TSP-2 Software to Point SAR Targets

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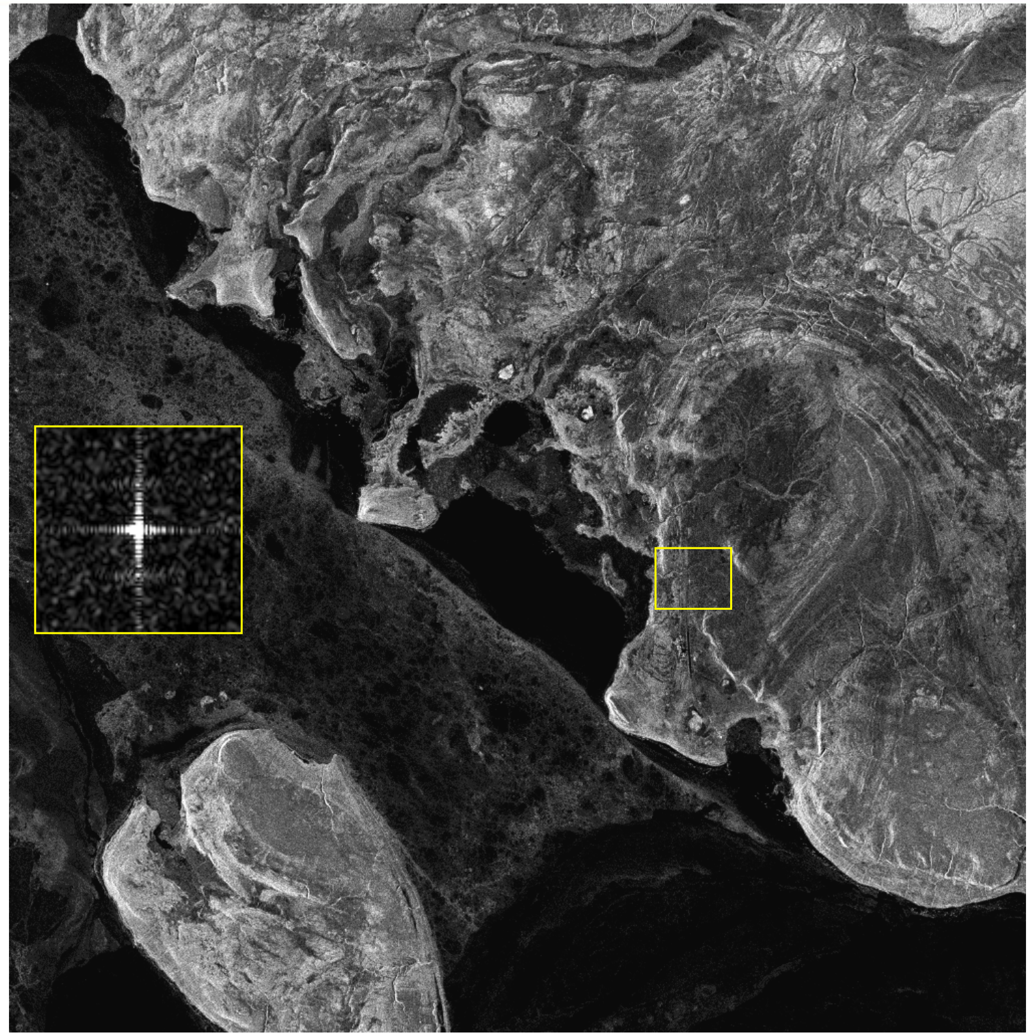
Gibson, Crocker

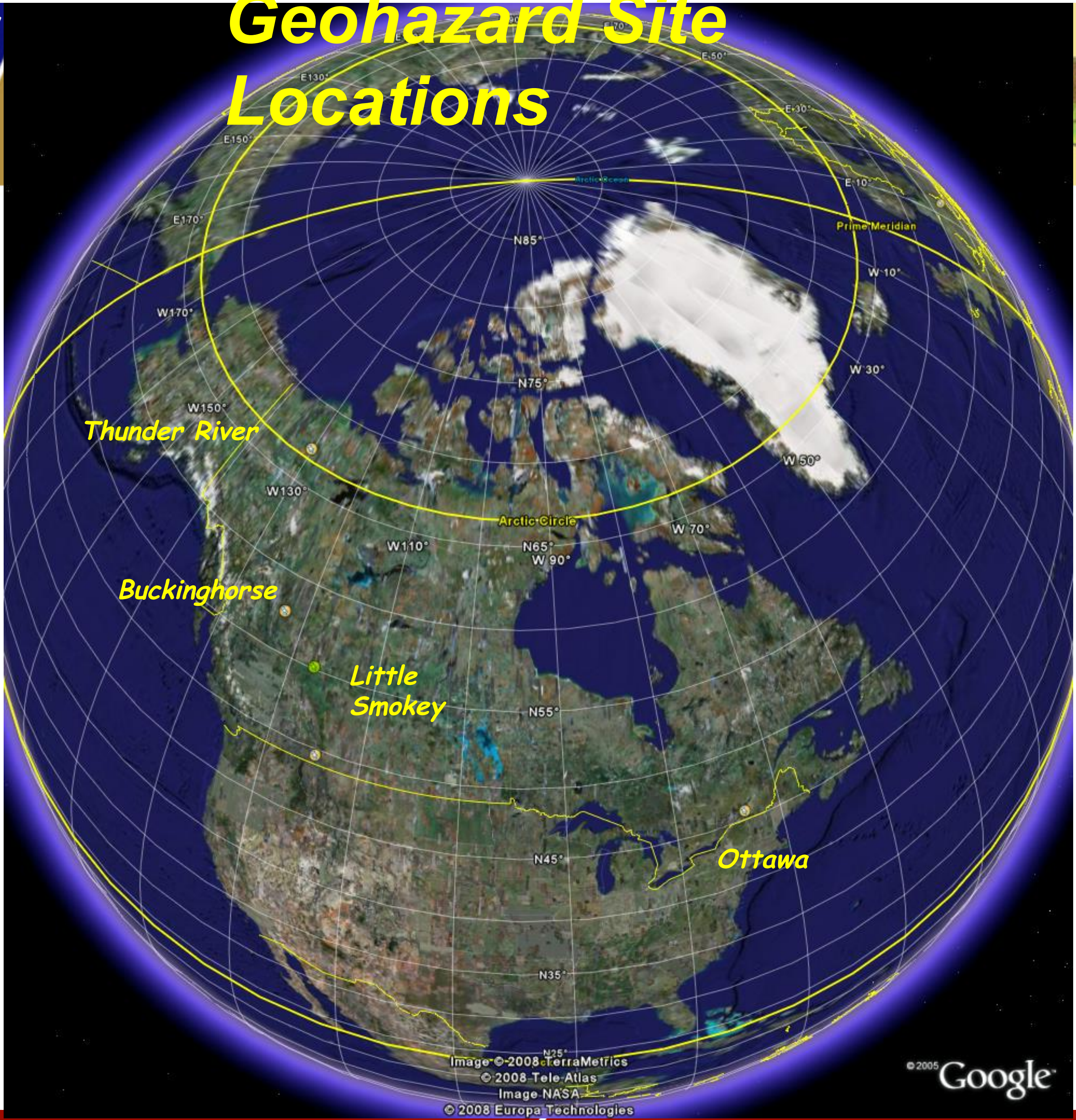
Some Context

Outline

- **Purpose**
- **Geometry**
  - Optimal Pointings
- **Finding the Satellite**
  - Requirements
  - Coordinate Transforms
- **Operation**
- **Results**
  - RS2
- **Accuracy Testing**
  - Vs. RPT Results
  - Vs. STK
- **Conclusions**



