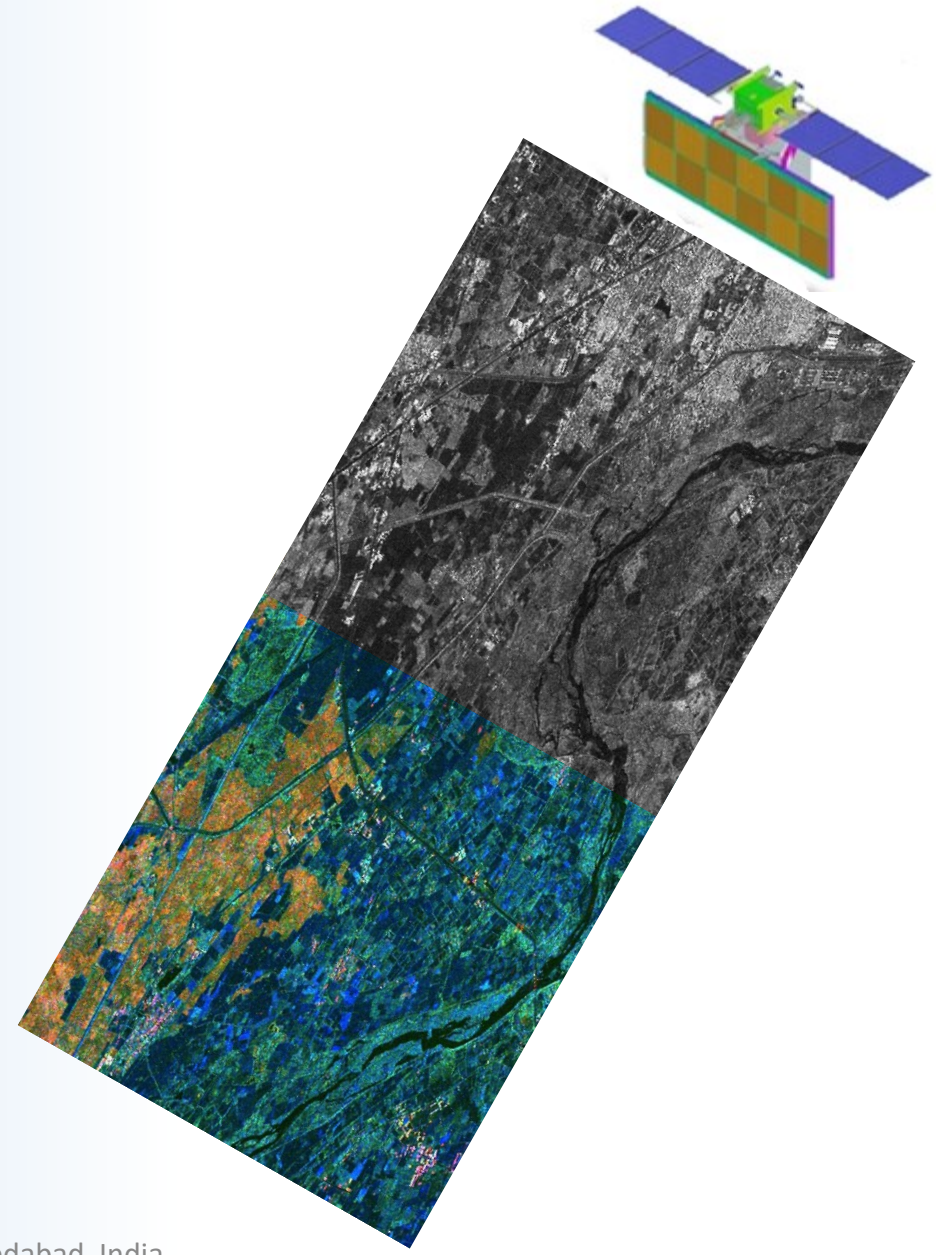
Analysis of KARI Corner Reflector in Mongolia Site for KOMPSAT 6 Calibration and Image Quality Measure



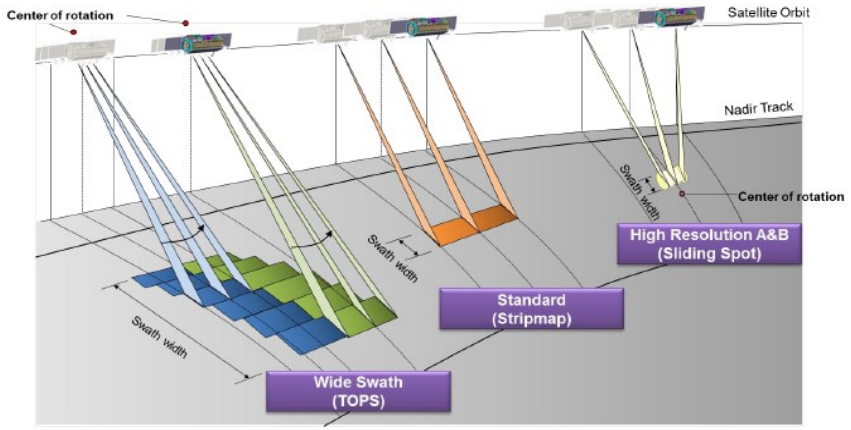
Korea Aerospace Research Institute

Horyung Jeong, Dochul Yang, Woosung Park, and Doochun Seo

Overview of KOMPSAT-6

- **KOMPSAT(KOrea Multi-Purpose SATellite)**
- **Mission Objectives**
  - "Expedite provision of the space-borne SAR standard images with sub-meter resolution [illegible] for the national demand in GIS (Geographical Information Systems), Ocean & Land management, Disa[illegible] nd ENvironment monitoring"
- **Launch Date / Life Time**
  - First quarter of 2025 / 5 years
- **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)

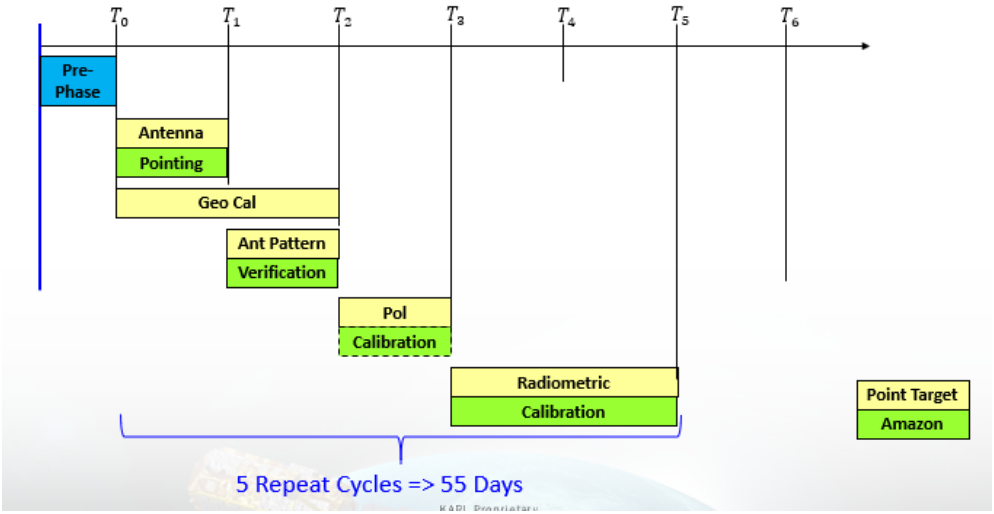
Kompsat-6 Configuration



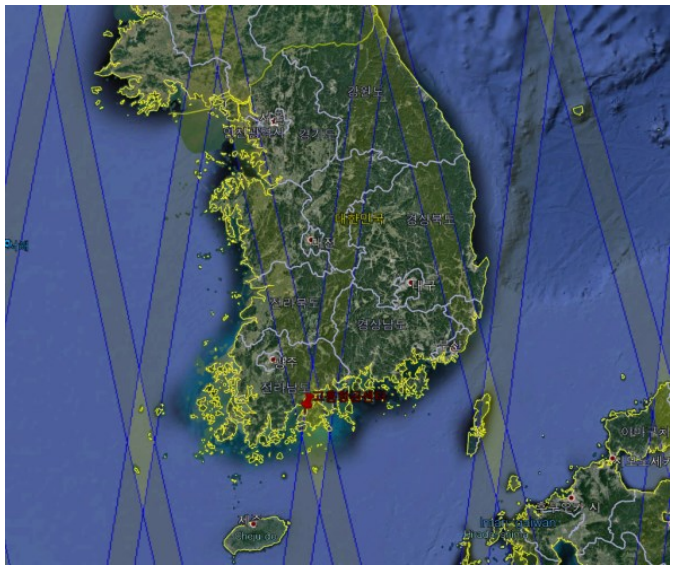
K6 SAR Imaging Modes

K6 Calibration Period and Equipment

- **Calibration Period (55 days) with 25 days of Imaging (6 AM / 6 PM)**
  - K6 calibration period: Total of 55 days (5 repetition cycles)
  - K6 repetition cycle: 11 days
  - Imaging days: 5 days of imaging per repetition cycle
- **Calibration Equipment:**
  - Installation and operation: 3 trihedral corner reflectors, 3 dihedral corner reflectors are selected for installation and operation.
  - Spare equipment are 3 trihedral corner reflectors, 4 dihedral corner reflectors (support stands)



Plan of K6 Calibration period (55 days)

