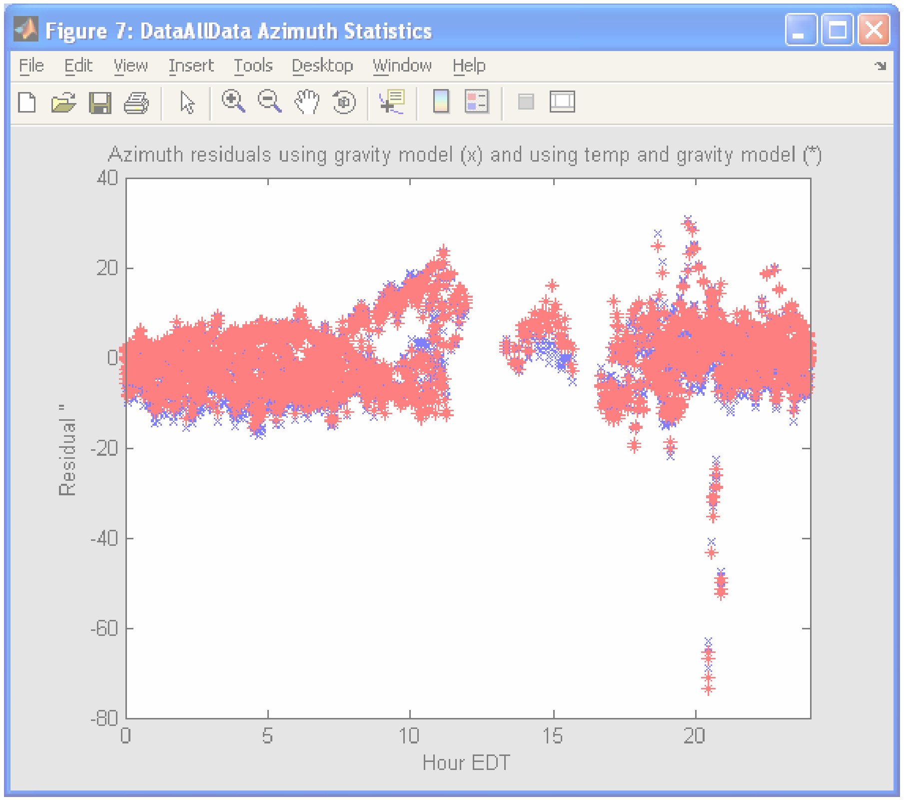


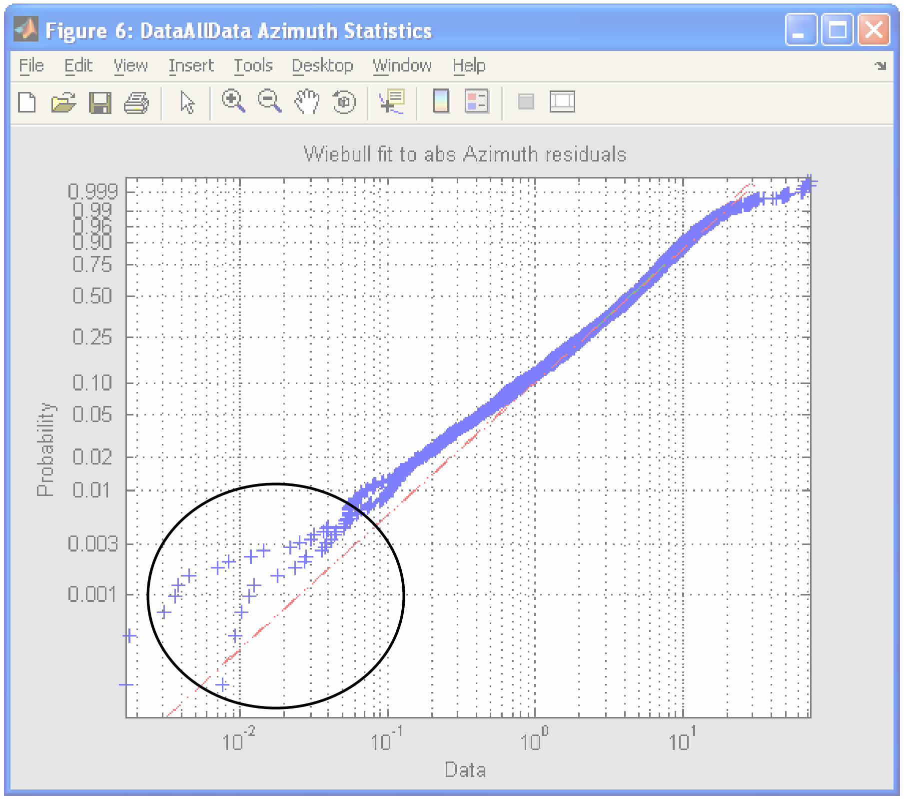


Geometry, Grav, and Differential Temp: Azimuth

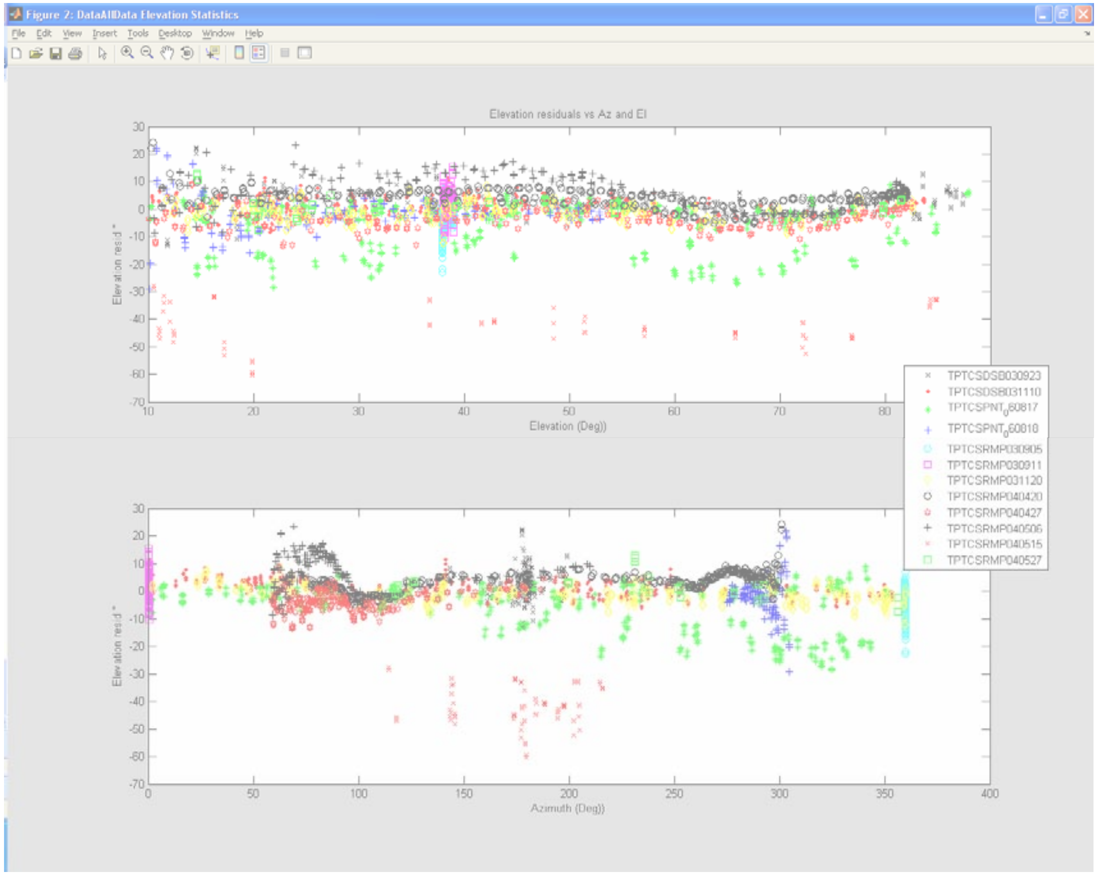


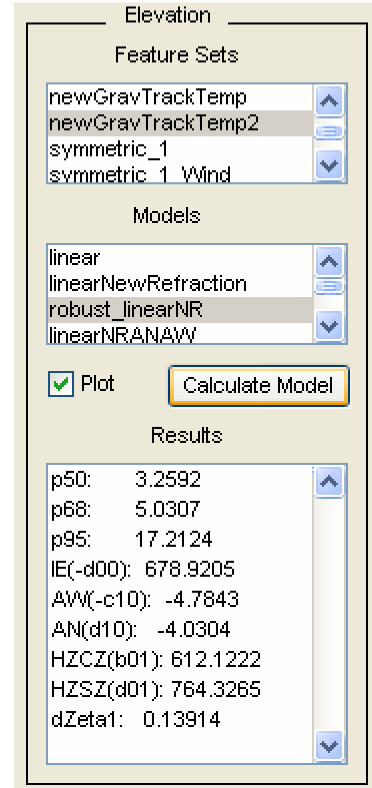
Geometry, Grav, and Differential Temp: Azimuth