Geohazard Site Locations




2006.10.30 23:03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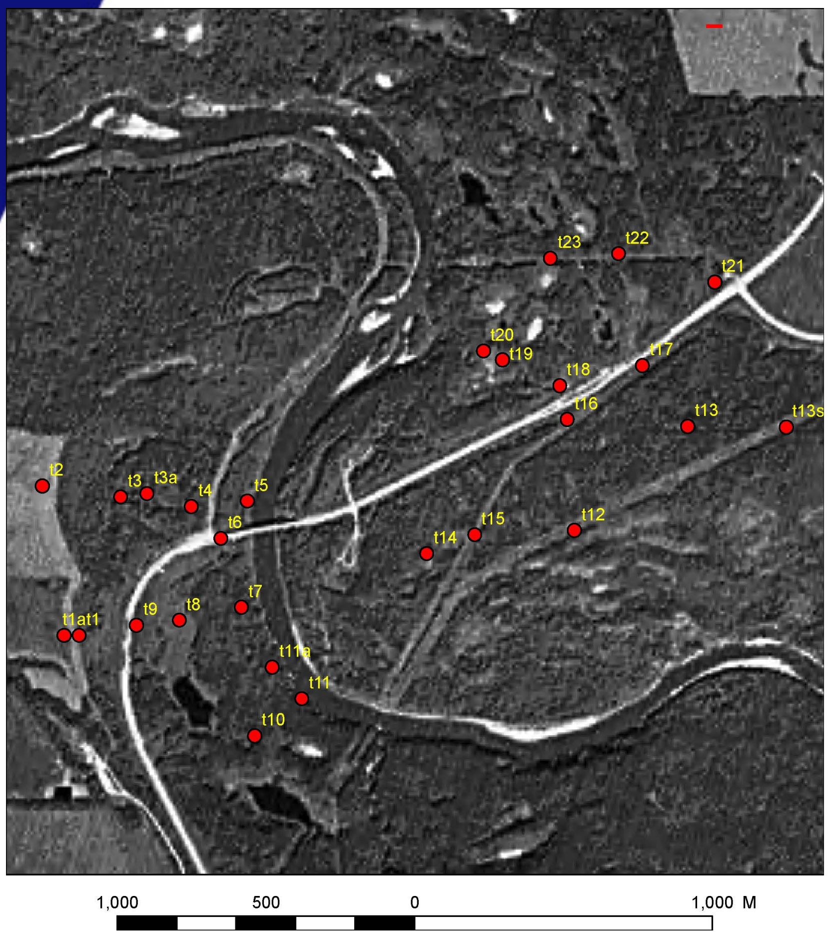
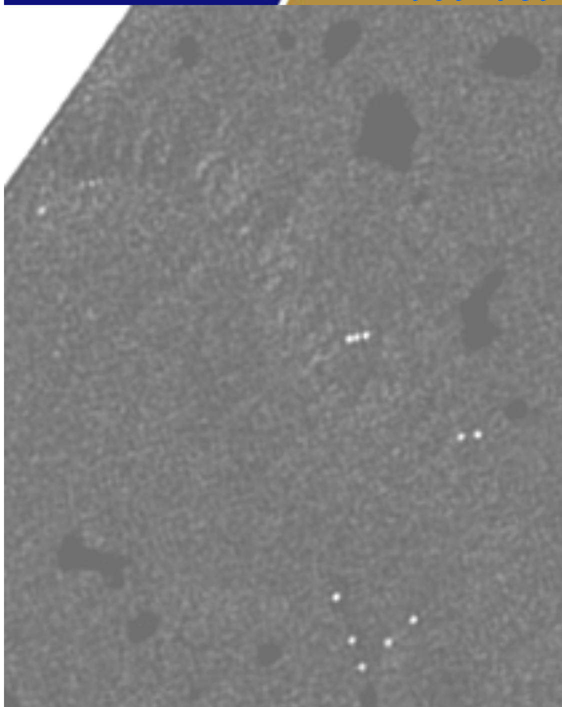
Geo-Hazards In-SAR Study RS-1 Imagery Little Smokey



Thunder River Site



Purpose in Developing TSP

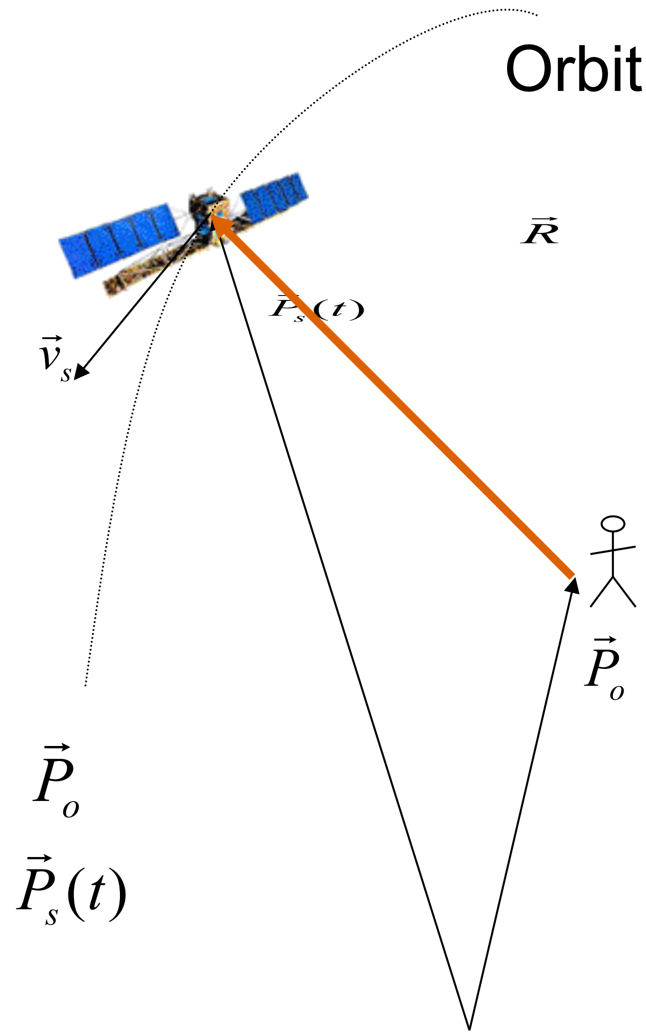
Determine Azimuth & Elevation pointings for RS-2

- Arbitrary location on earth
- Initially for RS-2 transponder
- Extended to other satellites:
  - RS-1, ENVISAT, TerraSAR-X, ALOS COSMO-SkyMed
- Extended for CRs and other targets
- General need for user community

Yaw-Steered Pointing – RS-2

$$\frac{d\phi}{dt} = \frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right) = 0$$

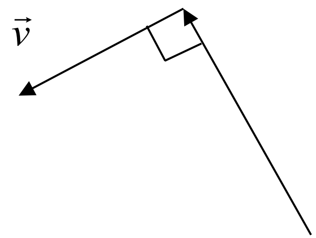
$$\frac{d}{dt}\left(\left|\vec{P}_s(t) - \vec{P}_o\right|\right) = \frac{dR}{dt} = 0$$



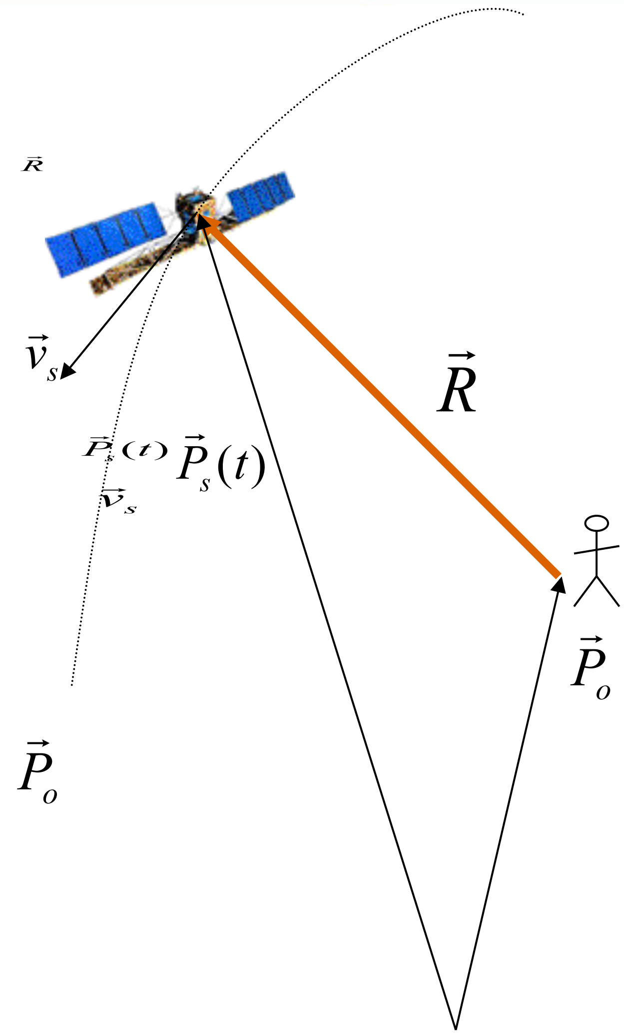
- **Requires Target location**
- **Requires Satellite location**

