# Radiometric Calibration and Image Quality Assessment of NISAR Products

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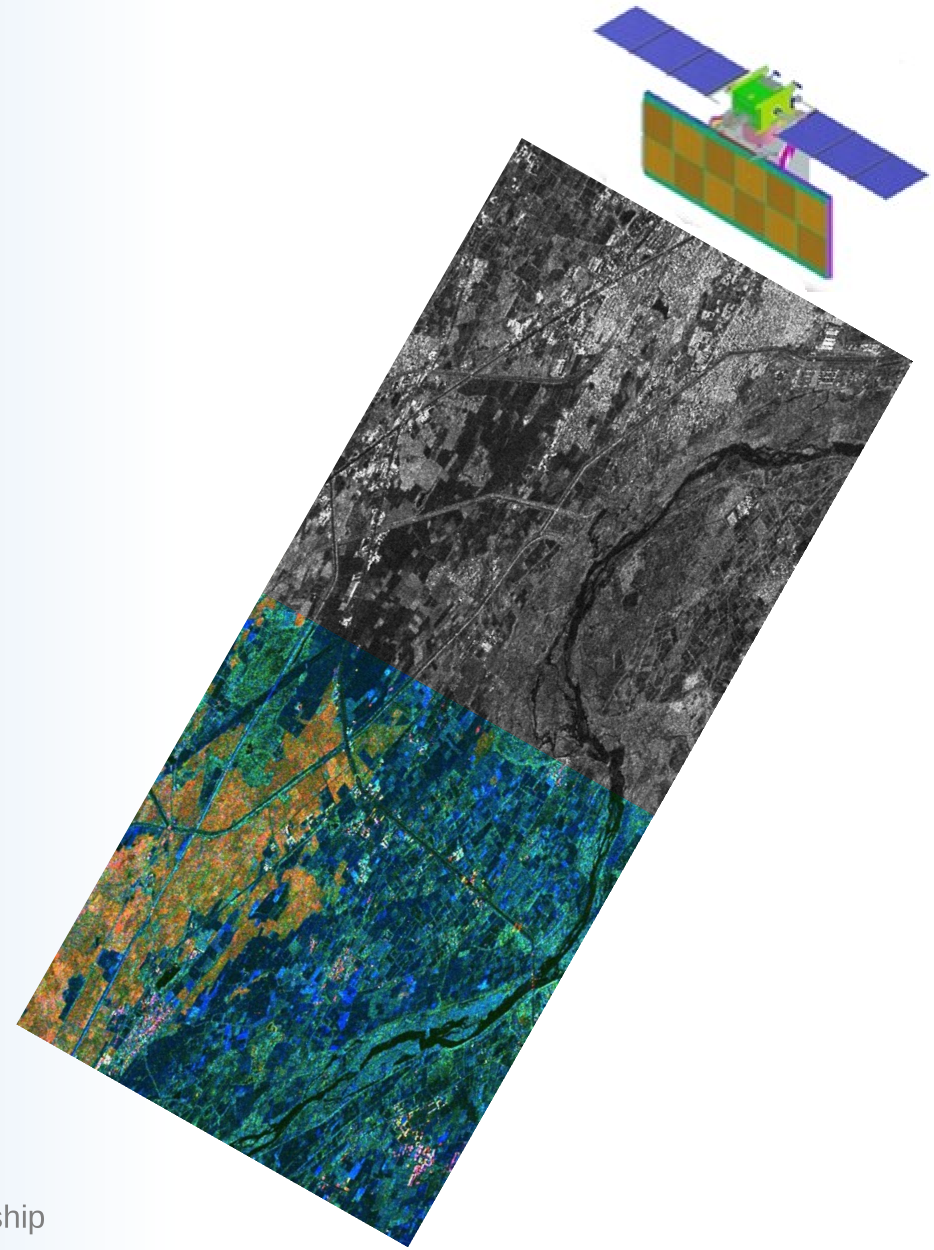


# Introduction

- Accurate calibration is critical to science-readiness of NISAR products, including Range-Doppler and Geocoded Single-Look Complex (RSLC & GSLC) products
- Quality Assurance (QA) tools ensure the fidelity of the L-band SAR (LSAR) instrument data and processing
- Use corner reflectors (CRs) for external calibration and image quality assessment
- Many more tools beyond those discussed here!

# Introduction

- The Absolute Radiometric Calibration (AbsCal) tool estimates a scaling factor for radiometric calibration of RSLC data
- The Point Target Analysis (PTA) tool measures impulse response characteristics of RSLC and GSLC images and is used in geometric calibration
- Used to populate an external calibration file used by the LSAR RSLC processor
- Integrated into automated QA workflows for NISAR LSAR products over calibration sites
- Implemented in the open-source library ISCE3

https://github.com/isce-framework/isce3

# Absolute Radiometric Calibration (AbsCal) Tool

- Geophysical applications expect image data in area-normalized backscatter units ($\beta_0$, $\sigma_0$, $\gamma_0$)
- The AbsCal tool estimates a scaling factor to apply to RSLC data to convert from Digital Numbers (DN) to normalized backscatter
- Compares predicted Radar Cross-Section (RCS) of known targets to their apparent RCS in partially-calibrated RSLC data

$$\underbrace{\begin{bmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{bmatrix}}_{\text{Uncalibrated Scattering Matrix}} = \underbrace{a e^{-j\frac{4\pi r}{\lambda}}}_{\text{Absolute Calibration Factor}} \underbrace{\begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{bmatrix}}_{\text{Crosstalk \& Channel Imbalance (Rx)}} \underbrace{\begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix}}_{\text{Faraday Rotation (Rx)}} \underbrace{\begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}}_{\text{Calibrated Scattering Matrix}} \underbrace{\begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix}}_{\text{Faraday Rotation (Tx)}} \underbrace{\begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{bmatrix}}_{\text{Crosstalk \& Channel Imbalance (Tx)}}$$

# Triangular Trihedral Targets

The scattering matrix for a triangular trihedral-shaped target is

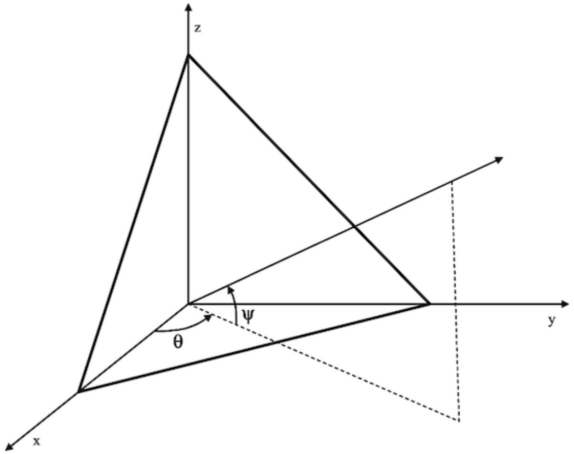
$$\begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} = \sqrt{\sigma_{tri}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

where

$$\sigma_{tri} = \frac{4\pi l^4}{\lambda^2} \begin{cases} \left( \sqrt{3}(P_x + P_x + P_z) - \frac{2}{\sqrt{3}(P_x + P_y + P_z)} \right)^2 & \text{, if } P_x + P_y \geq P_z \\ \left( \frac{4P_x P_y}{P_x + P_x + P_z} \right)^2 & \text{, if } P_x + P_y \leq P_z \end{cases}$$

is the monostatic RCS of the target

*https://uavsar.jpl.nasa.gov/cgi-bin/calibration.pl*




*$(P_x, P_y, P_z)$ are components of the target-to-platform unit look vector in the CR coordinate system, chosen such that $P_x \leq P_y \leq P_z$*

