# Verification of Pointing Calibration Methods for Kompsat-6

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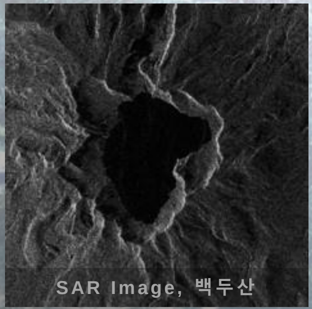
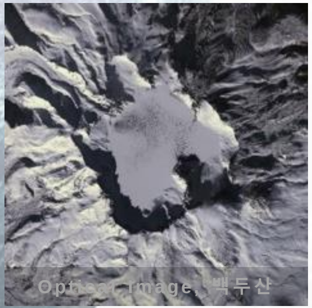

SAR Image, 백두산


Optical Image, 백두산

# Agenda

- Introduction
- Method
- Verification
- Conclusions

# Introduction

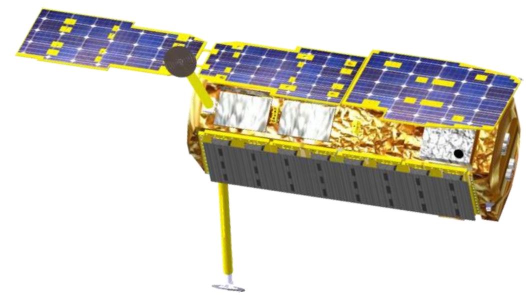
# Kompsat-6 (K6)

## Mission Objectives

- “Expedite provision of the space-borne Synthetic Aperture Radar images with sub-meter resolution required for the national demand in GIS (Geographical Information Systems), Ocean & Land management, Disaster monitoring, and ENvironment monitoring”

## Launch Date / Life Time

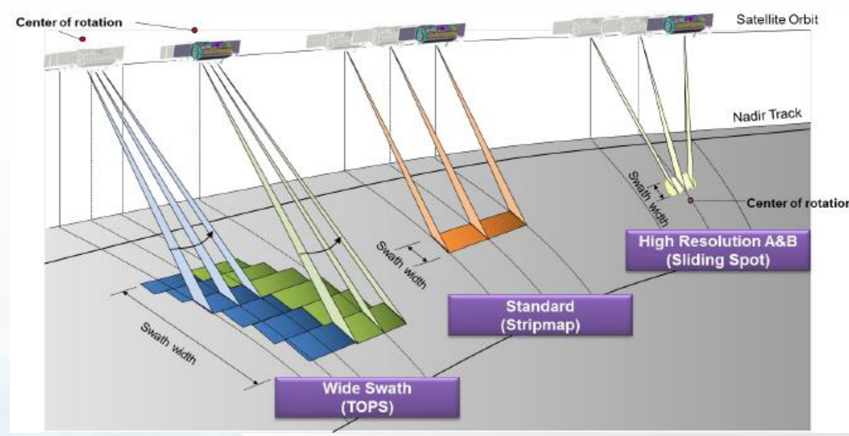
- November-2021 / 5 years



Kompsat-6 Configuration

## SAR Payload

- Space-borne Synthetic Aperture Radar
- X-band with an active phased array antenna
- Four Imaging modes
  - ✓ High Resolution-A: 0.5 m resolution, 5 km swath
  - ✓ High Resolution-B: 1 m resolution, 10 km swath
  - ✓ Standard: 3 m resolution, 30 km swath
  - ✓ Wide Swath (TOPS): 20 m res., 100 km swath
- Coherent Dual Polarization
- Quad Pol. & ATI/GMTI as Experimental Mode
- InSAR Capability (orbital tube with 250 m radius)