Geometry, Grav, Differential Temp, FA Temp, Track: Elevation



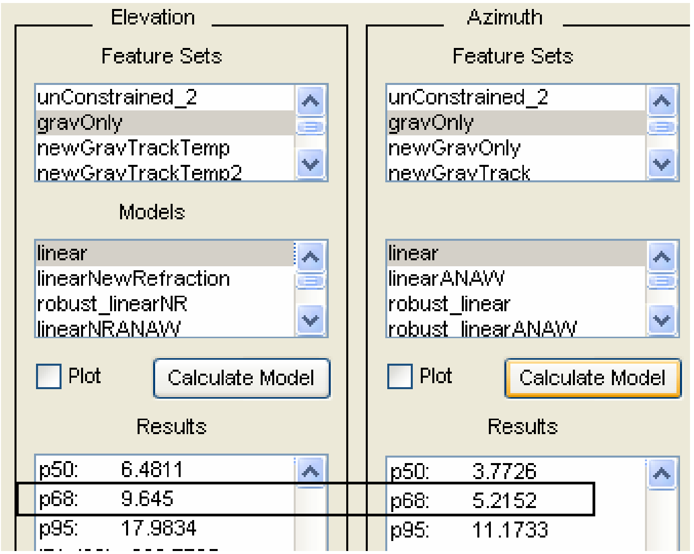


dZeta1 term is 0”.13 elevation per 1” difference of “X” inclinometers.
Bulk temp effect is -0”.4/C.

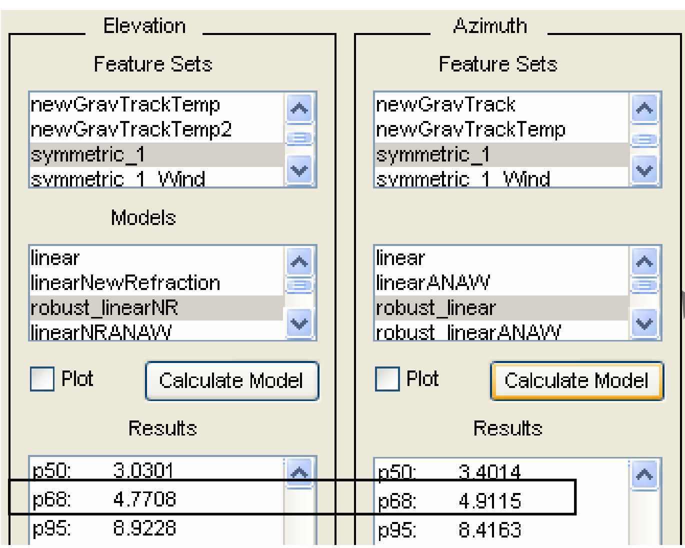
Comparative Performance

- Remove noisy datasets
  - No NCP, delete PTCSRMP040427, TPTCSRMP040515, TPTCSPNT060817
- Restrict elevation range to [25º,80º]
  - < 25º has noisy result due to refraction uncertainty
  - > 80º has (might have) tracking error due to high rates
- Restrict wind range to [0,3] m/s
  - Empirical…
  - Wind (better) model is upcoming

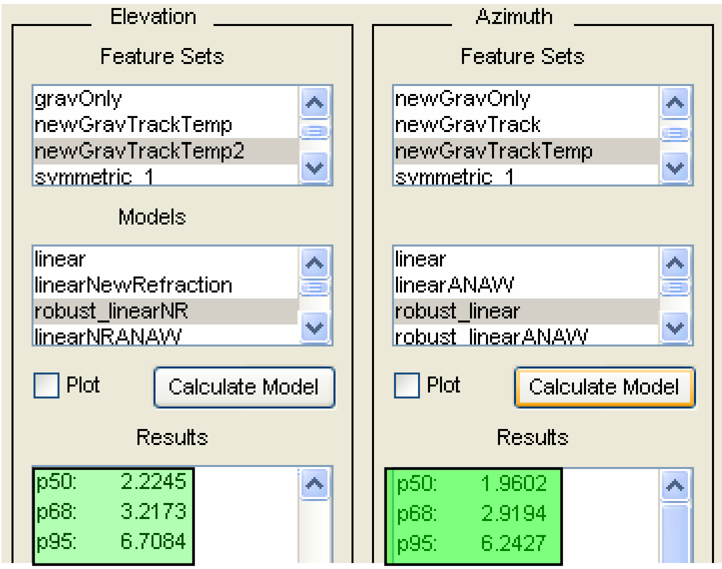
The Good, Better, and Best



Gravity and Geometry

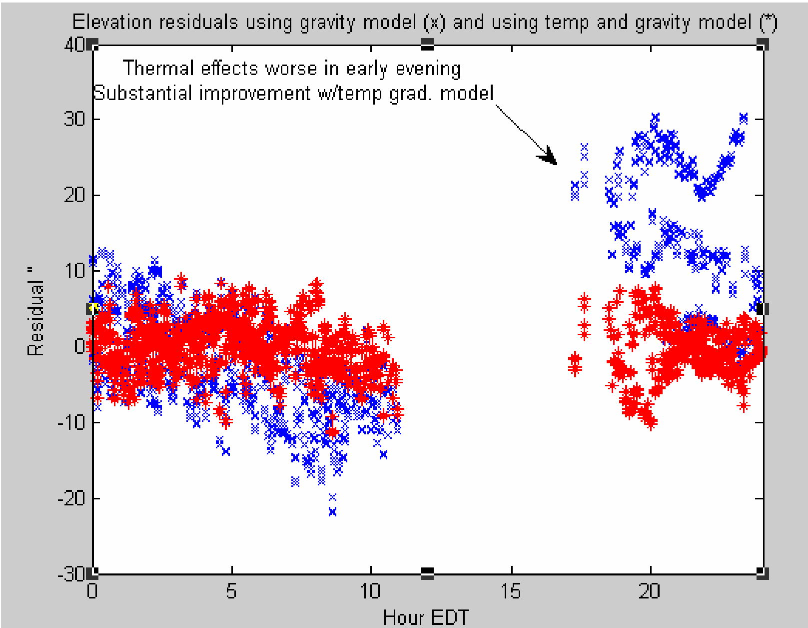


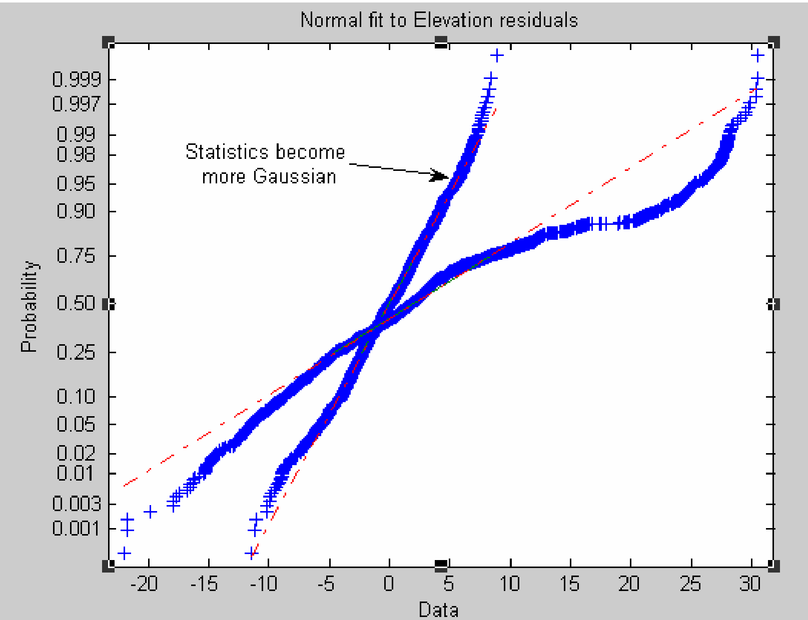
Gravity, Geometry, Temp Grad.

