



Korea Aerospace Research Institute
115 Gwahangro, Yuseong-gu Daejeon, 305-333, Korea

Calibration and Validation for KOMPSAT-3

June 4, 2014

DongHan Lee^{a,b}, DooChun Seo^a, HeeSeob Kim^a

EungSik Lee^a, HaeJin Choi^a

^a Korea Aerospace Research Institute (KARI)

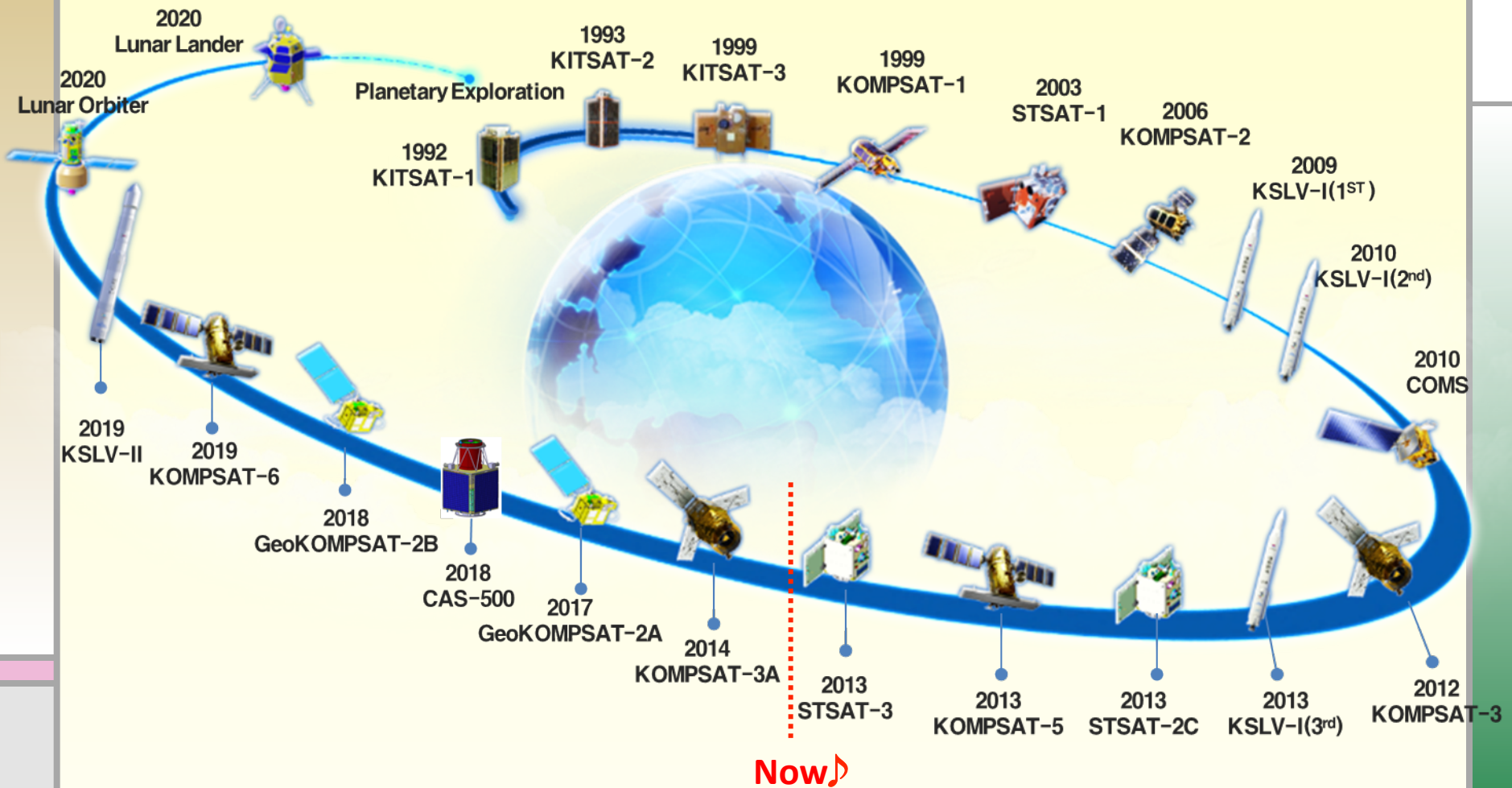
^b USGS EROS Visiting Scientist

Agenda

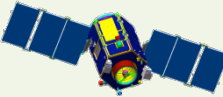
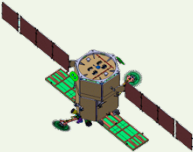
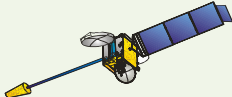
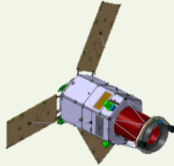
- KOMPSAT-3 Cal/Val Overview
 - ✓ KOMPSAT Program in KARI
 - ✓ KOMPSAT-3 Calibration and Validation
- KOMPSAT-3 Cal/Val in Cal/Val Phase after Launch
 - ✓ Radiometric Cal/Val
 - ✓ Spatial Cal/Val