K6 SAR Imaging Modes

# Doppler Centroid (DC)

## Definition

- Doppler frequency at the time that the beam center crosses a target

## Importance

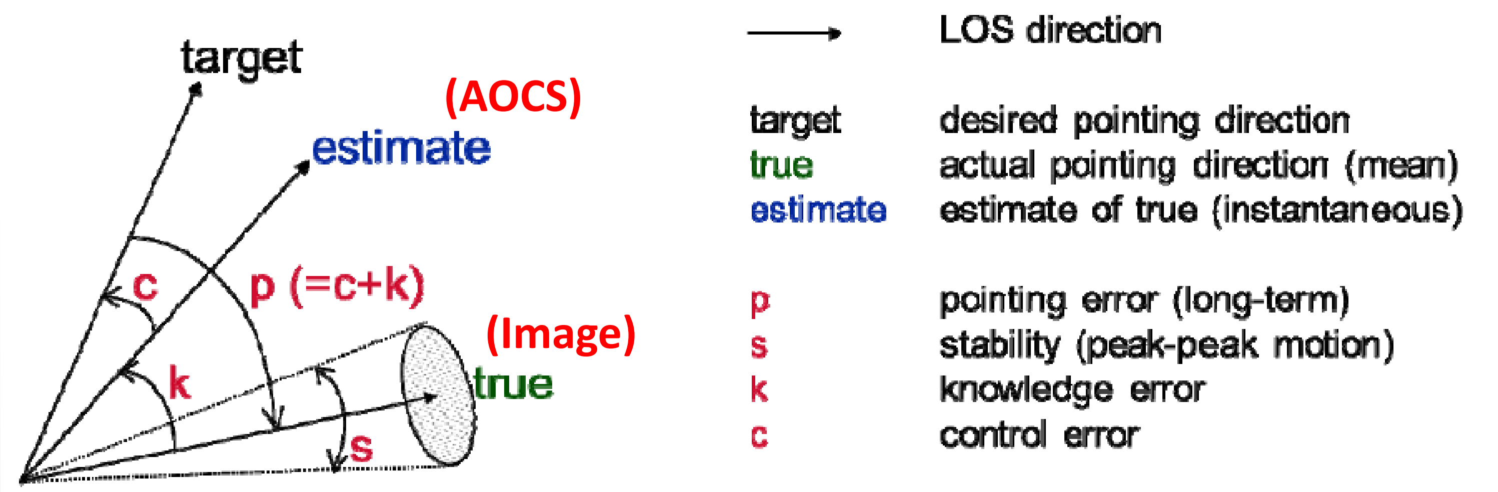
- SAR processing aspect
  - ✓ Necessary for SAR image processing in azimuth direction required for operations such as range cell migration correction, azimuth compression, and image registration.
- Calibration aspect
  - ✓ Necessary for satellite attitude correction or beam pointing calibration

## Estimation Method

- Geometry method
  - ✓ DC is calculated from geometric information including the satellite's orbit, attitude, antenna misalignments, beam steering etc.
  - ✓ DC estimate is <u>sometimes</u> not accurate enough due to uncertainties in geometric information (especially attitude), but is stable not depending on image by image
- Image method
  - ✓ DC is calculated from magnitude or phase information of SAR images
  - ✓ DC estimate is accurate but depending on image quality (ex. Homogeneity)

# Satellite Attitude Estimation from SAR

- Satellite Attitude Characteristics
  - ✓ Measured satellite attitude from attitude and orbit control system (AOCS) can be deviated from true attitude
  - ✓ Satellite attitude estimated directly from SAR images is considered close to true attitude
- Attitude Compensation
  - ✓ DC difference (delta DC) from geometric information and from image can be used to estimate satellite attitude error.