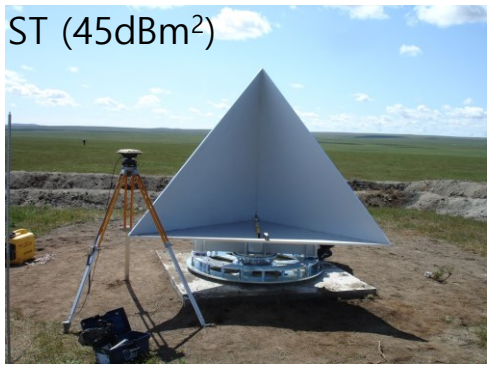


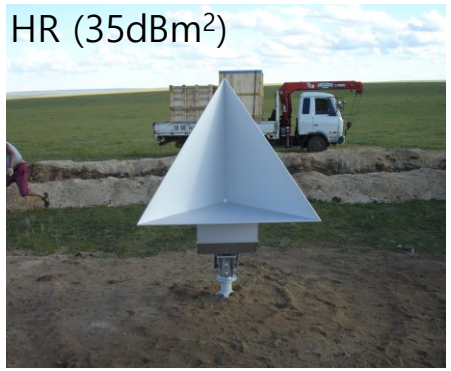
Inc. Angle	Beam No.	Trans.Pol. (Dual)	Access Time
Low	ST 1	H	Day 6 Dusk(asc)
Low	WS 1-2	V	Day 4 Dawn(des)
Mid	ST 9	V	Day 10 Dawn(des)
Mid	WS 3-1	H	Day 11 Dusk(asc)
High	HRA 86	H	Day 5 Dawn(des)
High	HRB 43	V	Day 5 Dusk(asc)

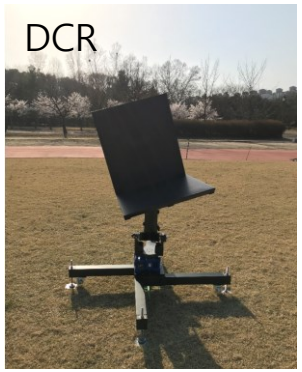
K6 Goheung visit and imaging available days

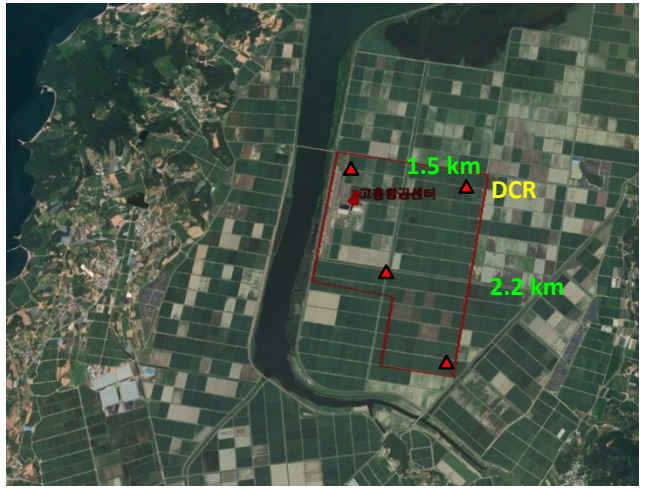
External Calibration Site for K6

- **Goheung Calibration Site**
  - Utilize campus of Goheung Aviation Center (GAC) with area of $2.2\ km \times 1.5\ km$
  - Dihedral CRs will be installed
  - Dihedral CRs maintenance will be provided by developing contractor
  - Dihedral CRs installation and operation will be performed with a separate contract
    - Site survey, installation, operation
- **Mongol Calibration Site**
  - Total 52 trihedral corner reflectors has been installed
    - CRs for ST mode(20), CRs for HR mode(32)
  - Maintenance is provided by Information and Research Institute of Meteorology, Hydrology and Environment (IRIMHE) under yearly maintenance contract

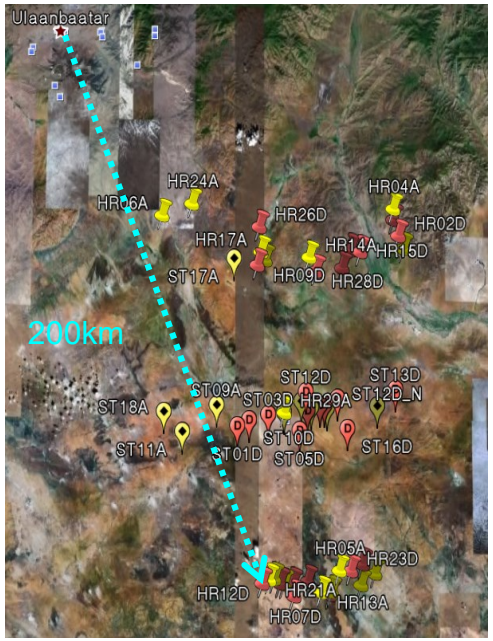








Goheung Aviation Center Google Map



Location of CR at Mongol Site

Procedure to install CR in the Calibration Site

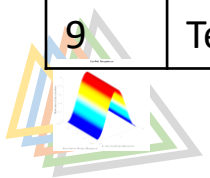
- **Procedure to install CR in the Calibration Site**

1	Installation of CR Tripod on Concrete base
	Installation of pedestal & Reflector
2	Installation of GPS Measurement Device
	Measurement of True-North & East/West Direction using GPS Measurement Result
3 [MTG]	CR True-North Alignment
	Azimuth & Elevation Alignment

Measurement Results for Mongolia K5 Corner Reflector

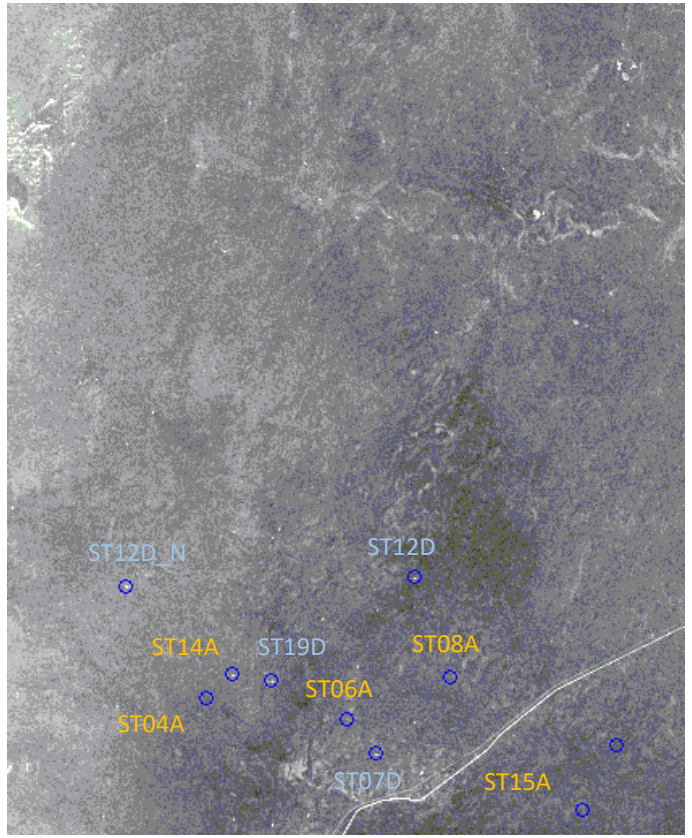
- **Analysis Result about Corner Reflector**

			Requirement	Measurement / Analysis Result	Reference Document
1	Frequency		9660MHz(±1200MHz)	9660MHz(±1200MHz)	RCS Measurement Report
2	RCS	ST CR	+45 dBm² (±1dB)	45.94 dBm2	Evaluated from Simul. SW
		HR CR	+35 dBm² (±1dB)	35.96 dBm2	Evaluated from Simul. SW
3	RCS Stability		0.1 dB	0.1 dB	RCS Measurement Report
4	Pointing	Elevation	35°~ 70°	35 ~ 70°	CR Design Doc.
		Azimuth	360°	360°	CR Design Doc.
5	Residual Motion		≤ 0.5 mm	≤ 0.5 mm	Manufacturing Report
6	Size	ST CR	≤1.72x1.72m² (surface)	≤1.72x1.72m² (surface)	CR Design Doc.
		HR CR	≤ 1 x 1 m² (surface)	≤ 1 x 1 m² (surface)	CR Design Doc.
7	Wind Stability		200km/h	200km/h	Wind Stability Test Report
8	Load Test	ST CR	≤3mm (≥1000kg)	< 2mm (≥1000kg)	Load Test Report
		HR CR	≤10mm (≥330kg)	< 4mm (≥330kg)	Load Test Report
9	Temperature Range		-40°/+50°	-40°/+50°	Manufacturing Report



Why K5 Images Useful to Verify K6 CAL Targets

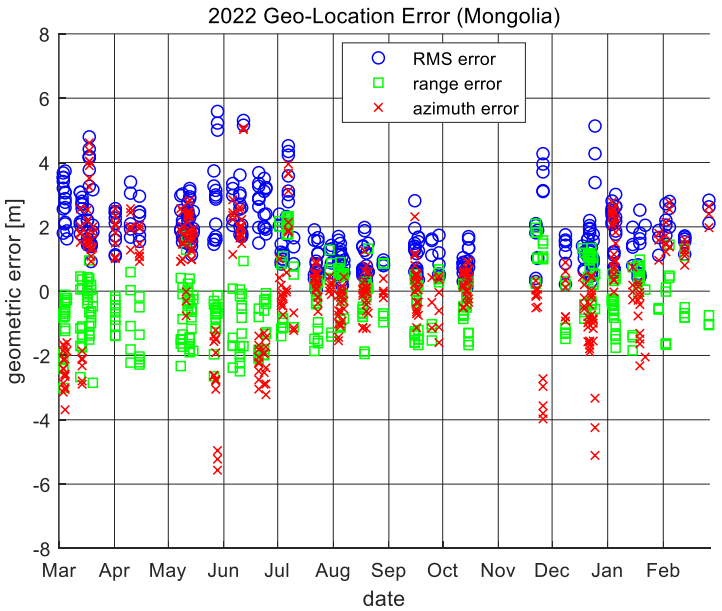
- **The process of Validating Satellite Calibration Equipment Using Satellite Imagery is Crucial.**
  - Satellite images capture actual data of the Earth's surface and reflect geographic features under various environmental conditions.
  - By utilizing these images, we can evaluate the performance of calibration equipment in a more practical manner.
- **K5 imagery Allows Us to Verify the Accuracy and Reliability of the Equipment.**
  - By comparing satellite images with data collected from the calibration equipment, we can identify the margin of error.
  - This process provides essential information needed for the calibration and improvement of the equipment.
- **The Validation Process Using K5 imagery Provides Foundational Data for the Continuous Improvement of Calibration Equipment.**
  - Adjustments and optimizations can be made to the design or operation of the equipment, enabling more accurate and efficient outcomes in future tasks.
  - This comprehensive process plays a vital role in enhancing the performance of satellite systems and contributes to scientific research and practical applications.