 - ✓ Geometric Cal/Val
- KOMPSAT-2 vs. KOMPSAT-3

KOMPSAT Program in KARI

Space Program of Korea



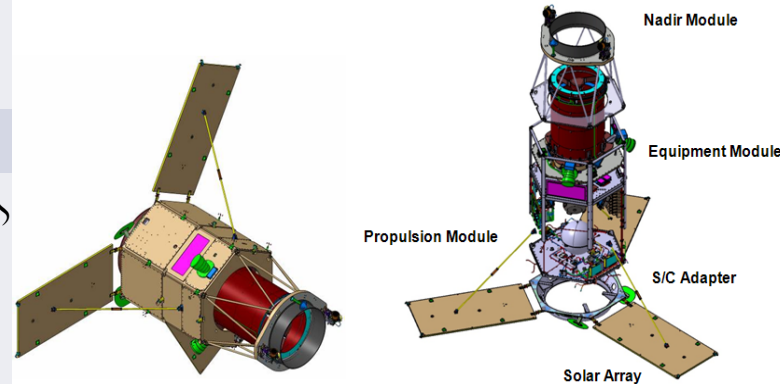
KOMPSAT Program in KARI

	KOMPSAT-1♪	KOMPSAT-2♪	KOMPSAT-3♪	KOMPSAT-5♪	COMS♪	KOMPSAT-3A♪
						
Payload♪	EOC, OSMI♪	MSC♪	AEISS♪	COSI♪	MI, GOCI♪	KISS♪
	Visual♪	Visual♪	Visual♪	SAR-X♪	Meteorology♪	Visual+MWIR♪
Launch♪	1999~2008♪	2006~♪	2012.5~♪	2013.7~♪	2010~♪	2014.00♪
Performance♪	6.6m (EOC) 1km (OSMI)♪	1m, 4m 10bit♪	0.7m, 2.4m 14bit♪	1m, 3m X-band♪	500m♪	0.55m, 2.2m 5.5m (MWIR)♪
Image mode♪	Strip♪	Strip♪	Spot, Strip, Wide♪	HR, Strip, Wide♪		Spot, Strip, Wide♪
Swath♪	15km♪	15km♪	15km♪	15km♪	2,500km♪	15km♪
Orbit♪	Sun-Sync♪	Sun-Sync♪	Sun-Sync♪	Sun-Sync♪	Geo-Station♪	Sun-Sync♪