# Obtaining the Absolute Radiometric Calibration Factor

$$\begin{bmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{bmatrix} = ae^{-j\frac{4\pi r}{\lambda}} \begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{bmatrix}$$

After correcting for crosstalk/channel imbalance/Faraday rotation

$$\begin{bmatrix} Z'_{hh} & Z'_{hv} \\ Z'_{vh} & Z'_{vv} \end{bmatrix} = ae^{-j\varphi} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

For a triangular trihedral target:

$$\begin{bmatrix} Z'_{hh} & Z'_{hv} \\ Z'_{vh} & Z'_{vv} \end{bmatrix} = ae^{-j\varphi} \sqrt{\sigma_{tri}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$a = \sqrt{\frac{Z'_{hh} Z'^{*}_{hh}}{\sigma_{tri}}}$$

# Obtaining the Absolute Radiometric Calibration Factor

- Estimate AbsCal factor using partially-calibrated RSLC data that have been corrected for crosstalk, channel imbalance, and Faraday rotation
- Compute the predicted RCS, $\sigma_{tri}$, of a set of corner reflectors from calibration sites and compare with the measured RCS, $\sigma_{RSLC} = Z'Z'^{*}$, in RLSC data
- Model AbsCal factor as a linear function of elevation angle $\theta_{EL}$

$$a(\theta_{EL}) = a_0 + a_1\theta_{EL}$$

# Algorithm Overview: AbsCal Factor Estimation

**Inputs**

- Set of partially-calibrated RSLCs over calibration sites
- CSV file containing corner reflector survey records

**Procedure**

- For each RSLC:
    - Down-select corner reflectors
    - For each corner reflector:
        - Estimate $\sigma_{tri}$
        - Compute $\sigma_{RSLC}$
        - Compute $\theta_{EL}$
- Fit a line to $\sqrt{\sigma_{RSLC}/\sigma_{tri}}$ vs $\theta_{EL}$ using Ordinary Least Squares (OLS)

**Outputs**

- AbsCal polynomial coefficients (bias $a_0$ and slope $a_1$)

Corner reflector record:

- Unique ID
- Latitude/Longitude/Height
- Azimuth/Elevation
- Side length
- Survey Date
- Validity Flags
- Velocity East/North/Up

Filter corner reflectors by:

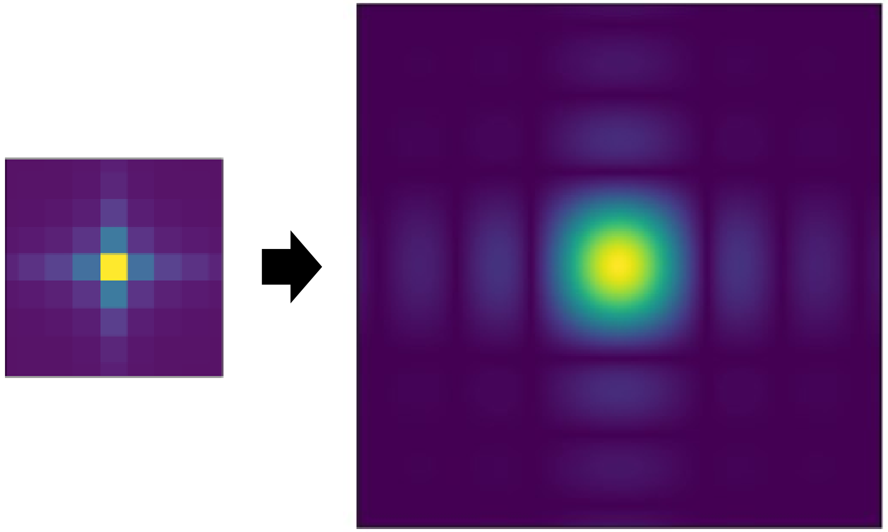
- Validity – Is the target suitable for radiometric calibration?
- Survey date – When was the target last surveyed prior to the radar observation?
- Location – Is the target within the image bounds?
- Heading – Is the target oriented towards the sensor?

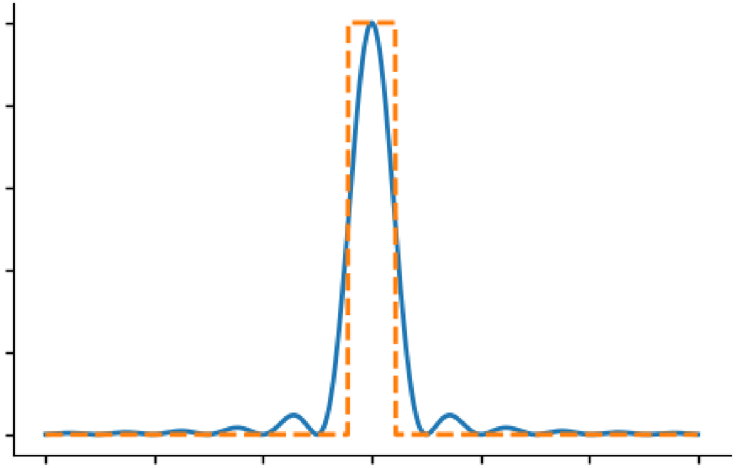
# Algorithm Overview: Measure Corner Reflector RCS