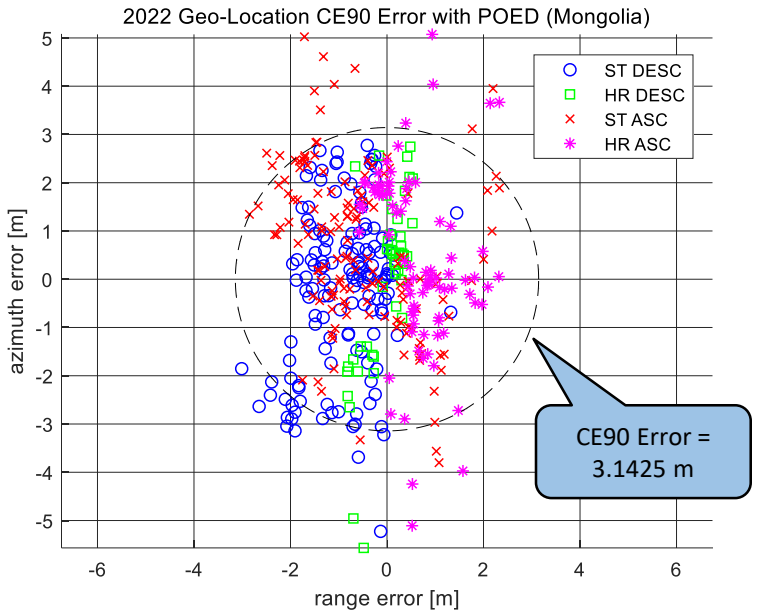
Example of K5 Mongolia Calibration Site Image

KOMPSAT 5 IQ Measurements – 2022 Year (1/3)

- **2022 Location Accuracy Measurement Results**
  - Using Mongolia region CR images taken from March 2022 to February 2023.
    - Measurement results affected by orbit adjustments, weather, etc., were excluded from the analysis.
  - It was confirmed that the K5 location accuracy remained stable without an increasing trend over time.
  - The CE90 error is 3.1425m, which sufficiently complies with the K5 requirements.
    - .



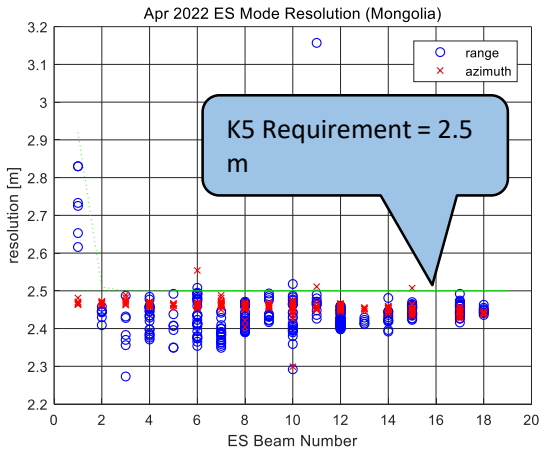
2022 yearly variation of K5 location accuracy errors by time period



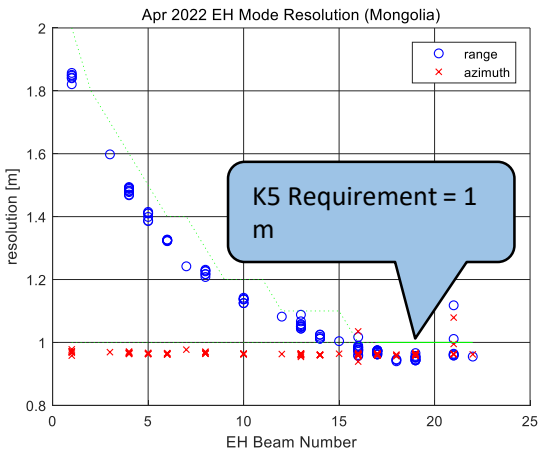
CR location accuracy error distribution and K5 CE90 error

KOMPSAT 5 IQ Measurements – 2022 Year (2/3)

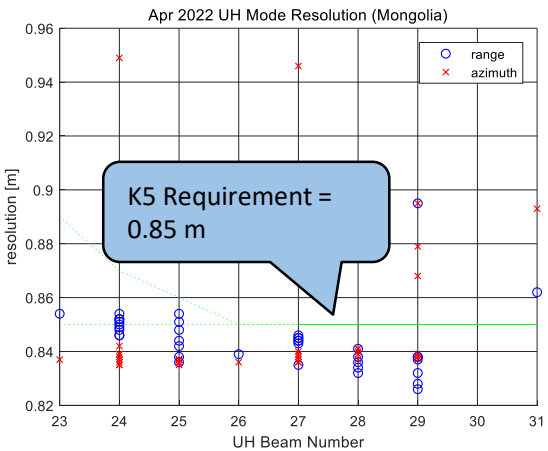
- **2022 Resolution Measurement Results**
  - Using Mongolia region CR images taken from March 2022 to February 2023.
  - Almost all measurement results, except for a few, meet the K5 requirements.
    - For ES-05 to ES-19, within 2.5m.
    - For EH-17 to EH-31, within 1m.
    - For UH-27 to UH-31, within 0.85m.
  - Cases that did not comply with the requirements are expected to be caused by environmental factors of the Mongolia CR (snow, rain, or cleaning conditions).
  - The Near Side beam, which is not defined in the requirements, also satisfies the design specifications.
    - The dotted line in the figure represents beams defined outside the requirements.



K5 ES mode resolution



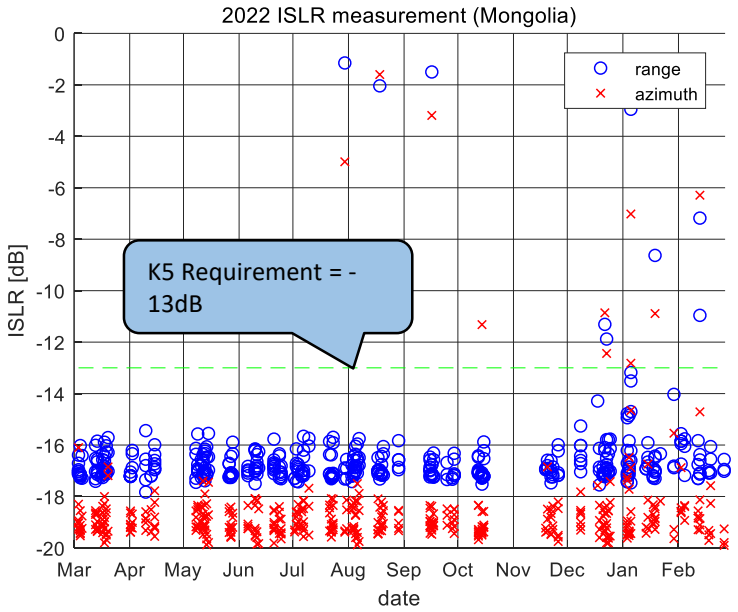
K5 EH mode resolution



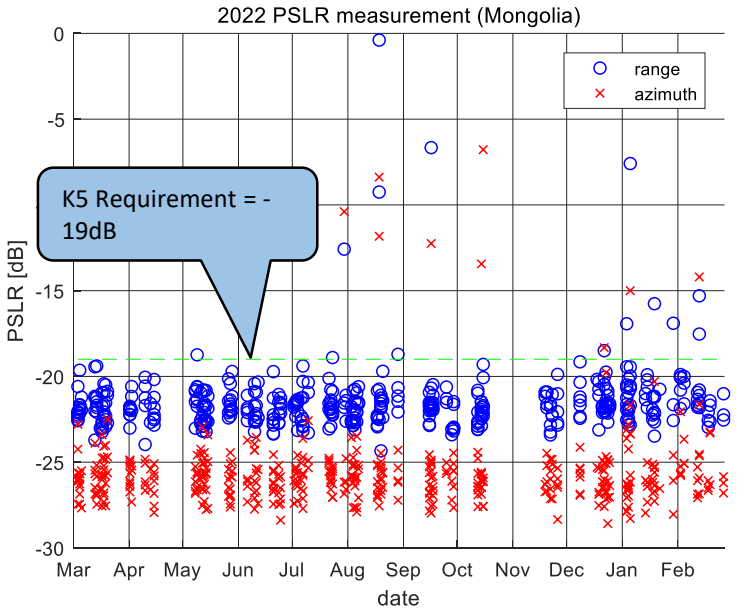
K5 UH mode resolution

KOMPSAT 5 IQ Measurements – 2022 Year (3/3)

- **2022 ISLR and PSLR Measurement Results**
  - Using Mongolia region CR images taken from March 2022 to February 2023.
  - The majority of cases, except for a few, meet the K5 requirements.
    - K5 requirements = ISLR below -13dB, PSLR below -19dB.
  - Cases that did not comply with the requirements are expected to be caused by environmental factors of the Mongolia CR (snow, rain, or cleaning conditions).



