Geolocation Assessment Tool and Correction Model for JPSS CrIS

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6. Exelis, Fort Wayne, IN
7. ERT Inc., Laurel, MD

SUOMI NPP SDR Science and Validated Product Maturity Review
College Park, MD; December 18-20 2013

Content

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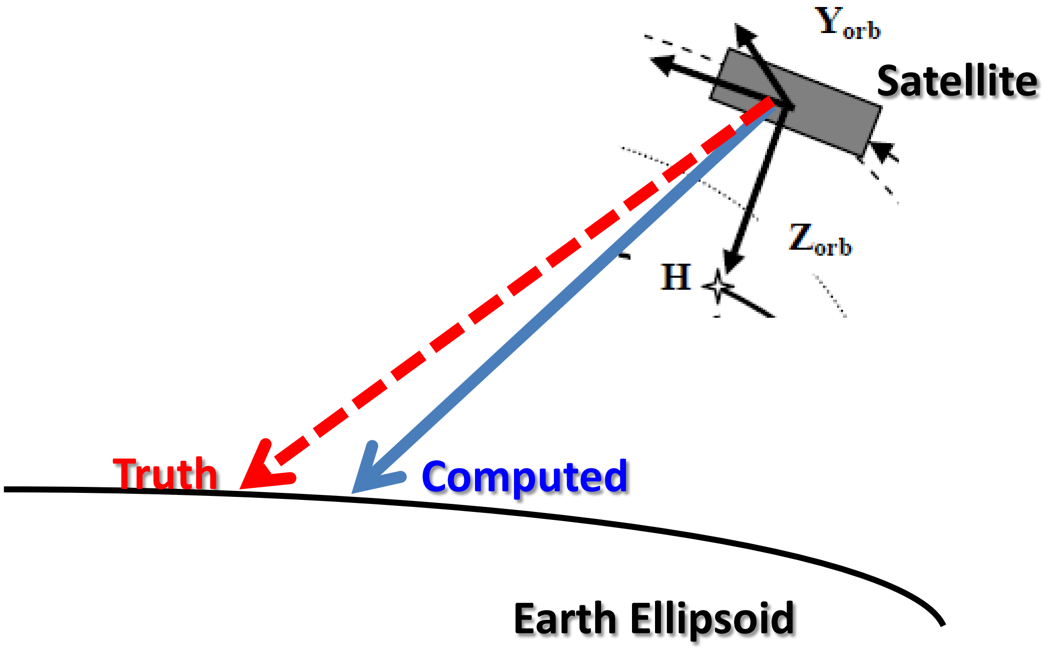
    - Specification, Algorithms, and Issues
2. Assessment Method
    - Using VIIRS Image Bands as a truth
    - New Collocation Method (Super Fast !!!)
    - Full Angles Assessment (All Scan Positions)
    - The results are based on angles instead of distance.
3. Correction Model
    - New Geometric Calibration Parameters based on Assessment Results
4. Summary and future work

Geolocation Accuracy

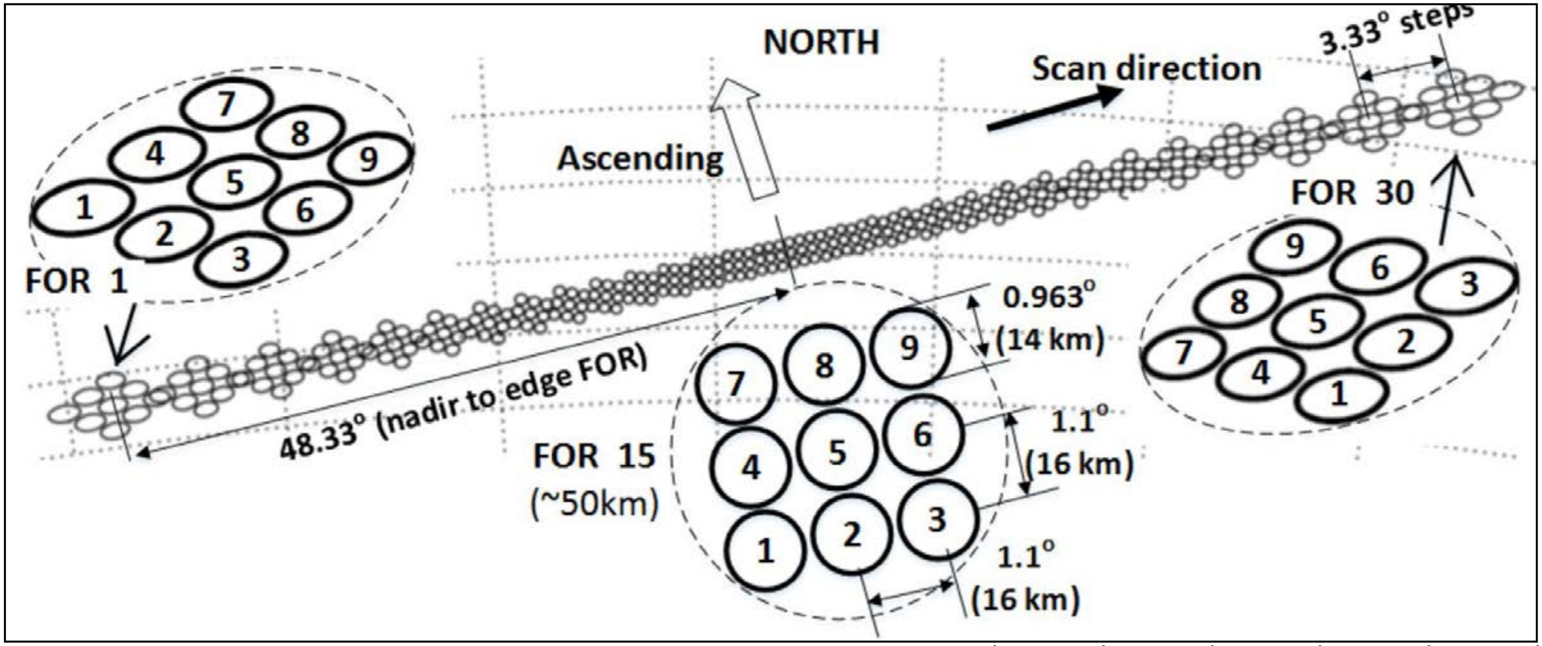
- The goal of the geometric calibration is to map CrIS line-of-sight (LOS) pointing vectors to geodetic longitude and latitude at each field of view (FOV) (9) for each scan position (30).

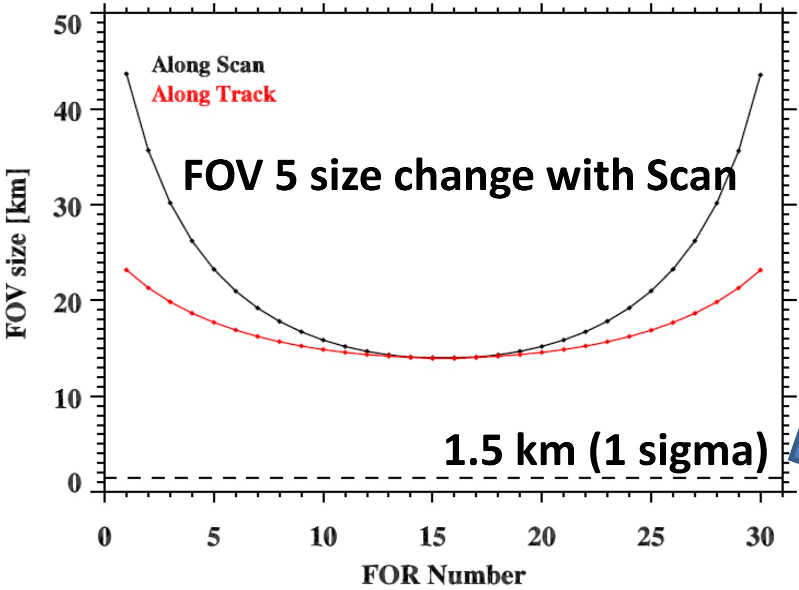
- The purpose of geolocation assessment is to identify the error characteristics of LOS pointing vector by comparing them with the truth.

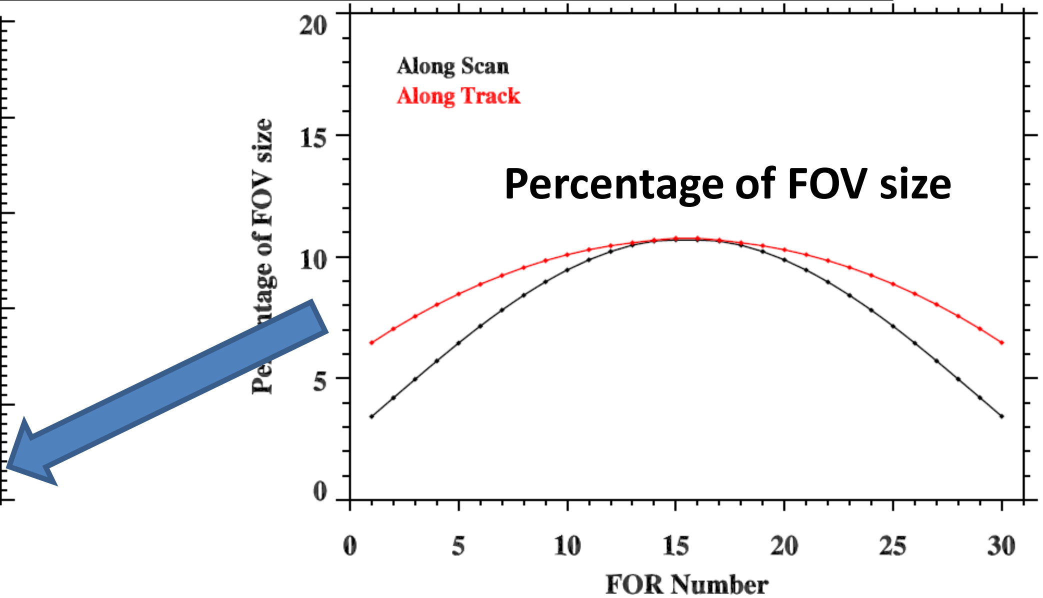
- Furthermore, if the systematic errors are found, a new set of co-alignment parameters should be retrieved based on assessment results to improve the geolocation accuracy.



CrIS Scan Patterns and Specification







Overview of Satellite Geolocation Components

CrIS (or other instrument)

Coordinate transformation

- Interferometer
- SSM
- Sensor Isolation system
- Spacecraft

JPSS or any satellite

COMMON GEO

- Spacecraft
- Orbital
- ECI
- ECEF(ECR)
- Geodetic

Function call to common geo:
ellipIntersect(outPt,inst2SC,exitVec, dlat,lon,satazm,satzen,range)

feedback

Geolocate each FOV

GEOLOCATION ASSESSMENT

- GCP/Maps/Ground truth
- the other instrument measurements with enough geolocation accuracy
- Comparing the truth and CrIS Geo fields

ADCS

Pos/Vel/Quaternion (RPY)

Attitude Determination & Control System (ADCS)

SGP4

Modified from C. Cao

CrIS Geometric Calibration Algorithm
Sensor Specific Algorithm

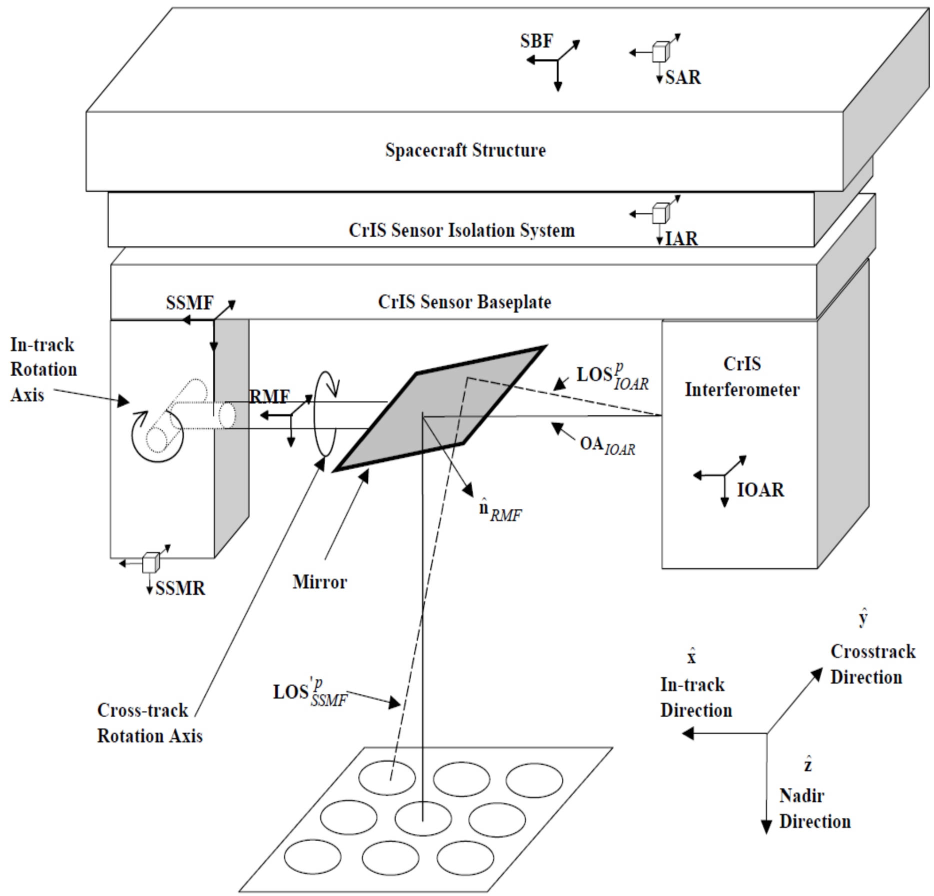


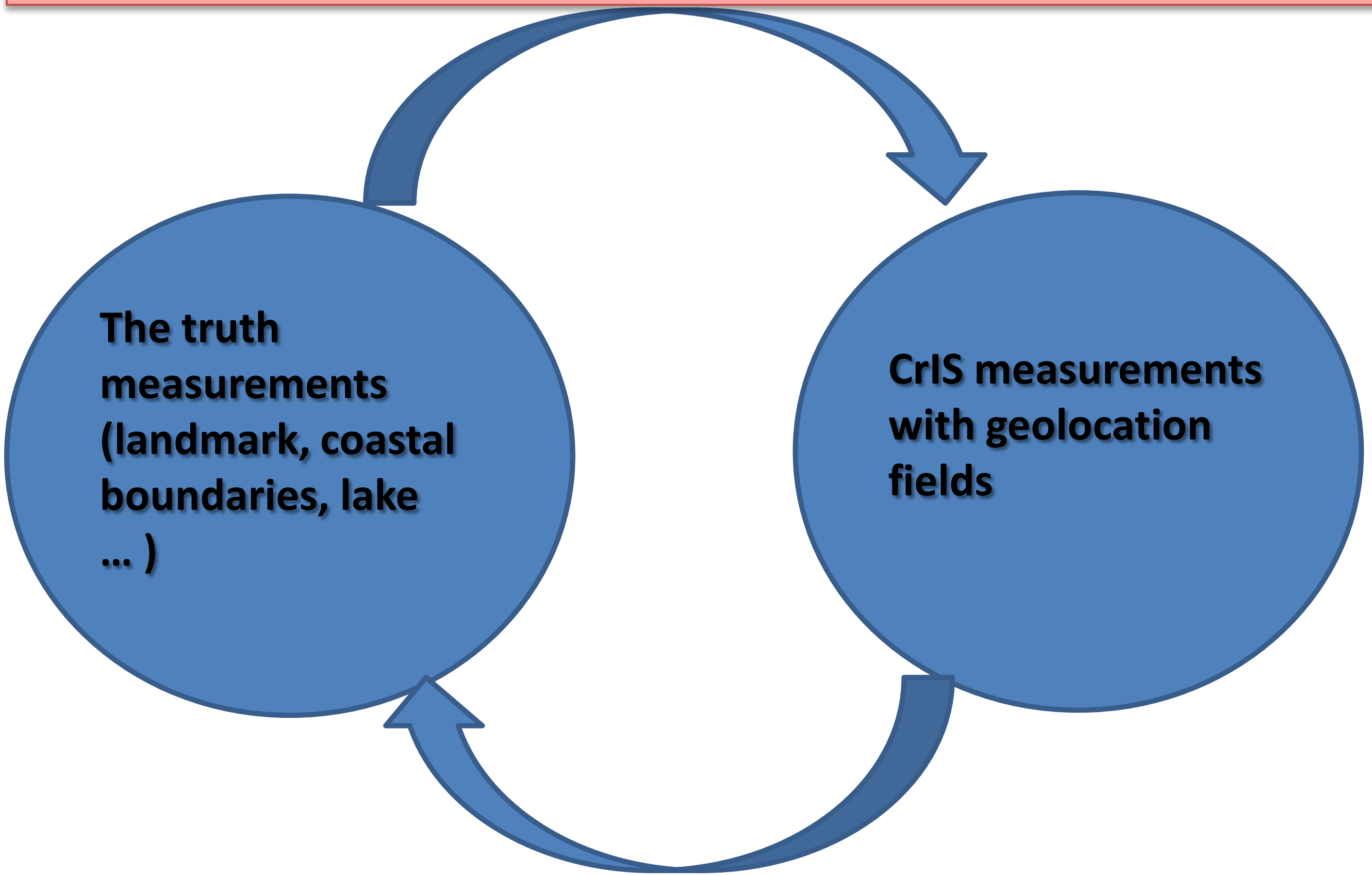
Figure 48: Sensor Algorithm Level Coordinate Systems