**Inputs**
- RSLC product
- Corner reflector record

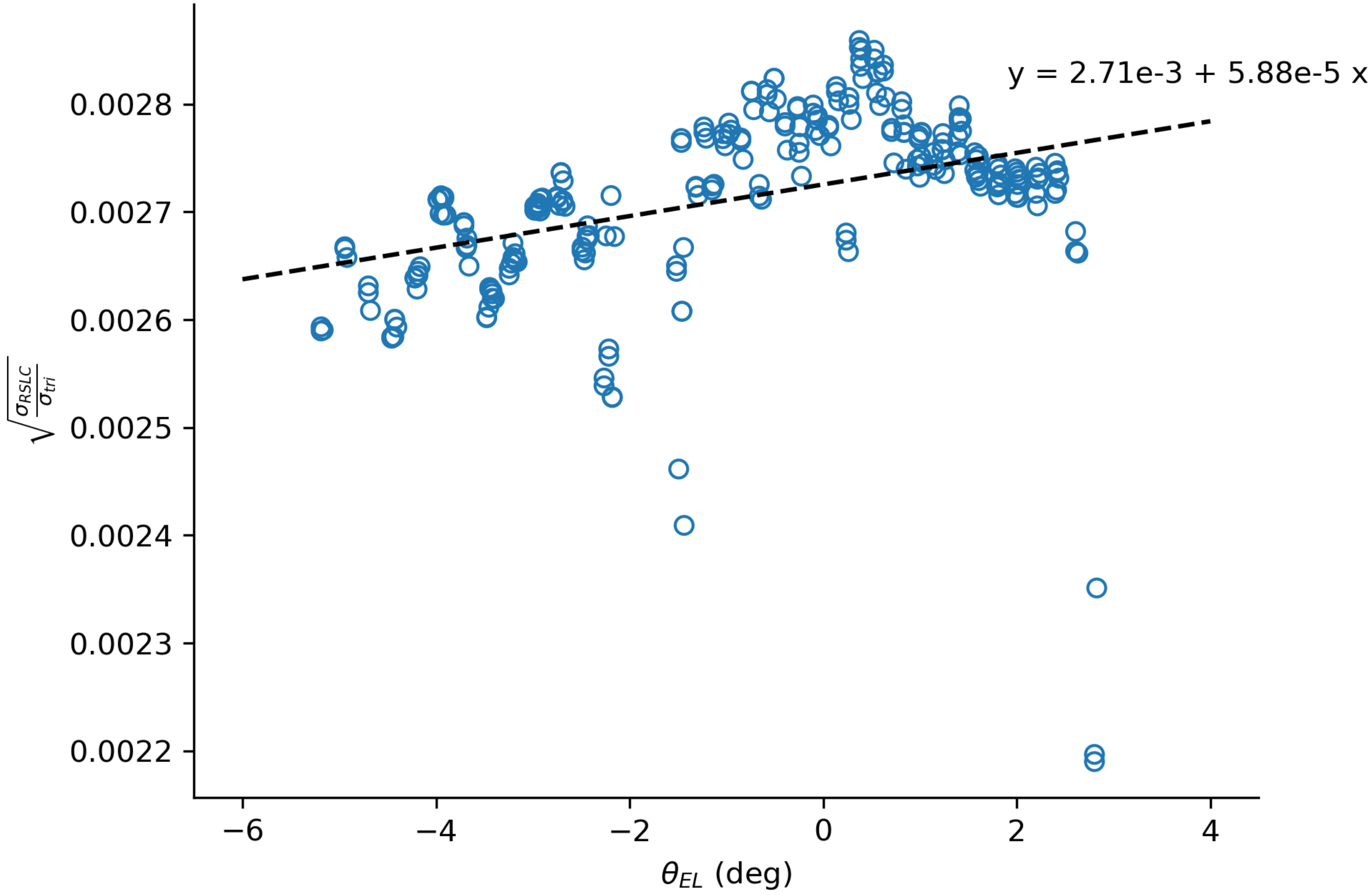
**Procedure**
- Get expected target position in image grid from geographic coords
- Upsample a small block of SLC data around the target
- Estimate peak power by fitting a 2-D quadratic
- Estimate 3dB width in range (cross-track) & azimuth (along-track)
- Measure RCS using the “box” method

**Outputs**
- Measured RCS $\sigma_{RSLC}$





# Absolute Radiometric Calibration Factor Estimation



# Point Target Analysis (PTA) Tool

- Evaluates fidelity of radar images by measuring the impulse response of point-like targets
- Used for geometric calibration of NISAR products by estimating common azimuth & range delays and channel-specific range delays
- Computes characteristics of the azimuth & range Impulse Response Function (IRF)
  - Amplitude & phase
  - Integrated Sidelobe Ratio (ISLR)
  - Peak-to-Sidelobe Ratio (PSLR)
  - 3dB response width
- Plots magnitude & phase cuts of the IRF in azimuth & range
- Measures peak position offsets in azimuth & range (RSLC) or X & Y (GSLC) w.r.t. the expected target location

# Algorithm Overview: RSLC PTA for Geometric Calibration

**Inputs**
- Set of RSLCs over calibration sites
- CSV file containing corner reflector survey records

**Procedure**
- For each RSLC:
  - Down-select corner reflectors
  - For each corner reflector:
    - Estimate slant range offset $\Delta r$ and azimuth time offset $\Delta t$ between expected & measured peak location
    - Correct for environmental effects at radar observation time (troposphere, ionosphere, solid earth tides, plate motion)*
- Compute average delay

**Outputs**
- Common azimuth & range delay
- Channel-specific differential range delays

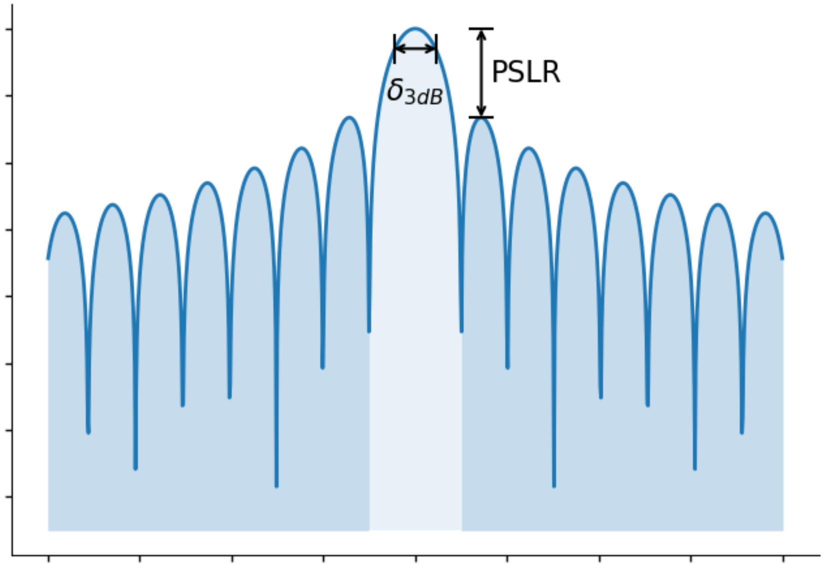
* These corrections aren't included in RSLC & GSLC QA products

# Algorithm Overview: RSLC PTA for Quality Assurance

**Inputs**
- RSLC product
- Corner reflector record

**Procedure**
- Get expected target position in image grid from geographic coords
- Upsample a small block of SLC data around the target
- Find peak index within block
- Take 1-D azimuth & range slices centered on peak index
- Estimate 3dB width in azimuth & range
- Estimate ISLR & PSLR in azimuth & range

**Outputs**
- Impulse response metrics (ISLR, PSLR, 3dB width)
- Magnitude & phase cuts
- Geometric offsets $(\Delta r, \Delta t)$
- Local phase slope