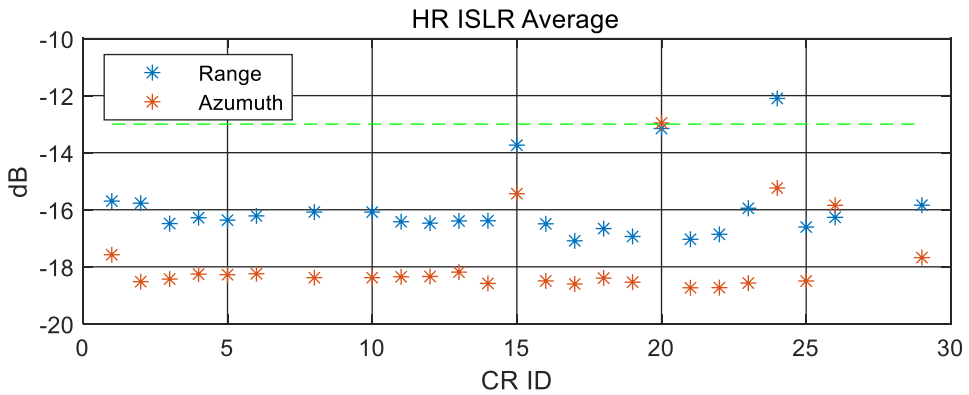
2022 yearly variation of K5 ISLR by time period

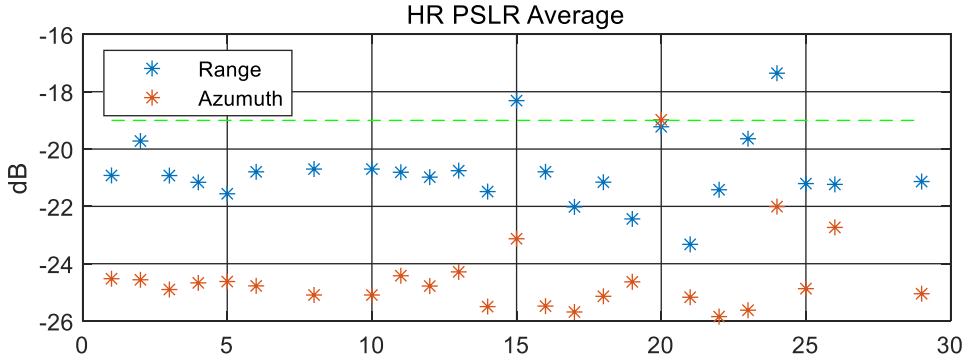


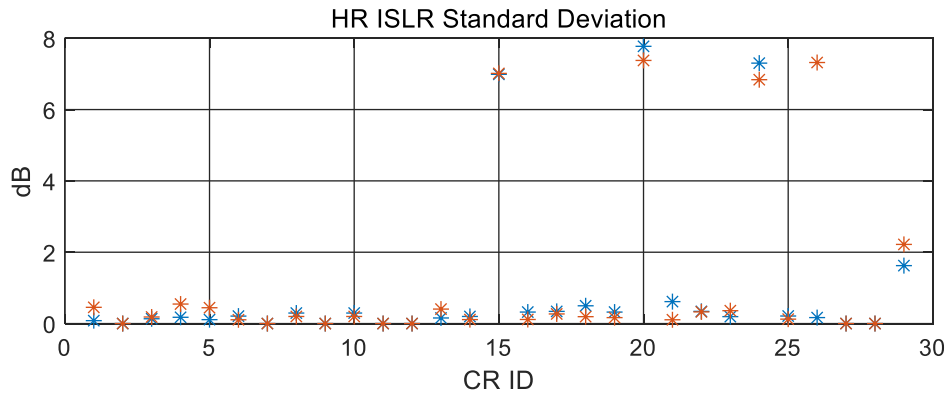
2022 yearly variation of K5 ISLR by time period

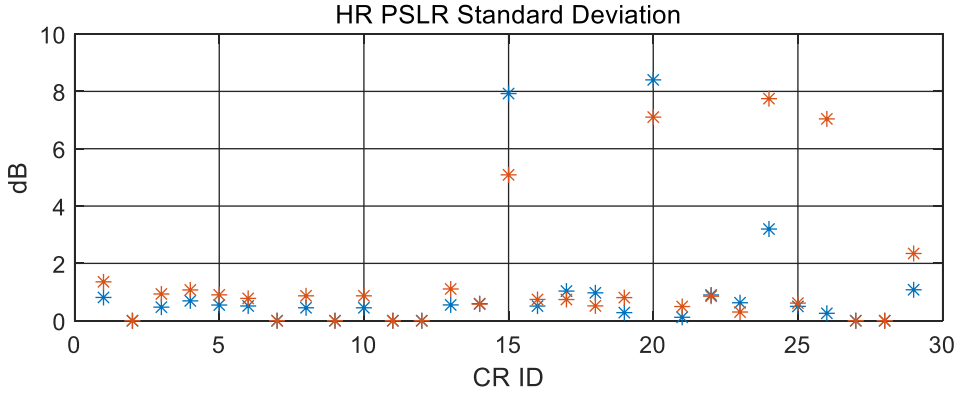
ISLR and PSLR Measurements Summary (1/2)

- **ISLR and PSLR Measurements Summary (for HR mode)**
  - The ISLR of the HR CR is approximately -16 dB for range and about -18 dB for azimuth
  - The PSLR is approximately -21 dB for range and about -25 dB for azimuth.
  - The standard deviations of the ISLR and PSLR for HR CRs generally show quite stable values
    - Unstable standard deviation are expected to indicate that the CR is not functioning properly due to external factors.



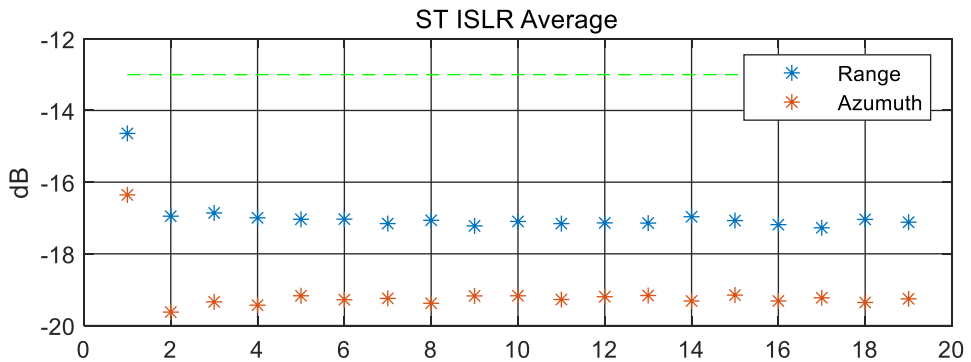


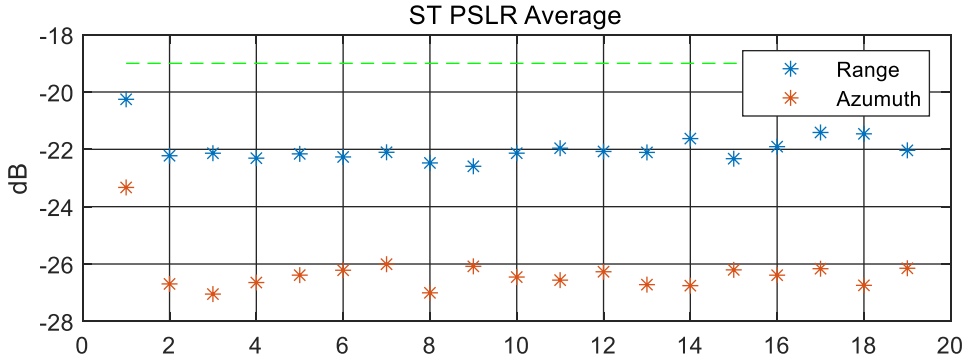


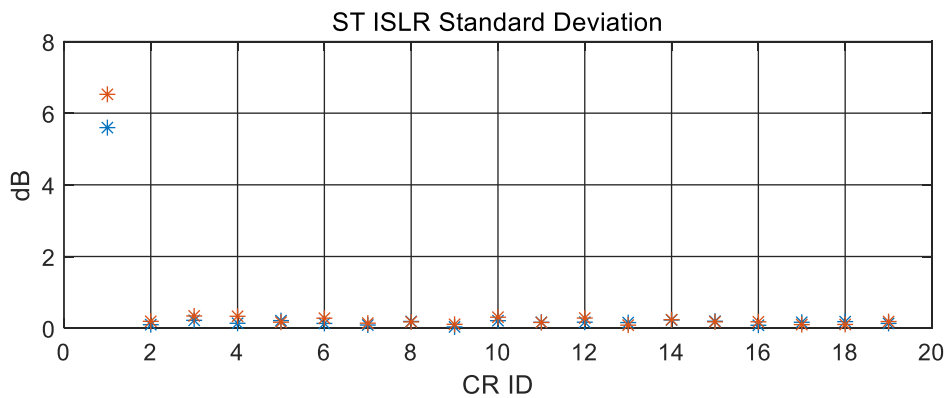


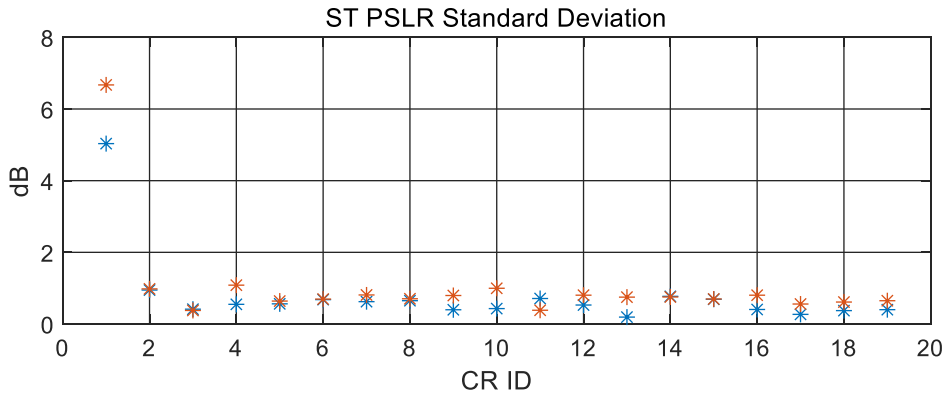
ISLR and PSLR Measurements Summary (2/2)