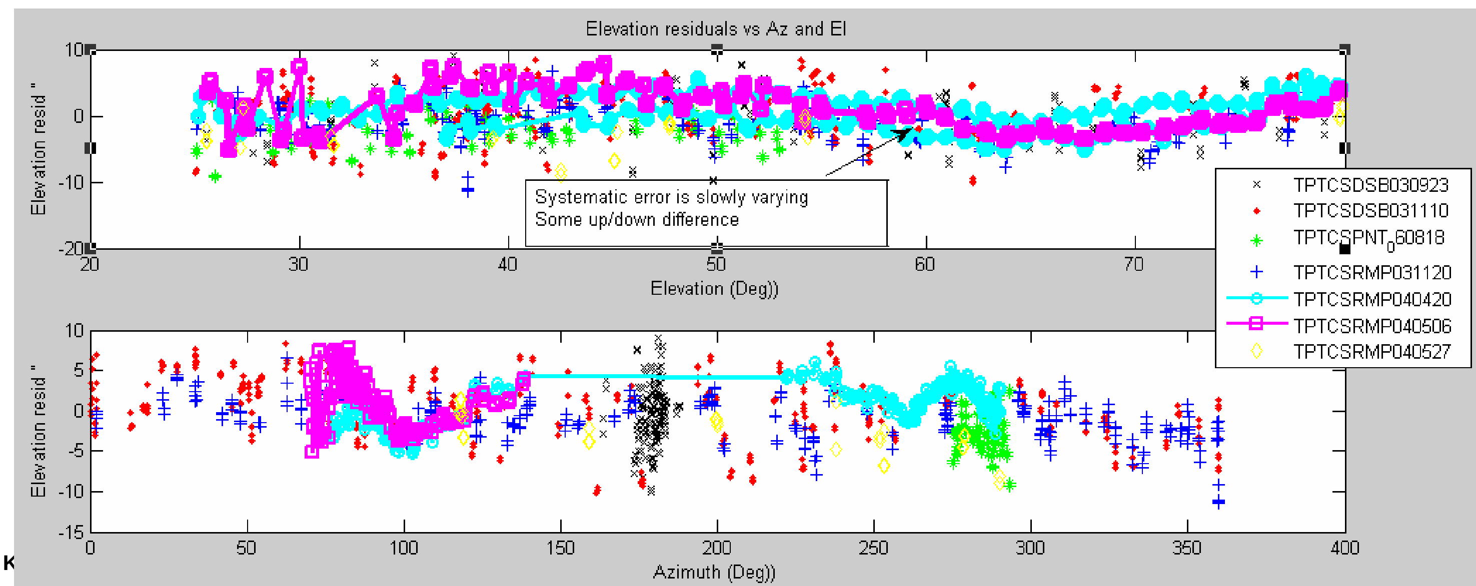


Gravity, Geometry, Temp Grad., Bulk Temp., Track

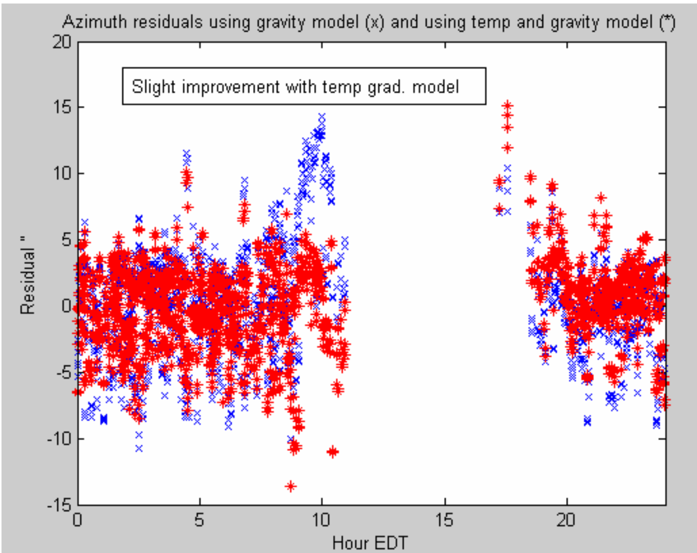
Best Model, Elevation

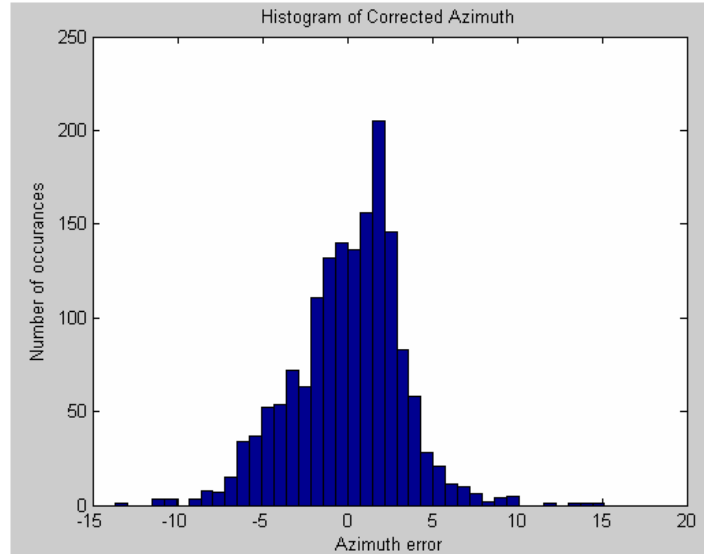


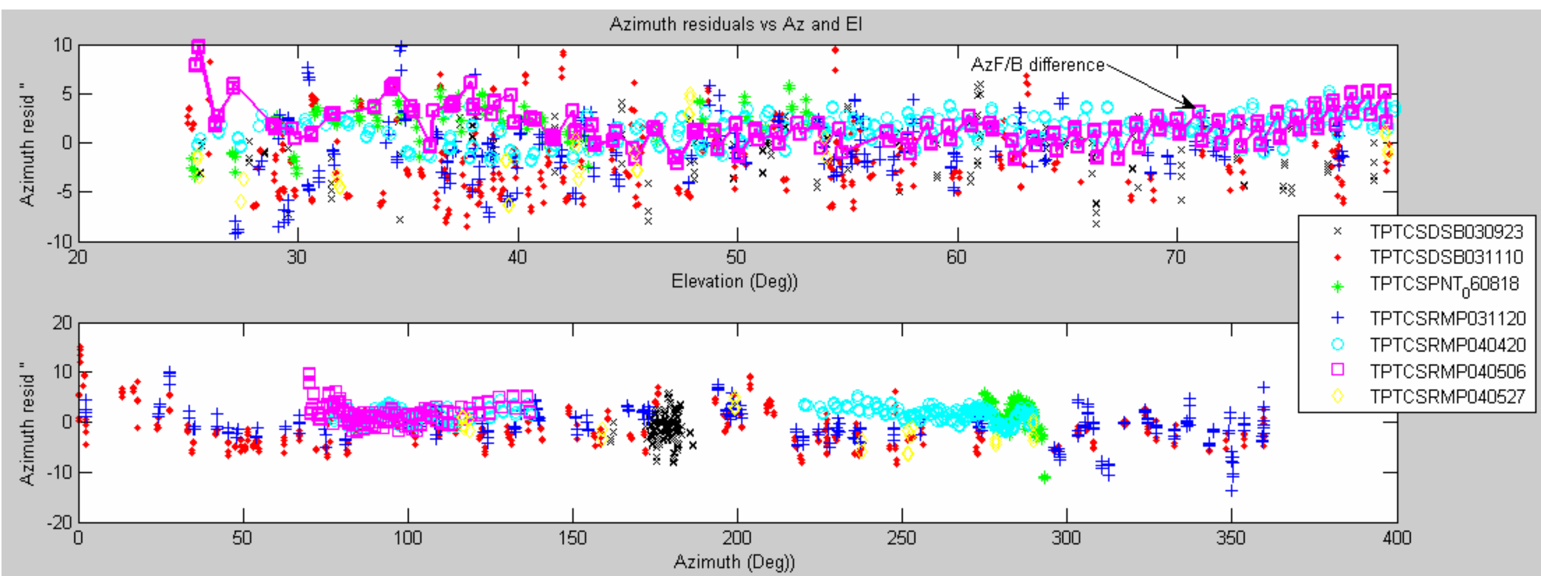




Best Model, Azimuth



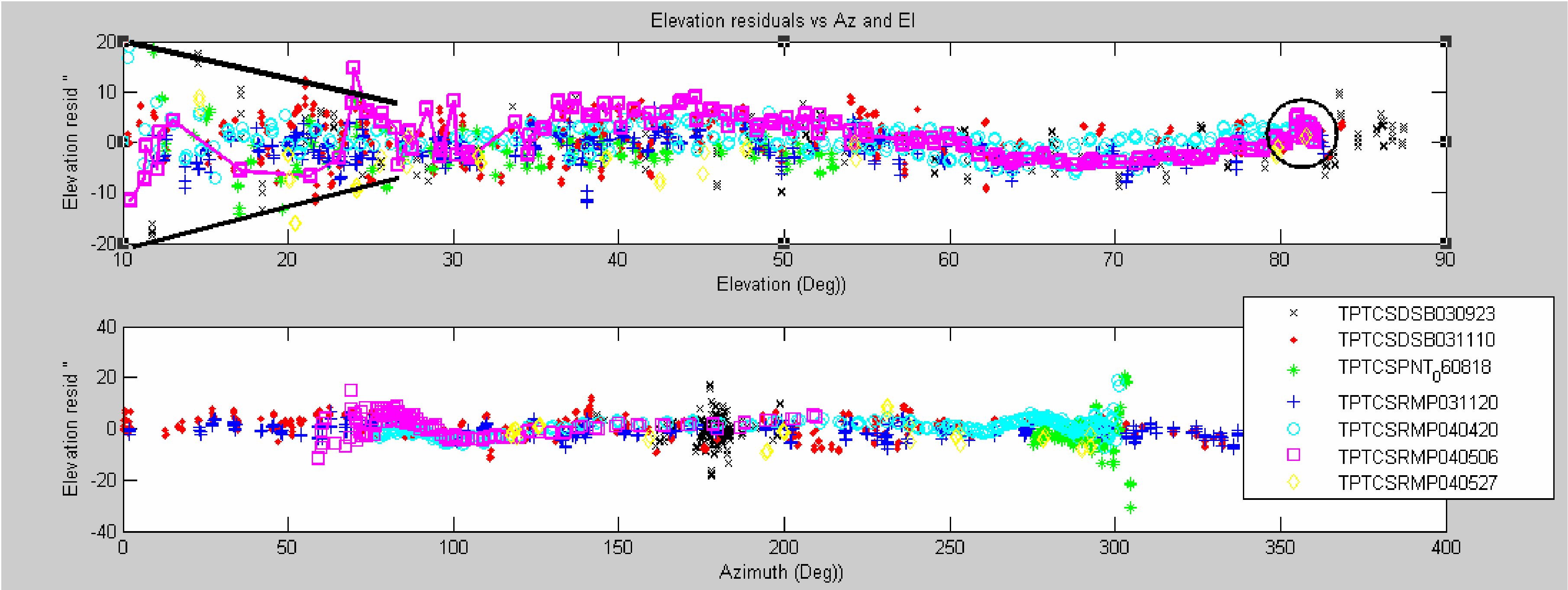




Comments

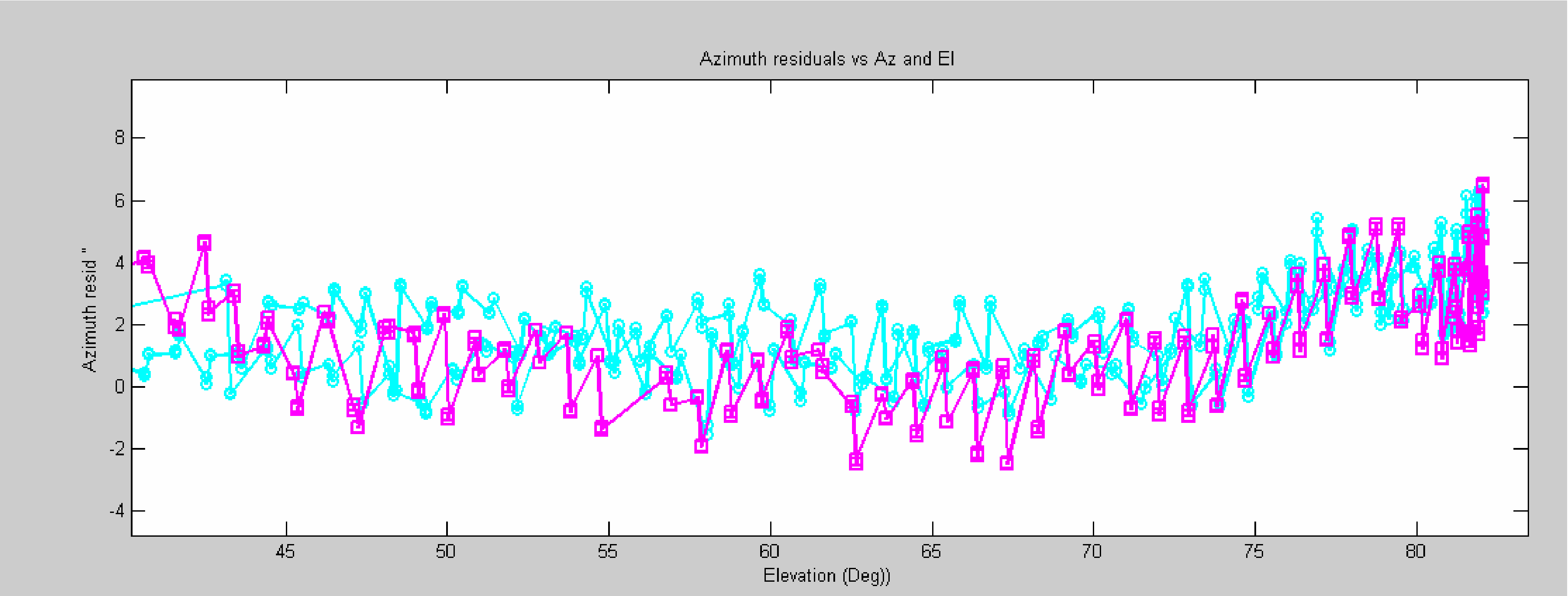
- Are fundamentally data (astronomy) limited
  - Noisy data sets don't permit estimation of more subtle effects- E.g., non-linear modulus of elasticity and CG/moment alidade twist
  - Lack of track data contemporaneous with astronomy- Track almost certainly shifts on a day-to-day basis (see PTCS PN 44)
- Need to implement temperature stability metric
  - Operational use to predict time scale of thermal pointing shifts
  - Use to de-weight data in fitting process
- Need to implement time-series analysis to quantify performance against PTCS PN 27