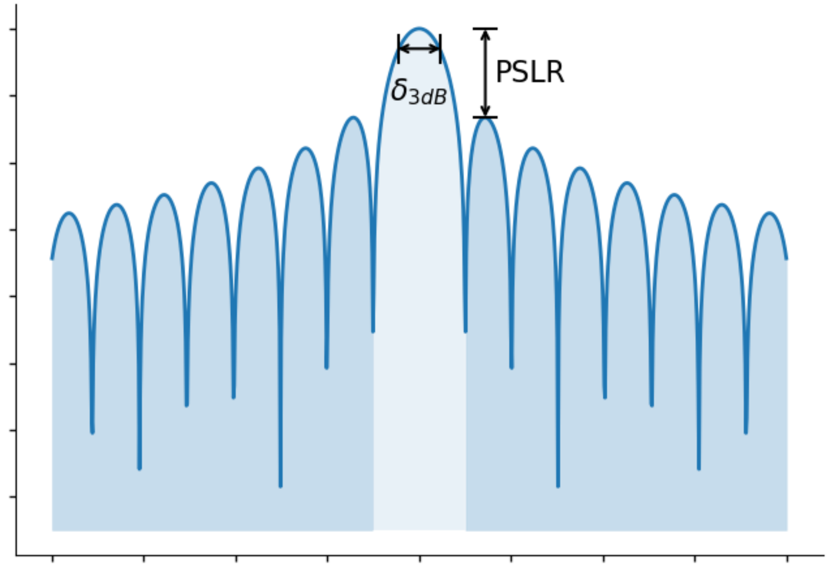


# Algorithm Overview: ~~RSLC~~ GSLC PTA for Quality Assurance

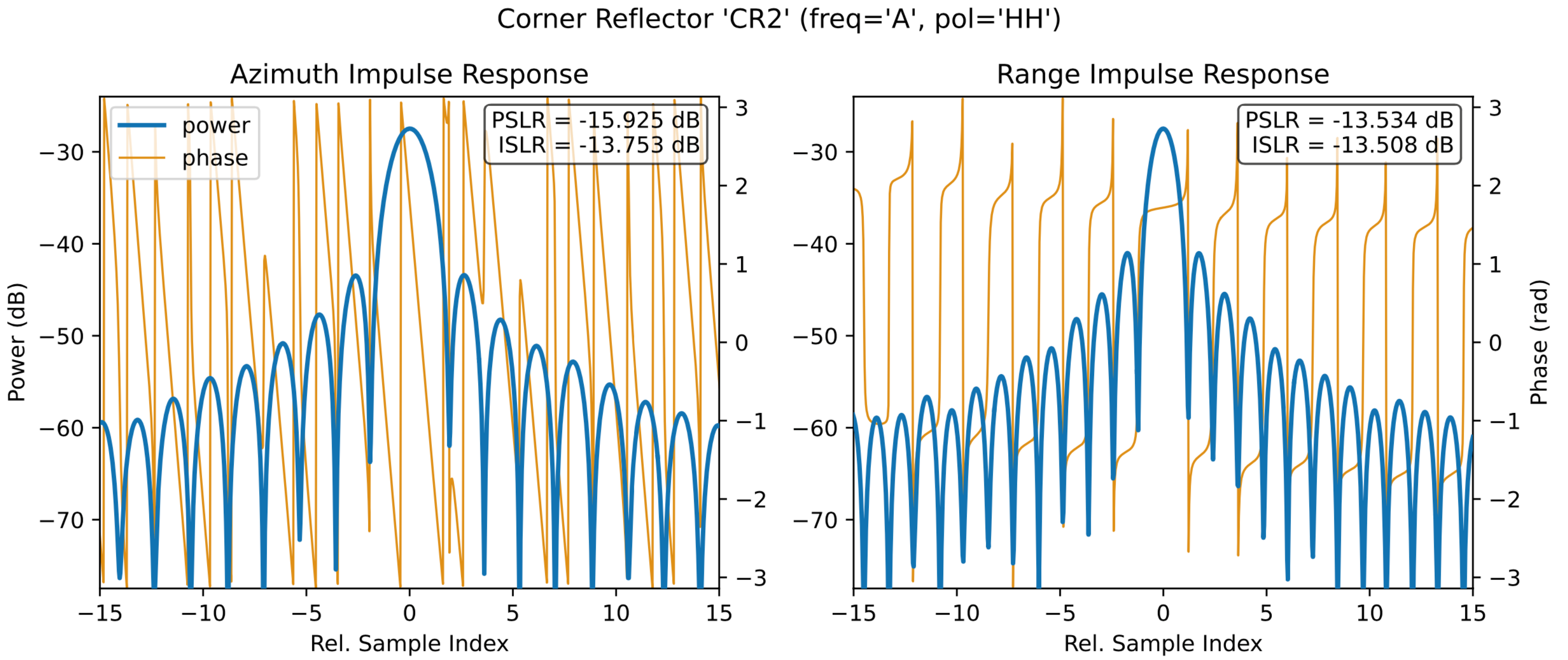
**Inputs**
- ~~RSLC~~ GSLC product
- Corner reflector record

**Procedure**
- Get expected target position in image grid from geographic coords
- Compute and remove flattening phase (if applicable)
- Upsample a small block of SLC data around the target
- Find peak index within block
- ~~Take 1-D azimuth & range slices centered on peak index~~
- Resample the data rotated by the heading & look angles to form 1-D azimuth & range slices centered on peak index
- Estimate 3dB width in azimuth & range
- Estimate ISLR & PSLR in azimuth & range

**Outputs**
- Impulse response metrics (ISLR, PSLR, 3dB width)
- Magnitude & phase cuts
- Geometric offsets (~~$\Delta r, \Delta t$~~ $\Delta x, \Delta y$)
- Local phase slope



# RSLC Point Target Analysis

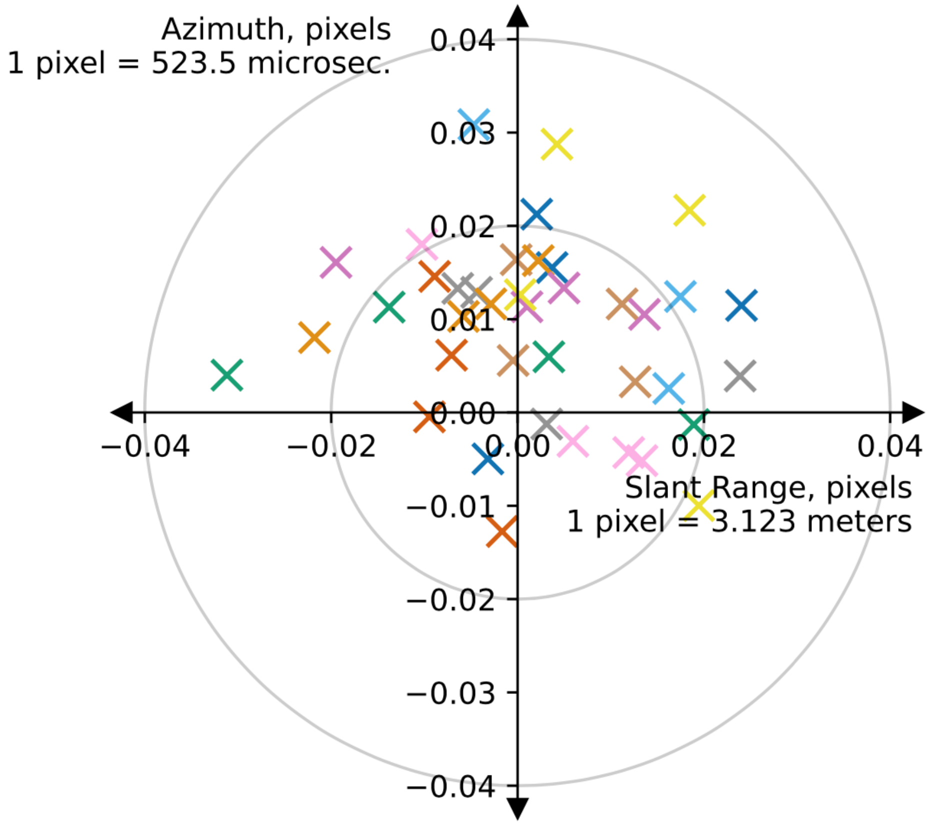



**Observation time (UTC) :**
2021-12-31T11:46:22.063544562

**Elevation angle (deg) :**
-6.575022368342623

# RSLC Point Target Analysis

Corner Reflector (CR) Slant Range/Azimuth Position Error
freq='A', pol='HH'