- **ISLR and PSLR Measurements Summary (for ST mode)**
  - The ISLR of the HR CR is approximately -17 dB for range and about -19 dB for azimuth
  - The PSLR is approximately -22 dB for range and about -29 dB for azimuth.
  - The standard deviations of the ISLR and PSLR for HR CRs generally show quite stable values, too
  - The reason the ISLR/PSLR of the ST CR is lower than that of the HR CR is likely due to the relatively larger size of the ST CR, which results in a higher RCS and consequently a more stable signal-to-clutter ratio



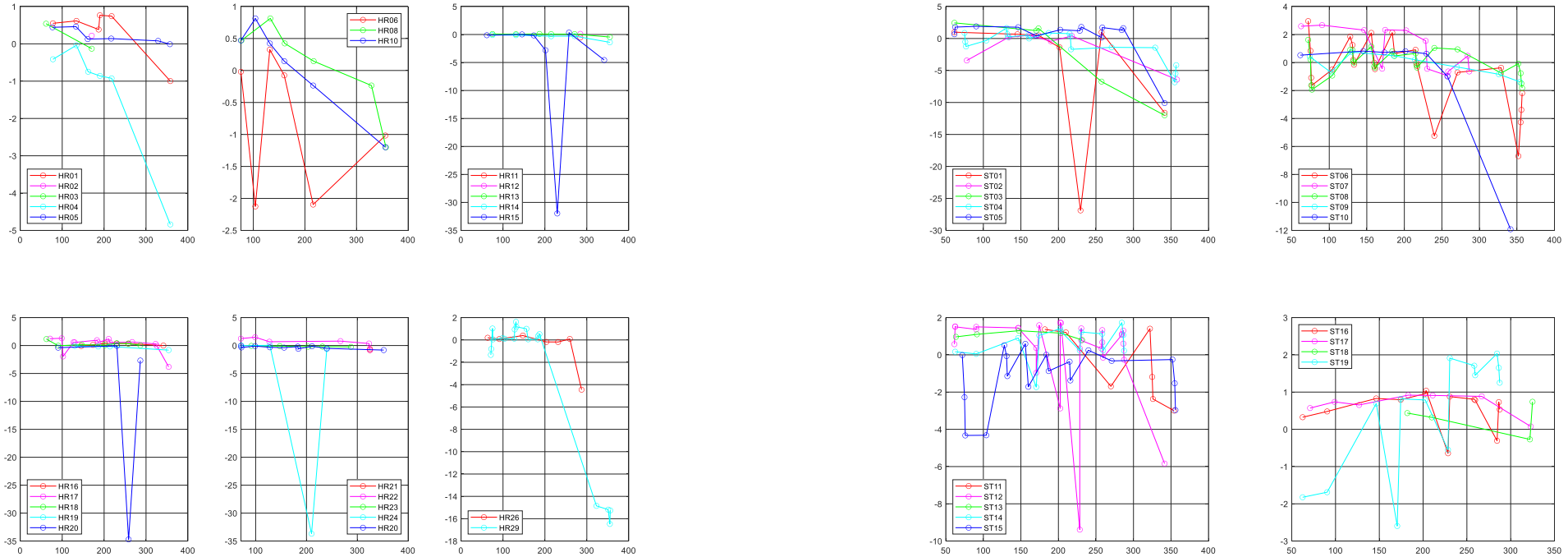






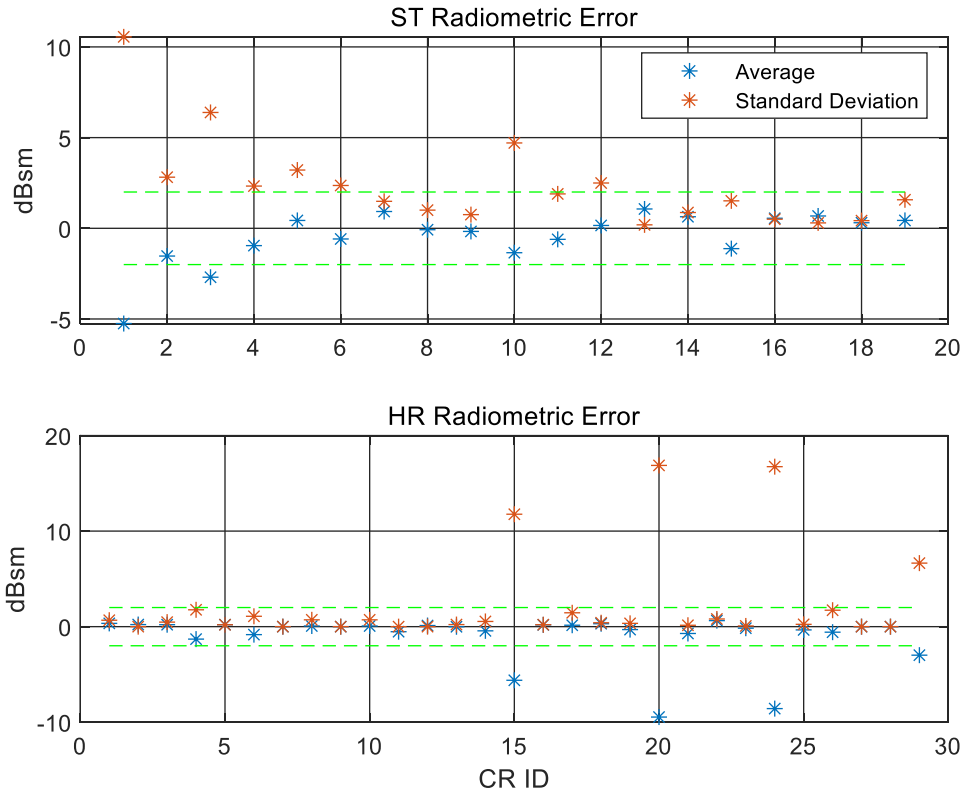
Radiometric Error Analysis for Each CR (1/2)

- **Radiometric Error vs. Time Graph for Each CR**
  - The six graphs summarize the Radiometric Error measurement results for 52 ST and 20 HR CRs, divided into groups of five.
    - The results of the CRs with significantly low radiometric error measurements were excluded from the graph
  - As shown in each graph, some CRs exhibit significant changes in Radiometric Error over time, while others maintain a stable Radiometric Error regardless of the time.
  - By examining these graphs, we will categorize the CRs that demonstrate stable Radiometric Error and plan to use them for K6 calibration.



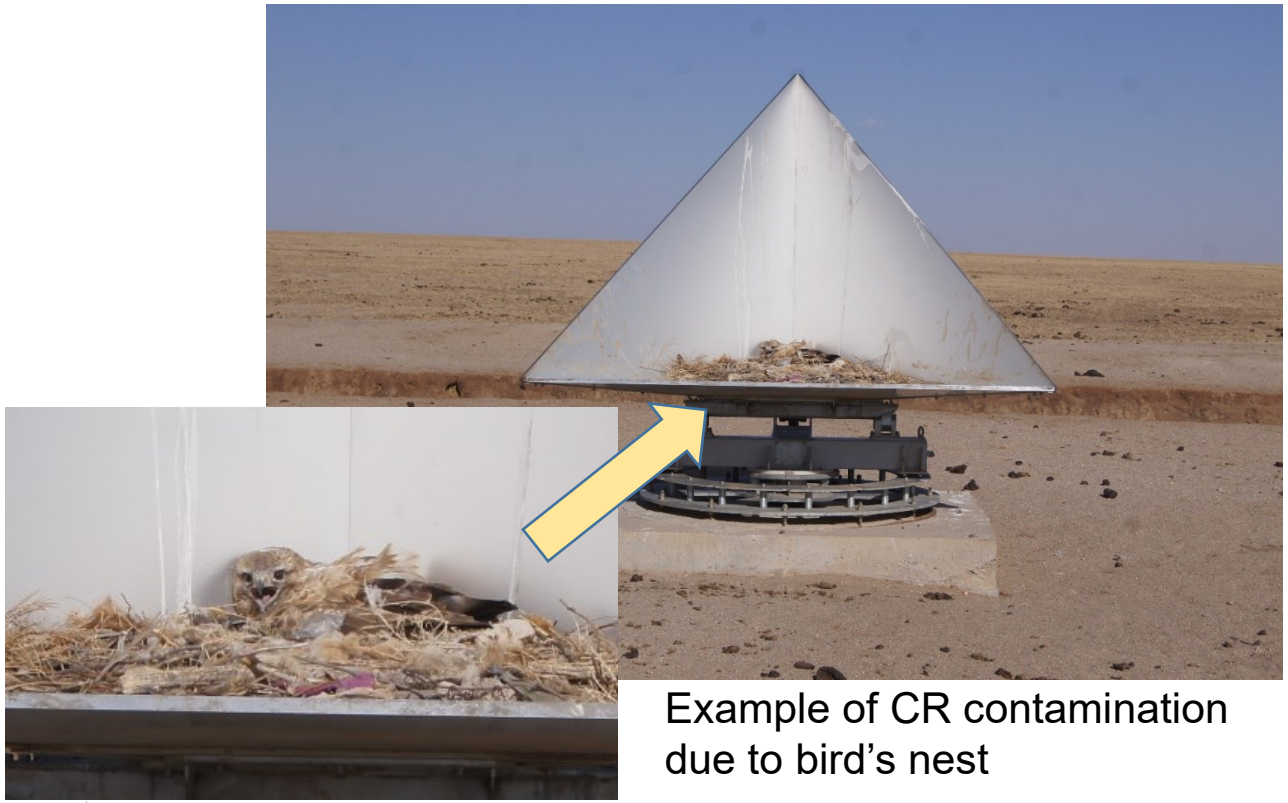
Radiometric Error Analysis for Each CR (2/2)