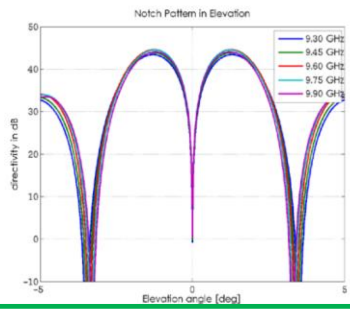


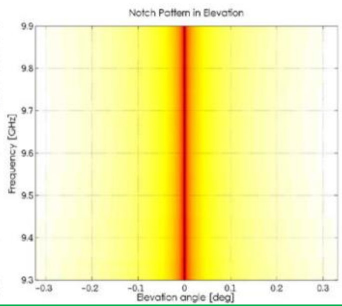

Satellite Attitude Error Definitions

# K6 Pointing Calibration Concept

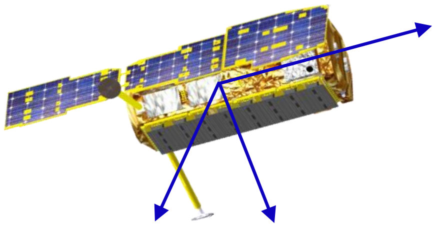
## Notch Method

- Elevation/Azimuth Notch Patterns
  - ✓ Compare reference vs. measured patterns



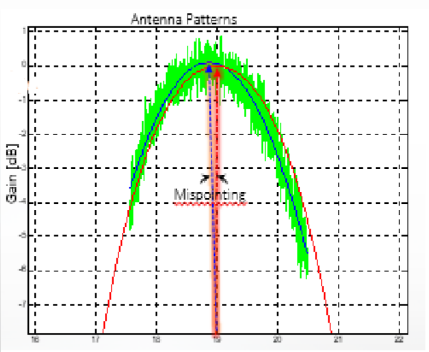



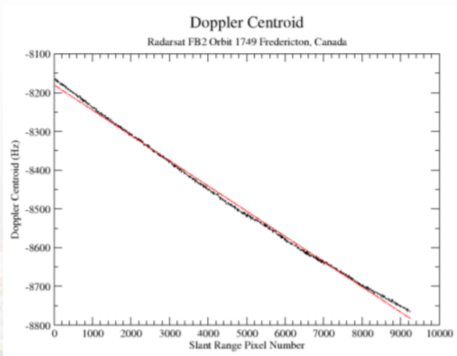

- Satellite Attitude Offset Estimation
  - ✓ Roll-Pitch-Yaw offsets



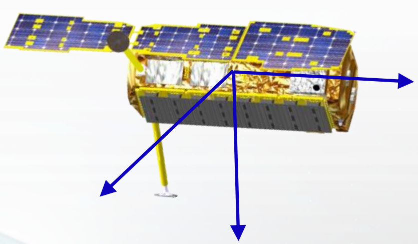
## Doppler Centroid Method

- DC Geometry & DC Image Measurements
  - ✓ Compare DC geometry vs. DC image




- Satellite Attitude Offset Estimation
  - ✓ Pitch-Yaw offsets



# Research Motivation & Objective

## Motivation

- Accurate DC estimation and satellite attitude compensation are essential part of SAR processing and sensor calibration
- Kompsat-6 requires very high DC and satellite attitude estimation accuracy
  - ✓ K6 DC accuracy requirement: $\leq$ 5 Hz
  - ✓ K6 Pointing Knowledge req.: $\leq$ 0.032° (R), $\leq$ 0.024° (P), $\leq$ 0.017° (Y) [3$\sigma$]

## Objective

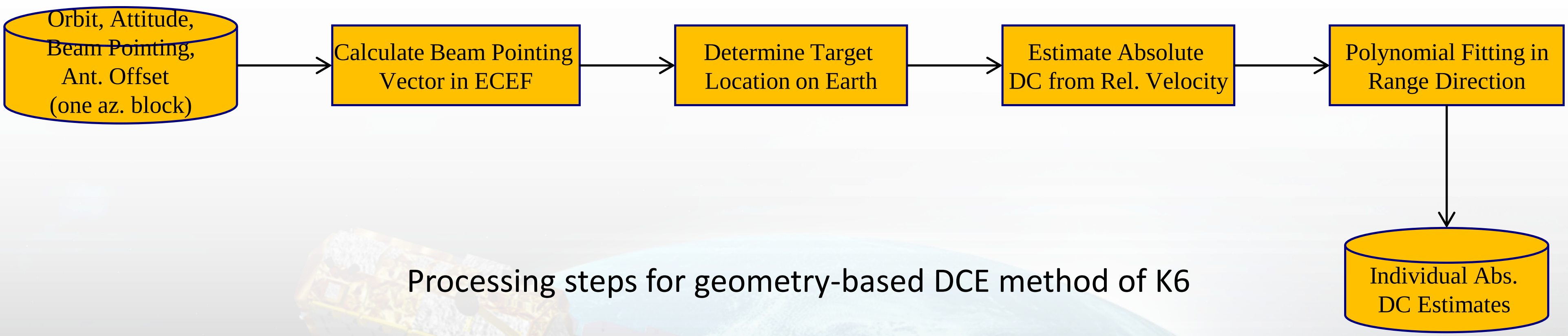
- To develop stable and accurate DC estimation algorithm for Kompsat-6
- To develop accurate satellite attitude offset estimation algorithm from DC measurements for Kompsat-6
- To verify the K6 satellite attitude compensation algorithm using simulated data and actual Kompsat-5 data

# Method

# K6 Doppler Centroid Estimation (DCE) Methods (1)

## Geometry Method

- Consider all necessary geometric information required to determine DC
  - ✓ Satellite state vector, attitudes, attitude offsets, antenna position offsets, antenna misalignments, beam pointing direction, beam pointing offsets, etc.
- Apply satellite sensor modeling to determine precise location of a target on Earth
- Consider various time (range/azimuth) error sources including internal hardware delay, atmospheric delay, etc.
- DC estimation is performed at each block center after subdividing an image into blocks in the azimuth and range directions
- Polynomial fitting is performed for DC estimates in the range direction




Processing steps for geometry-based DCE method of K6

# K6 DCE Methods (2)

## Image Method

- DC is estimated after subdividing an image into blocks in the azimuth and range directions
- Doppler ambiguity is calculated from geometry-based method (may not necessary due to K6 accurate zero-Doppler steering)
- Baseband Doppler centroid within PRF is estimated from raw image using average cross correlation coefficient (ACCC) at lag one
- DC estimates are unwrapped in the range direction
- Absolute DC are estimated by combining the unwrapped DC estimates and Doppler ambiguity
- Polynomial fitting is performed for DC estimates in the range direction
- Calculation of ACCC at lag one in the azimuth direction:

$$c(\eta) = \sum_{\eta} s(\eta + \Delta\eta) s^*(\eta)$$

$$\phi_{accc} = \angle c(\eta)$$

$$f_{DC} = \frac{\phi_{accc}}{2\pi} PRF$$

$s(\eta)$ = a complex sample of an image

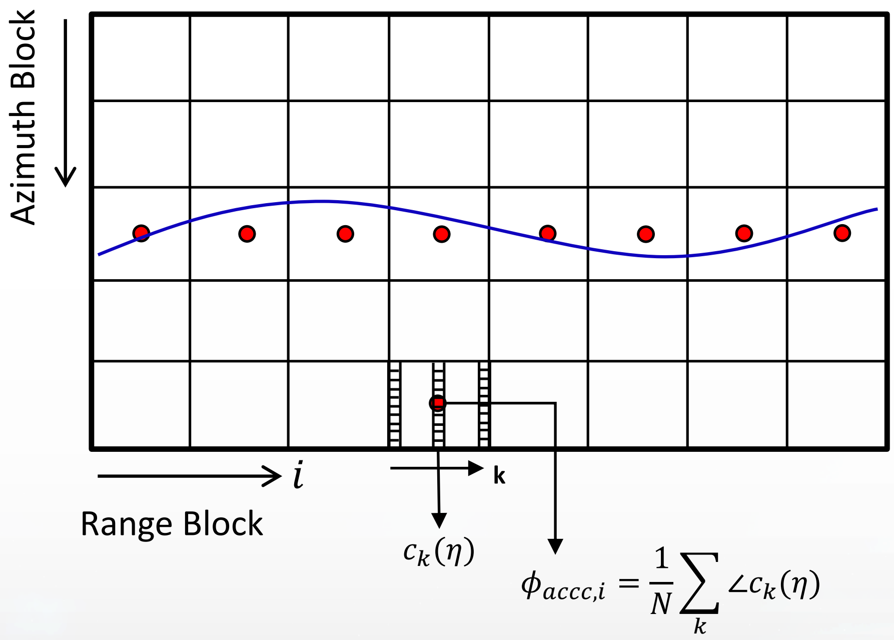
$\Delta\eta$ = the azimuth sample interval (1/PRF)

$s(\eta + \Delta\eta)$ = next complex sample in the azimuth direction

# K6 DCE Methods (3)

## Block Processing

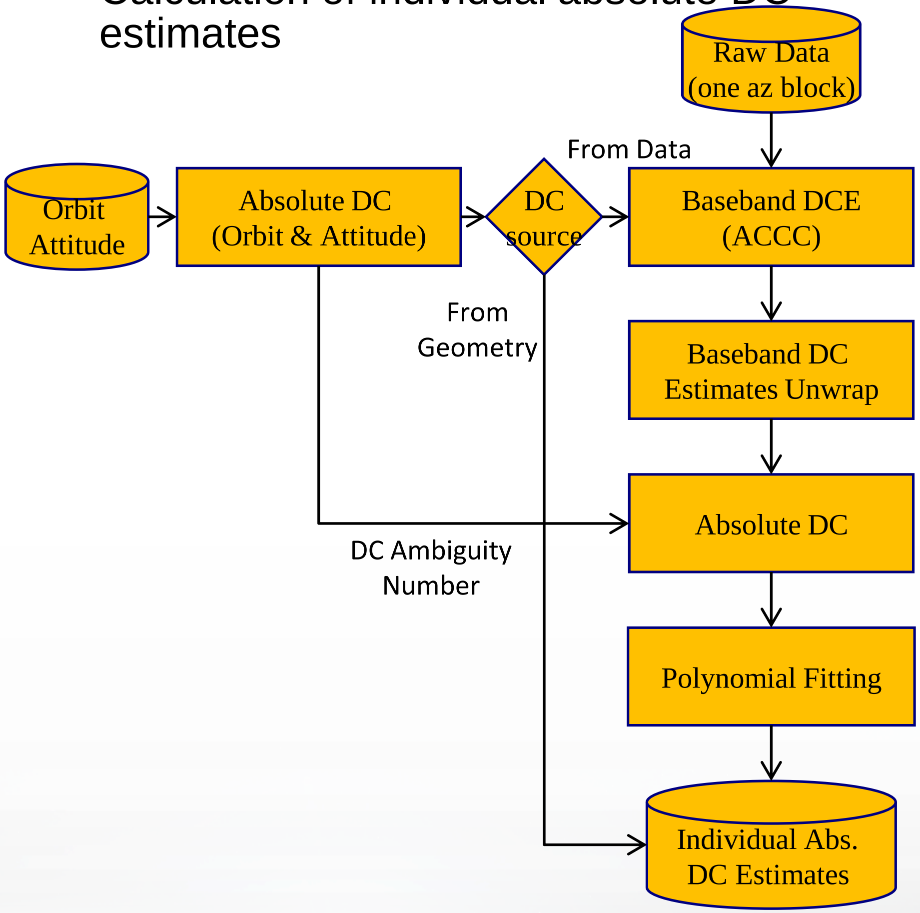
- ✓ The size and the number of the azimuth and range blocks are configurable