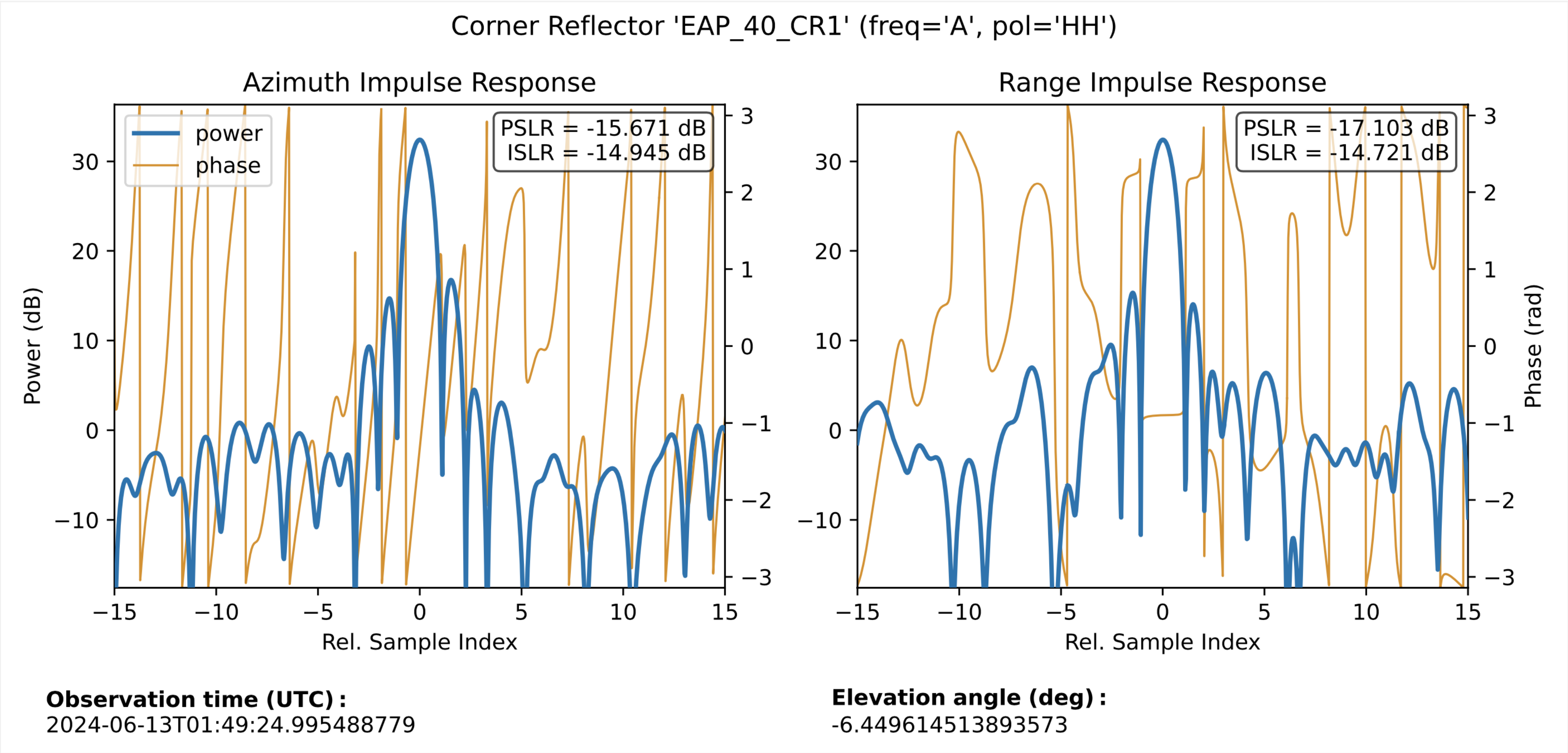

## Azimuth CR Offsets

| | in pixels | in microsec. |
|---|---|---|
| Mean | 0.008676486992417501 | 4.542140931528764 |
| Std. Dev. | 0.00961618161986845 | 5.03407106802441 |
| Min | -0.012754923981901811 | -6.677202691292449 |
| Max | 0.030852838343434996 | 16.151460840778604 |

## Slant Range CR Offsets

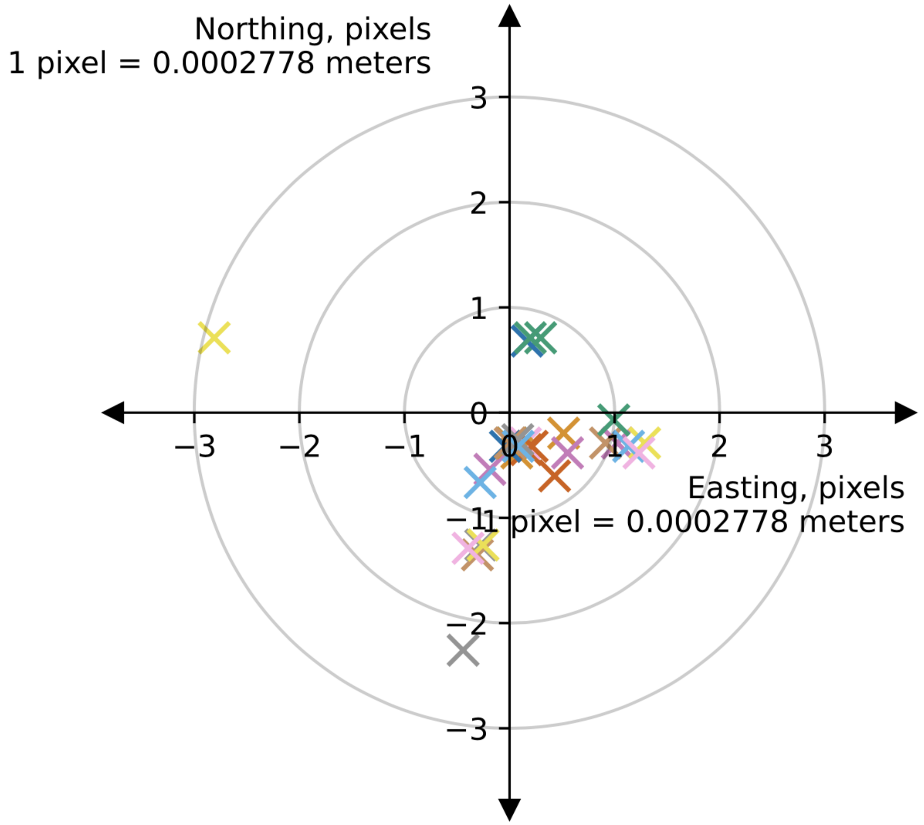
| | in pixels | in meters |
|---|---|---|
| Mean | 0.0020583749893807505 | 0.006427971849501866 |
| Std. Dev. | 0.01242334847819587 | 0.03879610600905104 |
| Min | -0.031191338920507405 | -0.09740550170093731 |
| Max | 0.024024005135288462 | 0.07502307865117448 |

# GSLC Point Target Analysis



# GSLC Point Target Analysis

Corner Reflector (CR) Easting/Northing Position Error
freq='A', pol='HH'