- **Summary of Radiometric Error Measurements from Mongolia Corner Reflectors**
  - Using Mongolia CR images taken from March 2022 to February 2023.
  - Almost all measurement results, except for a few, meet the K5 requirements.
  - Cases that did not meet the requirements are expected to be caused by environmental factors of the Mongolia CR (snow, rain, or cleaning conditions)

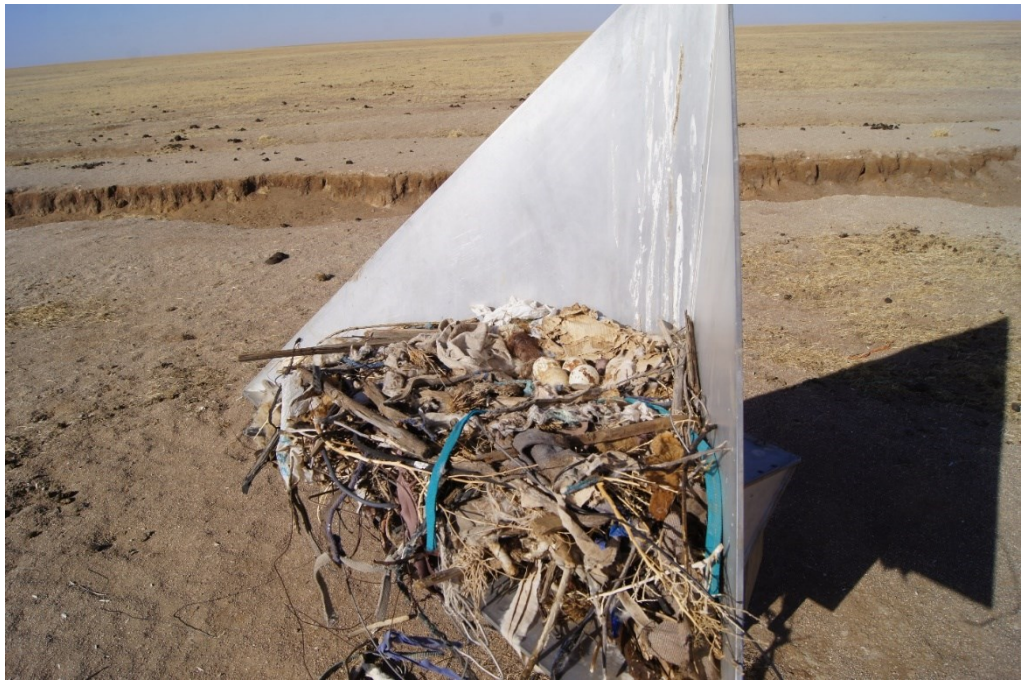


External Factors Resulting in Improper Response (1/2)

- **Examples of Maintenance for Mongolia Site SAR Calibration Targets (2019)**
  - The CR is unable to perform its proper target function due to a bird's nest.
  - The CR is unable to perform its proper target function due to a pile of garbage accumulated by locals.



Example of CR contamination due to bird's nest



Example of CR contamination due to a pile of garbage

External Factors Resulting in Improper Response (2/2)

- **Examples of Maintenance for Mongolia Site SAR Calibration Targets (2019)**
  - Due to aging, the surface coating has peeled off, revealing black stains.
  - Due to aging, the azimuth angle adjuster has rusted and is unable to function properly.

Aging of the surface condition

Aging of the angle adjuster

Analysis of the Mongolia CR Census Survey Report

- **Analysis of the 2019 Mongolia CR Maintenance**
  - Period: October 6, 2019 - October 13, 2019
  - Key Contents
    - Conducted a comprehensive field survey of Mongolia CRs to prepare for the calibration
    - Detailed investigation and condition check of problematic CRs
    - Test operation for direction setting of CR
    - Operational plan and discussions on CR usage between KARI and the IRIMHE
  - Mongolia CR checklist was reported in order to identify CRs complying with the requirements

Mongolia CR-Site(B4) CHECK LIST

2019.10.

설치 주변 환경점검 : 길, 계르, 동물, 웅덩이, 등의 변화된 상황 명시
현장사진 : ① 정면-근접 ② ID 확인 ③ 후면-근접 ④ 정면-와이드(구덩이포함) ⑤ 배수구멍 ⑥ 파손-근접(여러
사용분류 : ① K6 main(valid) ② K6 support(suspicious condition) ③ Need to be fixed/repaired ④ Not use

CR	Az.(deg.)	El.(deg.)	CR 구분	Serial	현장사진	S/N 확인	AZ Setting 각도 확인	EL Setting 각도 확인	자산 스티커	방호구덩이 상태점검	외곽 방호 구덩이 상태	CR 설치 상태점검	CR 배수구멍	설치 주변 환경점검	검수확인 날짜/시간	사용분류	특이 사항
HR21A_F	261.04	44.96	MTG	M2-CR 01	1 O 2 O 3 O 4 O 5 O 6 O	OK	267 (266.76)	11.8 11.8 (11.9)	Good	양호	N/A	Very Good	양호	돌, 자갈	2019.10.0	상 (1)	언덕 중간에 위치 작은 염소 배 많음.
HR16D	99.61	49.55	MTG	M2-CR 01	1 O 2 O 3 O 4 O 5 O 6 O	OK	99.2 (99.4)	16.60 16.70 (16.71)	Good	양호	N/A	Very Good	양호	양호	2019.10.0	상 (1)	방호구덩이에 염소 잡아먹은 쓰레기 있음. 특이사항 없음.
HR25A	261.67	40.92	MTG	M2-CR 02	1 O 2 O 3 O 4 O 5 O 6 O	OK	263.5 (267.4)	7.50 7.60 (7.83)	Good	양호	N/A	Very Good	양호	양호	2019.10.0	상 (1)	뒷커버 나사 4개 유실(2개 찾아 연결)
HR03D	101.46	66.06	MTG	M2-CR 02	1 O 2 O 3 O 4 O 5 O 6 O	OK	100.7 (101.05)	33.10 33.15 (32.69)	Good	흔적만 있	N/A	Very Good	양호	양호	2019.10.0	상 (1)	모래로 된 지형, 이상한 풀이 자람. 방호구덩이 거의 유실
HR07D	100.87	60.27	MTG	M2-CR 03	1 O 2 O 3 O 4 O 5 O 6 O	OK	101 (100.55)	27.30 27.50 (27.12)	Good	양호	N/A	Very Good	양호	양호	2019.10.0	상 (1)	방호구덩이에 풀 많이 자람. 뒷커버 나사 1개 유실
HR31D	97.31	35.31	MTG	M2-CR 02	1 O 2 O 3 O 4 O 5 O 6 O	OK	97.8 (97.17)	2.35 2.25 (2.19)	Good	양호	N/A	Good	양호	돌발	2019.10.0	상 (1)	뒷커버 나사 유실(한쪽 모두 유실)

분류	HR CR	ST CR
K6 Main (Valid)	HR14A, HR28D, HR06A, HR24A, HR26D, HR17A, HR22A, HR09D, HR18D, HR01A, HR10A, HR12D, HR19A, HR23D, HR05A, HR27D, HR13A, HR21A_F, HR16D, HR25A, HR03D, HR07D, HR31D, HR08A, HR02D, HR30D, HR04A	ST13D, ST02A, ST16D, ST12D_N, ST04A, ST14D, ST19D, ST09A, ST18A, ST11A, ST10D, ST03D, ST17A, ST06A, ST07D, ST08A,ST15A,
K6 Support (Suspicious Condition)	HR15D, HR11D, HR21A	ST01D
Need to be fixed/repaired	HR20D, HR29A	ST05D
Not Used		ST12D
Reserved		