Menagerie of Defects: Refraction Noise and Tracking Error



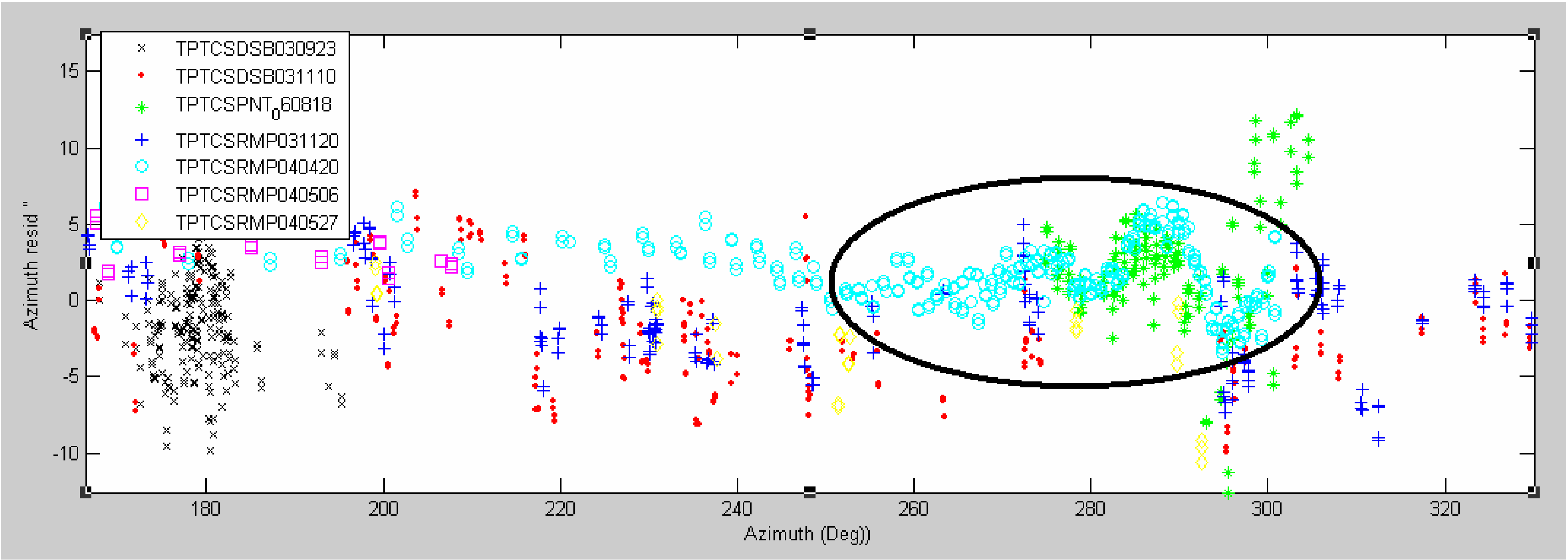
- Probable refraction error due to uncertain differences between model atmosphere and real atmosphere
    - Optical depth of atmosphere at high frequencies deprecates high frequency observing at less than 25º
    - Don’t use low elevation data in model fits
- Test for rate-dependent tracking error

Menagerie of Defects: AzF/B Hysteresis (?)



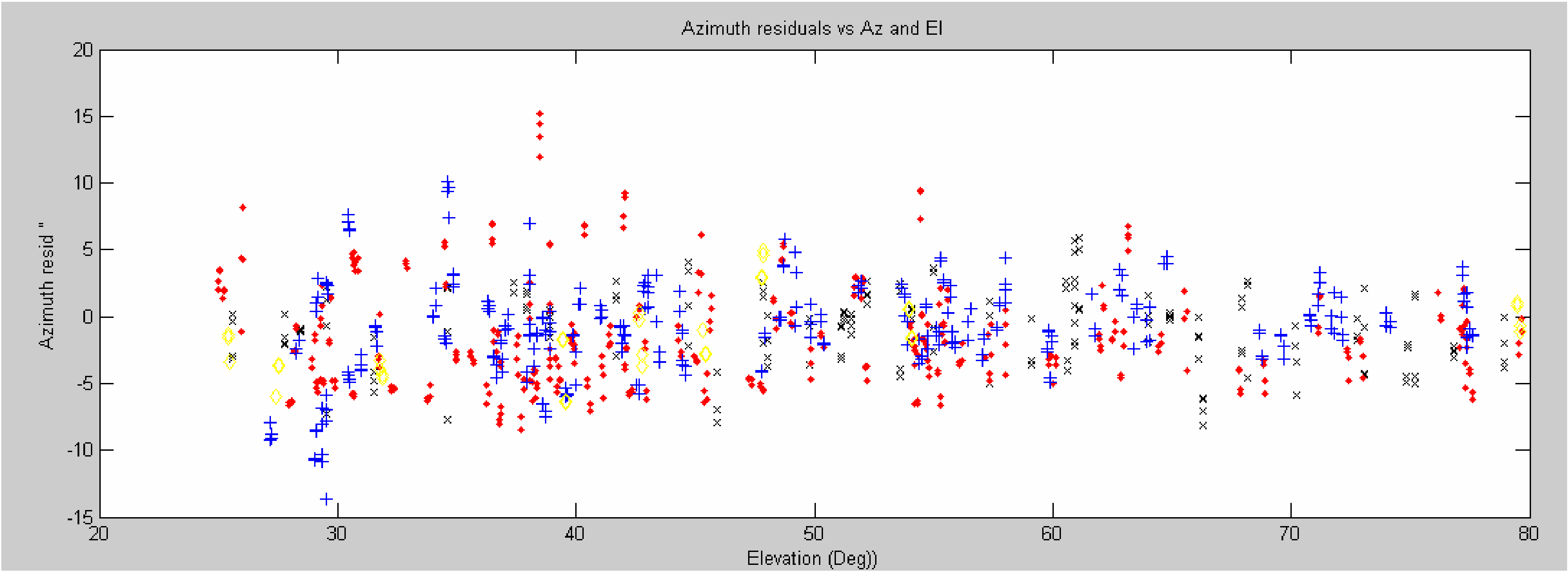
See flow chart of effects and tests…

Menagerie of Defects: Residual Track Effect



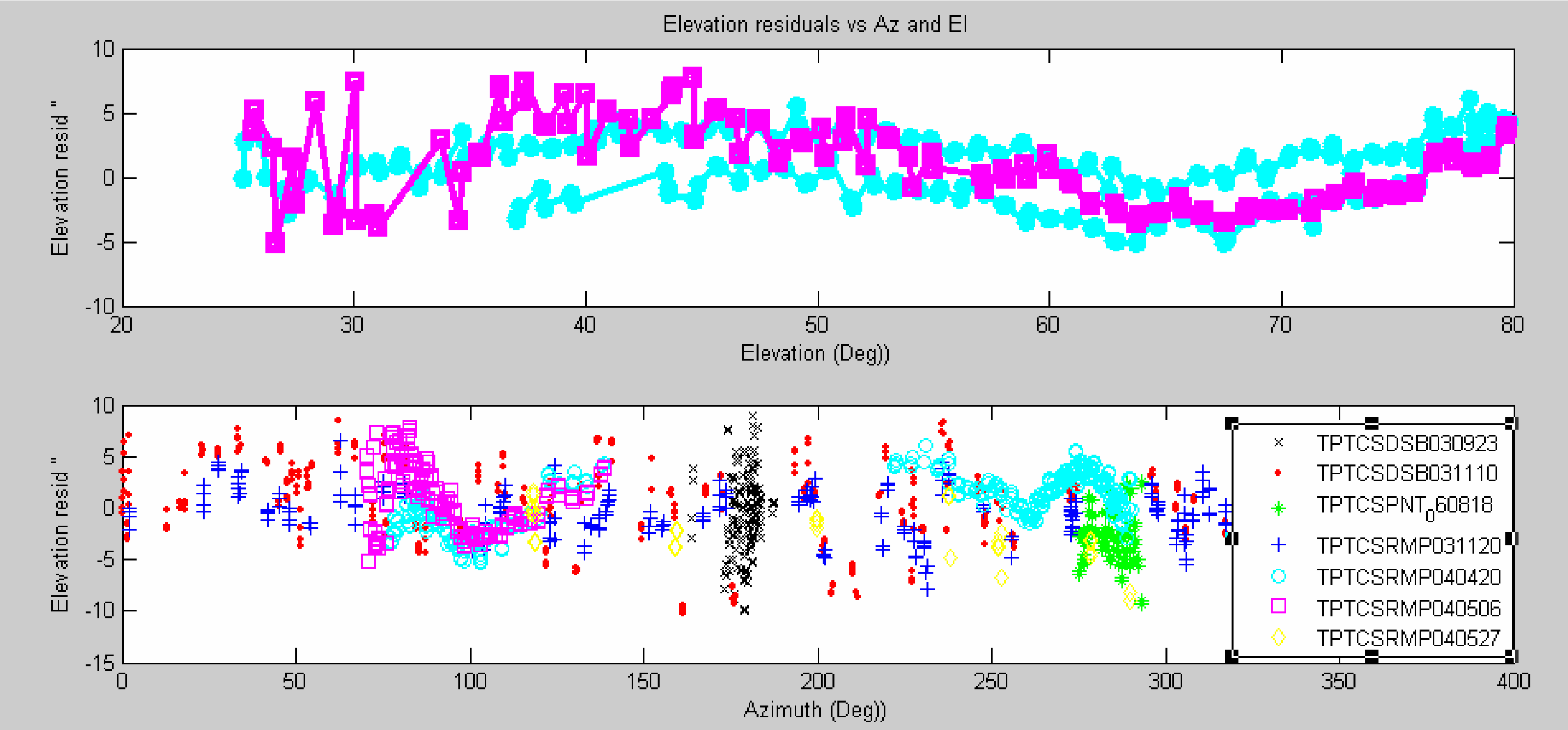
- Possible undersampling of track effects
  - Finer sampling via better signal processing of inclinometers
- Possible mezo-term track subsidence, etc,
  - Track map per pointing run (or more)