## Northing CR Offsets

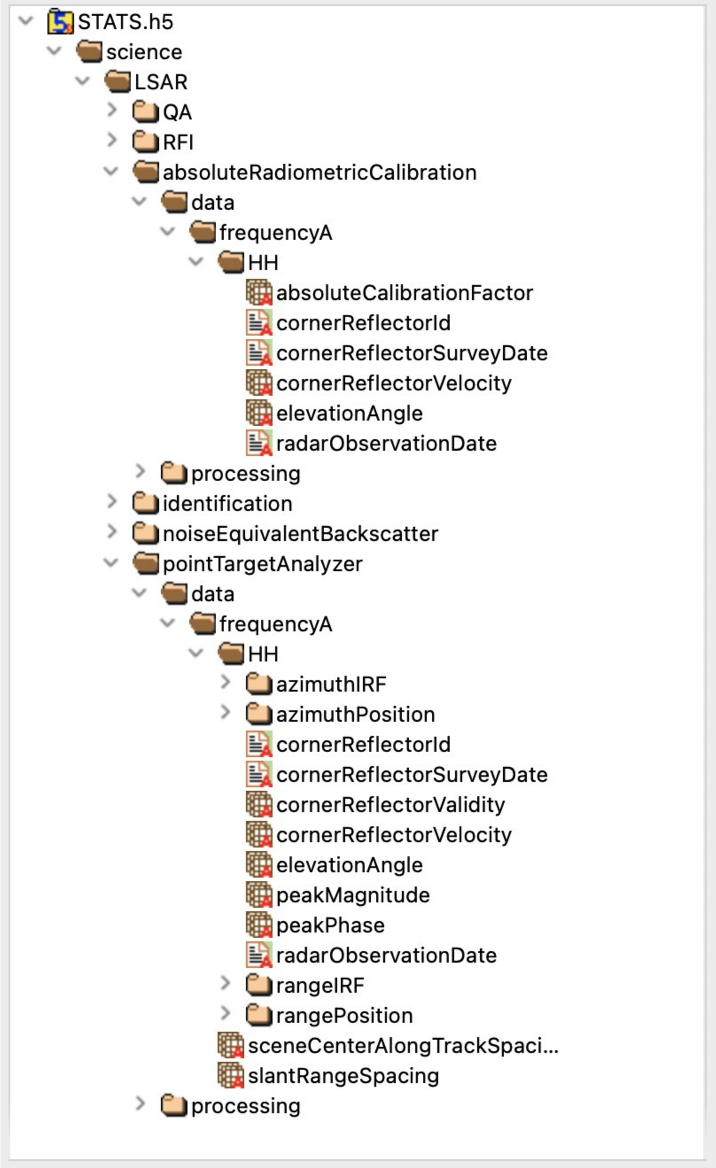
| | in pixels | in meters |
|---|---|---|
| Mean | -0.39080752706662075 | 0.00010855764640740335 |
| Std. Dev. | 0.629821678907786 | 0.00017495046636328786 |
| Min | -2.2574741937332874 | -0.00019757661285188042 |
| Max | 0.7112758062667126 | 0.00062707616492596344 |

## Easting CR Offsets

| | in pixels | in meters |
|---|---|---|
| Mean | 0.1517213387155986 | 4.2144816309891876e-05 |
| Std. Dev. | 0.7359755620922538 | 0.00020443765613675354 |
| Min | -2.810474842767235 | -0.0007806874563242944 |
| Max | 1.2856596489591539 | 0.0003571276802664602 |

# Cal Tools in NISAR Quality Assurance

- AbsCal and PTA tools are automated as part of QA checks over calibration sites
- Results of each tool are included in the QA output HDF5 file
- PTA results are included in the QA output report PDF
- Provides convenient access for quick review and trending analysis
- QA outputs will be available from Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC)



# Summary

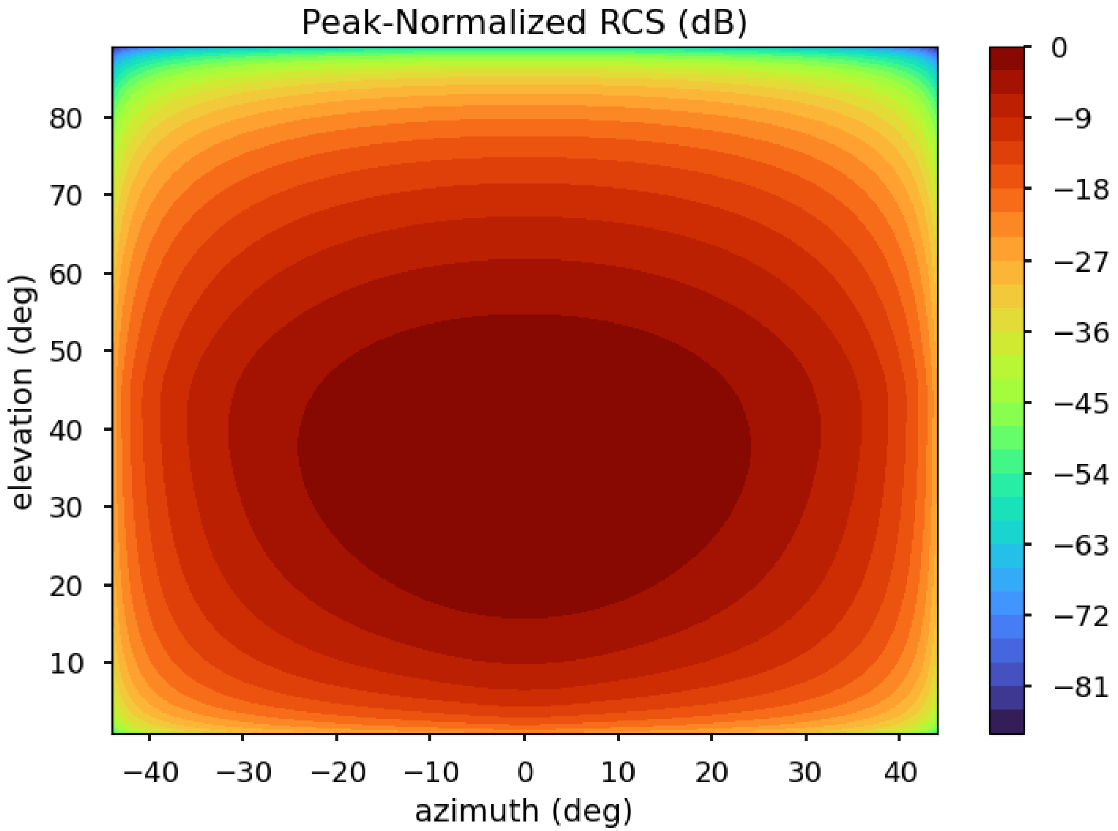
- The Absolute Radiometric Calibration (AbsCal) tool estimates a scaling factor for radiometric calibration of RSLC data
- The Point Target Analysis (PTA) tool measures impulse response characteristics of RSLC and GSLC images and is used in geometric calibration
- Both have been extensively tested using simulated NISAR products and ALOS/UAVSAR data
- Integrated into regular automated QA checks of NISAR products over designated calibration sites
- Implemented in the open-source library ISCE3

https://github.com/isce-framework/isce3

```
$ conda install isce3 -c conda-forge
```