KOMPSAT-6 (SAR) & COMS-2 will be developed by KARI after KOMPSAT-5 & COMS♪

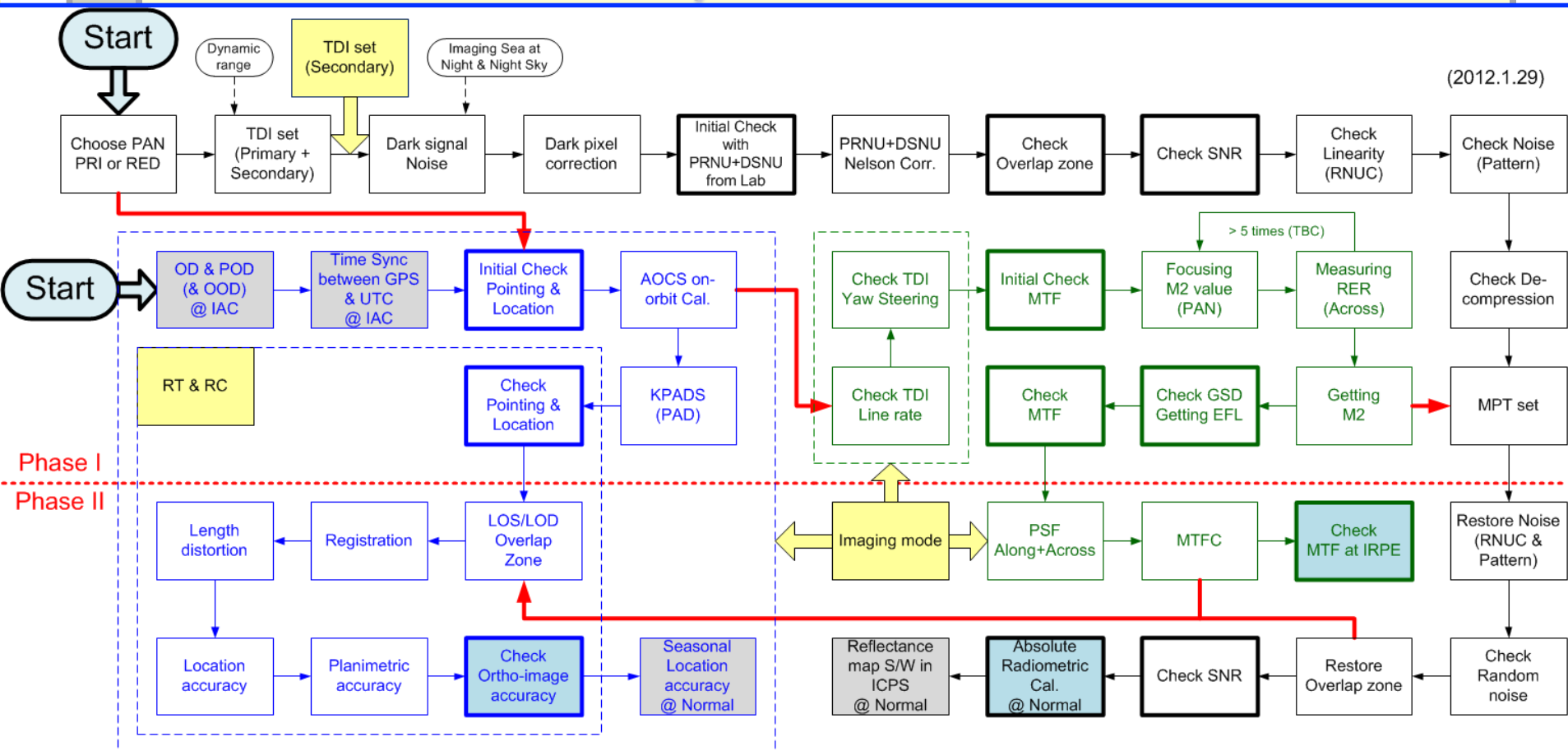
KOMPSAT-3 Overview

Ground Sampling Distance	(PAN) 0.7 m @altitude 685km(nadir) (MS) 2.8 m @altitude 685km(nadir)
Swath Width	16 km (nadir)
Spectral Bands	PAN : 450 ~ 900 nm MS1 (Blue) : 450 ~ 520 nm MS2 (Green) : 520 ~ 600 nm MS3 (Red) : 630 ~ 690 nm MS4 (NIR) : 760 ~ 900 nm
Dynamic Range	14 bits / pixel
Modulation Transfer Function	(PAN) 8%, (MS) 12%
Signal to Noise	> 100
Location Accuracy	< 70 m CE90 (< 30 m RMSE is expected)
Orbit	Sun Synchronous Orbit - Altitude : 685.13 ± 1 km - Inclination : 98.14 ± 0.05 degree MLTAN : 13:30 +10/-15 min



KOMPSAT-3 Calibration and Validation

KOMPSAT-3 Cal/Val work Flow in LEOP



- **Think line box:** Checking K3 Spec. value
- **Blue painted box:** Final Cal/Val work
- **Gray painted box:** @ IAC & @ Normal