SDR Algorithm Process

1) LOS in IOAR coordinate = ILS parameters (3x3)
2) Convert from IOAR to SSMF coordinate
3) Compute normal to SSM mirror in SSMF (30 Scan Pos)
4) Apply SSM mirror rotation to get LOS in SSMF coordinate
5) Convert from SSMF to SSMR coordinate
6) Convert from SSMR to IAR coordinate
7) Convert from IAR to SAR
8) SAR coordinate = SBF coordinate

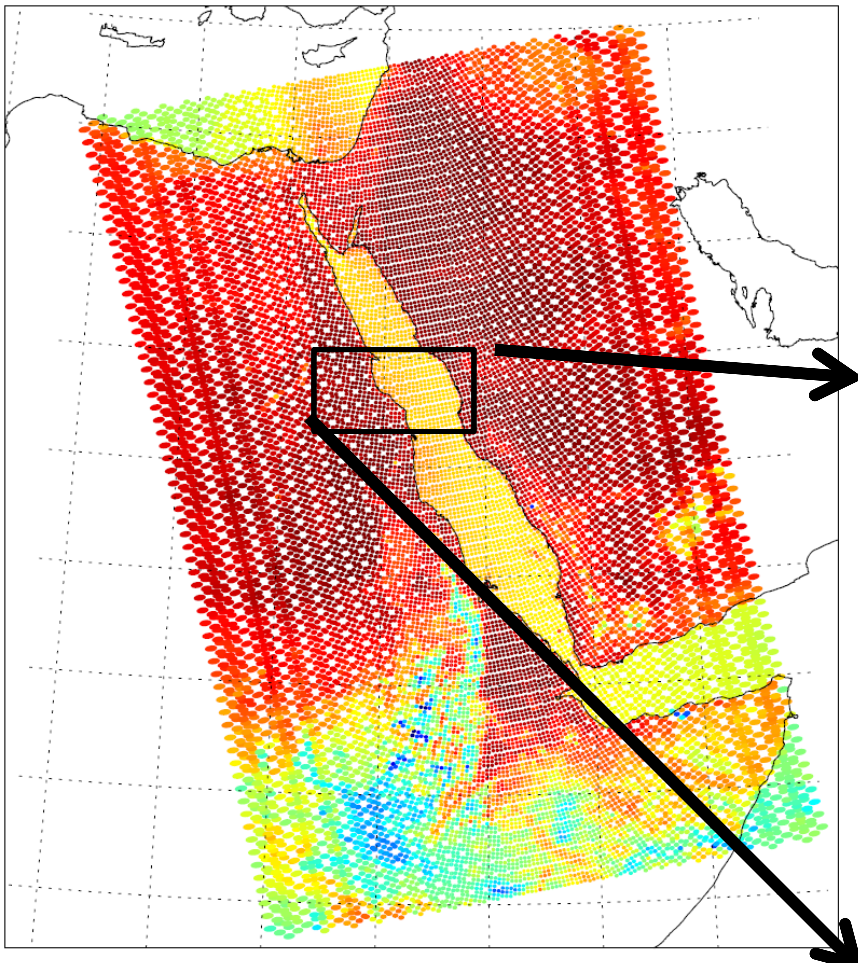
Geolocation Assessment Method

Method 2: 1) Simulating CrIS measurements from the truth measurements and 2) comparing them with accrual CrIS measurements



Method 1: 1) Retrieving land features (coast lines) from CrIS measurements; and 2) comparing then with the truth dataset

Method 1 Does Not Work



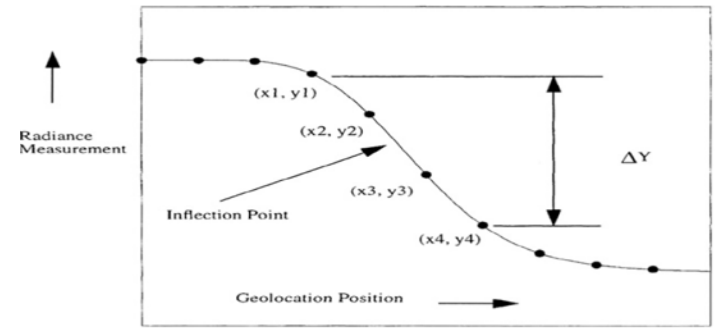
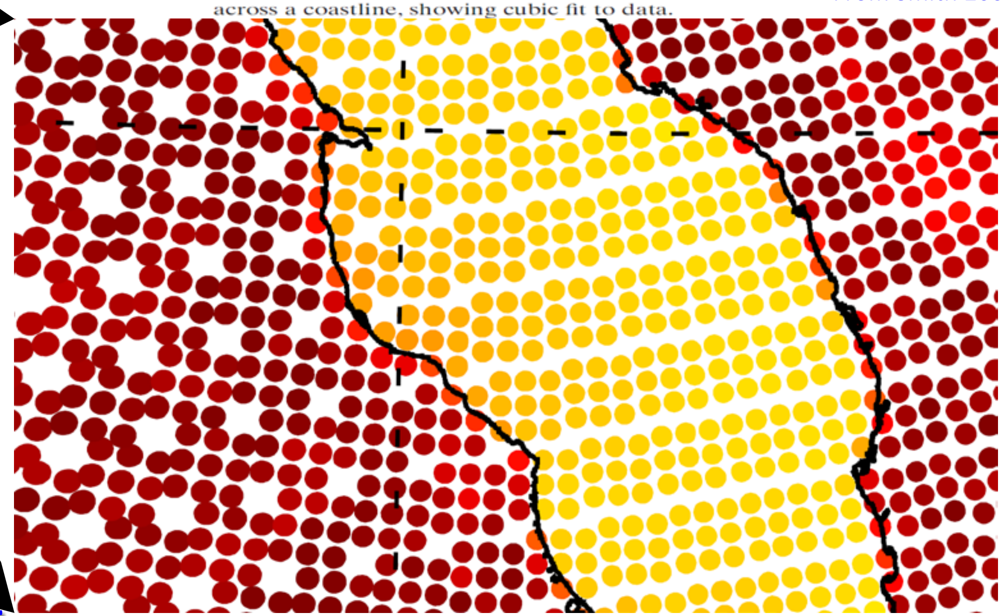


FIG. 5. Schematic of measurement change as radiometer scans across a coastline, showing cubic fit to data.

From Smith 2009

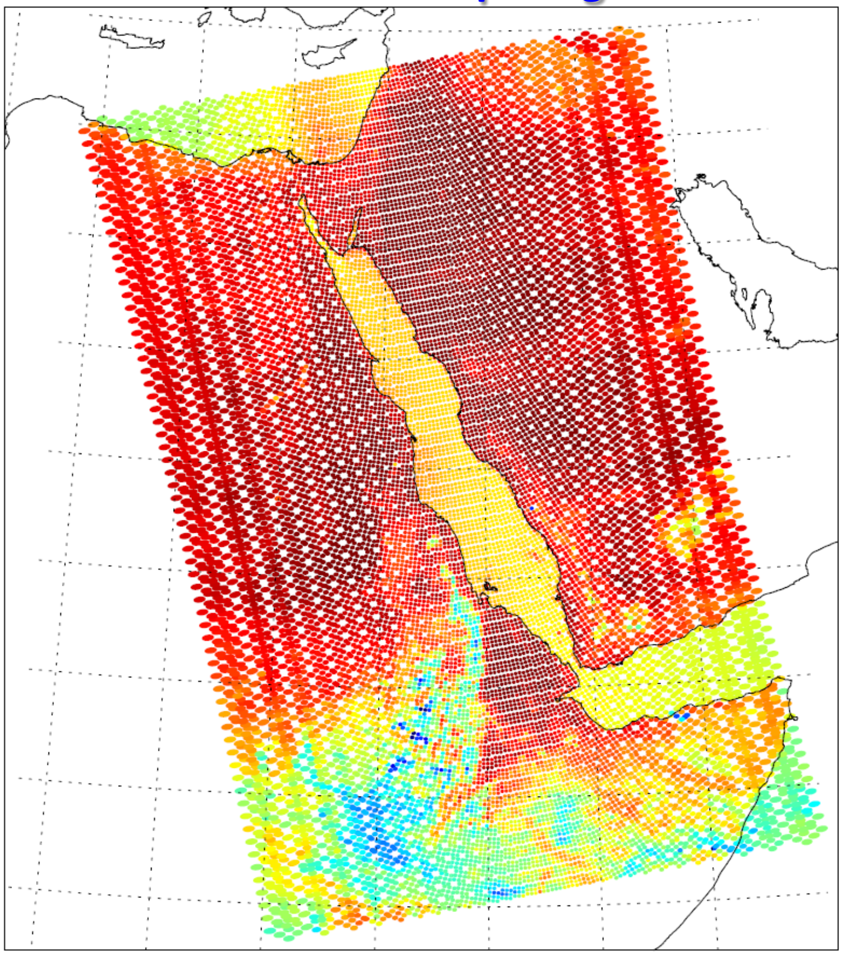


CrIS data with 3-km sub-pixel geolocation Errors

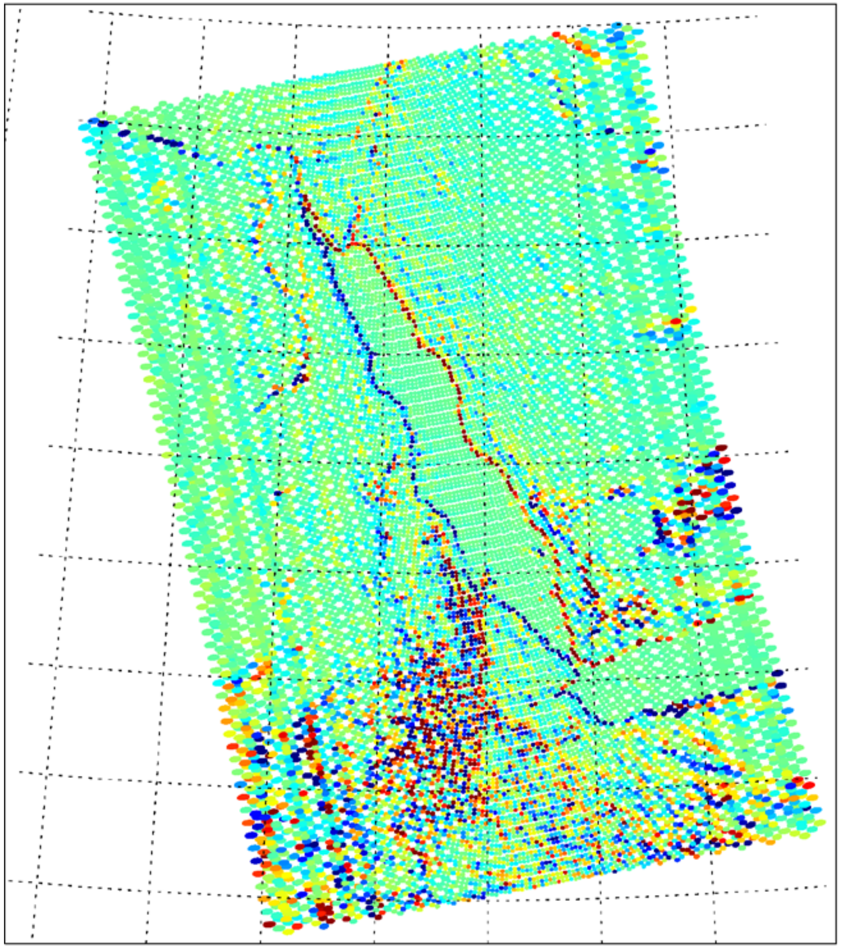
Unlike an imager, it is very hard to assess geolocation sub-pixel accuracy for CrIS using the land feature method because of 1) relatively large footprint size (above 14 km); 2) the gap between footprints; and 3) Uneven spatial distribution of CrIS Footprints