Non-steered Pointing - RS-1

$$\vec{R}(t) \bullet \vec{v}(t) = 0$$



$$\left(\vec{P}_s(t) - \vec{P}_o\right) \bullet \frac{d\vec{P}_s(t)}{dt} = 0$$



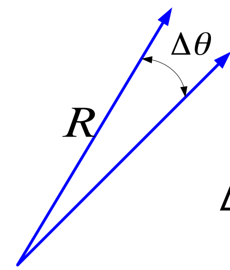
- Require Target location
- Require Satellite location
- Require Satellite velocity

Finding Satellite Position

- **How do we implement this? –Use NORAD TLEs**
  - Freely available
  - Standard for Orbit description
  - Well established propagators available for development
- **SGP-4 (Simplified General Perturbations) Propagator**
  - Position, velocity wrt time from TLEs
  - Existing MATLAB® code
- **Other issues**
  - Coordinate frames
  - Calculating Pointings

Pointing Requirements

- **Angular Resolution**
  - Δθ = ±0.01° for azimuth and elevation
  - For a target R=1000 km, Δs = ±170 m



$$\Delta\theta = \frac{\Delta s}{R} = 0.01^{o}$$

- **Time Resolution**
  - Not crucial for ‘event’ time
    - few seconds
  - Crucial for orbit propagation.
    - v ~ 7.5 km/s for RS-1
    - Can therefore travel 0.17 km in ~0.02 s

$$\Delta t = \frac{\Delta s}{v} = 0.02\ \mathrm{s}$$

Coordinate Transforms

- **Propagator output:**
  - True Equator Mean Equinox (TEME) frame
  - X axis in direction of vernal equinox, Z axis of rotation
- **Optimal satellite position calculation:**
  - Earth Centred, Earth Fixed (ECEF)
    - X axis points towards (0°,0°), Z axis of rotation
  - Local vertical (ENU) (East, North, Up)⇨ (X,Y,Z)
- **Azimuth and Elevation Calculation:**
  - Local Polar Coordinates (LPC) (Az, El, Range)

Coordinate Transforms

True Equator Mean Equinox (TEME)

↓

$$\vec{r}_{PEF} = \begin{bmatrix} \cos(-\theta_{GMST}) & \sin(-\theta_{GMST}) & 0 \\ -\sin(-\theta_{GMST}) & \cos(-\theta_{GMST}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \vec{r}_{TEME} \qquad \vec{v}_{PEF} = \begin{bmatrix} \cos(-\theta_{GMST}) & \sin(-\theta_{GMST}) & 0 \\ -\sin(-\theta_{GMST}) & \cos(-\theta_{GMST}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \vec{v}_{TEME} - \alpha(\vec{\omega}_{Earth} \times \vec{r}_{PEF})$$

$$\alpha = \begin{cases} 0 & \text{non-steered SARs} \\ 1 & \text{yaw steered SARs} \end{cases}$$

↓ Neglecting polar wobble

Earth Centred Earth Fixed (ECEF)

Latitude λ, longitude φ

↓

$$\vec{r}_{satellite\_ENU} = \begin{bmatrix} -\sin\phi & \cos\phi & 0 \\ -\cos\phi\sin\lambda & -\sin\lambda\sin\phi & \cos\lambda \\ \cos\phi\cos\lambda & \cos\lambda\sin\phi & \sin\lambda \end{bmatrix} \left[\vec{r}_{satellite\_ECEF} - \vec{r}_{observer\_ECEF}\right] \qquad \vec{v}_{satellite\_ENU} = \begin{bmatrix} -\sin\phi & \cos\phi & 0 \\ -\cos\phi\sin\lambda & -\sin\lambda\sin\phi & \cos\lambda \\ \cos\phi\cos\lambda & \cos\lambda\sin\phi & \sin\lambda \end{bmatrix} \vec{v}_{satellite\_ECEF}$$

↓

Local Vertical, East-North-Up (ENU)

↓

$$range = \left|\vec{r}_{ENU}\right| \qquad azimuth = \arctan\left(\frac{y_{ENU}}{x_{ENU}}\right) \qquad elevation = \arctan\left(\frac{z_{ENU}}{\sqrt{x_{ENU}^2 + y_{ENU}^2}}\right)$$

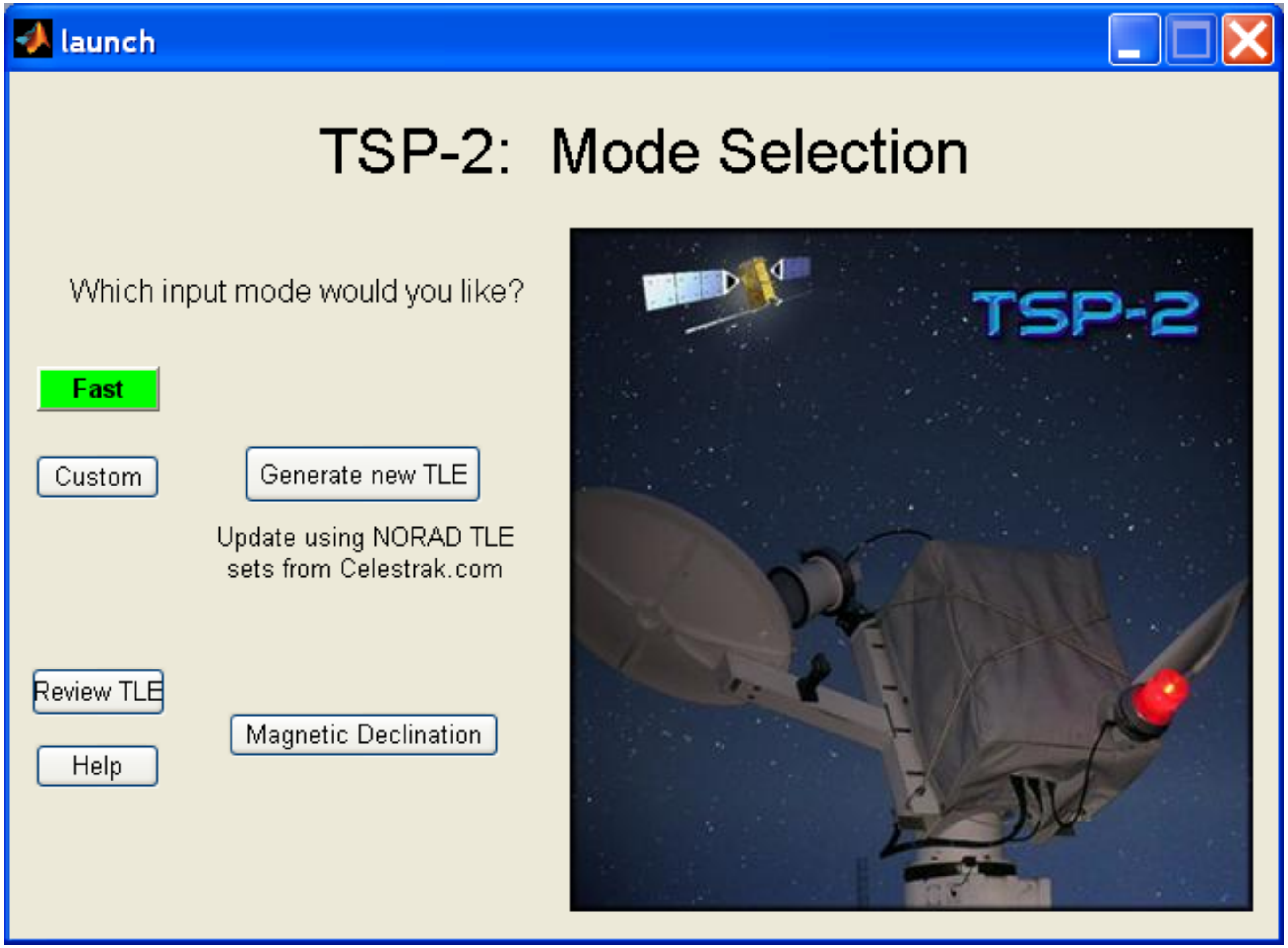
↓

Range, Azimuth, and Elevation (LPC)