- Black box: Radiometric Cal/Val
- Green box: Spatial Cal/Val
- Blue box: Geometric Cal/Val

KOMPSAT Cal/Val Site, Target, S/W, Equipment

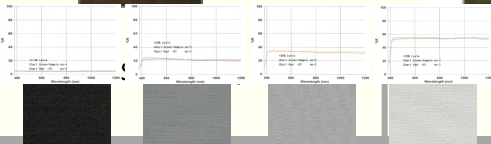
Item	Cal/Val Parameter, Detailed	Remark
Night Lamp	MTF, PSF	Portable
Star	MTF, PSF	Night
Tarp	Linearity, Radiometric	Portable
GCP DB	Pointing & Location accuracy KPADS, AOCS, Registration Mapping quality	Korea, Mongol
MAP data	Pointing & Location accuracy KPADS, AOCS, Registration	Korea, Mongol, Worldwide
Radiometric equipment	Spectro-radiometer	Portable
	Sun-photometer	
	Multi-Filter Rotating Shadow band Radiometer	
	Ultraviolet Multi-Filter Radiometer Temperature measurement equipments	
Geometric equipment	GPS instrument	Portable
	Total station	

Item	Cal/Val Parameter, Detailed	Remark
S/W	ENVI, ERDAS, MODTRAN, STK, Imatest	Commercial
	Matlab, Visual Studio	
	Cal/Val SW	Develop
	MTF Measurement SW	Develop
GRDB	Geometric Cal/Val site, Ortho image	Develop
	MS SQL DBMS & Server+RAID	
Radiance Map in Worldwide	Radiance map in Worldwide	Develop
	Radiance prediction S/W for ICPS	
Site	GCP DB, DSM site	Korea
	GCP DB, Edge	Mongolia

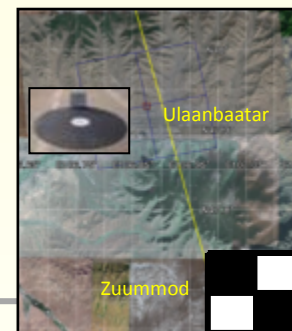
Red: Developed by KARI Cal/Val team



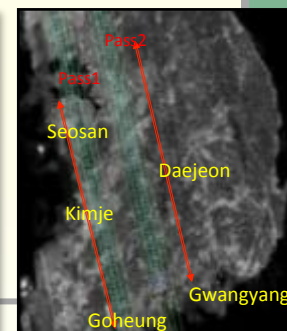
CEOS



Korea Aerospace Research Institute
Satellite data Calibration and Validation



Mongolia



Korea

LEOP Cal/Val Phase(CVP) I & II

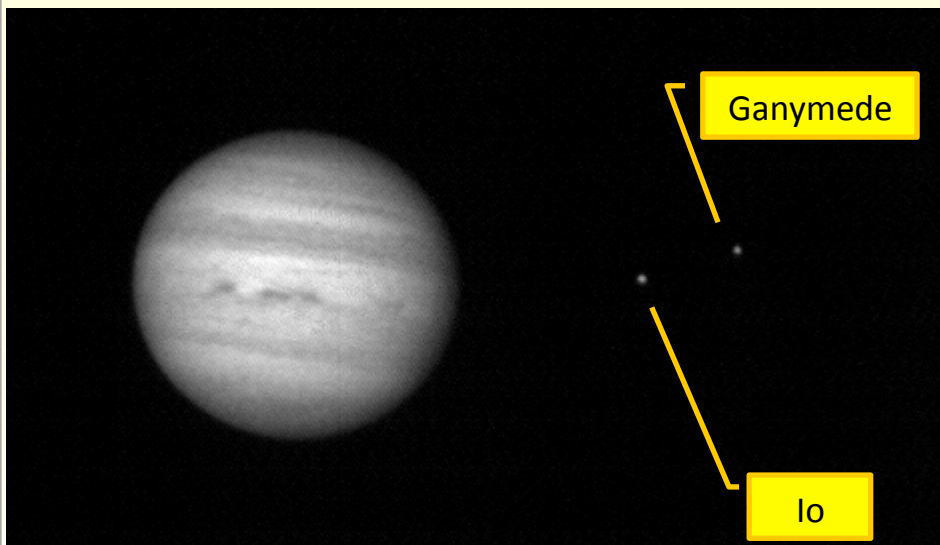
	System Cal/Val	Product Cal/Val
LEOP Cal/Val Phase	I	II
Work	Calibration & Validation Characterization	Image data Restoration
Document	Cal/Val Plan + Doc. + Procedure + Report	
Working Group	GSC WG (+FOWG)	
Leader	DongHan & Dr. Kim	DongHan Lee
Image data Level	Level 0	Level 1R + Level 1G
Requirement	System Spec.	System Spec. (Quality Req.)
Target	Satellite & AEISS(Camera)	IRPE PMS (Processing system)
Step	After IAC	After CVP I
Duration	2012. 6.8 ~ 8.17	2012. 8.20 ~ 12.31