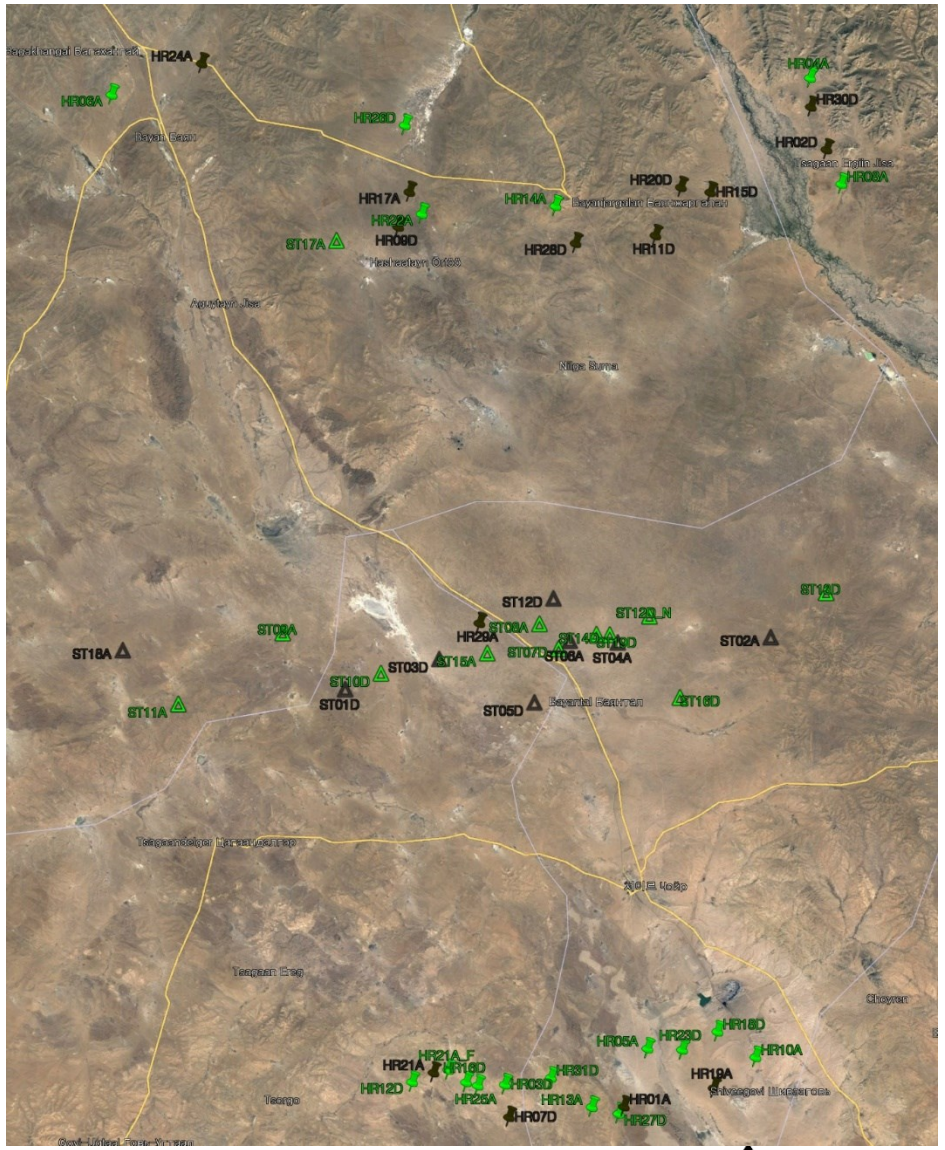
(1st) Selection of Mongolia CR for K6 Use (Considering Performance and Distribution)

- **K6 Main Mongolia CR Selection Task (2023.3.2)**
  - Based on 2019 Mongolia CR Census Survey Report
  - Use CR Performance Analysis via 2022 K5 Images
  - Consideration of the regional distribution of each CR

- **Candidates for Mongolia CR to be used in K6:**
  - HR: 18 units (Total 32 units)
  - ST: 12 units (Total 20 units)

- **K6 Main Mongolia CR List**

	HR CR	ST CR
K6 Main	HR03D, HR03A, HR05A, HR06A, HR08A, HR10A, HR12D, HR13A, HR14A, HR16D, HR18D, HR21A_F, HR22A, HR23D, HR25A, HR26D, HR27D, HR31D	ST07D, ST08A, ST09A, ST10D, ST11A, ST12D_N, ST13D, ST14D, ST15A, ST16D, ST17A, ST19D

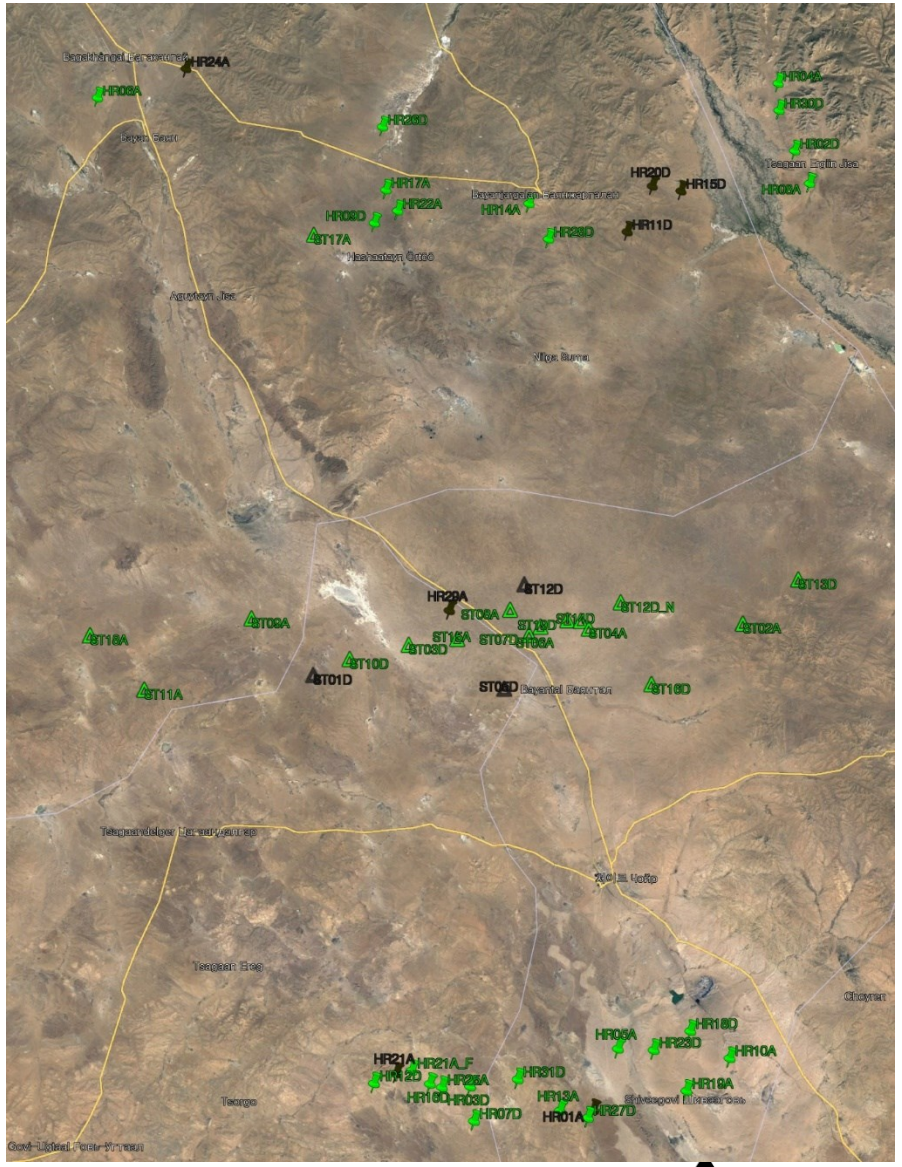


(2nd) Selection of Mongolia CR for K6 Use (Considering Performance)

- **K6 Main Mongolia CR Selection Task (2023.3.6)**
  - Based on 2019 Mongolia CR Census Survey Report
  - Use CR Performance Analysis via 2022 K5 Images
  - Objective to secure as many CRs as possible
  - Regional distribution of CRs was not considered

- **Candidates for Mongolia CR to be used in K6:**
  - HR: 25 units (Total 32 units)
  - ST: 17 units (Total 20 units)

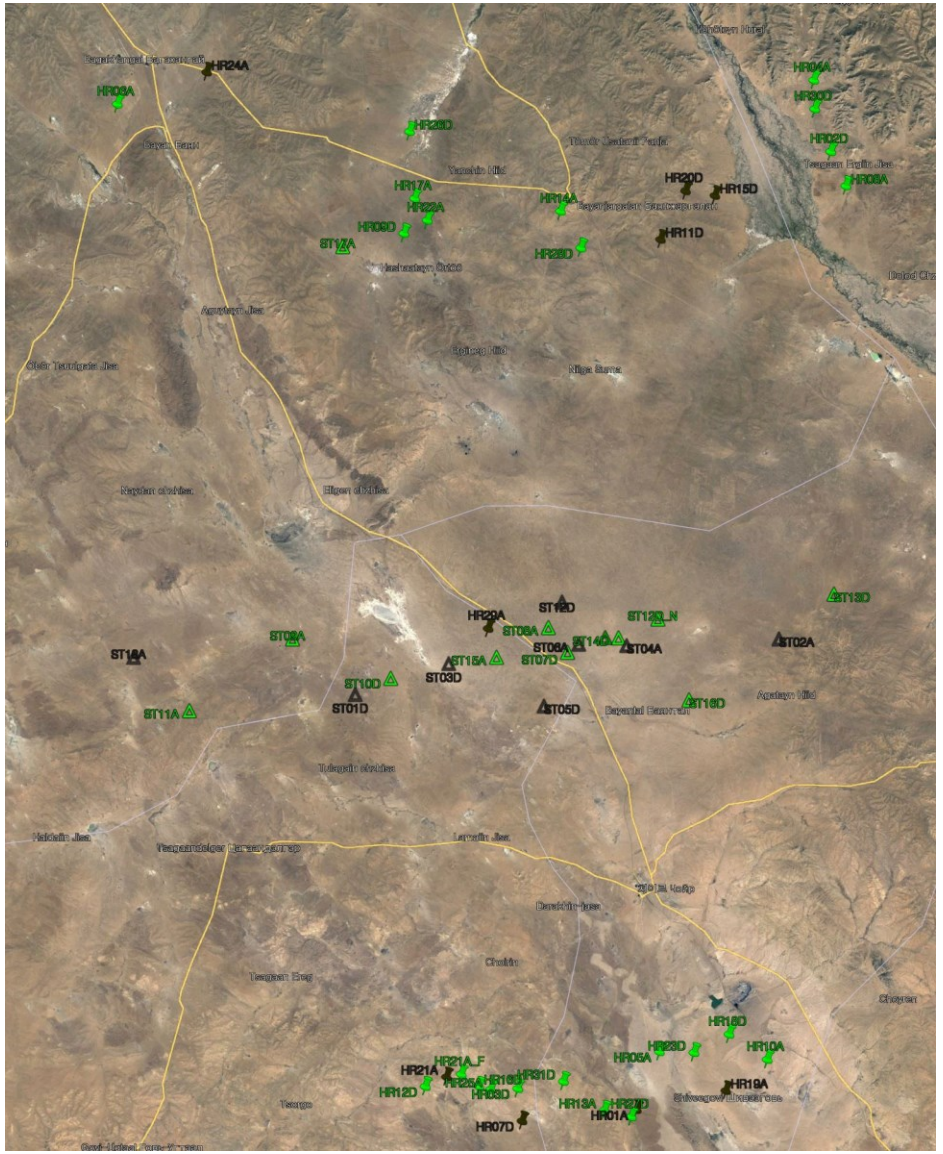
	HR CR	ST CR
K6 Main	HR02D, HR03D, HR04A, HR05A, HR06A, HR07D, HR08A, HR09D, HR10A, HR12D, HR13A, HR14A, HR16D, HR17A, HR18D, HR19A, HR21A_F, HR22A, HR23D, HR25A, HR26D, HR27D, HR28D, HR30D, HR31D	ST02A, ST03D, ST04A, ST06A, ST07D, ST08A, ST09A, ST10D, ST11A, ST12D_N, ST13D, ST14D, ST15A, ST16D, ST17A, ST18A, ST19D