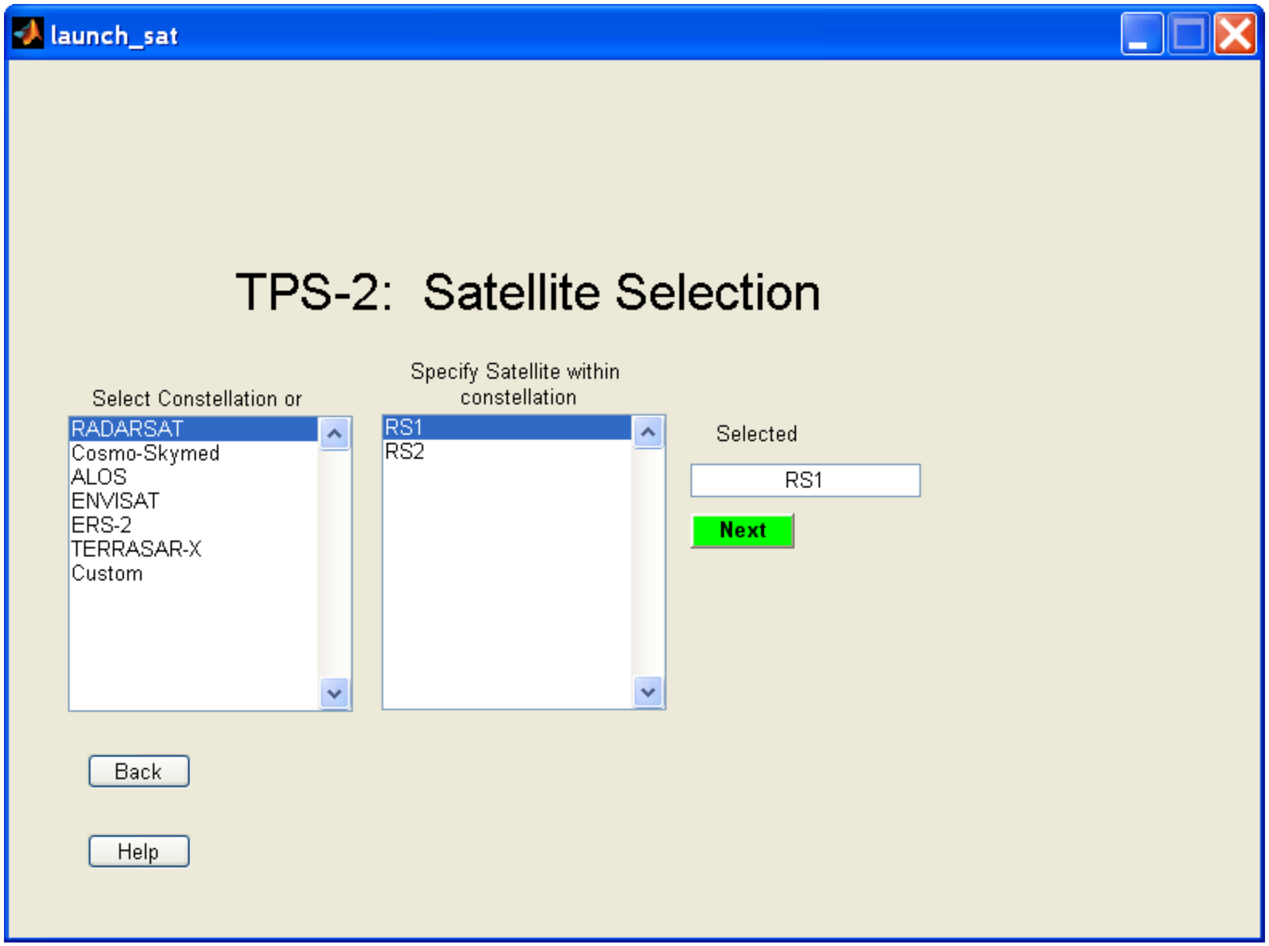
Operation

- **SW written in MATLAB®, two primary modes:**
- **Fast**
  - Inputs: satellite, target location, and approximate event time
  - Orbit found from TLE archive
  - Outputs: Optimal pointing
- **Custom**
  - Inputs: satellite, target location, time window, initial time step, Specific TLE, and polar wobble coordinates
  - Orbit found from specific TLE
  - Outputs: Optimal pointing
- **Batch**
  - Table input/output