Performance of KOMPSAT-3 after Cal/Val

	Key Item	Requirement Value	Validated Value	Condition
CVP I	SNR	100	>> 100 (TDI 64)	
	MTF	8%(PAN) 12%(MS)	Across: 8~10% (TDI 64) Along: 6~8% (TDI 64) > 19% (MS)	Strip imaging Level 0
	GSD	0.7m(PAN) 2.8m(MS)	0.7m (PAN)	Strip & Nadir imaging
	Pointing accuracy	1.2km	Across: 90m Along: 1 sec	Strip imaging
	Location accuracy	70m CE90	< 70m CE90	With POD & PAD Strip imaging
CVP II	MTF after MTFC	13%(PAN) 19%(MS)	> 20% (PAN)	Level 0
	Registration	0.5pixel RMS (MS)	0.5pixel RMS (MS)	Strip imaging
	Ortho-image accuracy	3.5m CE90 (Horizontal)	3.5m CE90 (Horizontal)	Strip imaging

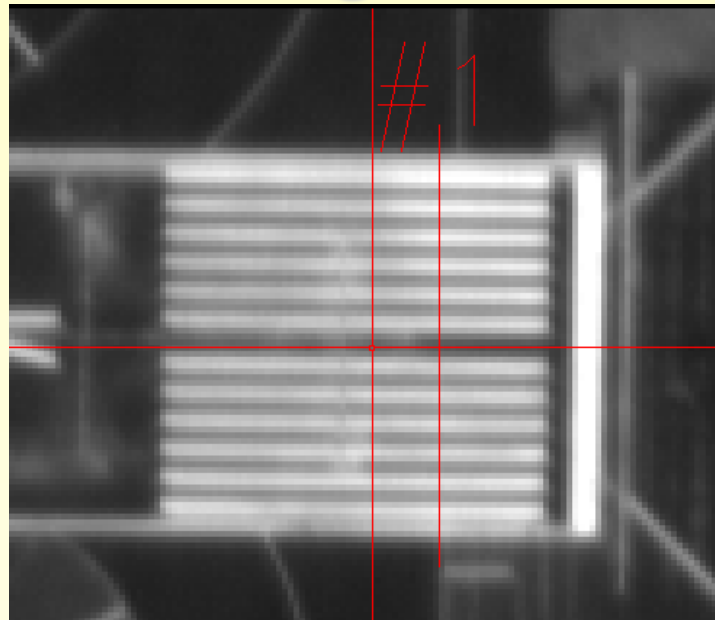
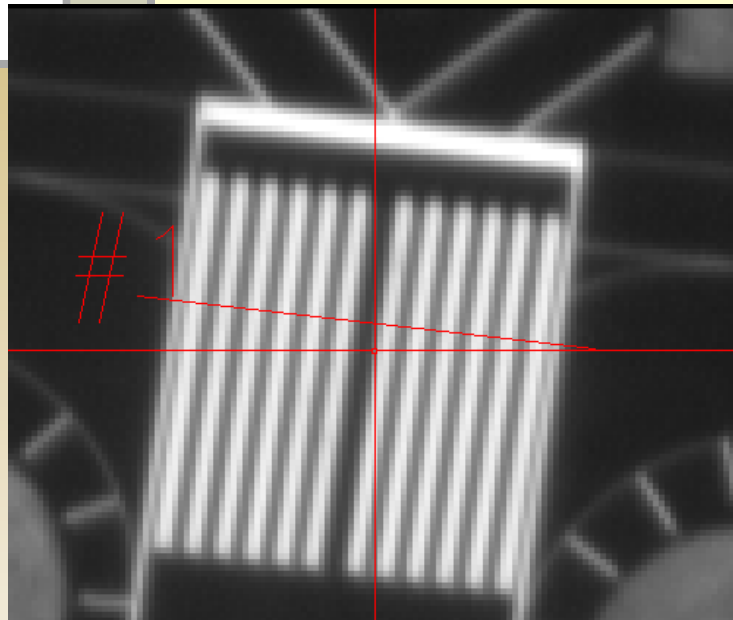
Radiometric Cal/Val for KOMPSAT-3