Schematic plot of DCE block processing

## Processing Flow

- ✓ Calculation of individual absolute DC estimates




Processing steps for image-based DCE method of K6

# K6 Satellite Attitude Estimation Methods (1)

## Attitude Rotation and Azimuth Displacement

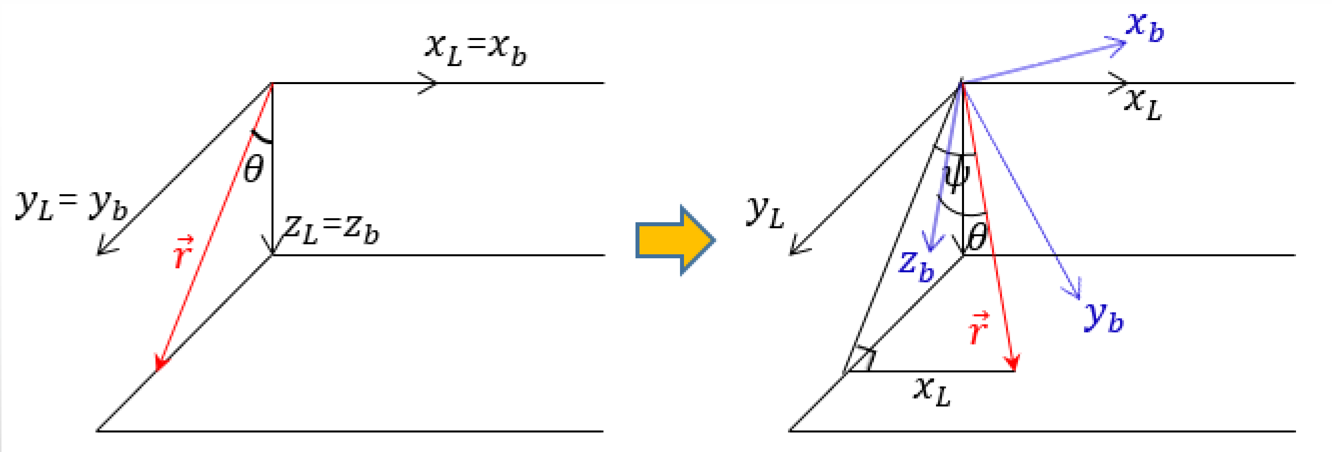
- Coordinates Systems
  - ✓ Zero Doppler frame: $\vec{X}_L = [x_L, y_L, z_L]$, Satellite body frame: $\vec{X}_b = [x_b, y_b, z_b]$
- Assumption: roll[R]-pitch[P]-yaw[Y] (1-2-3) rotation sequence & small angle rotation
- Relation

$$\vec{X}_b = R_Y R_P R_R \vec{X}_L \Leftrightarrow \vec{X}_L = R_R^{-1} R_P^{-1} R_Y^{-1} \vec{X}_b$$

$$\vec{X}_L = \begin{bmatrix} x_L \\ y_L \\ z_L \end{bmatrix} = \begin{bmatrix} 1 & -Y & P \\ Y + RP & 1 - RPY & -R \\ RY - p & R + PY & 1 \end{bmatrix} \begin{bmatrix} 0 \\ r\sin\theta \\ r\cos\theta \end{bmatrix}$$

- DC is related to azimuth displacement ($x_L$) & squint angle ($\psi$)

$$\sin\psi = {x_L}/{r} = [-Y\sin\theta + P\cos\theta]$$




Beam pointing variation due to satellite attitude rotation

# K6 Satellite Attitude Estimation Methods (2)

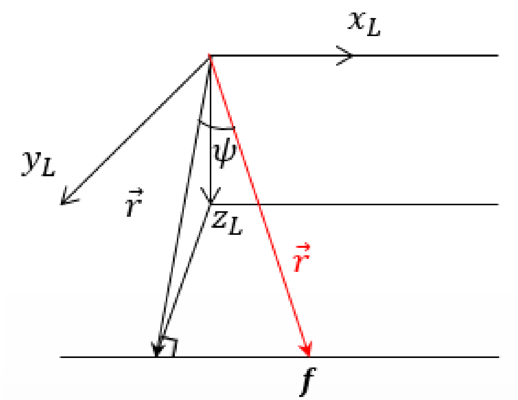
## Doppler Centroid ($f$) and Azimuth Squint Angle ($\psi$)