# Backups

# Triangular Trihedral RCS

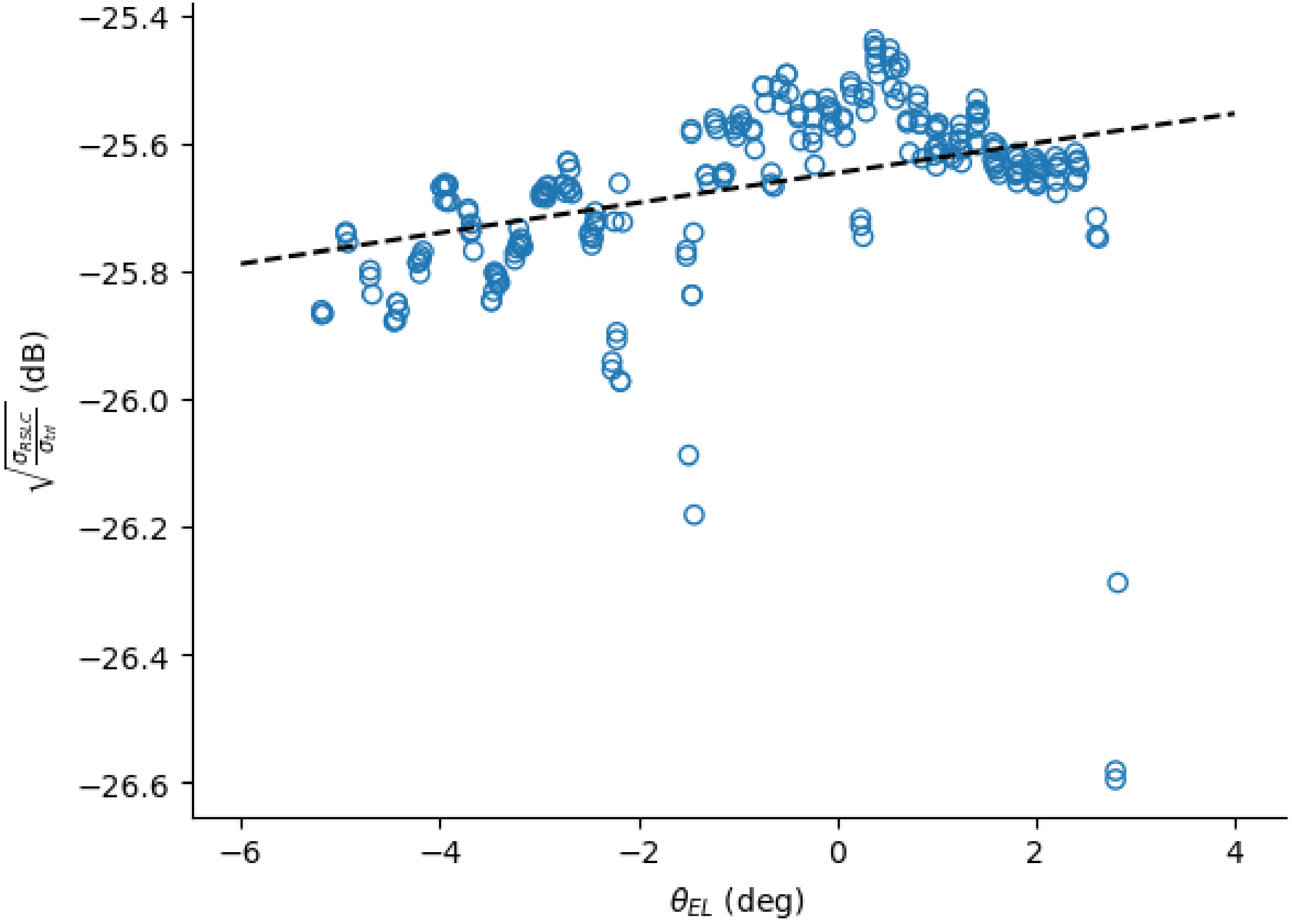



*The 3dB azimuth beamwidth of a triangular trihedral is ~40°*

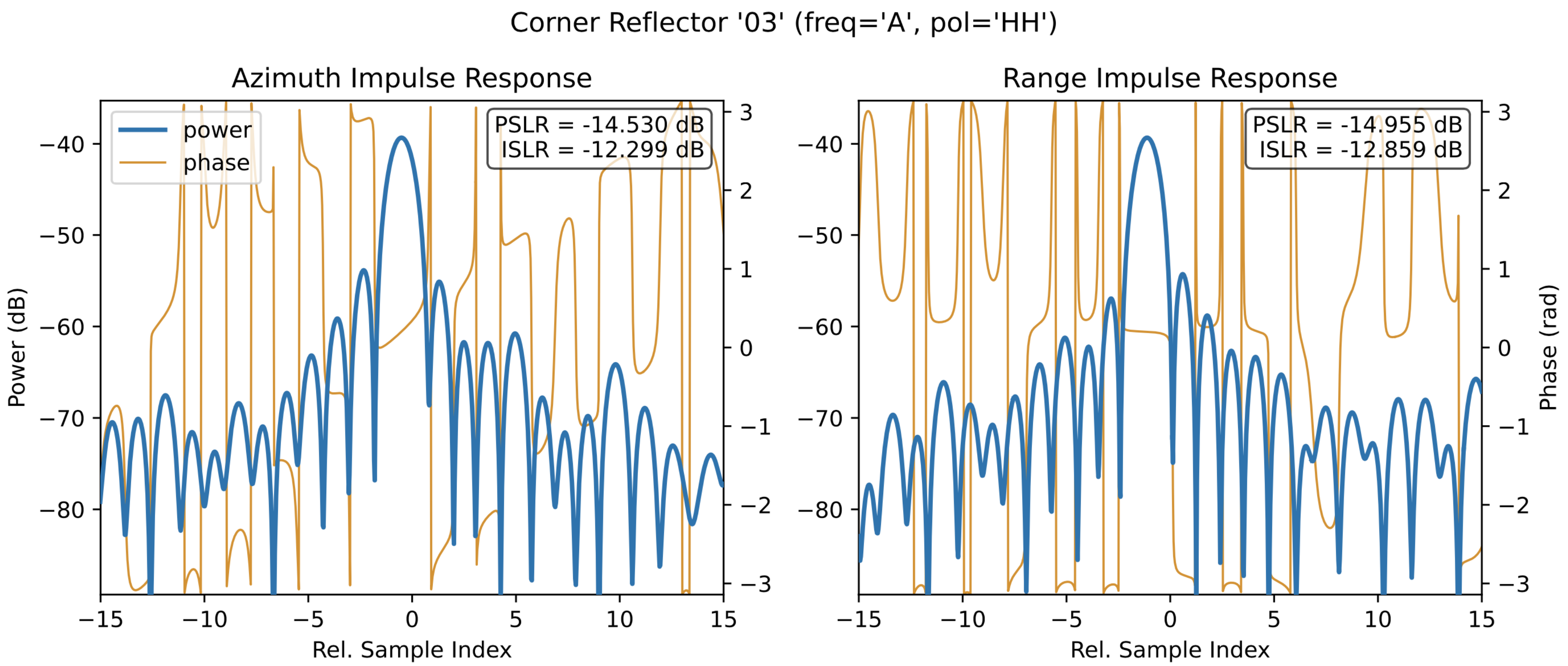
# Algorithm Overview: Predict Corner Reflector RCS

| |
|---|
| **Inputs**<br>• RSLC product<br>• Corner reflector record |
| **Procedure**<br>• Get target-to-platform line-of-sight vector in ECEF coords<br>• Transform from ECEF to CR-intrinsic coords<br>• Evaluate triangular trihedral RCS equation |
| **Outputs**<br>• Predicted RCS $\sigma_{tri}$ |