Method 2 Does Work

CrIS data with 3-km sub-pixel geolocation Errors

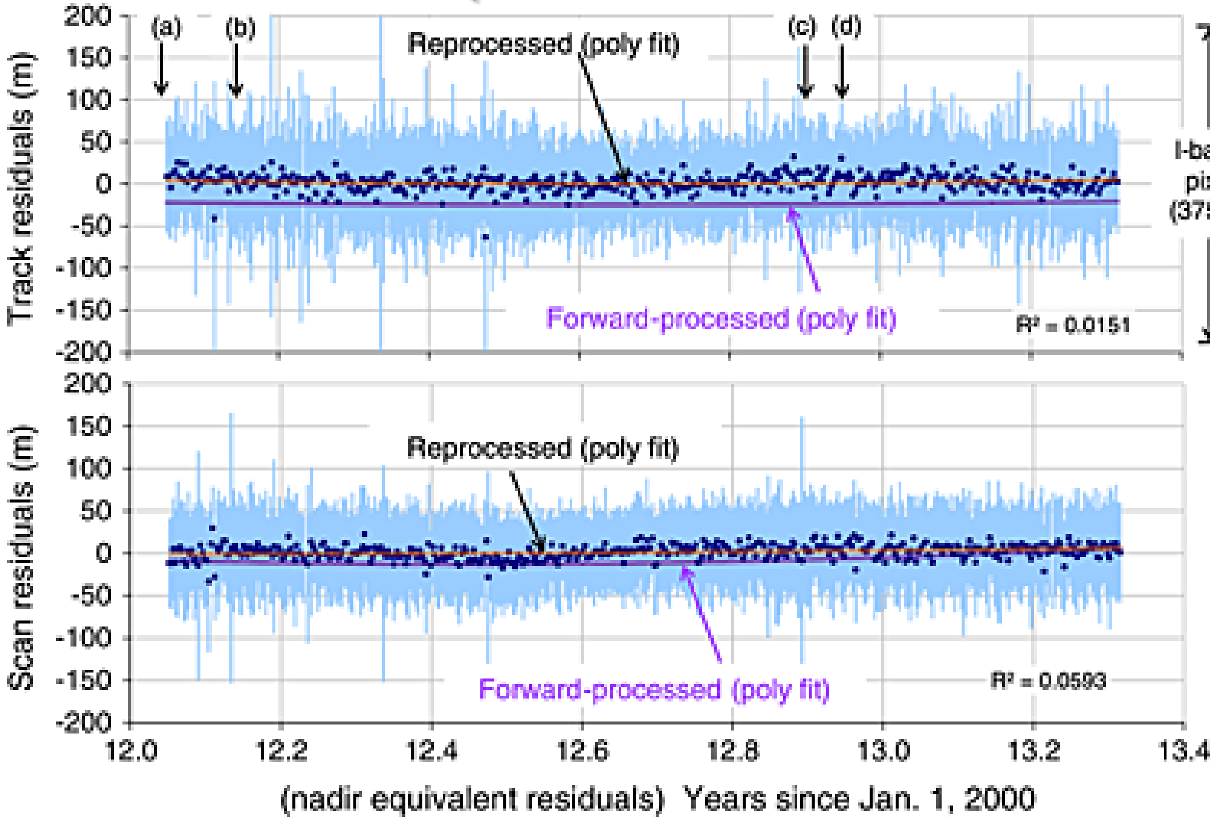


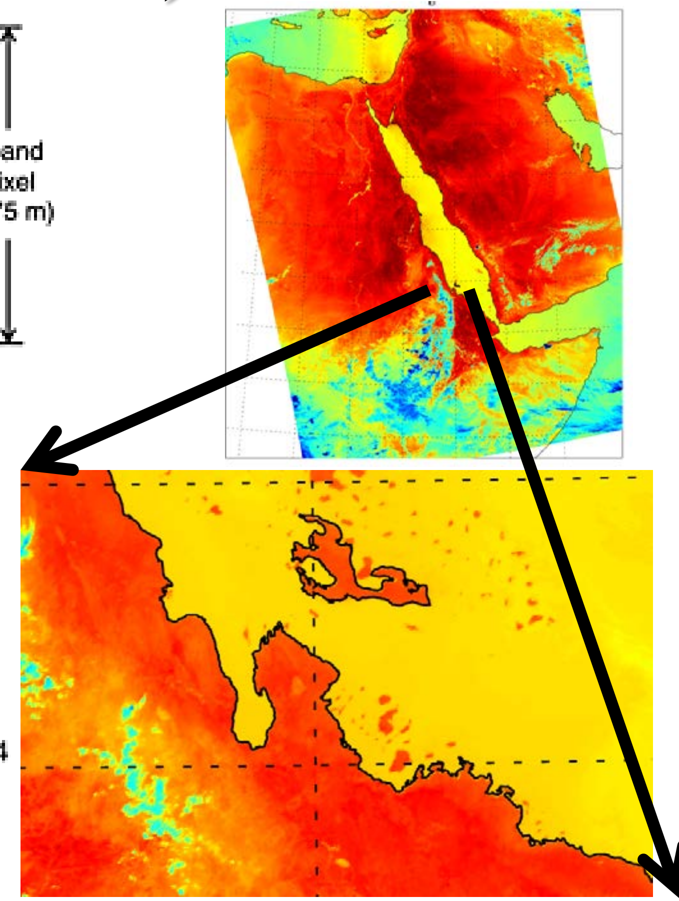
original CrIS-VIIRS Image



Using VIIRS to simulate CrIS and then take the difference between CrIS and VIIRS, the geolocation errors immediately showed up.

Reference: Using VIIRS Geolocation (I5 band: 375m resolution)





from Wolf et al. 2013

Table 2. VIIRS Geolocation Accuracy

Residuals	First Update 23 February 2012	Second Update 18 April 2013
Track mean	−24 m, −7%	2 m, 1%
Scan mean	−8 m, −2%	2 m, 1%
Track RMSE	75 m, 20%	70 m, 19%
Scan RMSE	62 m, 17%	60 m, 16%

CrIS Geolocation Assessment for NPP - what have not been done

JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 1–15, doi:10.1002/2013JD020376, 2013

Paper published in Suomi NPP Cal/Val Special Issue

Geolocation assessment for CrIS sensor data records

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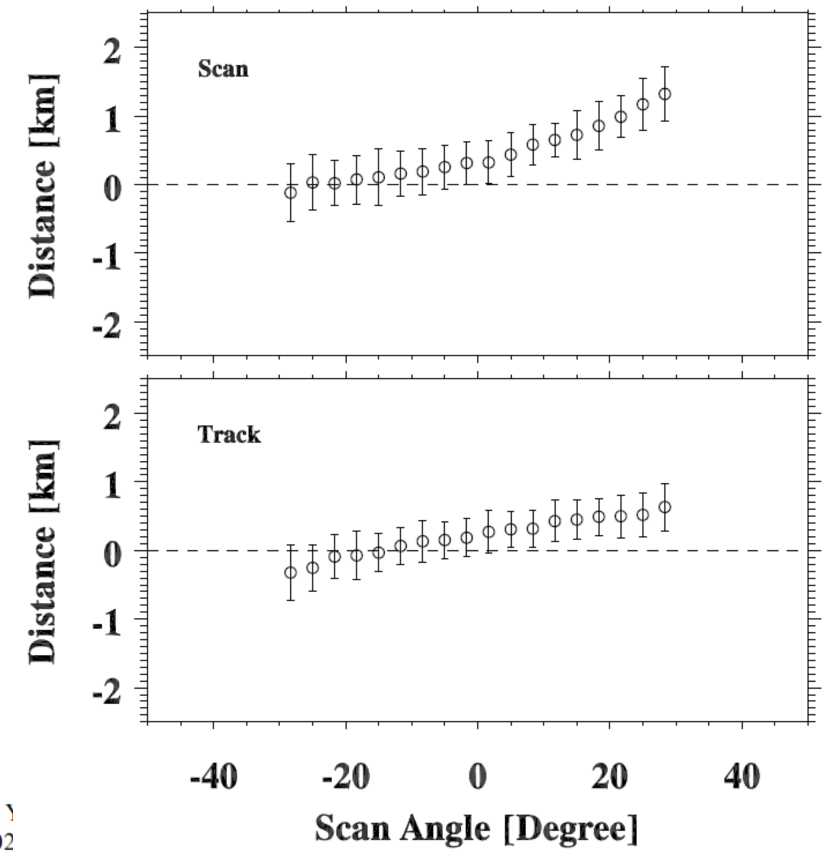
Received 17 June 2013; revised 23 October 2013; accepted 27 October 2013.

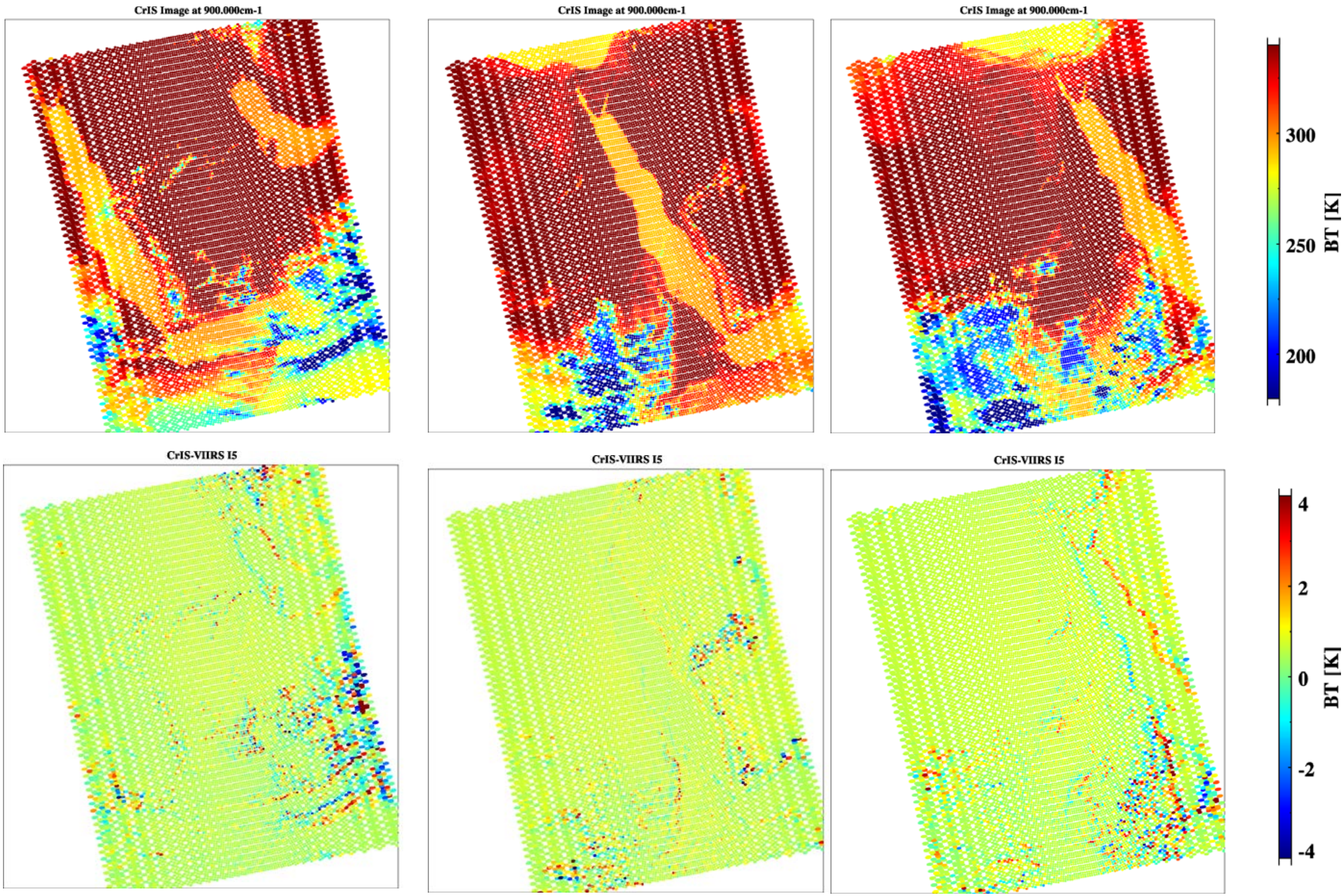
[1] As important as spectral and radiometric calibration, the geometric calibration is one of the requisites for the Suomi National Polar-Orbiting Partnership Cross-track Infrared Sounder (CrIS) Sensor Data Records (SDR). In this study, spatially collocated measurements from the Visible Infrared Imaging Radiometer Suite (VIIRS) band I5 are used to evaluate the geolocation performance of the CrIS SDR by taking advantage of high spatial resolution and accurate geolocation of VIIRS measurements. The basic idea is to find the best collocation position between VIIRS and CrIS measurements by shifting VIIRS images in the track and scan directions. The retrieved best collocation position is then used to evaluate the CrIS geolocation performance by assuming the VIIRS geolocation as a reference. Sensitivity tests show that the method can well detect geolocation errors of CrIS within 30° scan angle. When the method was applied to evaluate the geolocation performance of the CrIS SDR, geolocation errors that were caused by software coding errors were successfully identified. After this error was corrected and the engineering packets V35 were released, the geolocation accuracy is 0.347 ± 0.051 km (1σ) in the scan direction and 0.219 ± 0.073 km in the track direction at nadir.

Citation: Wang, L., D. A. Tremblay, Y. Han, M. Esplin, D. E. Hagan, J. Predina, L. Suwinski, X. Jin, and Y
Geolocation assessment for CrIS sensor data records, *J. Geophys. Res. Atmos.*, *118*, doi:10.1002/2013JD02



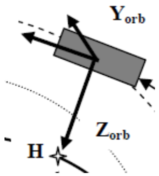
1. Limited to scan angles less than 30 degree, especially at nadir ➔ **full angles' assessment**
2. Assessments are based on distance in in-track and cross-track direction ➔ **based on angles**
3. Correction model ➔ **a new set of co-alignment parameters**

Misalignment between CrIS and VIIRS at the end of scan



Retrieved the true LOS vector

Satellite

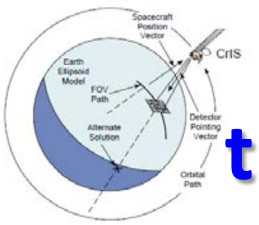


LOS vector in S/C

LOS vector in orbit frame

LOS vector in ECEF or ECR

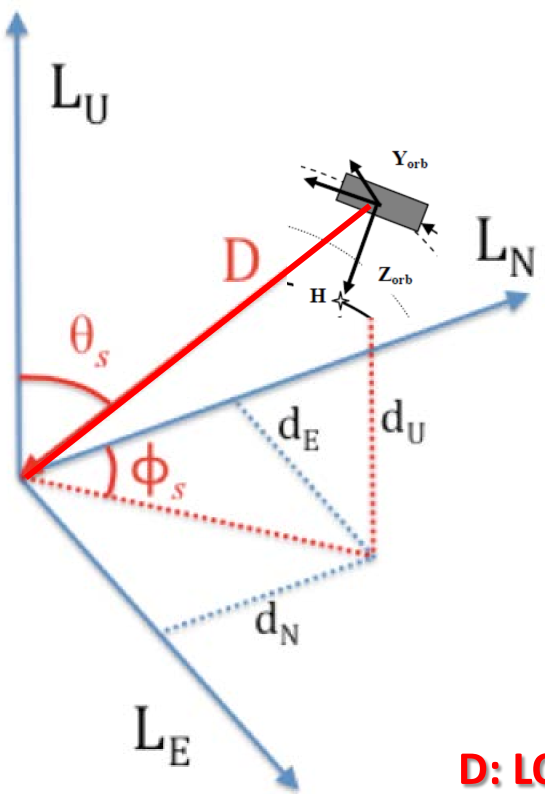
Geolocation Fields

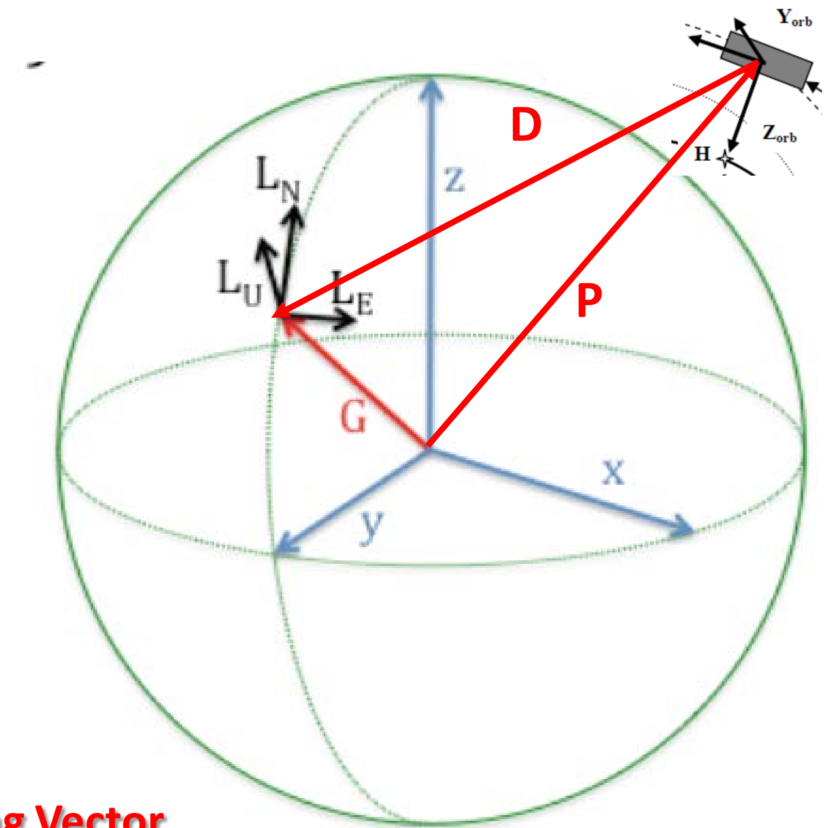


the Earth

Assuming that Common Geolocation part is correct

Retreived CrIS LOS Pointing Vector in ECR or ECEF



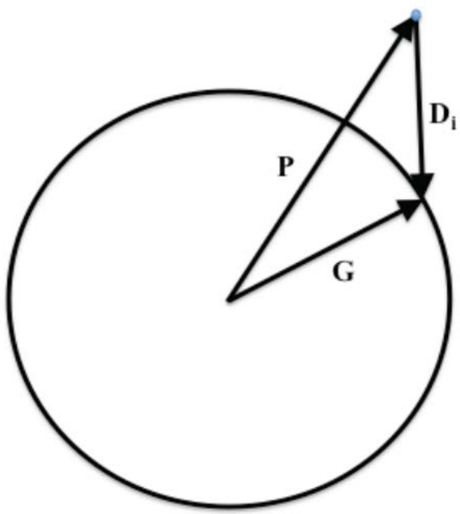


D: LOS Pointing Vector
P: Satellite Position Vector
G: FOV position Vector on Earth Ellipsoid