Menagerie of Defects: Noisy All Sky Data



- Possible structural vibration due to large slews:
  - FOM on peak fit (baseline and peak width/shape)
  - Inclinometers and Rcvr Cabin accelerometer
- Possible high (temporal) rate on thermal gradients
  - Thermal stability metric
  - Correlation of air temp lapse with elevation angle
- Possible mechanical lash/hysteresis/control error in subreflector, primary, receiver mounts
  - Correlate with directional accelerations
  - Correlate with actual vs commanded positions

Menagerie of Defects: Elevation Systematic Error



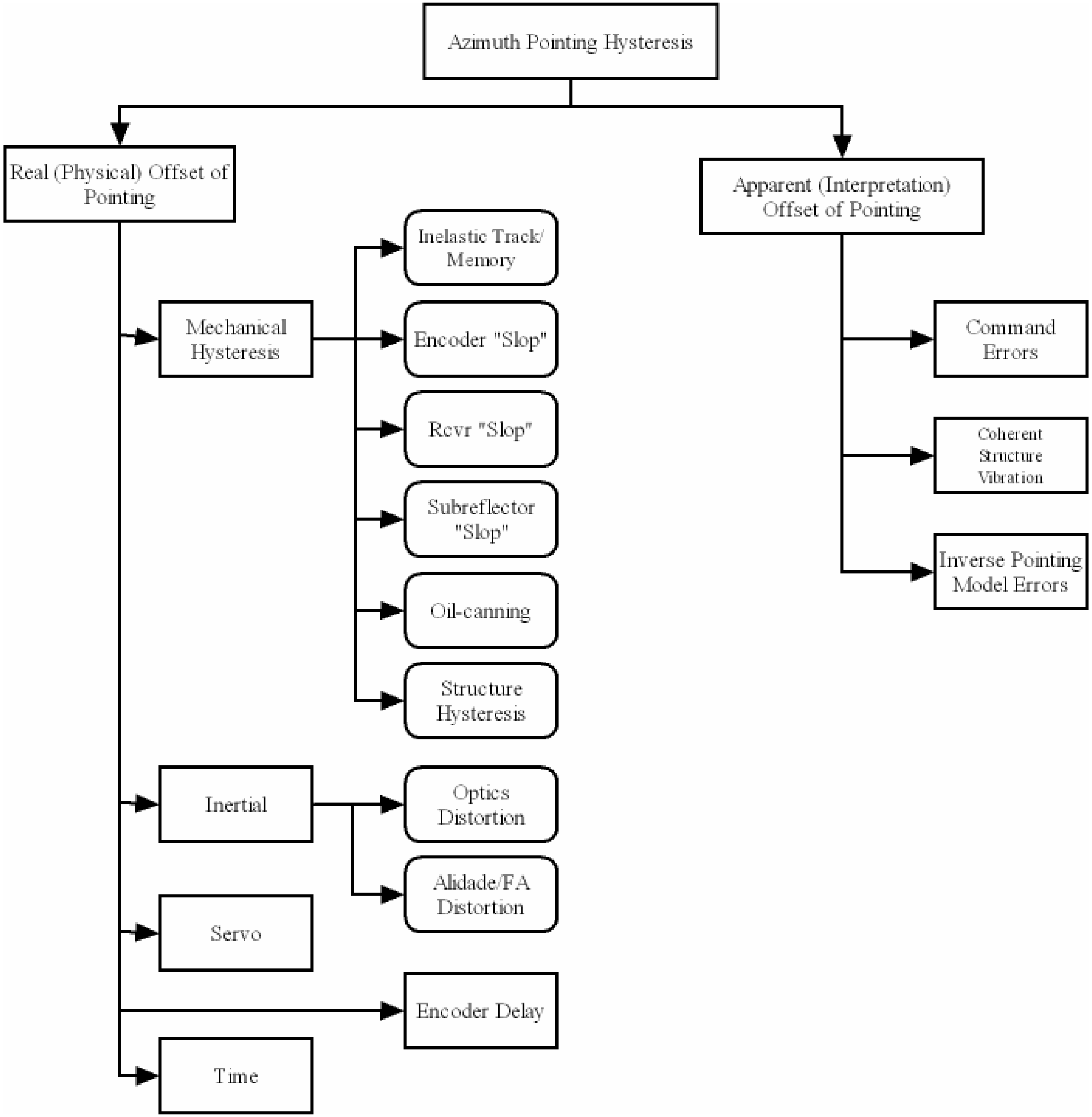
- "Sinusoidal" error as fcn of elevation
  - Probable quadratic or cubic nonlinearity of elastic modulus
  - Effect dominates in horizontal and vertical feedarm
  - Stable estimate possible with cleaner astronomical data
- Up/down error
  - Probable subtle shift in foundation, change in effective AN/AW terms

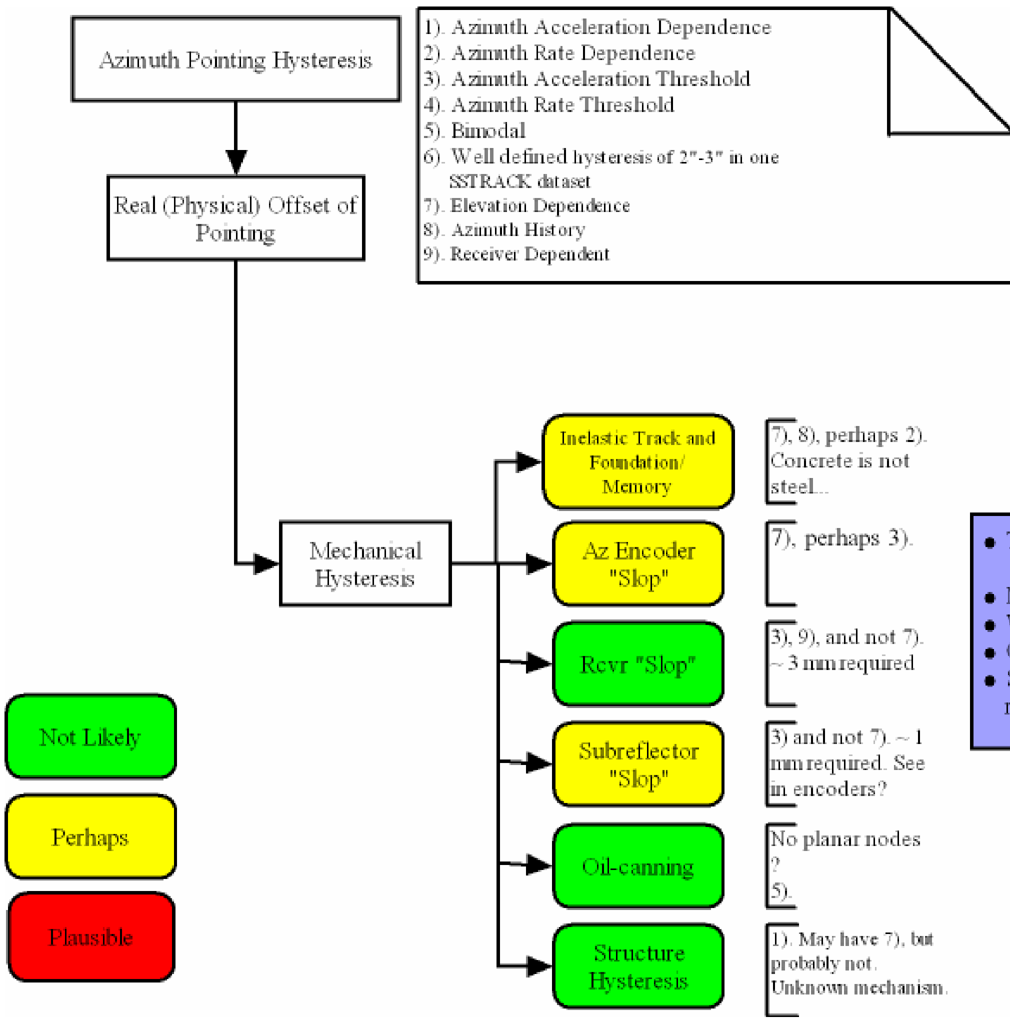
What Remaining Errors are Most Important?