# Absolute Radiometric Calibration Factor Estimation



# RSLC Point Target Analysis – ALOS over Rosamond

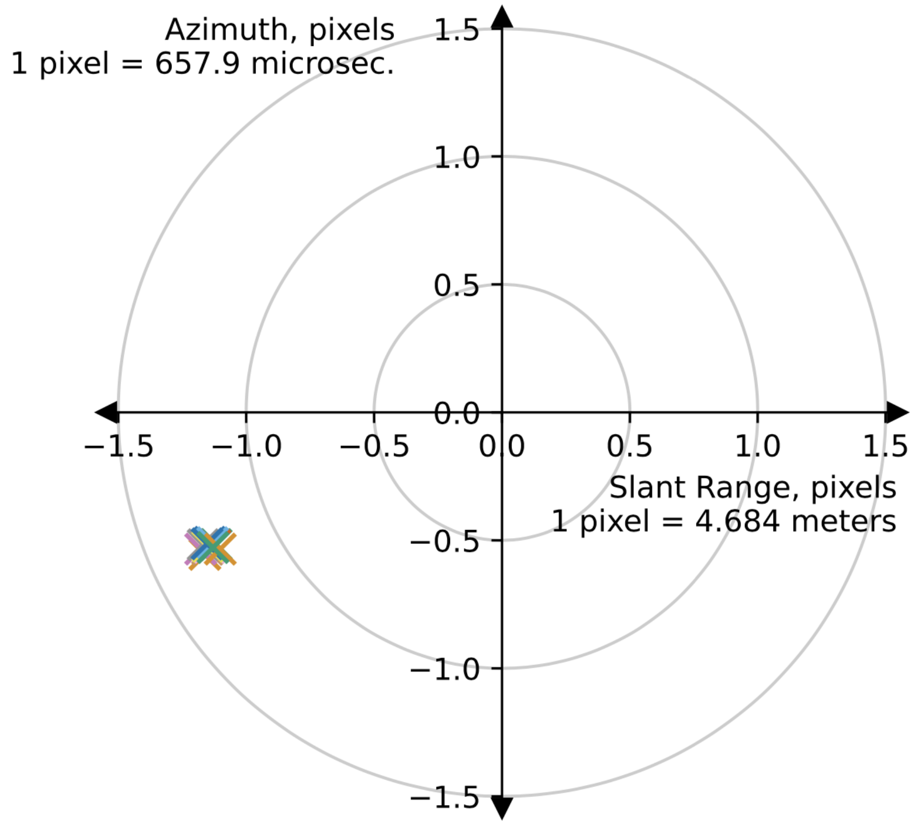



**Observation time (UTC):**
2008-02-18T06:20:10.247269435

**Elevation angle (deg):**
0.7989511201633271

# RSLC Point Target Analysis – ALOS over Rosamond

Corner Reflector (CR) Slant Range/Azimuth Position Error
freq='A', pol='HH'



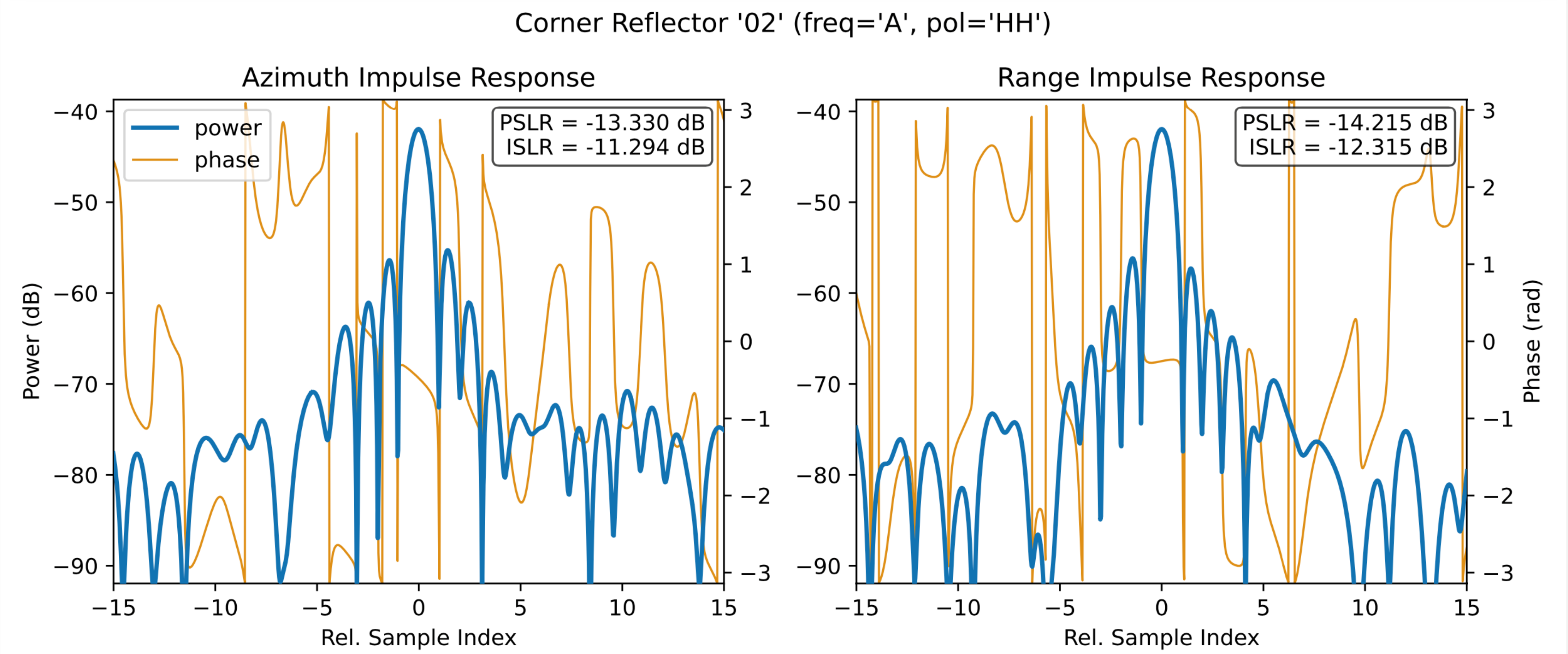

### Azimuth CR Offsets

| | in pixels | in microsec. |
|---|---|---|
| Mean | -0.5244437355655603 | -345.028773398395 |
| Std. Dev. | 0.012436627434628561 | 8.18199173330826 |
| Min | -0.5546512946602888 | -364.90216753966365 |
| Max | -0.5076514398097061 | -333.9812104011224 |

### Slant Range CR Offsets

| | in pixels | in meters |
|---|---|---|
| Mean | -1.1423682925631231 | -5.351146849511903 |
| Std. Dev. | 0.020611792789845176 | 0.09655093787897445 |
| Min | -1.1780227823774112 | -5.518161648576925 |
| Max | -1.1015063208378706 | -5.159738866039404 |

# GSLC Point Target Analysis – ALOS over Rosamond




**Observation time (UTC) :**
2008-02-18T06:20:10.258534616

**Elevation angle (deg) :**
0.7736988581252843

# Line-of-Sight Unit Vector Using ISCE3

```python
import isce3
import nisar
import numpy as np

rslc = nisar.products.readers.RSLC(hdf5file="...")
freq = "A" if ("A" in rslc.frequencies) else "B"
orbit = rslc.getOrbit()
doppler = rslc.getDopplerCentroid(freq)
radar_grid = rslc.getRadarGrid(freq)

lon, lat, height = ...
ellipsoid = isce3.core.WGS84_ELLIPSOID
target_pos_ecef = ellipsoid.lon_lat_to_xyz([lon, lat, height])

aztime, _ = isce3.geometry.geo2rdr_bracket(
    xyz=target_pos_ecef,
    orbit=orbit,
    doppler=doppler,
    wavelength=radar_grid.wavelength,
    side=radar_grid.lookside,
)
platform_pos_ecef, _ = orbit.interpolate(aztime)

def normalize(vec):
    return np.asarray(vec) / np.linalg.norm(vec)

los_unit_vec = normalize(platform_pos_ecef - target_pos_ecef)
```