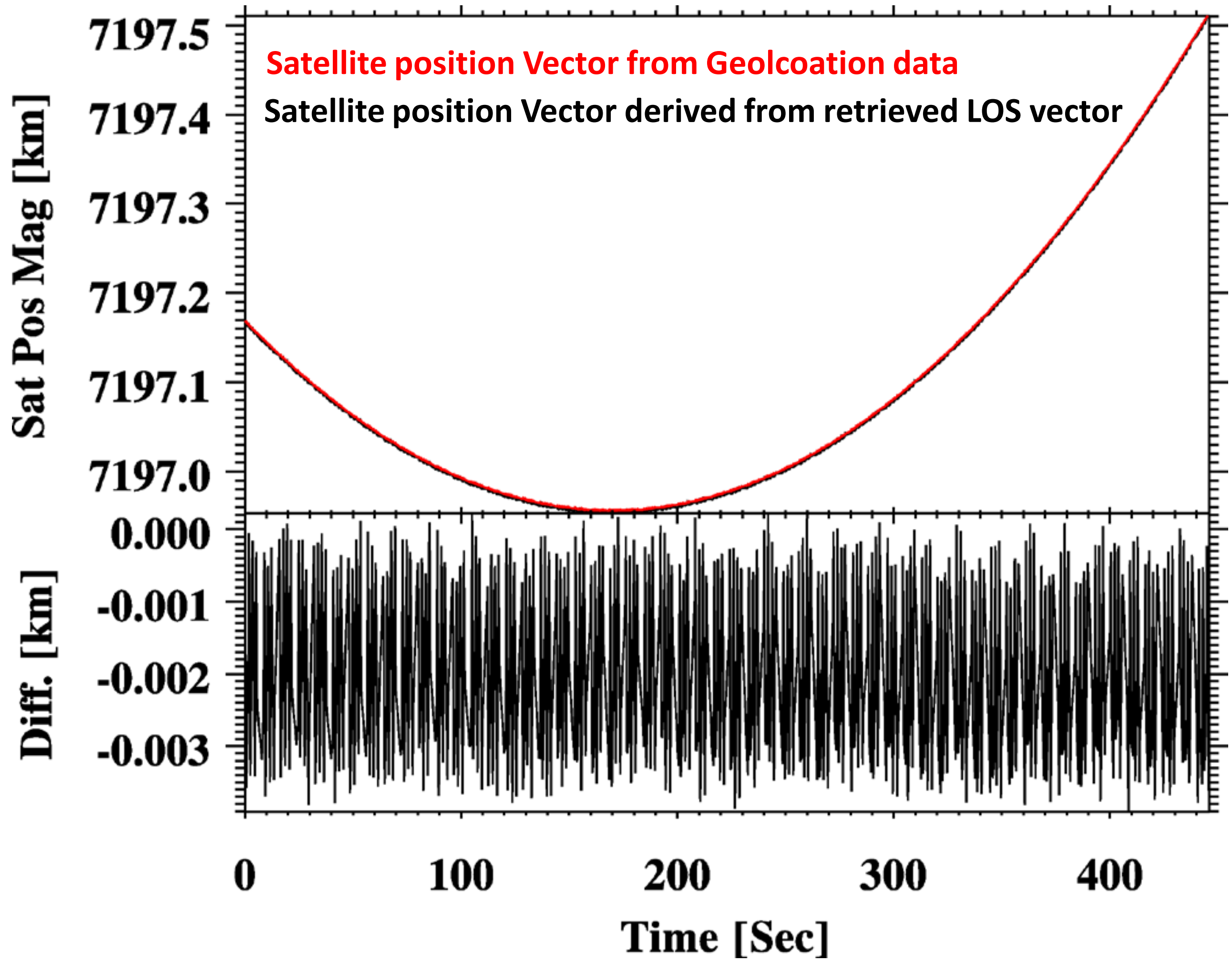
[Zenith, Azimuth, Range] ➔ [East, North, Up] in local Cartesian (ENU) coordinates

[East, North, Up] + [Lon, Lat] ➔ [X, Y, Z] in ECEF

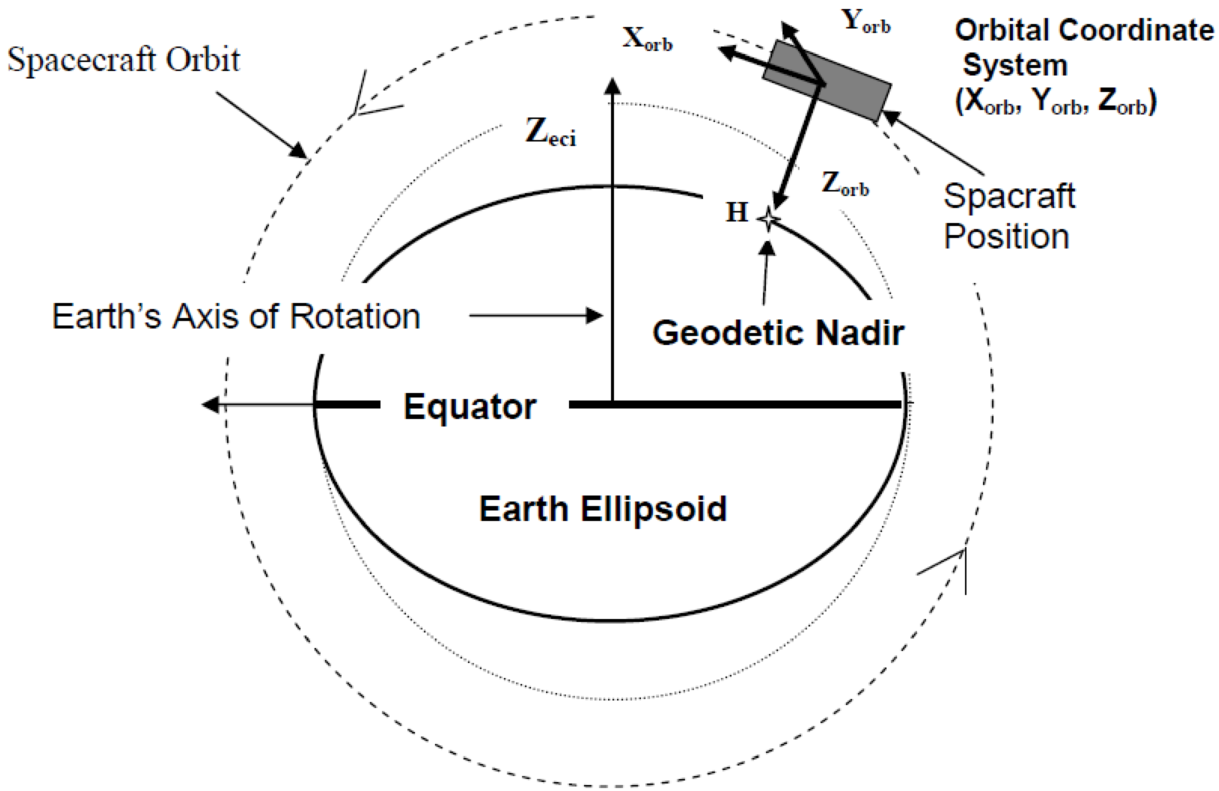
Validation of Retrieved LOS Pointing Vector



The retrieved LOS vectors **D** can be indirectly validated by comparing two satellite position vector: the ones saved in CrIS geolocation data and the others derived from the retrieved vector **G** and **D** (**P = G – D).**



Build Orbital Coordinate System (OCS) in ECR or ECEF



- P_sat and V_sat in ECEF are saved in Geolocation dataset
- P_sat => Z axis
- Y axis => crossp(Z, V_sat)
- X axis => crossp(Y, Z)

From ECEF → OCS

Summary [edit] **Triad method From Wikipedia**

We consider the linearly independent reference vectors $\vec{R}_1$ and $\vec{R}_2$. Let $\vec{r}_1, \vec{r}_2$ be the corresponding measured directions of the reference unit vectors as resolved in a body fixed frame of reference. Then they are related by the equations,

$$\vec{R}_i = A\vec{r}_i \quad (1)$$

for $i = 1, 2$, where A is a rotation matrix (sometimes also known as a proper orthogonal matrix, i.e., $A^T A = I, det(A) = +1$). A transforms vectors in the body fixed frame into the frame of the reference vectors. Among other properties, rotational matrices preserve the length of the vector they operate on. Note that the direction cosine matrix A also transforms the cross product vector, written as,

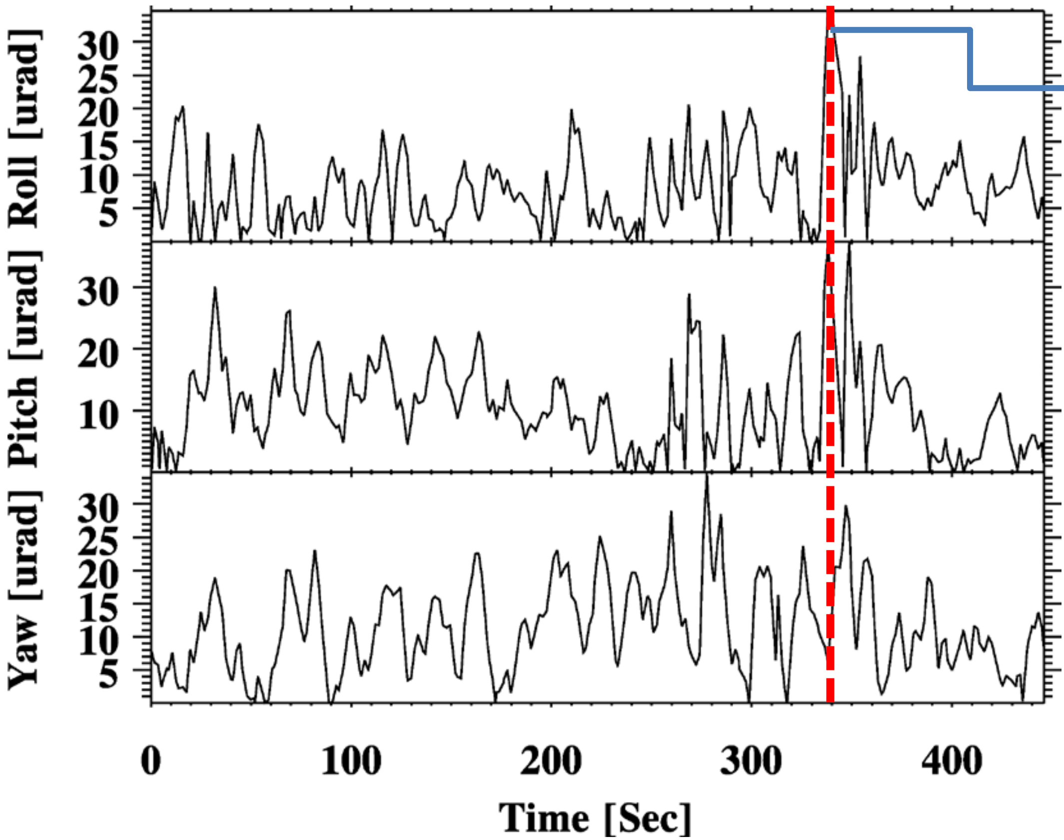
$$\vec{R}_1 \times \vec{R}_2 = A\left(\vec{r}_1 \times \vec{r}_2\right) \quad (2)$$

Triad proposes an estimate of the direction cosine matrix A as a solution to the linear system equations given by

$$\left[\vec{R}_1 \vdots \vec{R}_2 \vdots \left(\vec{R}_1 \times \vec{R}_2\right)\right] = A\left[\vec{r}_1 \vdots \vec{r}_2 \vdots \left(\vec{r}_1 \times \vec{r}_2\right)\right] \quad (3)$$

We have Z and X in ECEF, corresponding to [0, 0, 1] and [1, 0, 0] in OCS. And then we can derive transformation matrix A(ECEF=>OCS)

From OCS ➔ Spacecraft



(Roll , Pitch, Yaw) in μrad

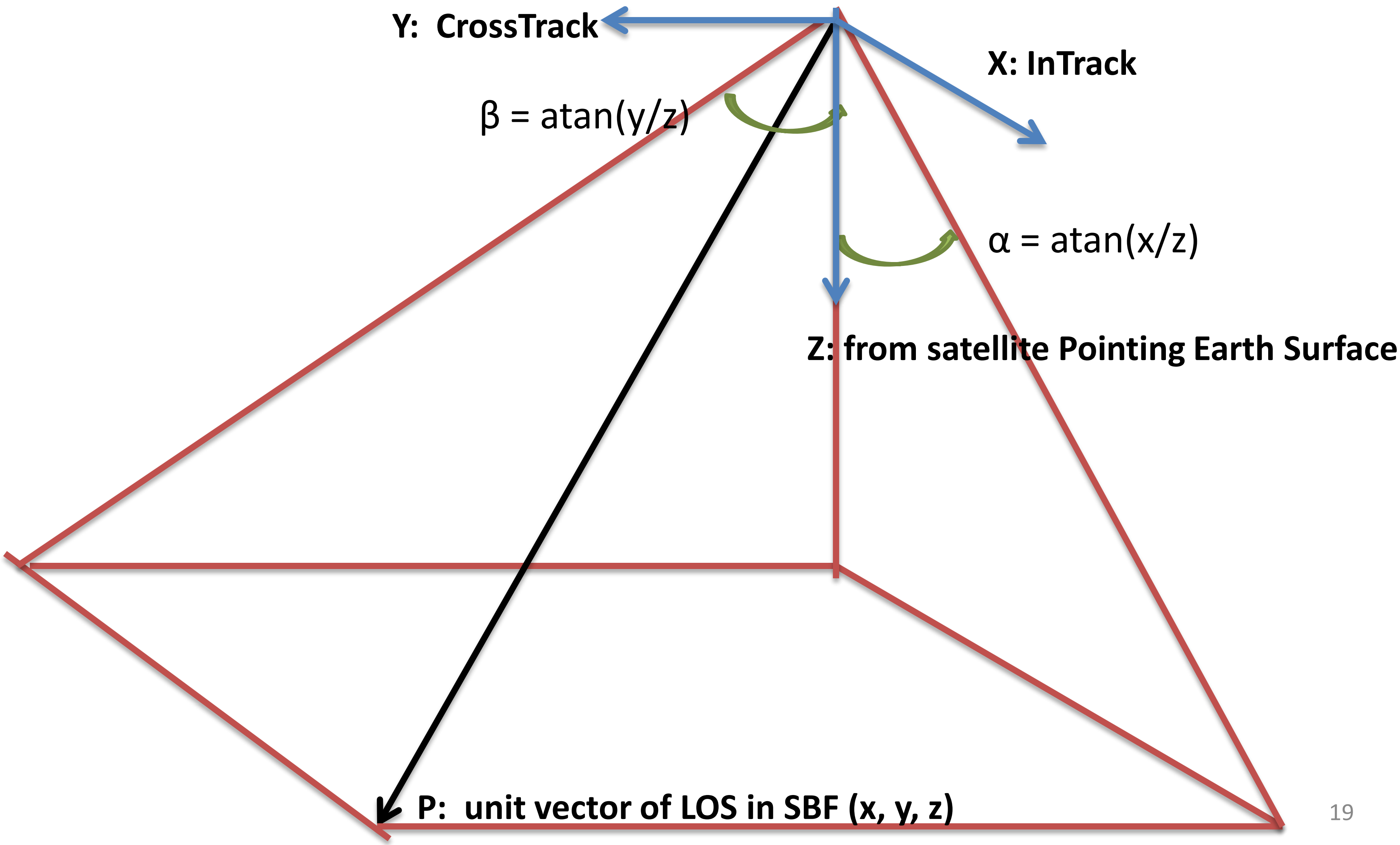
(34.607031 29.572295 12.285854)

$$\begin{pmatrix} 0.9999999995 & 0.0000122869 & -0.0000295723 \\ -0.0000122859 & 0.9999999993 & 0.0000346070 \\ 0.0000295727 & -0.0000346067 & 0.9999999990 \end{pmatrix}$$