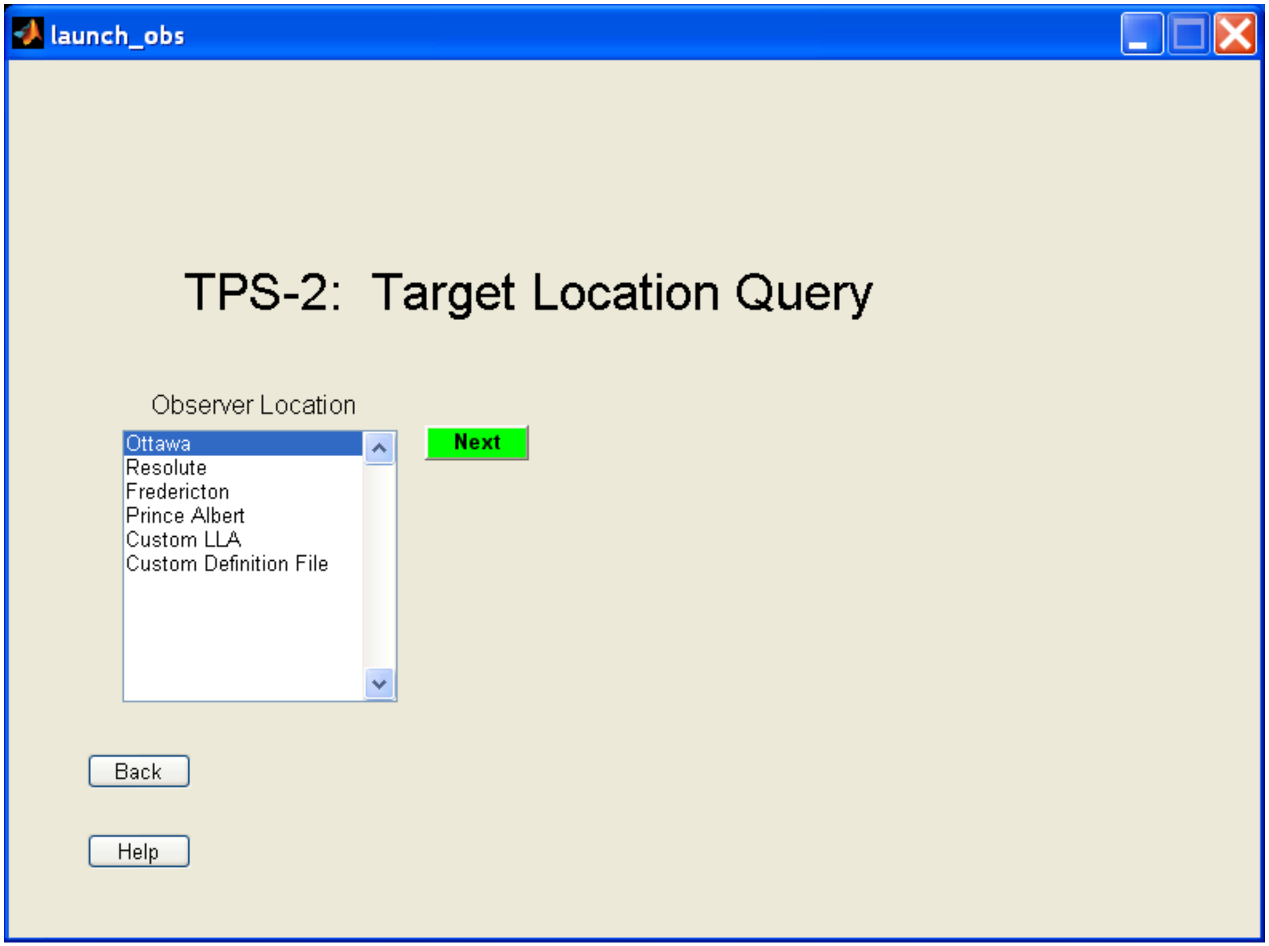
Opening Screen



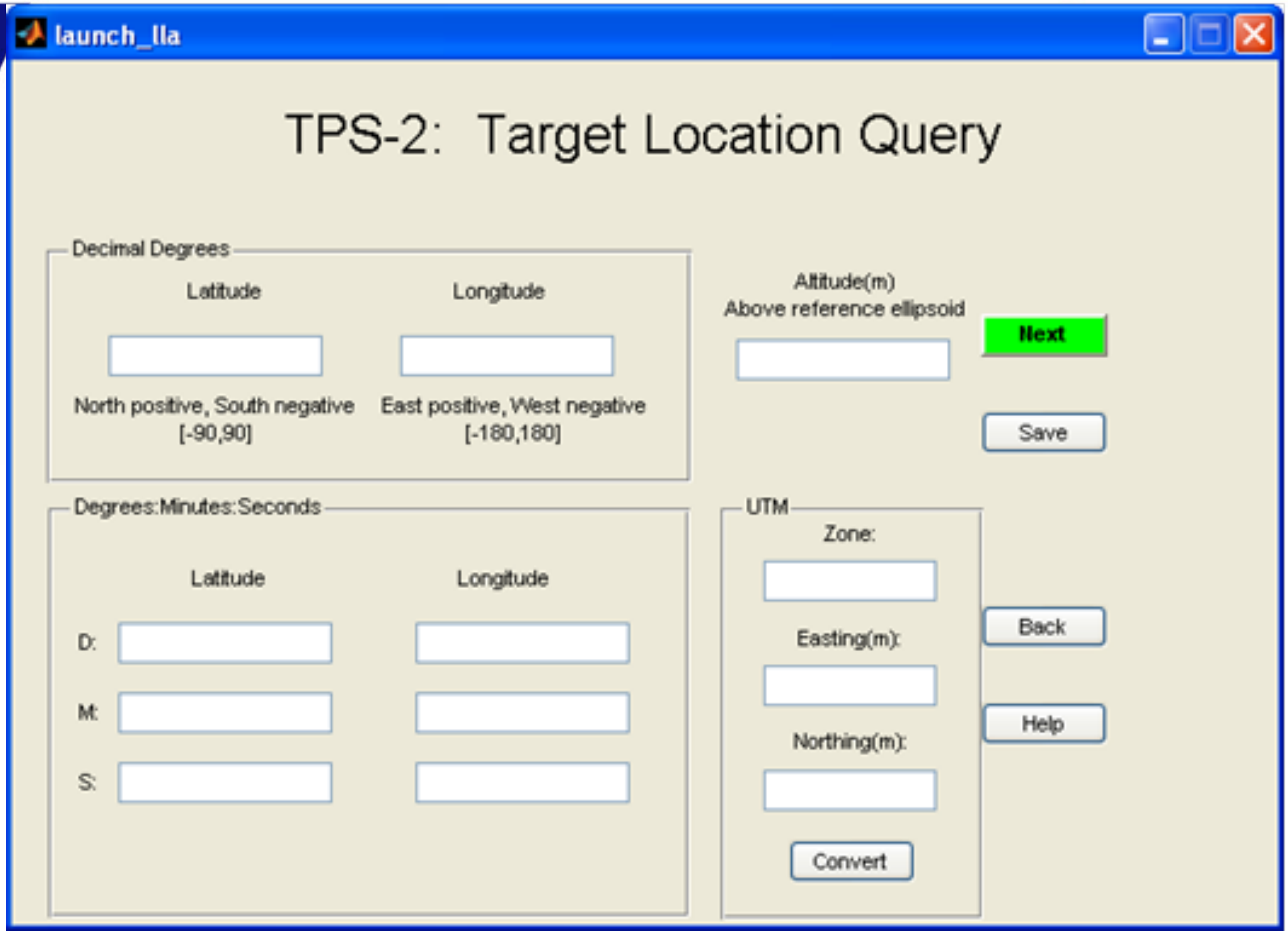
Satellite Selection -Canned or Custom



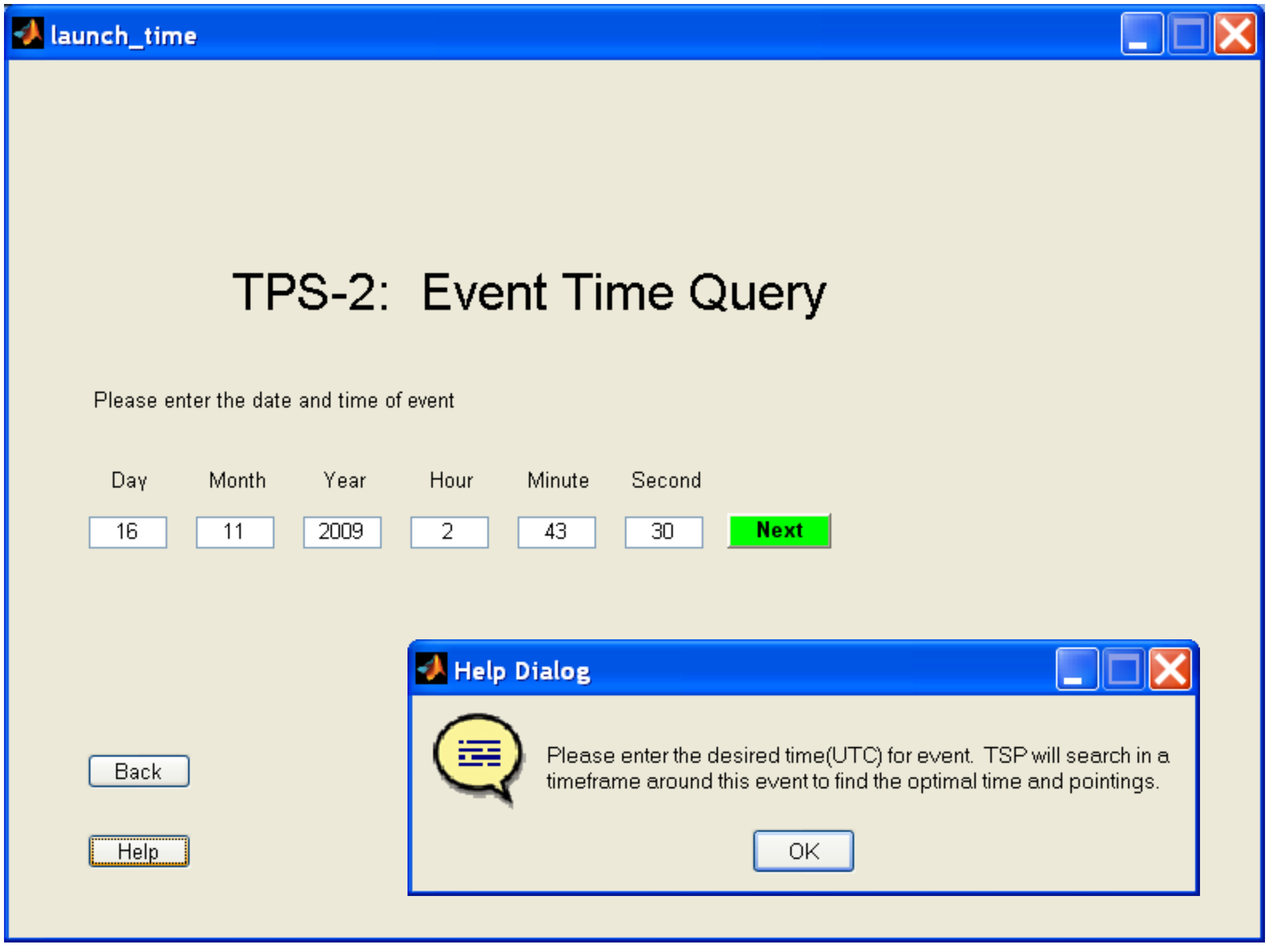
Target Location Selection – Canned or Custom