- Objectives are
  - Absolute Az (or El!) good enough to locate calibrator @ W band
  - ½ hour stability for tracking/integration

1. Noisy AllSky
2. Az hysteresis
3. Small delta azimuth angle track effects
4. Variation of track effects in time

- Need hypotheses and distinguishing experiments
- Need realtime track monitoring

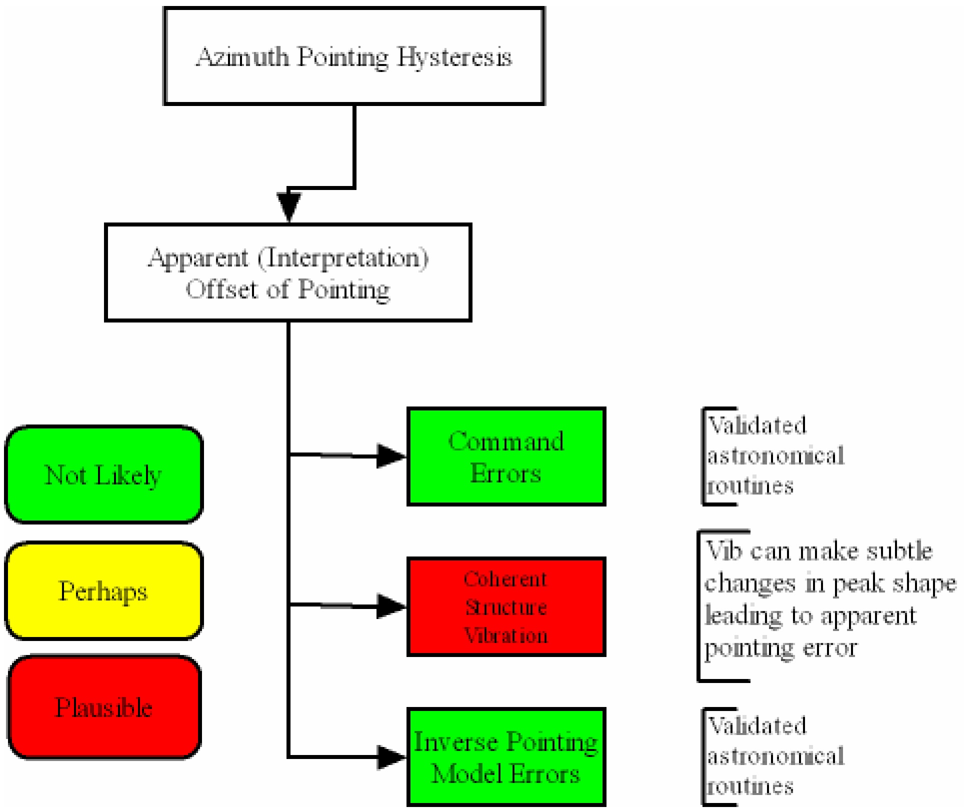

Azimuth Pointing Hysteresis
Real (Physical) Offset of Pointing
Apparent (Interpretation) Offset of Pointing
Mechanical Hysteresis
Inelastic Track/ Memory
Encoder "Slop"
Rcvr "Slop"
Subreflector "Slop"
Oil-canning
Structure Hysteresis
Inertial
Optics Distortion
Alidade/FA Distortion
Servo
Encoder Delay
Time
Command Errors
Coherent Structure Vibration
Inverse Pointing Model Errors

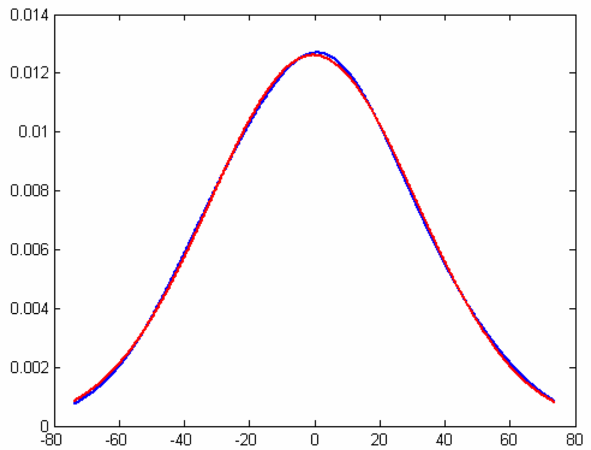


Primary Y rotation	$+1.77$ arcsec arcsec^{-1}
Primary X translation	$+2.7$ arcsec mm^{-1}
Primary Y translation	-1.9 arcsec mm^{-1}
Primary Z translation	-1.9 arcsec mm^{-1}
Subreflector X translation	-3.8 arcsec mm^{-1}
Subreflector Y translation	$+2.9$ arcsec mm^{-1}
Subreflector Z translation	$+2.1$ arcsec mm^{-1}
Subreflector X rotation	$+0.15$ arcsec arcsec^{-1}
Subreflector Y rotation	$+0.13$ arcsec arcsec^{-1}
Feed X translation	$+1.05$ arcsec mm^{-1}
Feed Y translation	-1.05 arcsec mm^{-1}
Feed Z translation	-0.25 arcsec mm^{-1}

- Test for 7) to eliminate Track and Az encoder.
- Mechanical check to eliminate Rcvr "slop"
- Way to lock SR actuators? Look for encoder variations?
- Oil-canning: Acoustic sensors to detect "ping"?
- Structure hysteresis probably would correlate with strain rates, i.e., 1).