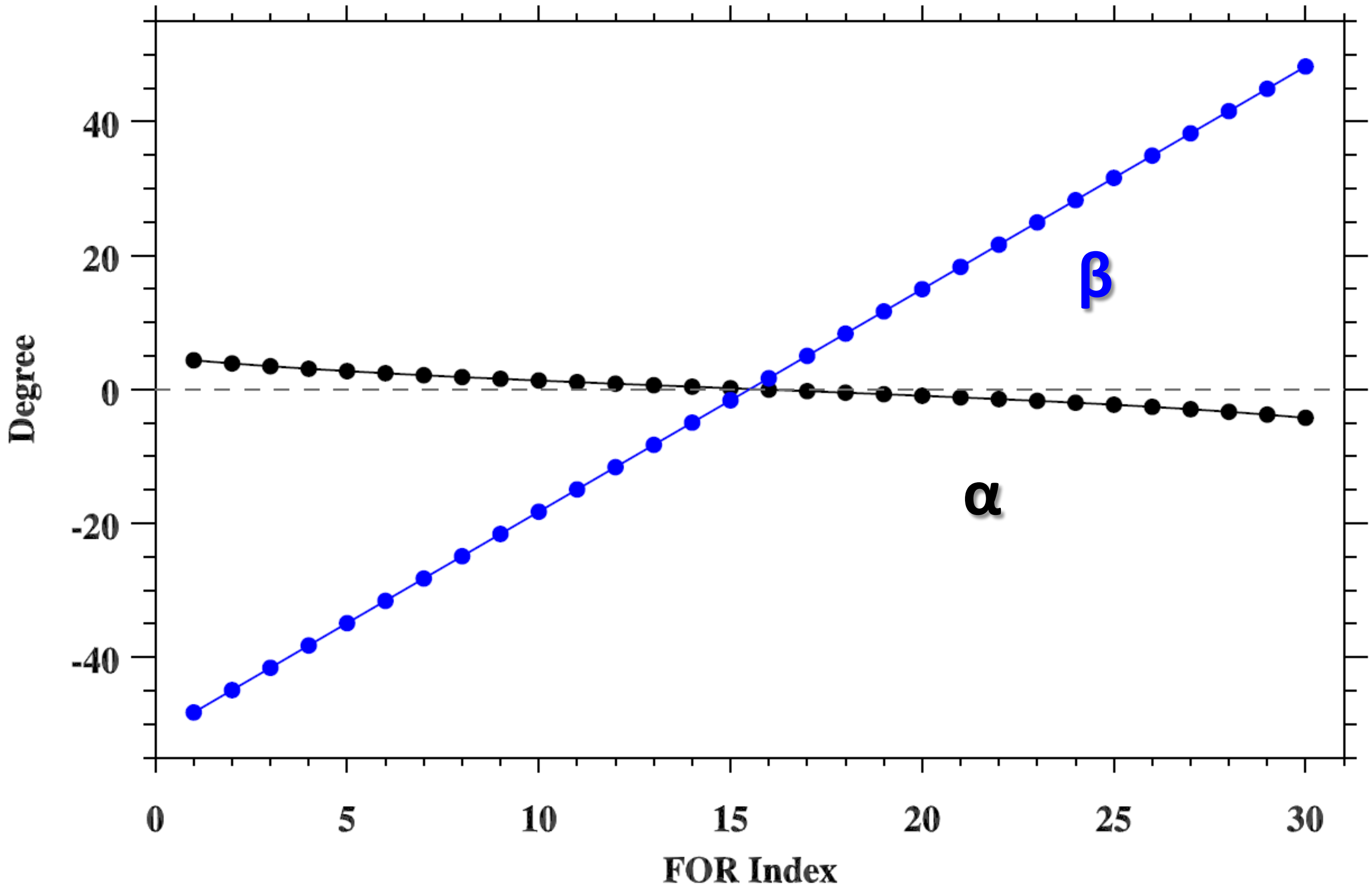
$T_{sc/orb} =$ **The transformation matrix from OCS to Spacecraft coordinates**

$$\begin{bmatrix} \cos\xi_y \cos\xi_p - \sin\xi_y \sin\xi_r \sin\xi_p & \sin\xi_y \cos\xi_p + \cos\xi_y \sin\xi_r \sin\xi_p & -\cos\xi_r \sin\xi_p \\ -\sin\xi_y \cos\xi_r & \cos\xi_y \cos\xi_r & \sin\xi_r \\ \cos\xi_y \sin\xi_p + \sin\xi_y \sin\xi_r \cos\xi_p & \sin\xi_y \sin\xi_p - \cos\xi_y \sin\xi_r \cos\xi_p & \cos\xi_r \cos\xi_p \end{bmatrix}$$

Defining α and β angles of CrIS LOS vector in Spacecraft Coordinate

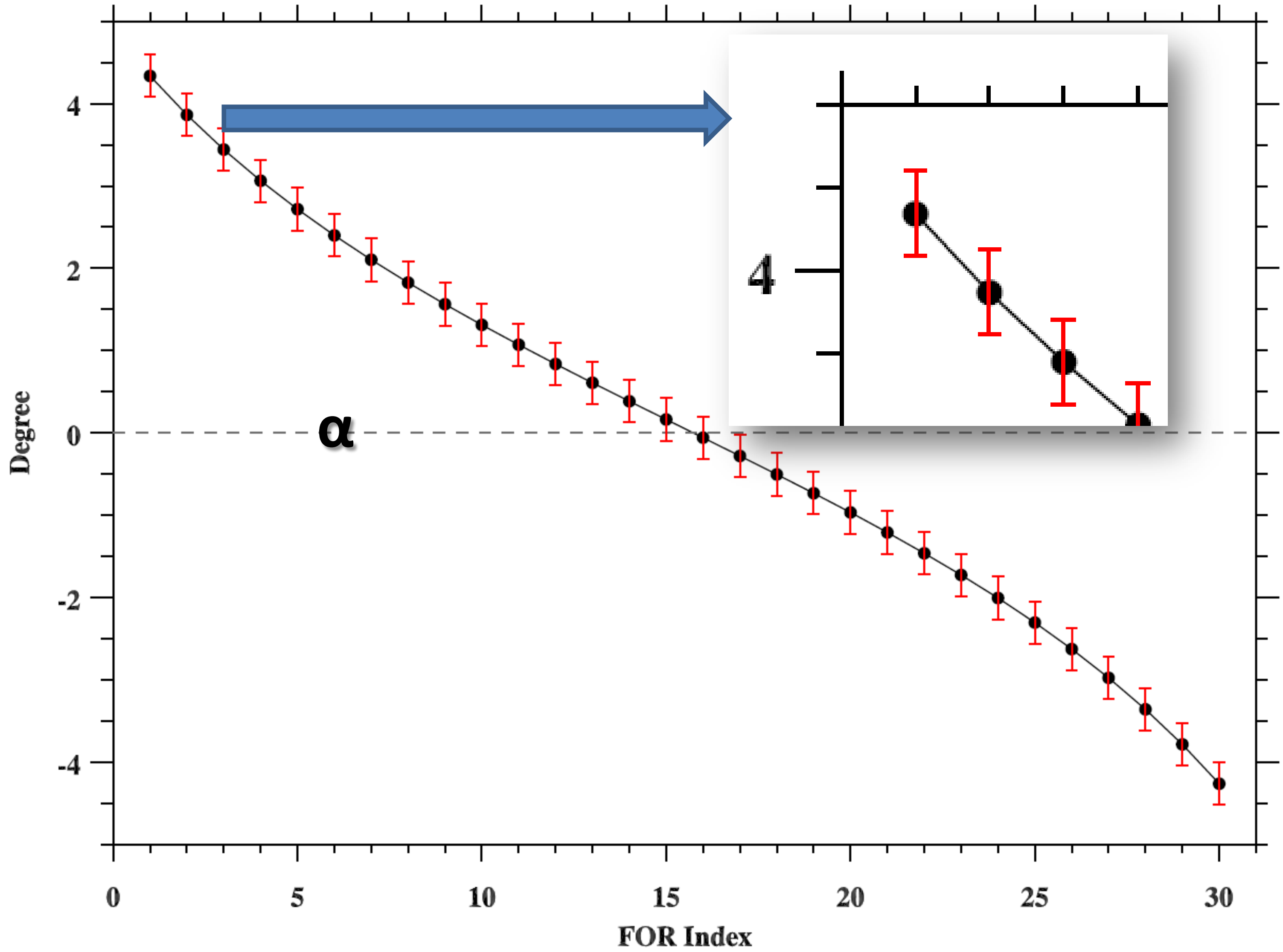


α and β Angles varying with Scan Position (FOV5)

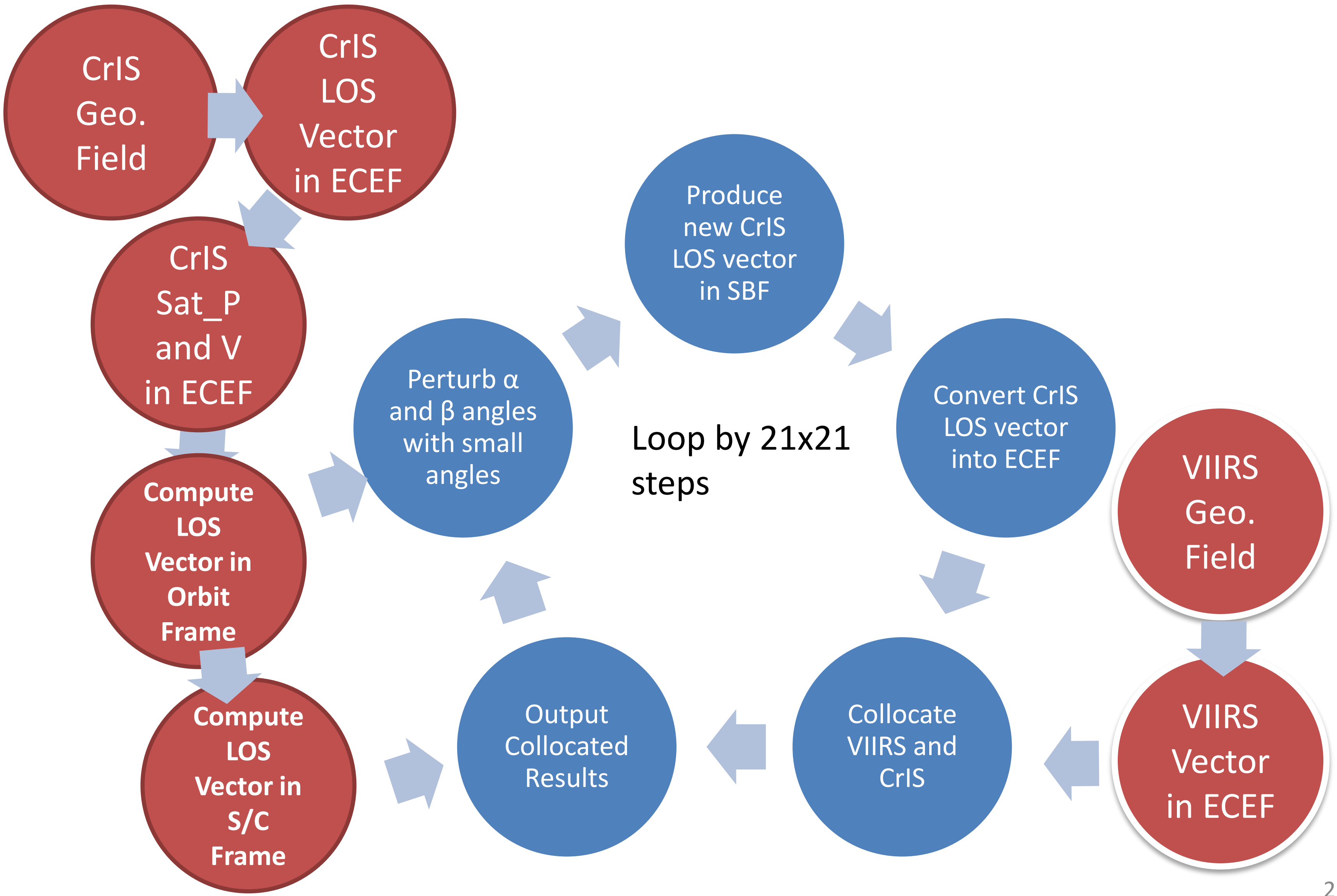


Noted that the yaw patterns of α angles are caused by the Earth Rotation

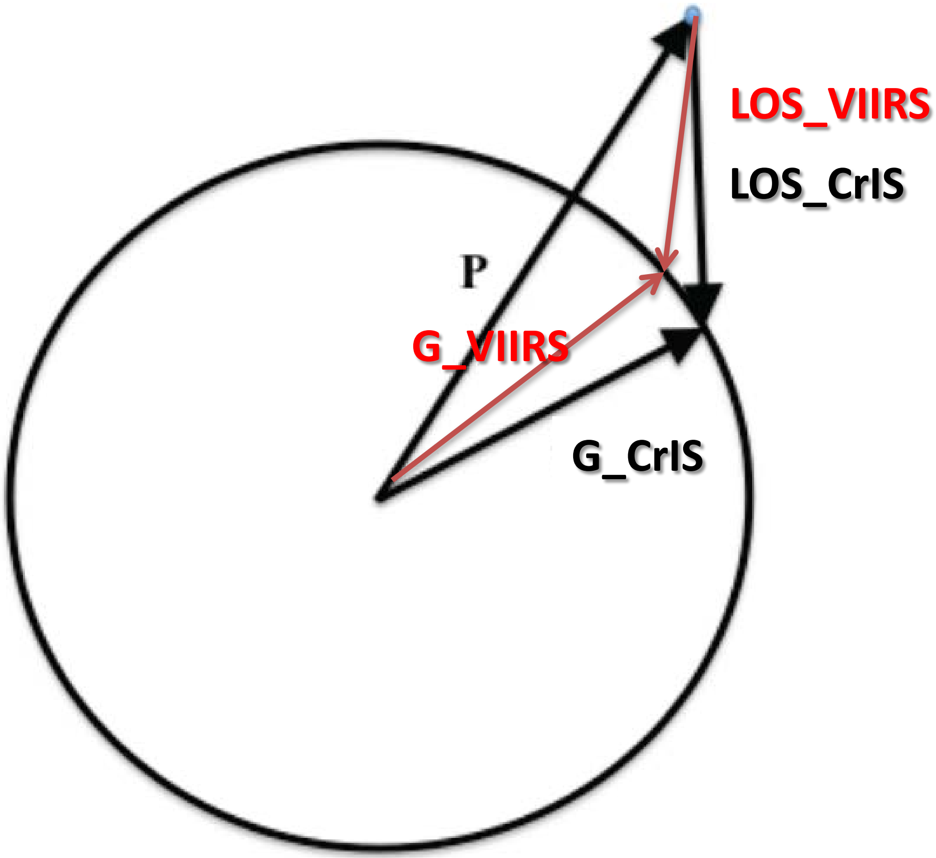
α and β angles are step-by-step perturbed by 21 steps with a angle of 375/833/1000.0