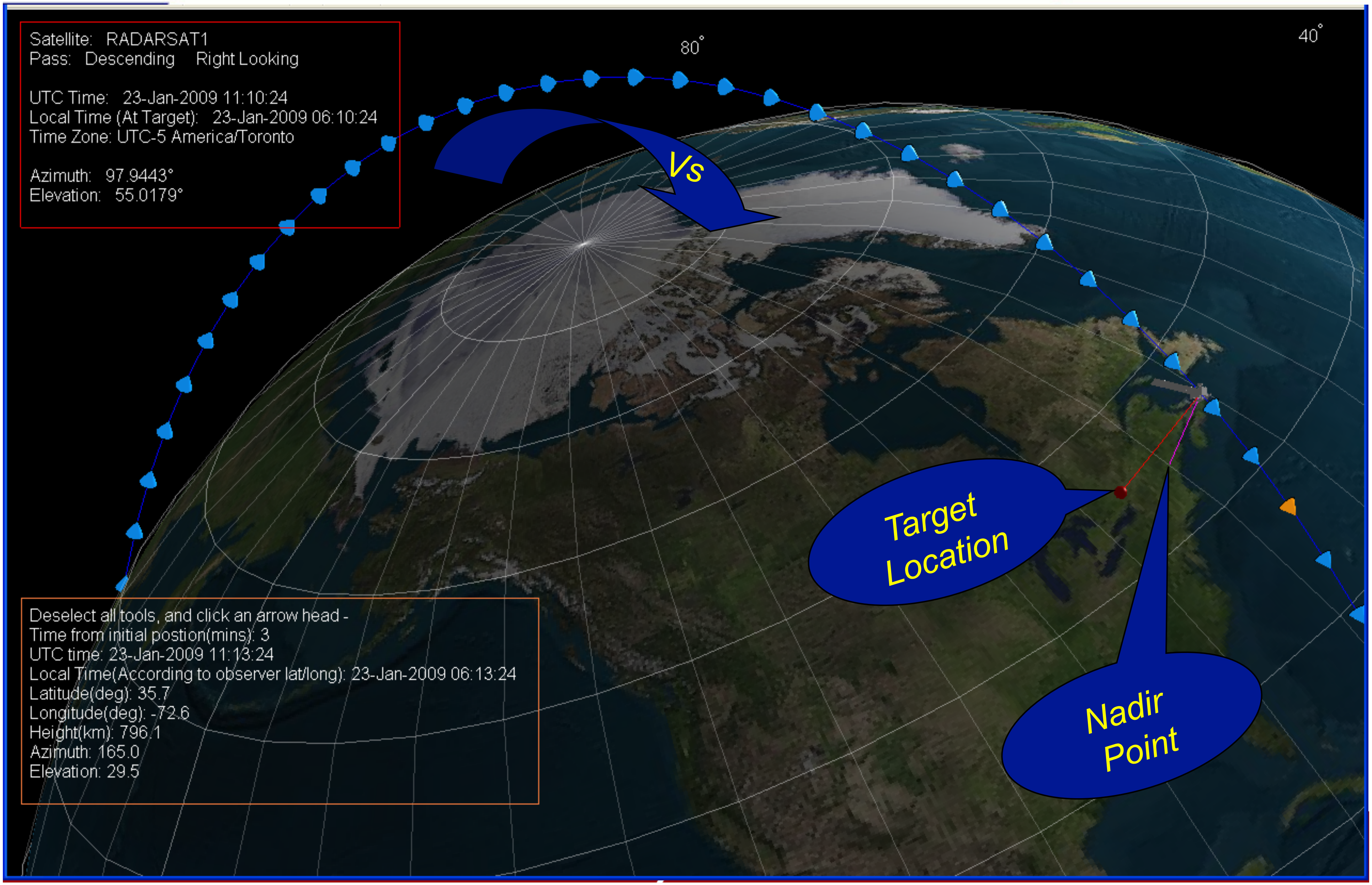
Target Location Query



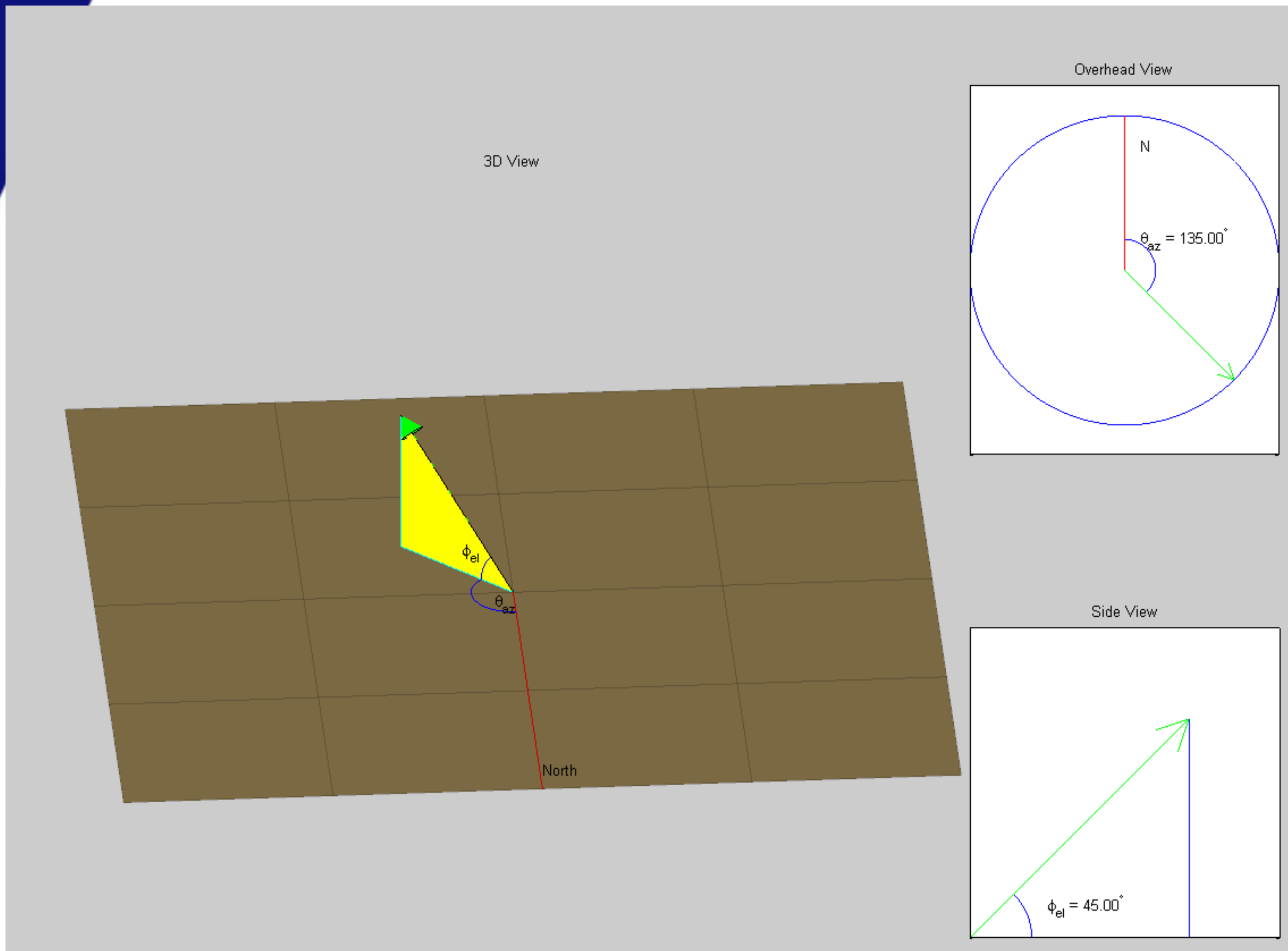
Time Selection - UTC



Geometrical Confirmation



Field Geometry



Example Textual Dump

```
*** TSP 2.0: Target-to-Satellite Pointings ***

Epoch time of TLE used for nominal orbit:  2008    7    9 23: 9:36.067378

ECEF coords written to tmat.out, first table entry @ TLE epoch

RADARSAT2

NORAD ID 32382
ONO


Optimal Setting:
Minimum distance from satellite to observer (km): 1006.9760
Minimum result record number: 29

Time (UTC): 2008/7/9 22:58:55.746972
Time from Epoch(min):    -10.67
X(km):       636.398      Y(km):     -5114.702      Z(km):      4977.960
Vx(km/s):     -2.535      Vy(km/s):      4.800      Vz(km/s):      5.242

Corresponding date: 06-Mar-2009 22:58:55
Observer Azimuth (degrees): 260.1358
Observer Elevation (degrees): 49.7105
Corner reflector elevation from base(degrees): 14.4461

Satellite Latitude: 44.1747
Satellite Longitude: -82.9074
Satellite Altitude(km): 797.7679

Angle between satellite and observer vector: 5.2104
Angle between satellite and range vector: 35.0466
Angle between observer and range vector: 139.7431
Magnitude of Satellite Position Vector(km): 7165.5614
Magnitude of Satellite Velocity Vector(km): 7.5461

Beam Velocity(km/s): 6.6782

Unit vector from Target to Satellite:  X(m):     -0.4661   Y(m):     -0.75   Z(m):      0.4642

Pointings saved to pointing.out
```