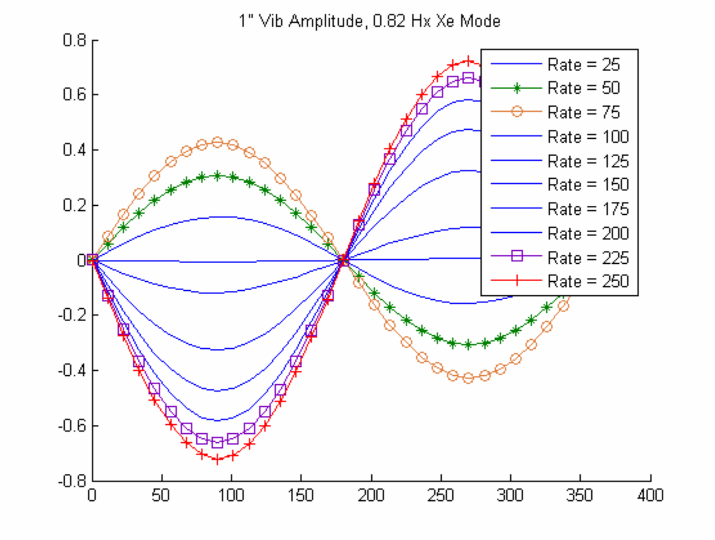
Apparent Az Error

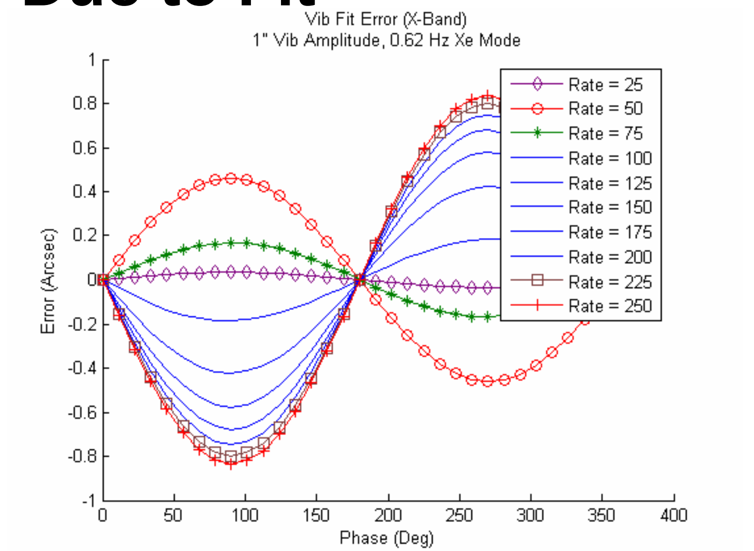


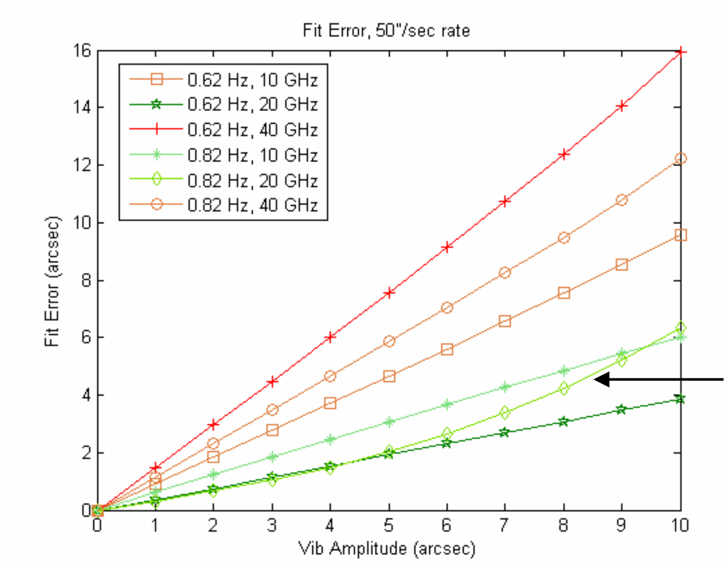


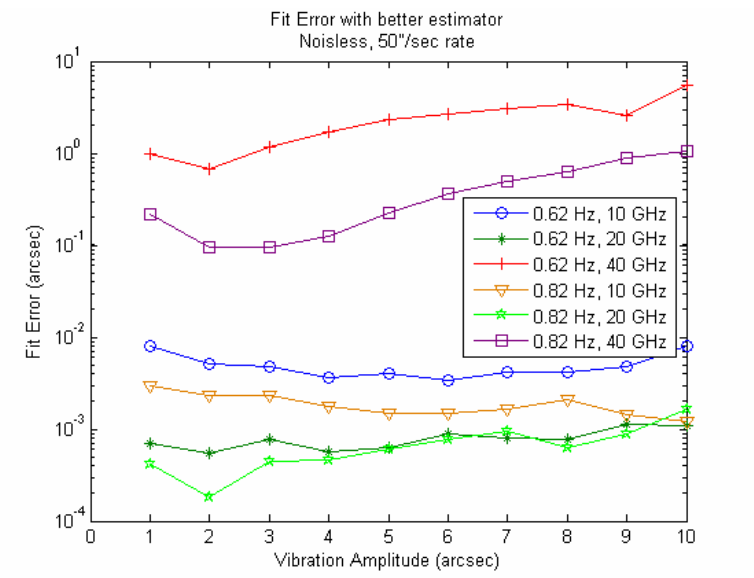
Comparison of Gaussian fit and Coherent vib-corrupted peak: X Band, 50”/sec rate, 1” vib amplitude, Worst-case phase.

Apparent Pointing Error Due to Fit









Az “Hysteresis” Experiments and Analysis

- Re-analyze e.g. TPTCSRMP040506, use fit with vib model.
- Analyze F/B in all-sky data
- New SSTrack with accels/incs.
  - Band-limited integration to position and get modal shapes as well.
  - Vib estimation in fit and/or metrology
  - Optimize receiver and scan rate
- Roll back and forth in region between grade walls to generate az track history, use incs (no astronomy needed?)

FRONT RUNNERS ARE TRACK MEMORY AND FITTING ERRORS

- **No clear elevation dependence in TPTCSRMP040506…**

Other Effects

- Noisy AllSky data- Probable mechanisms:
  1. Vibration/fit error, incoherent?
  2. Time dependent thermal gradients
- Systematic elevation error- Nonlinear Modulus?
  – Cleaner data needed to estimate effect
- Systematic azimuth error- Track residuals?
  – Need better signal processing (model-based) of inclinometer data

Experimental Data and Pre-Processing

- Astronomical and temp data as before, perhaps additional FOM on peak, baseline
- Sampler to log of metrological data @10 Hz:
  - Servomon/Antenna: Az,El,SR,AS encoders; main drive motor currents and tachs; commanded positions. Set sample rate to 10 Hz?
  - QD, Inclinometers, Accelerometers, Air Temp, Structure Temp, Weather Stations
- Pre-process metrological data
  - Flat file in IEEE floating point (double) at 10 Hz
  - Aux file with machine parsible field descriptions
  - General tool takes sequence of <manager>-<submanager>-<sampler>-<field> descriptions and date-time range, outputs flat file
- Model-based inclinometer signal processing (perhaps accelerometers as well)
- Inclinometer/accelerometer signal model

Experiments

- At least three Allsky runs (more is better)
  - Sparsely sample az/el space: [25º,80º] elevation, all azimuths
  - Three minimum for stable parameter estimates and bootstrap
  - Day/night, low wind
  - Sequential doubles for absolute/offset pointing metrics
- At least two SSTracks
  - Sources that transit ~ 80º elevation to North and to South
- Inclinometer and track memory
  - "Beat" on region between grade walls to see if az history is measurable
- Half-power tracks are lower priority for now

Vibration Suppression

- Vib is not only important for pointing model work but also for tracking and offset pointing
- Attempts/ruminations for suppression
  – Posicast in trajectories (Wells/Brandt/?): Hasn't worked well?
  – Notions of magneto-viscous dampers (Wells?)
  – Notions of active inputs (Payne, "Shaker")
- Difficulty of modifying existing M&C control, main drive limitations militate against using main drives
- Adding an active or passive damping system has advantages:
  – Can design to needed performance, rather than work around main drive limits
  – Is a "new" start in terms of control software, and design is largely unconstrained
- Have added advantages in that existing instrumentation (incs, accels, QD, etc.) are probably sufficient to estimating the state (in the state-space dynamical model sense) of the structure when coupled with a bit of astronomy (which might not be needed in the end…)
- Suppression system would not only damp main drive/track induced vib, but also might be possible to damp the wind-excited modes as well
- Good damping system completely obviates need for pointing/SR control at rates above ~0.3 Hz
- Good damping system could obviate need for careful SR control, i.e., making sure that SR motions do not induce undesired dynamics
- Good damping could improve observing efficiency- Could use more aggressive trajectories

Vibration Suppression, Cont.

- Design Issues:
  - Are existing instruments sufficent to “observe” (state-space sense) the structural vibs (not just freqs, but mode shapes)
  - Can an adequate dynamical model be easily (relatively) formulated?
  - Is active or passive damping best in terms of:
    - Cost/complexity
    - Safety- active damper could also excite a mode- would have to be able to!
    - Damping time- Active damper could have considerably shorter time to damped than equivalent mass passive damper.
  - What are the best locations for dampers? How many? How much mass and drive force/power required?
  - What is an acceptable time interval from typical vibration state to damped below a pointing threshold?
- Probably best to start design activity soon- implementation could take awhile. When would it be required?