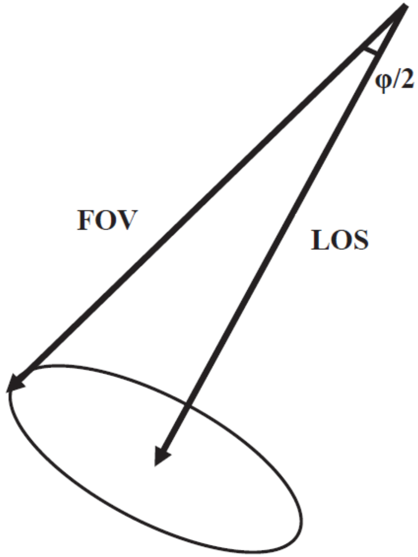


Flowchart for VIIRS-CrIS Geolocation



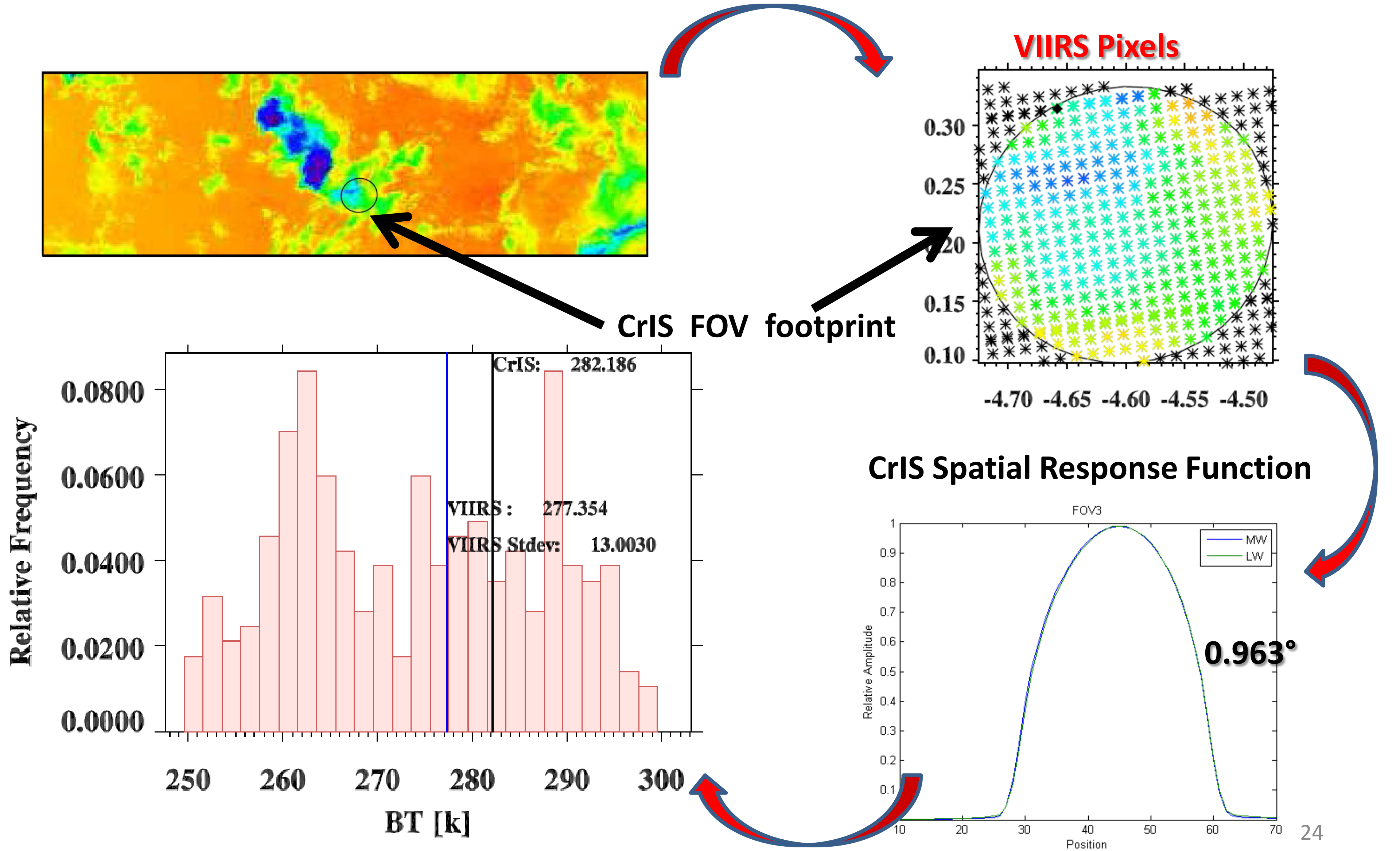
Collocation CrIS with VIIRS





The collocation problem is simplified as, check the angle between two vectors, [LOS_VIIRS, LOS_CrIS].

Collocating VIIRS with CrIS FOV



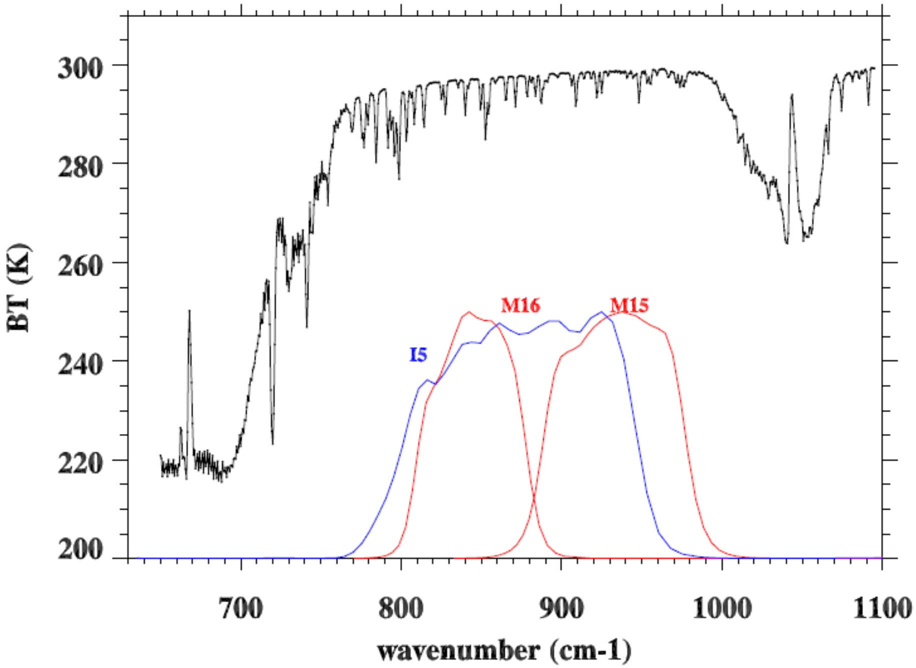
Histogram of VIIRS M16 in CrIS FOV

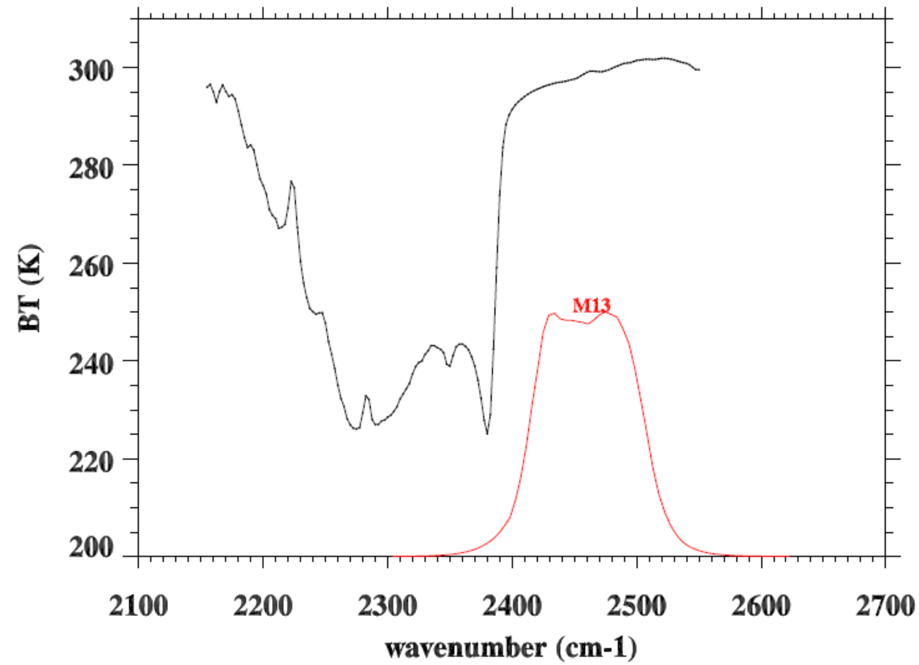
From Mark Esplin

Spectral Integration: from CrIS to VIIRS

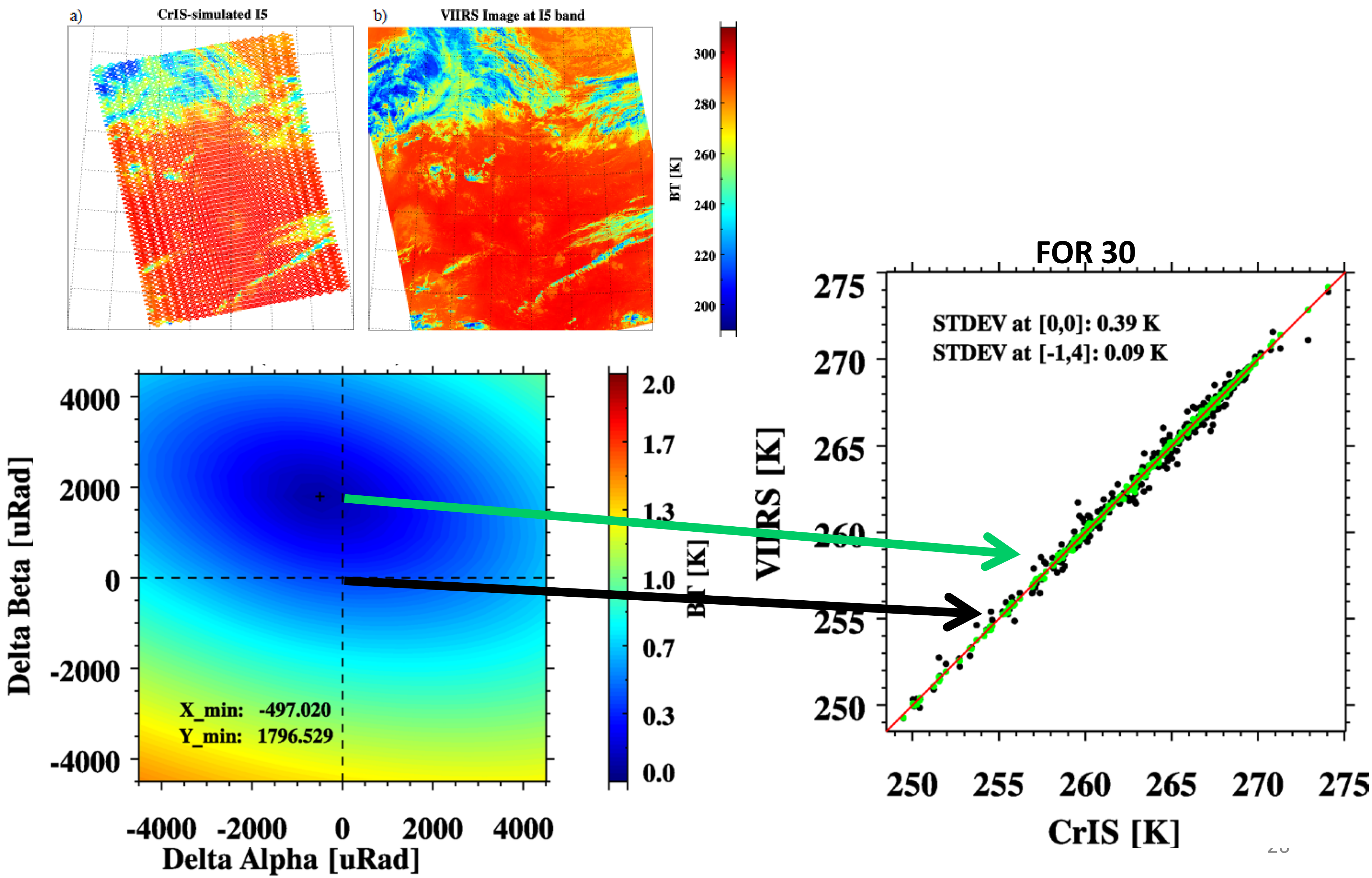
CrIS spectrum is convolved with VIIRS SRFs for I5 band (350m spatial resolution)

$$L_i = \frac{\int_{\nu_1}^{\nu_2} R(\nu) S_i(\nu) d\nu}{\int_{\nu_1}^{\nu_2} S_i(\nu) d\nu}$$