(3nd) Selection of Mongolia CR for K6 Use (Considering HR and TOPS Mode)

- **K6 Main Mongolia CR Selection Task (2023.3.22_01)**
  - Based on 2019 Mongolia CR Census Survey Report and Maintenance Service Result Report
  - Use CR Performance Analysis via 2022 K5 Images
  - Consideration of the regional distribution of each CR
  - Additional CRs added due to insufficient TOPS mode CR access identified in Calibration Schedule analysis
  - Regional distribution for TOPS mode CRs was not considered
- **Candidates for Mongolia CR to be used in K6:**
  - HR: 23 units (Total 32 units: Top 11 units, Bottom 12 units)
  - ST: 12 units (Total 20 units)
- **K6 Main Mongolia CR List**

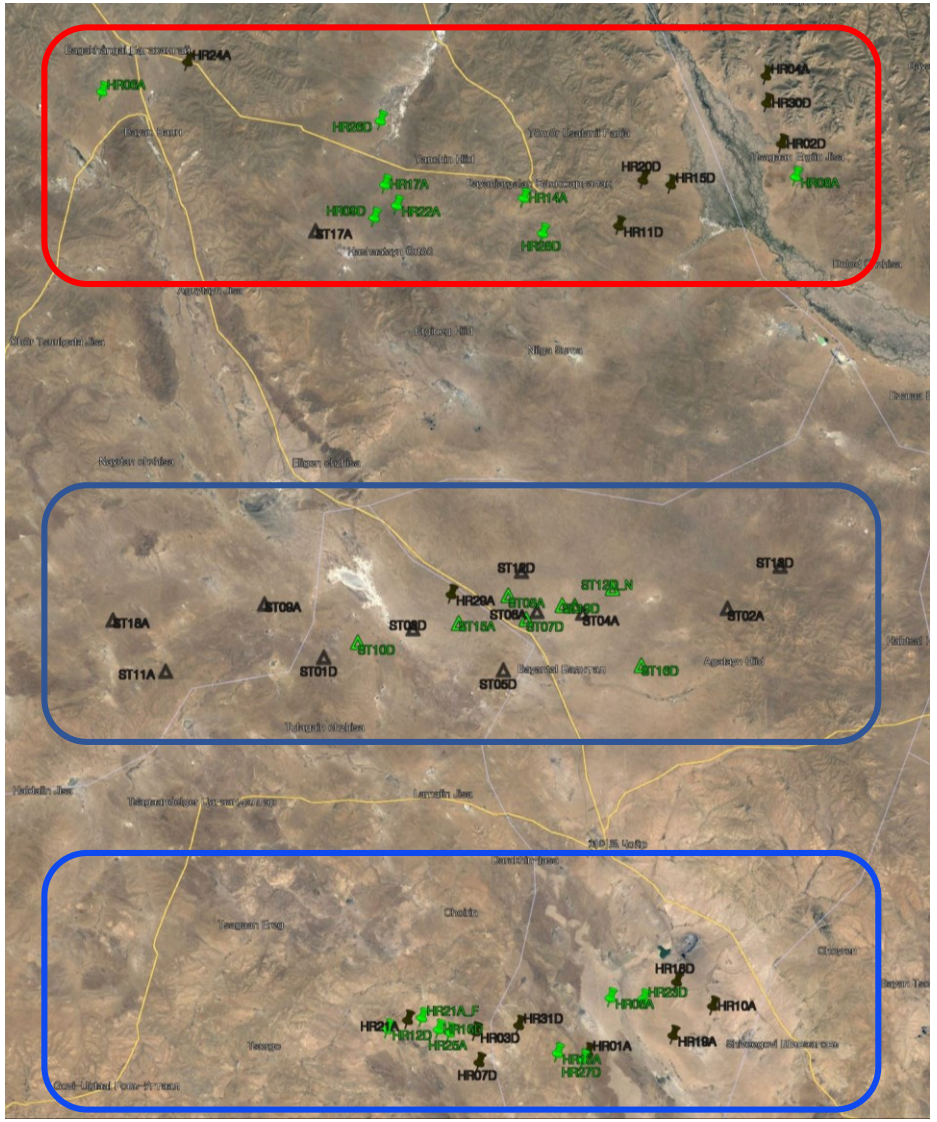
분류	HR CR	ST CR
K6 Main	HR02D, HR03D, HR03A, HR05A, HR06A, HR08A, HR09D, HR10A, HR12D, HR13A, HR14A, HR16D, HR17A, HR18D, HR21A_F, HR22A, HR23D, HR25A, HR26D, HR27D, HR28D, HR30D, HR31D	ST07D, ST08A, ST09A, ST10D, ST11A, ST12D_N, ST13D, ST14D, ST15A, ST16D, ST17A, ST19D



(Final) Mongolia CR Selection for K6 Calibration

- **K6 Main Mongolia CR Selection Task (2023.3.22_02)**
  - Based on 2019 Mongolia CR Census Survey Report and Maintenance Service Result Report
    - CR Performance Analysis via K5 Images
  - Consideration of the regional distribution of CR (Mid & Bottom)
  - Top CR was added to the list without considering regional distribution, and the final selection of CR was analyzed using the Cal Schedule.
  - Efficient access CR analysis by time and mode.
    - HR -> ST -> HR (One visit planned with three modes of shooting)
- **Final selection of Mongolia CR to be used in K6:**
  - HR: 16 units (Total 32 units: Top 8 units, Bottom 8 units)
  - ST: 8 units (Total 20 units)
- **K6 Main Mongolia CR List**

	HR CR	ST CR
K6 Main	HR06A, HR08A, HR09D, HR14A, HR17A, HR22A, HR26D, HR28D	ST07D, ST08A, ST10D, ST12D_N, ST14D, ST15A, ST16D, ST19D
	HR05A, HR12D, HR13A, HR16D, HR21A_F, HR23D, HR25A, HR27D	



Summary of Good-Performing CRs for K6 Calibration

- **Analysis of K5 Image Performance in 2022 in order to Select Good-Performing CRs**
  - Comprehensive evaluation of CR performance based on recordings conducted in 2022
  - Identification of consistently good-performing CRs through average and standard deviation analysis

CR ID	'19	R	I	P
HR01A	1	X	X	○
HR02D	1	△	○	○
HR03D	1	○	○	○
HR04A	1	○	○	○
HR05A	1	○	○	○
HR06A	1	○	○	○
HR07D	1	-	-	-
HR08A	1	○	○	○
HR09D	1	-	-	-
HR10A	1	○	○	○
HR11D	2	○	○	○
HR12D	1	○	○	○
HR13A	1	○	○	○
HR14A	1	○	○	○
HR15D	2	X	△	X
HR16D	1	○	○	○

CR ID	'19	R	I	P
HR17A	1	○	○	○
HR18D	1	○	○	○
HR19A	1	○	○	○
HR20D	3	X	△	△
HR21A	2	○	○	○
HR21A_F	1	○	○	○
HR22A	1	○	○	○
HR23D	1	○	○	○
HR24A	1	X	X	X
HR25A	1	○	○	○
HR26D	1	○	△	△
HR27D	1	-	-	-
HR28D	1	-	-	-
HR29A	3	X	△	△
HR30D	1	-	-	-
HR31D	1	-	-	-

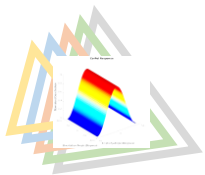
CR ID	'19	R	I	P
ST01D	2	X	△	△
ST02A	1	△	○	○
ST03D	1	X	○	○
ST04A	1	△	○	○
ST05D	3	△	○	○
ST06A	1	△	○	○
ST07D	1	○	○	○
ST08A	1	○	○	○
ST09A	1	○	○	○
ST10D	1	△	○	○

CR ID	'19	R	I	P
ST11A	1	○	○	○
ST12D	4	△	○	○
ST12D_N	1	○	○	○
ST13D	1	○	○	○
ST14D	1	○	○	○
ST15A	1	○	○	○
ST16D	1	○	○	○
ST17A	1	○	○	○
ST18A	1	○	○	○
ST19D	1	○	○	○

R : Radiometric Error, I : ISLR, P : PSLR

Summary & Conclusion

- **The K5 imagery was used to validate the calibration equipment of the K6 satellite, and the process was concluded to be successful.**
- **The comparison with K5 imagery confirmed the accuracy and reliability of the equipment, and necessary adjustments were identified.**
- **As a result, the performance of the K6 satellite is expected to improve further.**



THANKS FOR YOUR LOOK ATTENTIONS