TLE Epoch

TLE Norad ID

Target Range

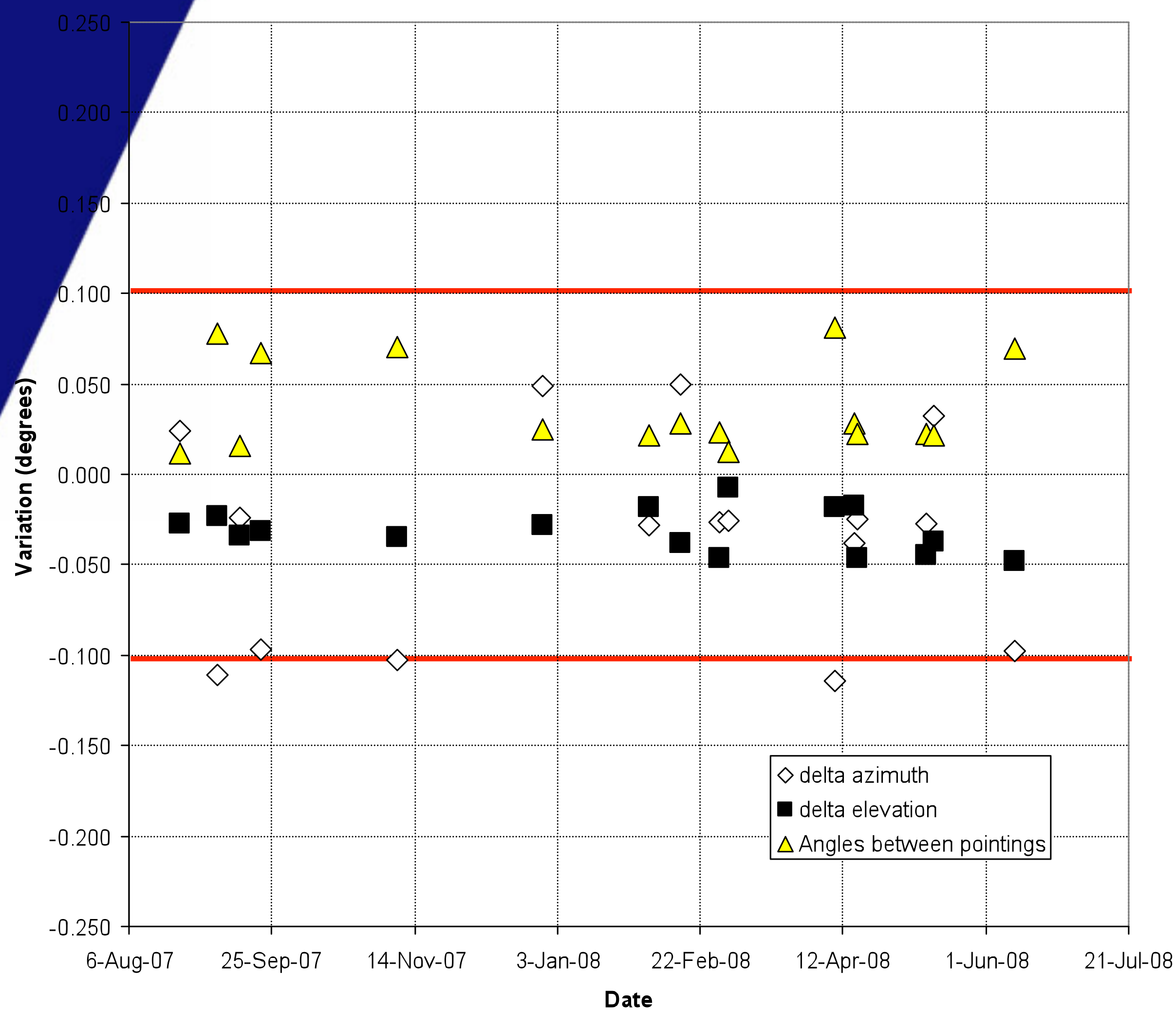
Satellite XYZ P/V/t

Target/Satellite Angles

Satellite lat/long/Alt

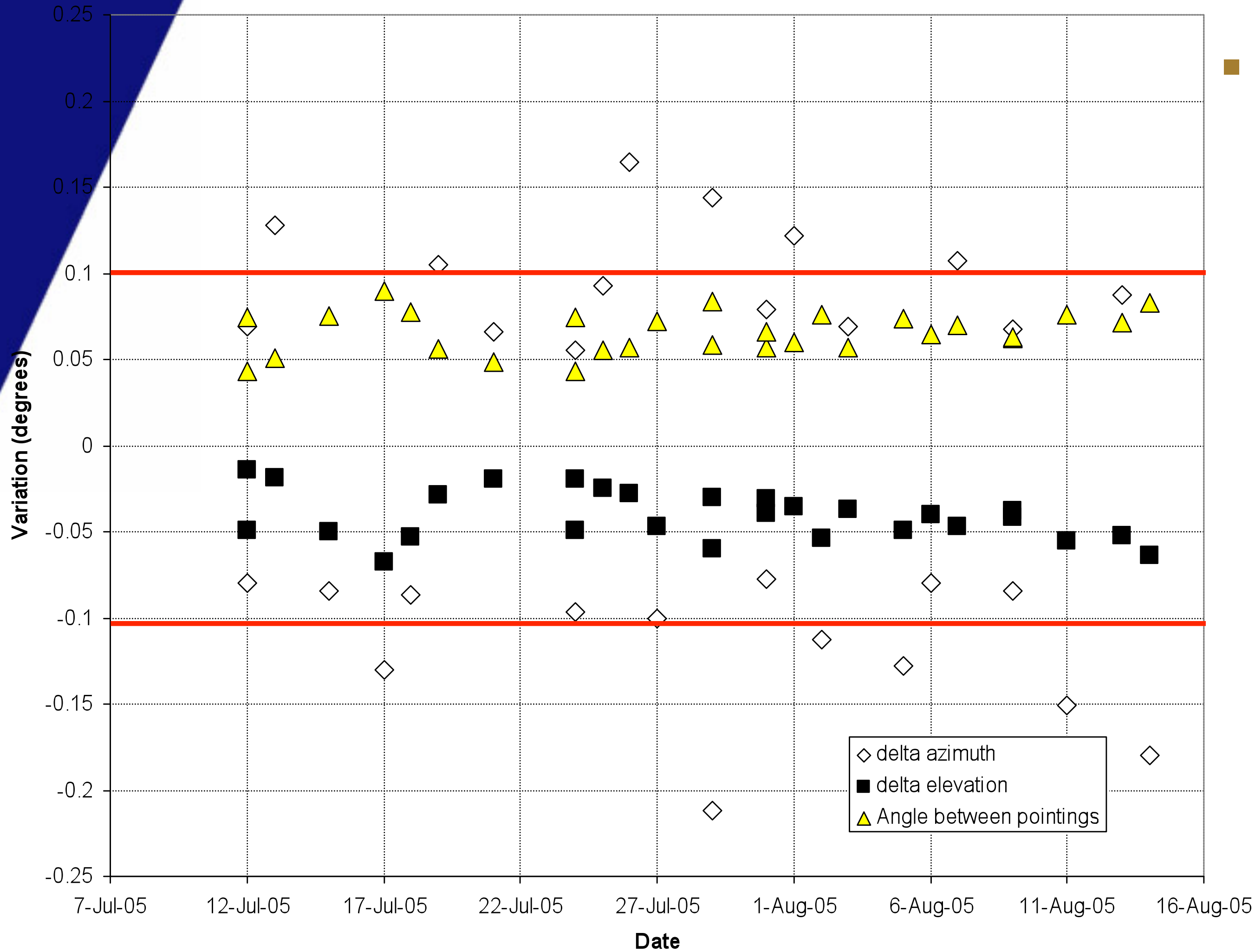
Beam Velocity

RS-1 vs TSP Results



- **Ottawa RPT Events 2007/08 to 2008/06**
  - RMS errors:
  - Azimuth 0.06°
  - Elevation 0.03°

ENVISAT vs TSP Results



- **Res RPT Events 2005/07 to 2005/08**
  - RMS errors:
  - Azimuth 0.11°
  - Elevation 0.04°

Conclusions

- A general new tool, TSP-2, has been developed and validated for Target Pointing.
- Currently being used for Validation of RS-2
- Government and Commercial Clients
- Available through CCRS
- Hire a Student or Two!