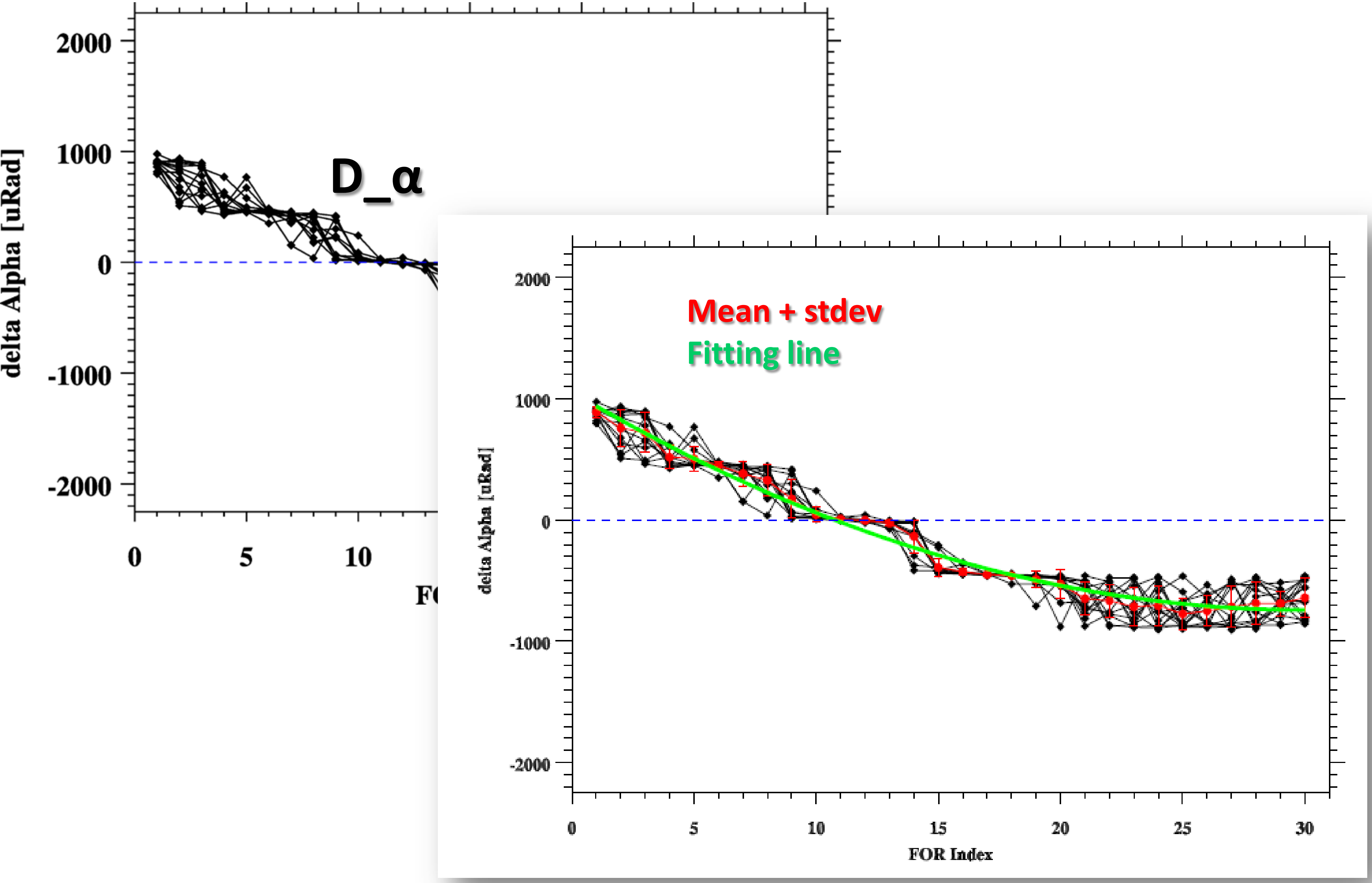




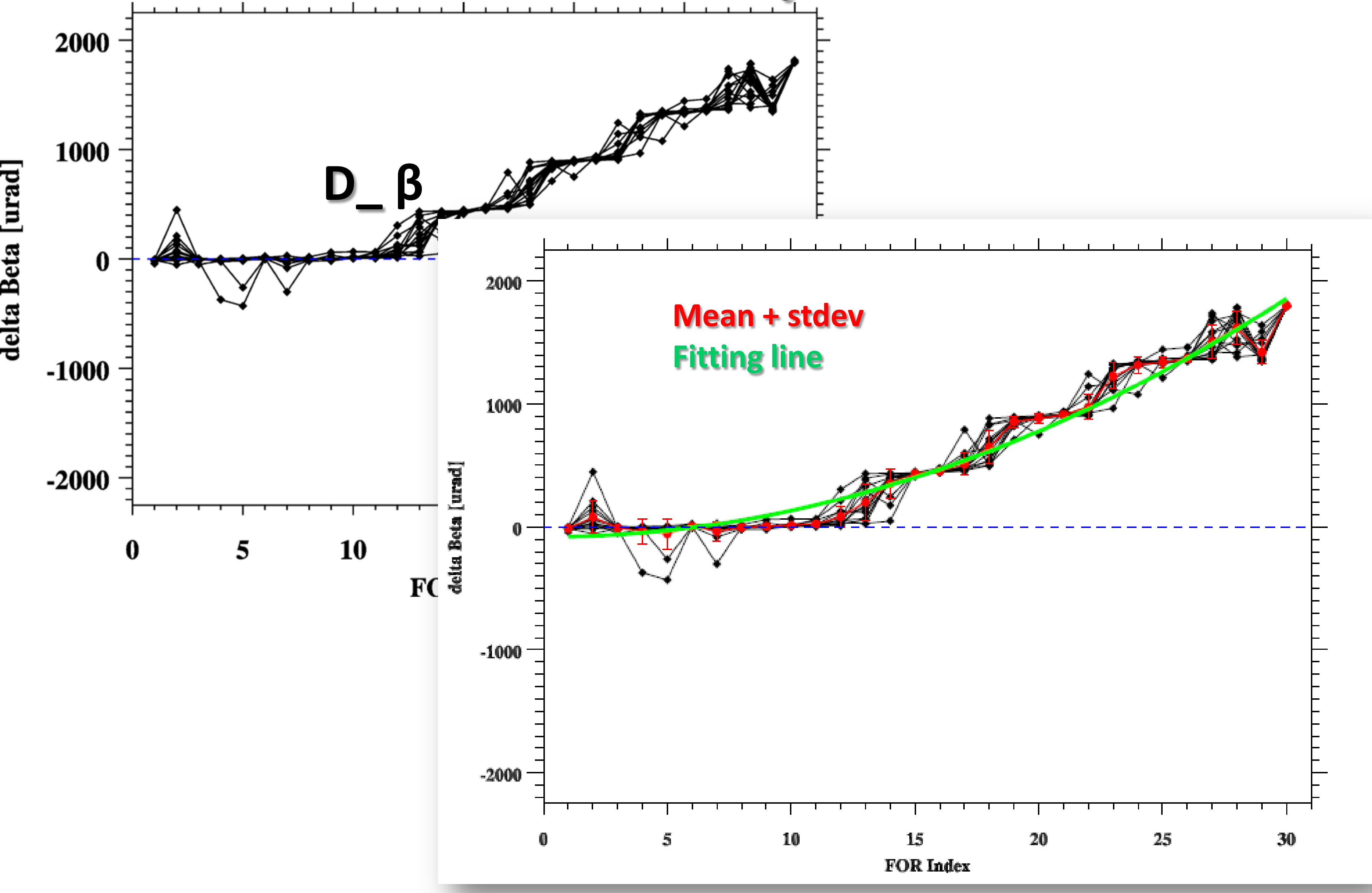
An Example


a) CrIS-simulated I5
b) VIIRS Image at I5 band
BT [K]
300
280
260
240
220
200
Delta Beta [uRad]
4000
2000
0
-2000
-4000
Delta Alpha [uRad]
-4000
-2000
0
2000
4000
X_min: -497.020
Y_min: 1796.529
2.0
1.7
1.3
1.0
0.7
0.3
0.0
BT [K]
FOR 30
STDEV at [0,0]: 0.39 K
STDEV at [-1,4]: 0.09 K
VIIRS [K]
275
270
265
260
255
250
CrIS [K]
250
255
260
265
270
275

D_α with FOR index based on 15 days' data



D_ β with FOR index based on 15 days' data



Retrieval of New Geometric Parameters

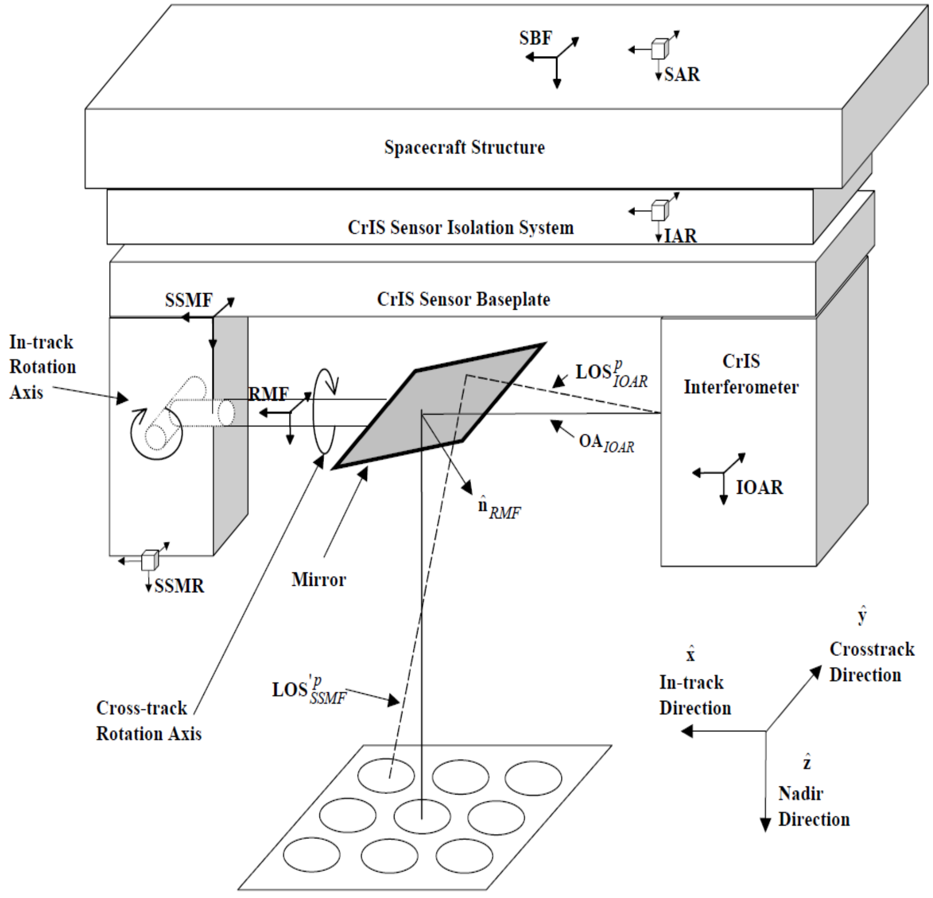


Figure 48: Sensor Algorithm Level Coordinate Systems

Given the assessment results with 60 angles, the best strategy is to retrieve 60 scan mirror rotation angles.

SDR Algorithm Process

1) LOS in IOAR coordinate = ILS parameters (3x3)
2) Convert from IOAR to SSMF coordinate **(2 angles)**
3) Compute normal to SSM mirror in SSMF (30 Scan Pos) **(60 angles)**
4) Apply SSM mirror rotation to get LOS in SSMF coordinate
5) Convert from SSMF to SSMR coordinate **(3 angles)**
6) Convert from SSMR to IAR coordinate **(3 angles)**
7) Convert from IAR to SAR **(3 angles)**
8) From SAR=> SBF coordinate **(0 angels)**
9) From SBF=> Spacecraft **(3 angles)**

Retrieval of New Geometric Parameters

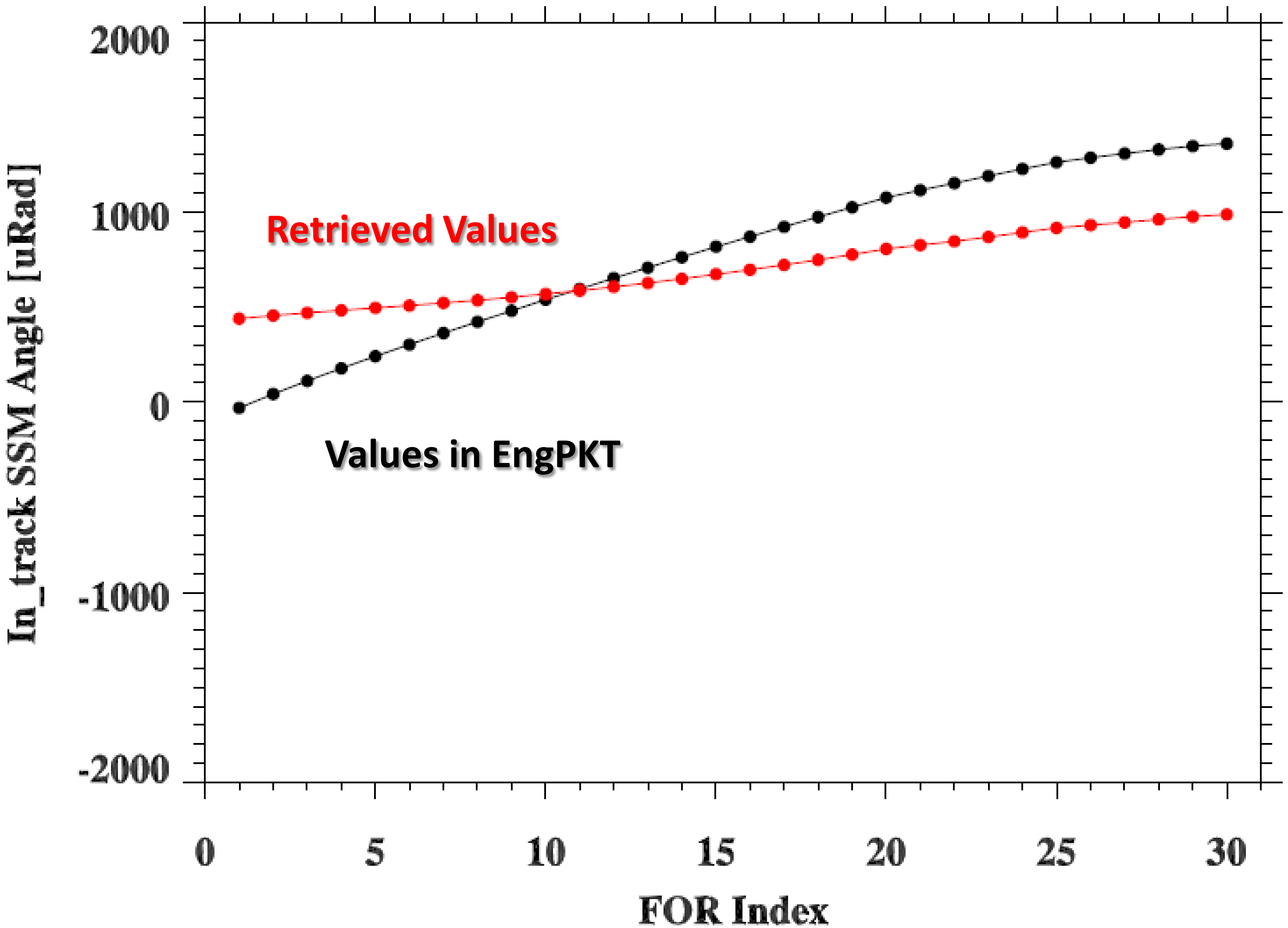
- Retreived $LOS_{S/C}$ at each scan position on D_α and D_β

- Step-by-step through each matrix to the coordinate SSMF:
  - $LOS_{S/C} \rightarrow LOS_{SBF} \rightarrow LOS_{SAR} \rightarrow LOS_{IAR} \rightarrow LOS_{SMR} \rightarrow LOS_{SSMF}$