- SAR imaging geometry

$$f = -\frac{2}{\lambda}|v_{st} - v_T| sin\psi$$

## Attitude Rotation and DC

$$\frac{-\lambda f}{2|v_{st} - v_T|} = [-sin\theta \quad cos\theta] \begin{bmatrix} Y \\ P \end{bmatrix}$$



Doppler centroid and azimuth squint angle

## Measurements in wide elevation range

$$\begin{bmatrix} \frac{-\lambda f_1}{2|v_{st,\mathbf{1}} - v_{T,\mathbf{1}}|} \\ \vdots \\ \frac{-\lambda f_n}{2|v_{st,\mathbf{n}} - v_{T,\mathbf{n}}|} \end{bmatrix} = \begin{bmatrix} -sin\theta_1 & cos\theta_1 \\ \vdots & \\ -sin\theta_n & cos\theta_n \end{bmatrix} \begin{bmatrix} Y \\ P \end{bmatrix} \Leftrightarrow y = Hx$$

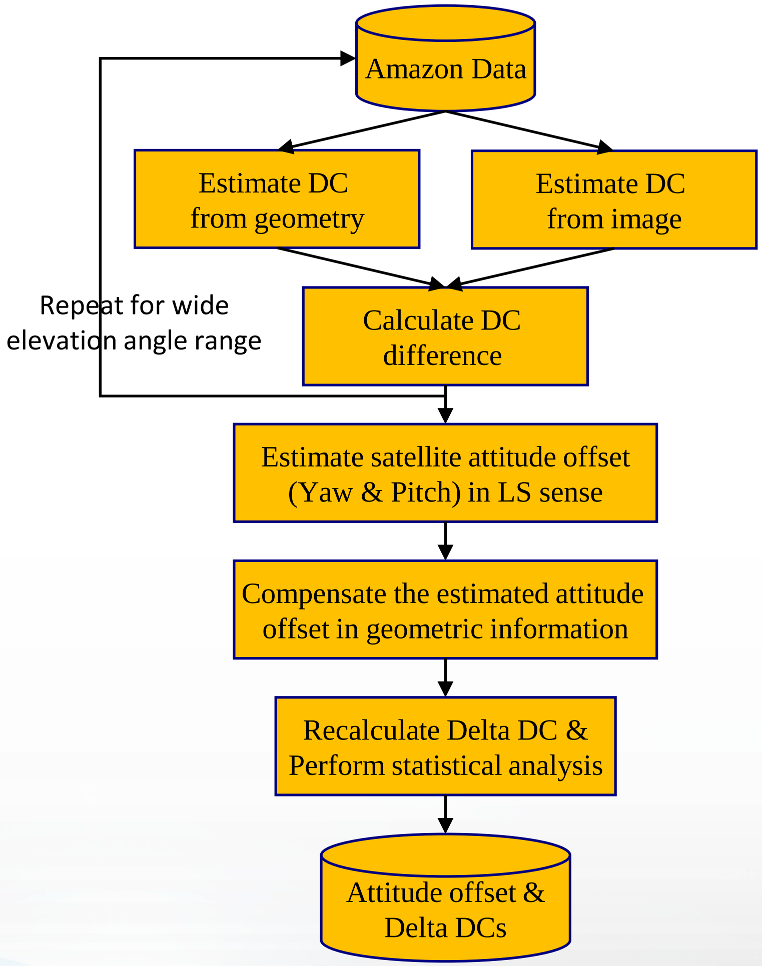
## Least Square Estimation

$$\hat{x} = \begin{bmatrix} \hat{Y} \\ \hat{P} \end{bmatrix} = (H^T H)^{-1} H^T y$$

# K6 Satellite Attitude Estimation Methods (3)

## Processing Procedure

- Step 1: Calculate DC from geometry by extracting geometric information from Amazon SAR images.
- Step 2: Calculate DC from image using the phase information of the same Amazon images.
- Step 3: Calculate the DC difference (delta DC) between DC from geometry and DC from image.
- Step 4: Repeat step 1 through step 3 over wide beam elevation angle range.
- Step 5: Estimate the satellite yaw and pitch offsets using the delta DC measurements in the Least Square optimization sense.
- Step 6: Calculate DC from geometry using the updated satellite attitude after compensating the estimated offset, and calculate the delta DC and its statistics.