TSP-2 ..Software for Pointing Radar Targets
Supported Satellites:
RADARSAT-1 /2
Cosmo-Skymed 1/2
ALOS
ENVISAT
ERS-2
TERRASAR-X
Satellite: RADARSAT-2
Pass: Ascending Right Looking
UTC Time: 24-Mar-2009 22:33:59
Local Time: 24-Mar-2009 18:33:59
Time Zone: UTC-4 America/Toronto
Azimuth(degrees): 255.13°
Elevation(degrees): 82.25°
CCRS contacts: Kevin Marshall, Jack Gibson, Bob Hawkins
Robert.Hawkins@NRCan.gc.ca, (613) 995-1067

Orbit Accuracy Testing

- **Historical RS-1 and ENVISAT RPT pointings**
  - RPT pointings empirically correct to ~0.1°
- **Compare TSP to STK results**
  - Premise: STK is industry standard propagator
  - STK allows TLE input

Pointing Error -TSP vs STK

- Pointings for events between 2008/07/02, 00:00:00 to 12:00:00
- Same TLE's used

Satellite	Location	Δ Azimuth (°)	Δ Elevation (°)	Δ Range (m)
RS2	ON0	0.001	0.001	-22.16
RS1	ON0	-0.001	-0.001	-9.94
ENVISAT	ON0	-0.001	0.000	-20.62
TERRASAR-X	ON0	0.000	-0.001	-5.51
ALOS	ON0	0.002	0.000	-20.46
RS2	NT0	-0.011	-0.001	-0.42
RS1	NT0	-0.001	0.000	-13.79
ENVISAT	NT0	0.001	-0.001	-17.74
TERRASAR-X	NT0	0.001	-0.001	-11.83
ALOS	NT0	-0.004	0.000	-18.48
RMS Average		0.004	0.001	15.66

Absolute Position Error – TSP vs STK

Difference in ECEF position

Satellite	Location	Δ X (m)	Δ Y (m)	Δ Z (m)	Δ R (m)	Relative Error (%)
RS2	ON0	7.06	-23.22	-6.72	25.18	0.0004%
RS1	ON0	7.99	-11.87	2.30	14.49	0.0002%
ENVISAT	ON0	-2.77	2.89	20.56	20.95	0.0003%
TERRASAR-X	ON0	9.66	-25.84	-11.33	29.82	0.0004%
ALOS	ON0	-4.03	-3.40	15.31	16.20	0.0002%
RS2	NT0	-1.36	199.65	70.35	211.69	0.0030%
RS1	NT0	6.54	16.45	23.34	29.29	0.0004%
ENVISAT	NT0	-9.03	22.51	23.73	33.93	0.0005%
TERRASAR-X	NT0	15.94	37.83	29.97	50.83	0.0007%
ALOS	NT0	-8.14	7.74	19.75	22.72	0.0003%
RMS Average		8.23	65.95	28.60	72.36	0.0010%

Along/Across Track Error – TSP vs STK

		Along track error	Radial error	Across track error
Satellite	**Location**	$\hat{v} \bullet \Delta r$ (m)	$\hat{r} \bullet \Delta r$ (m)	$\hat{v} \times \hat{r} \bullet \Delta r$ (m)
RS2	ON0	20.82	12.26	7.15
RS1	ON0	7.28	11.83	4.15
ENVISAT	ON0	16.99	12.02	-2.25
TERRASAR-X	ON0	27.07	11.98	3.71
ALOS	ON0	10.15	12.37	2.42
RS2	NT0	-210.90	16.86	6.65
RS1	NT0	22.44	16.95	-8.16
ENVISAT	NT0	29.23	17.08	-2.11
TERRASAR-X	NT0	46.79	17.08	-10.06
ALOS	NT0	14.79	17.20	1.14
RMS Average		70.61	14.77	5.57

- Majority of error in along-track direction (i.e. direction of velocity)
- Very small error in across-track direction

A Versatile Tools is available for Growing Community

- > $4M in CRs by one Cdn Company in 2008
- InSAR – Geohazards
  - Subsidence
  - Landslides
  - Plate shifting
- Phase Calibration
- Amplitude Calibration
- Positioning

Reflector Installation Above Permafrost

References

- FR Hoots and RL Roehrich. (1980). “Spacetrack Report #3: Models for Propagation of the NORAD Element Sets.” US Air Force Aerospace Defense Command, Colorado Springs, C.O. 90p.
- DA Vallado, P Crawford, R Hujsak, TS Kelso. (2006). “Revisiting Spacetrack Report #3”, AIAA 2006-6753, 88p.
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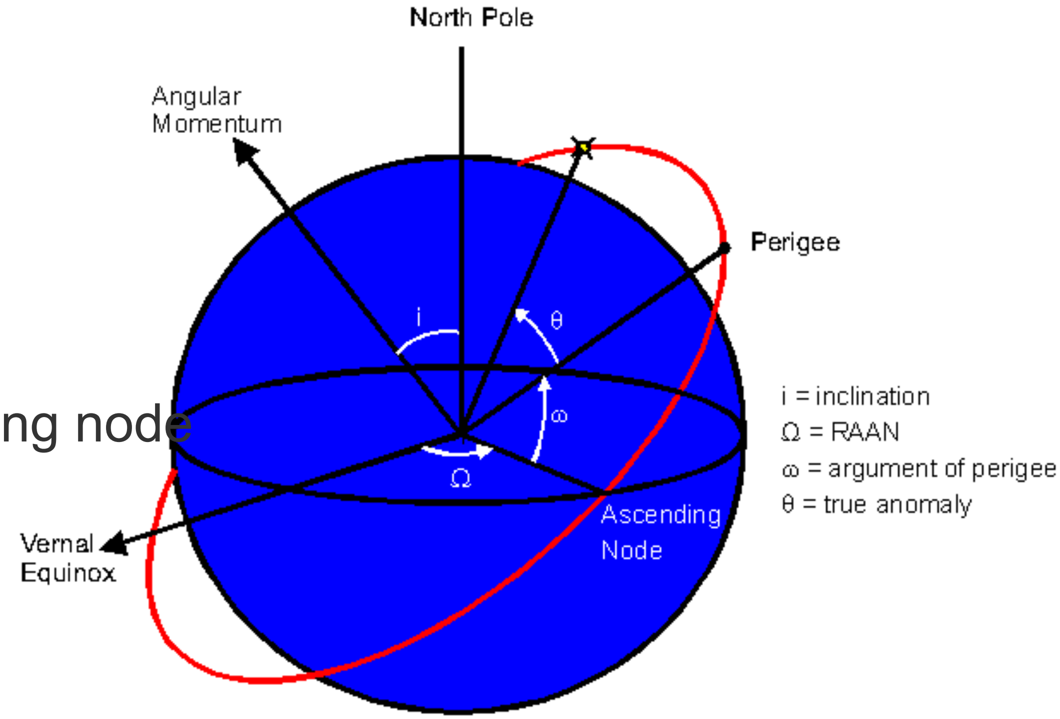
- ---(2007). “Conversion of Geodetic coordinates to the Local Tangent Plane.” Portland State Aerospace Society. Version 2.01 (2007.9.15)” http://www.psas.pdx.edu
- “NORAD Two-Line Element Set Format.” Accessed 2008/05/14. http://celestrak.com/NORAD/documentation/tle-fmt.asp
- “Brief Introduction To TLEs And Satellite IDs.” Accessed 2008/05/14. http://satobs.org/element.html

TLEs

Keplerian Elements:

- Semi-major axis of orbit
- Eccentricity of orbit
- Mean motion
- Inclination
- Right ascension of ascending node
- Argument of perigee
- True anomaly
- Mean motion dot
- Mean motion dot dot
- Bstar drag parameter



http://www.mindspring.com/~n2wwd/html/orbital_description.html