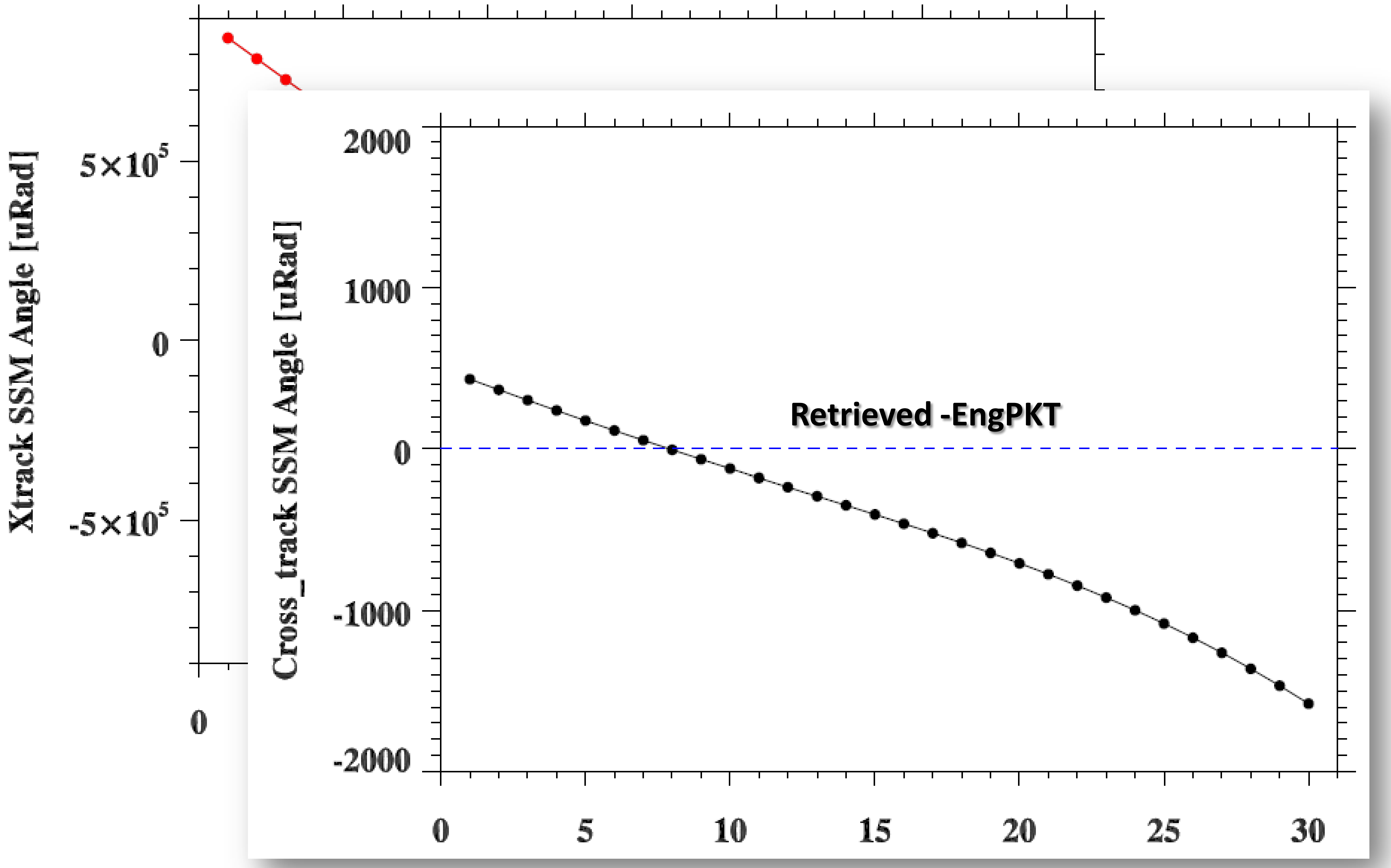
- Retrieve the normal vector $\mathbf{n}_{SSMF}$:
  - $LOS_{SSMF} = LOS'_{SSMF} - 2*(LOS'_{SSMF} \cdot \mathbf{n}_{SSMF})\, \mathbf{n}_{SSMF}$

- The normal vector $\mathbf{n}_{SSMF}$ can be used to retrieve the actual cross-track angle and actual in-track angles of Scan Mirror

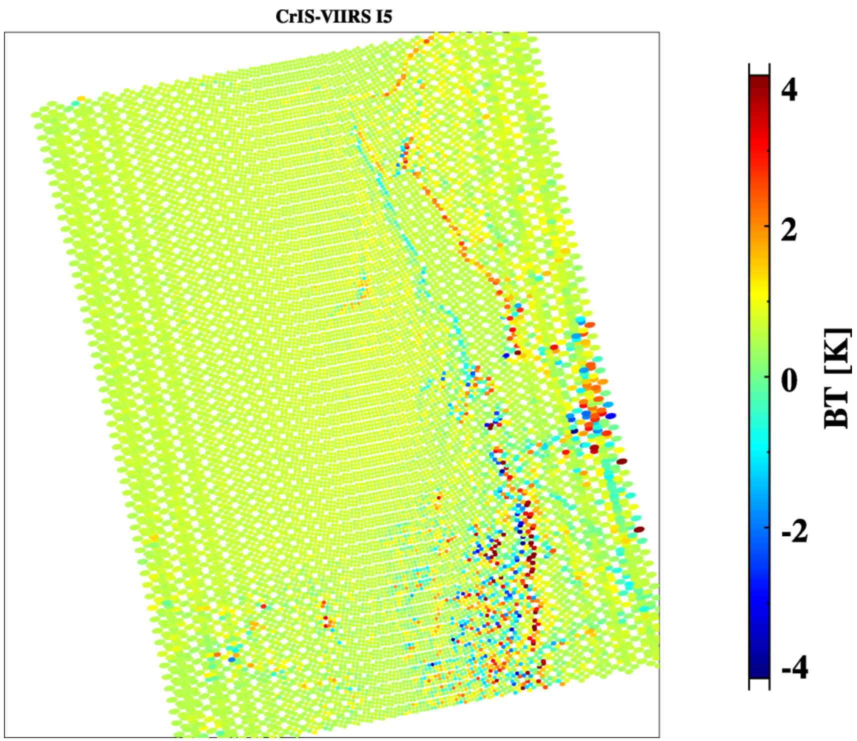
Retrieved SSMF In-track Angles

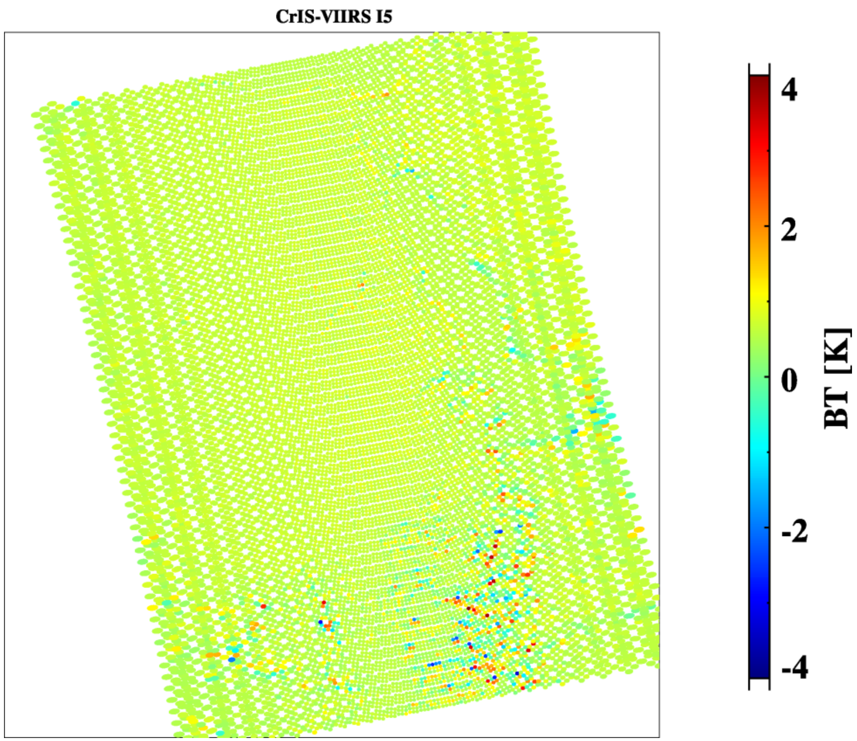


Retrieved SSMF Cross-track Angles

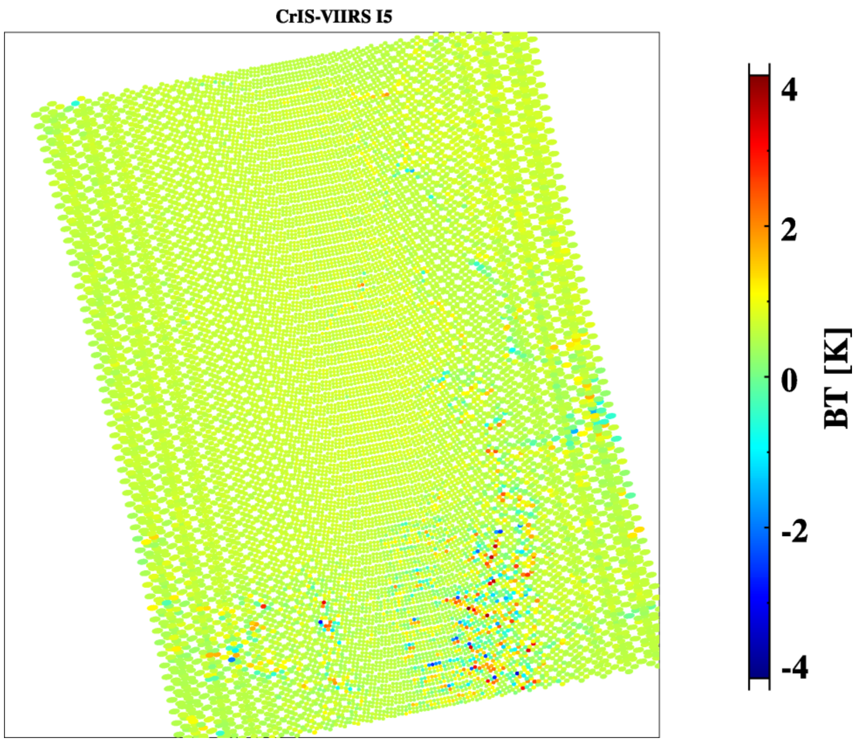


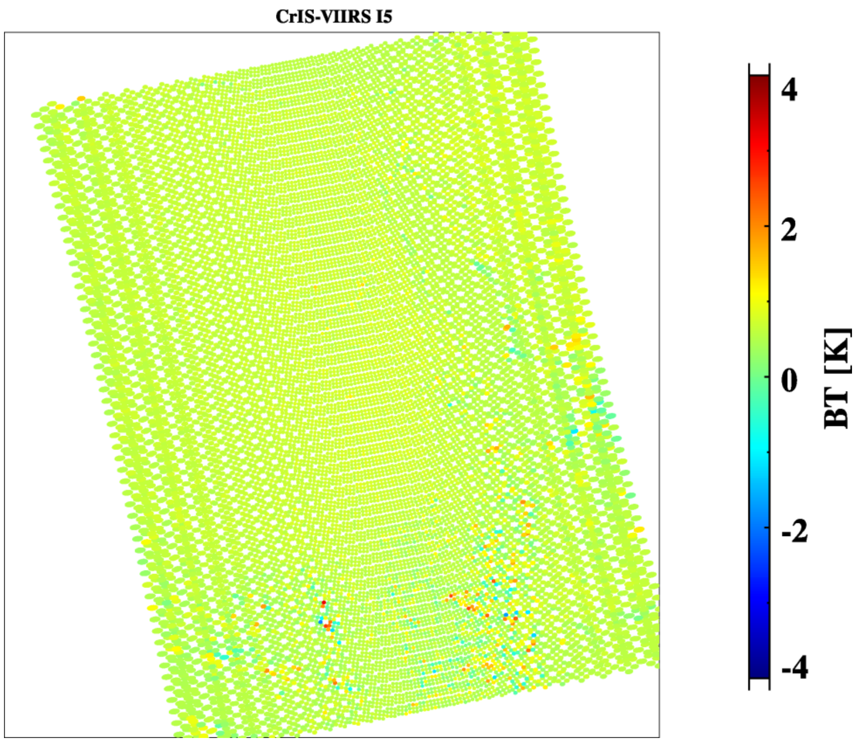
Only correct cross-track direction





Correct Both cross-track and in-track Direction





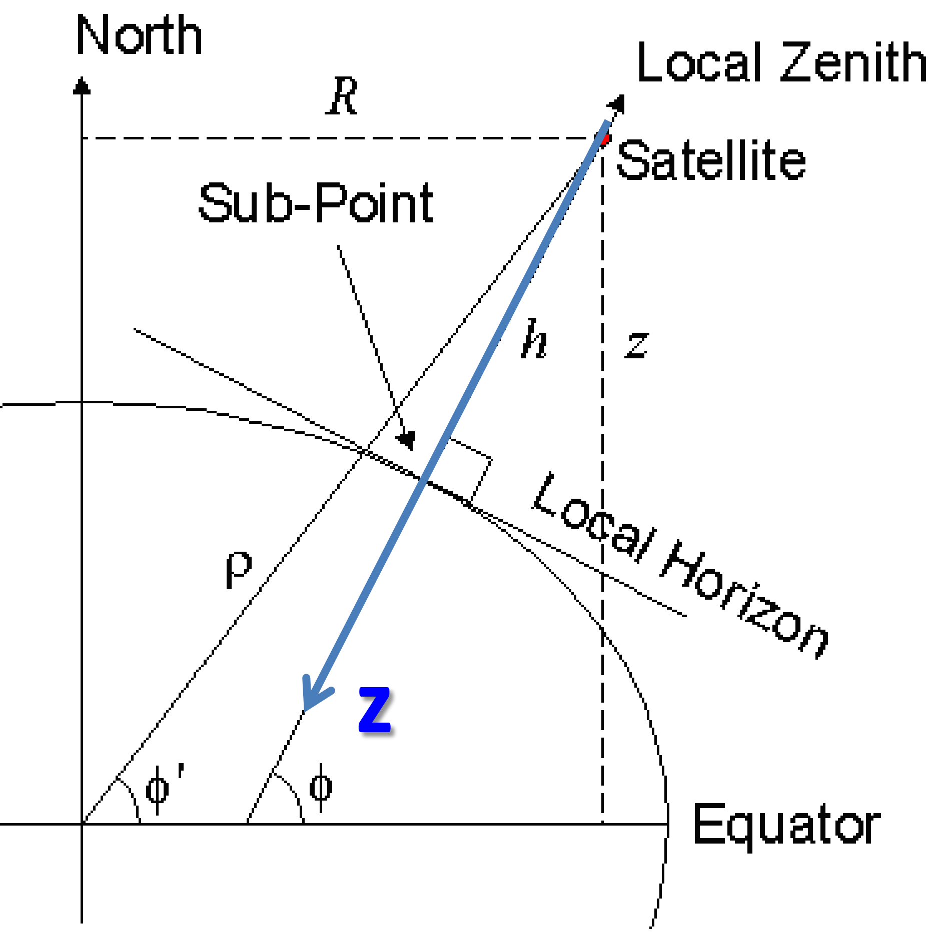
Conclusion and Future Work

- A new tool is developed to identify the error characteristics of CrIS LOS pointing vector at all scan positions.

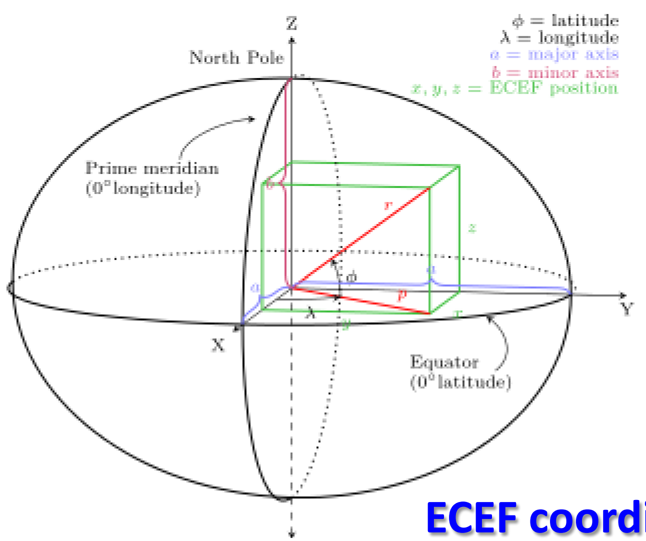
- A correction model is developed to retrieve a new set of SSMF scan angles based on assessment results to further improve the geolocation accuracy.

- **Future work**
  - **FOV5 off-axis angle sign change**
  - **Possible angle adjustment**

Define Orbital Coordinate System (OCS)



- P_sat and V_sat in ECEF are saved in SDR
- p_sat => Z axis
- Y axis => crossp(Z, V_sat)
- X axis => crossp(Y, Z)



ECEF coordinates system