Processing steps for K6 attitude estimation

# Verification

# Test Approach

## Simulated Data Test

- K6 satellite attitude offset estimation algorithm is tested with Kompsat-6 ICAS (Image Chain Analysis Software) Data
- Satellite attitude offset is intentionally applied to geometric (attitude) information
- Input satellite attitude offset is estimated using the difference between DC geometry and DC image
- Delta DCs are calculated after compensating attitude offset and statistical analysis is performed

## Kompsat-5 Data Test

- K6 satellite attitude estimation algorithm is tested K5 data over Amazon rainforest
- Satellite attitude offset is estimated using the difference from DC geometry and DC image
- The estimated attitude offset is compensated in the geometric information, and delta DCs are calculated and compared to the results from K5 LEOP calibration activity
- Amazon rainforest has homogeneous radar backscattering and is perfect place for estimating satellite attitude offset from DC information

# Test Results (1)

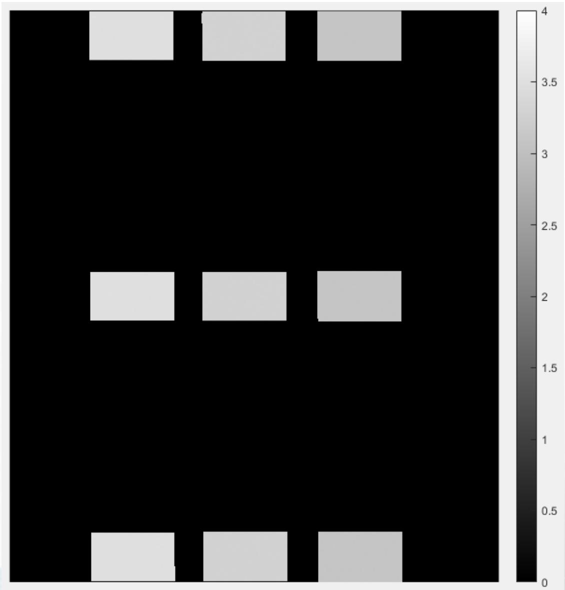
## Simulated Data Test

- K6 satellite attitude estimation algorithm is tested with Kompsat-6 ICAS Data
  - ✓ Attitude offset ($\Delta Y = 0.007°, \Delta P = -0.014°$) is intentionally applied to geometric information

| Image Name | DC Geometry (Hz) Offset ($\Delta Y$=0.007, $\Delta P$=-0.014) | DC Image (Hz) | ΔDC (Hz) without offset correction | ΔDC (Hz) with offset correction |
|---|---|---|---|---|
| ST-01 | -1603.1 | -1506.85 | 96.25 | -3.85 |
| ST-10 | -1338.9 | -1216.55 | 122.35 | -4.55 |
| ST-19 | -1102.3 | -971.14 | 131.16 | -4.53 |
| RMSE | | | **117.5 Hz** | **4.5 Hz** |

- Input attitude offset is re-estimated almost perfectly
- $\Delta DC$ after offset correction is reduced from $117.5$ to $4.5\ Hz$ $(RMSE)$

➡ K6 satellite attitude estimation algorithm works very precisely with K6 simulated data



K6 ICAS simulated raw image (ST-10)

# Test Results (2)

## K5 Data Test

- K6 satellite attitude estimation algorithm is tested with Kompsat-5 Amazon Data
  - ✓ Attitude offset ($\Delta Y = 0°, \Delta P = -0.012°$) from K5 LEOP calibration is compensated
  - ✓ New attitude offset ($\Delta Y = 0.007°, \Delta P = -0.014°$) is estimated and compensated

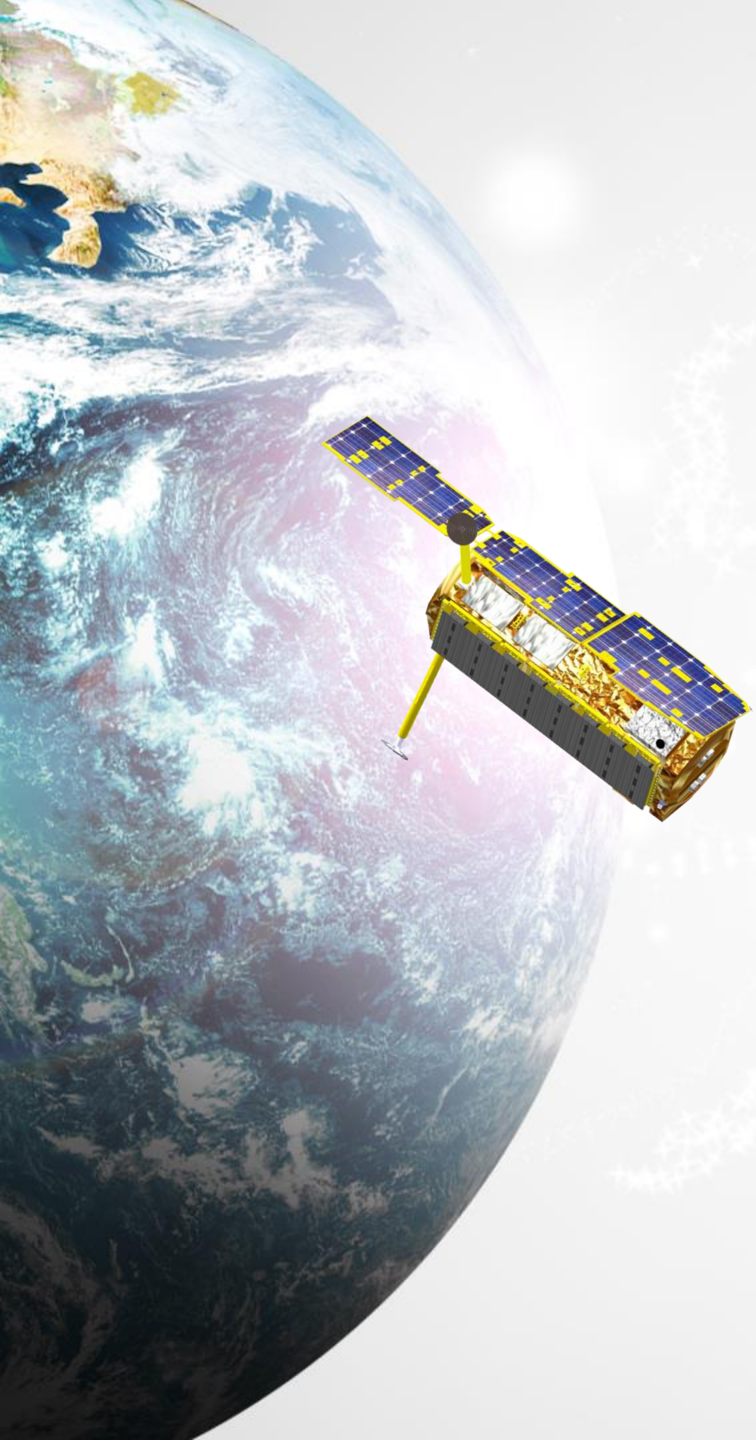
| Image Name | DC Image (Hz) | LEOP DC Geometry (Hz) after ($\Delta Y$=0, $\Delta P$=-0.012) | New DC Geometry (Hz) after ($\Delta Y$=0.017, $\Delta P$=-0.014) | LEOP ΔDC (Hz) | New ΔDC (Hz) |
|---|---|---|---|---|---|
| ES_01_HH | -395.4 | -394.7 | -396 | -0.7 | 0.6 |
| ES_01_VV | -710.6 | -709.5 | -710.8 | -1.1 | 0.2 |
| ES_09_HH | 188.4 | 174.1 | 154.3 | 14.3 | 34.1 |
| ST_03_HH | 221.1 | 202.8 | 196.5 | 18.3 | 24.6 |
| ES_05_HH | 405.6 | 422.1 | 411.4 | -16.5 | -5.8 |
| ST_16_HH | -9.9 | 32.4 | 3.1 | -42.3 | -13 |
| ES_19_HH | -23.7 | 0.3 | -31.8 | -24 | 8.1 |
| ST_08_HH | -491.5 | -480.2 | -497.5 | -11.3 | 6 |
| ES_16_HH | 29.8 | 39 | 9.7 | -9.2 | 20.1 |
| RMSE | | | | **19.4 Hz** | **16.6 Hz** |

- $\Delta DC$ with offset from LEOP: $19.4\ Hz\ (RMSE)$, $\Delta DC$ with new offset: $16.6\ Hz\ (RMSE)$
- $\Delta DC$ accuracy with newly estimated offset is increased by 15 %

➡ K6 satellite attitude estimation algorithm works very precisely with K5 data

# Conclusions

- Satellite attitude offset estimation algorithm and procedure are developed for K6 SAR processing and calibration
- The validity of suggested algorithm is tested using K6 simulated data and K5 data
- The intentionally applied satellite offset to simulated data was able to be precisely estimated, and $\Delta DC$ after offset correction is reduced from $117.5$ to $4.5\ Hz$ (RMSE)
- The satellite attitude offset was estimated from Kompsat-5 Amazon data, and it was compared to the value from K5 LEOP calibration activity
  - ✓ Attitude offset from K5 LEOP calibration: $\Delta Y = 0°, \Delta P = -0.012°$
  - ✓ Newly estimated attitude offset: $\Delta Y = 0.007°, \Delta P = -0.014°$
- $\Delta DCs$ after offset correction are compared
  - ✓ $\Delta DC$ with offset from LEOP: $19.4\ Hz\ (RMSE)$, $\Delta DC$ with new offset: $16.6\ Hz\ (RMSE)$
  - ✓ $\Delta DC$ accuracy with newly estimated offset is increased by $15\ \%$
- K6 satellite attitude offset estimation algorithm and procedure were performed very accurately with K6 simulated data and K5 data



# THANKS FOR YOUR ATTENTIONS

KOMPSAT-6