Spatial Cal/Val for KOMPSAT-3

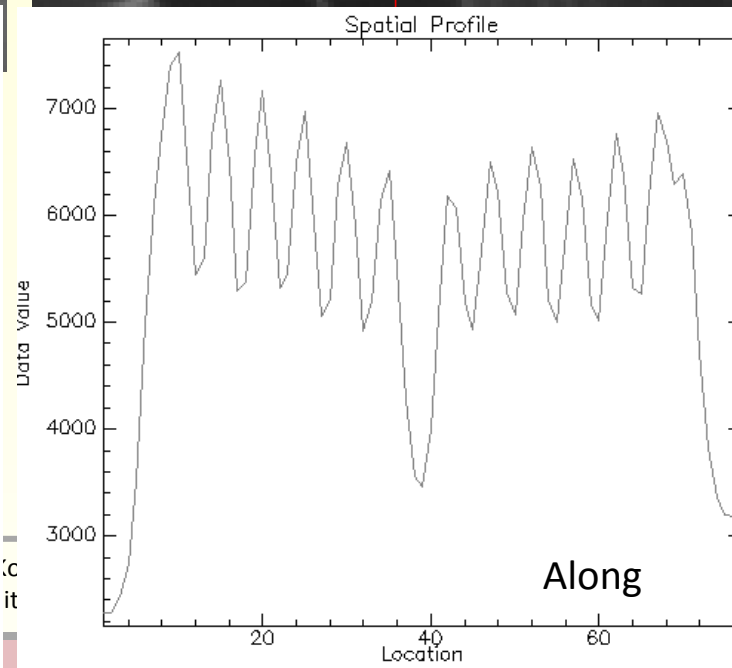
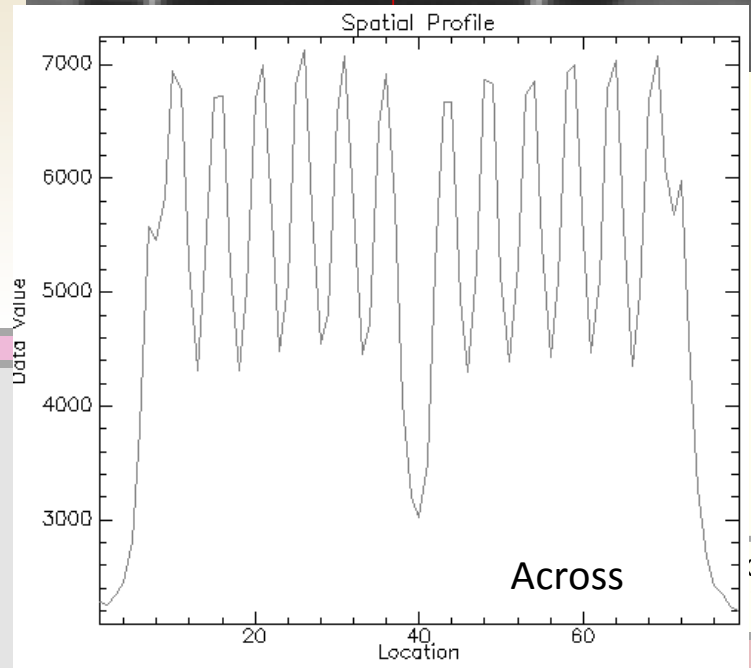


Jupiter~!
2012.07.18, PAN_3

Across & Along



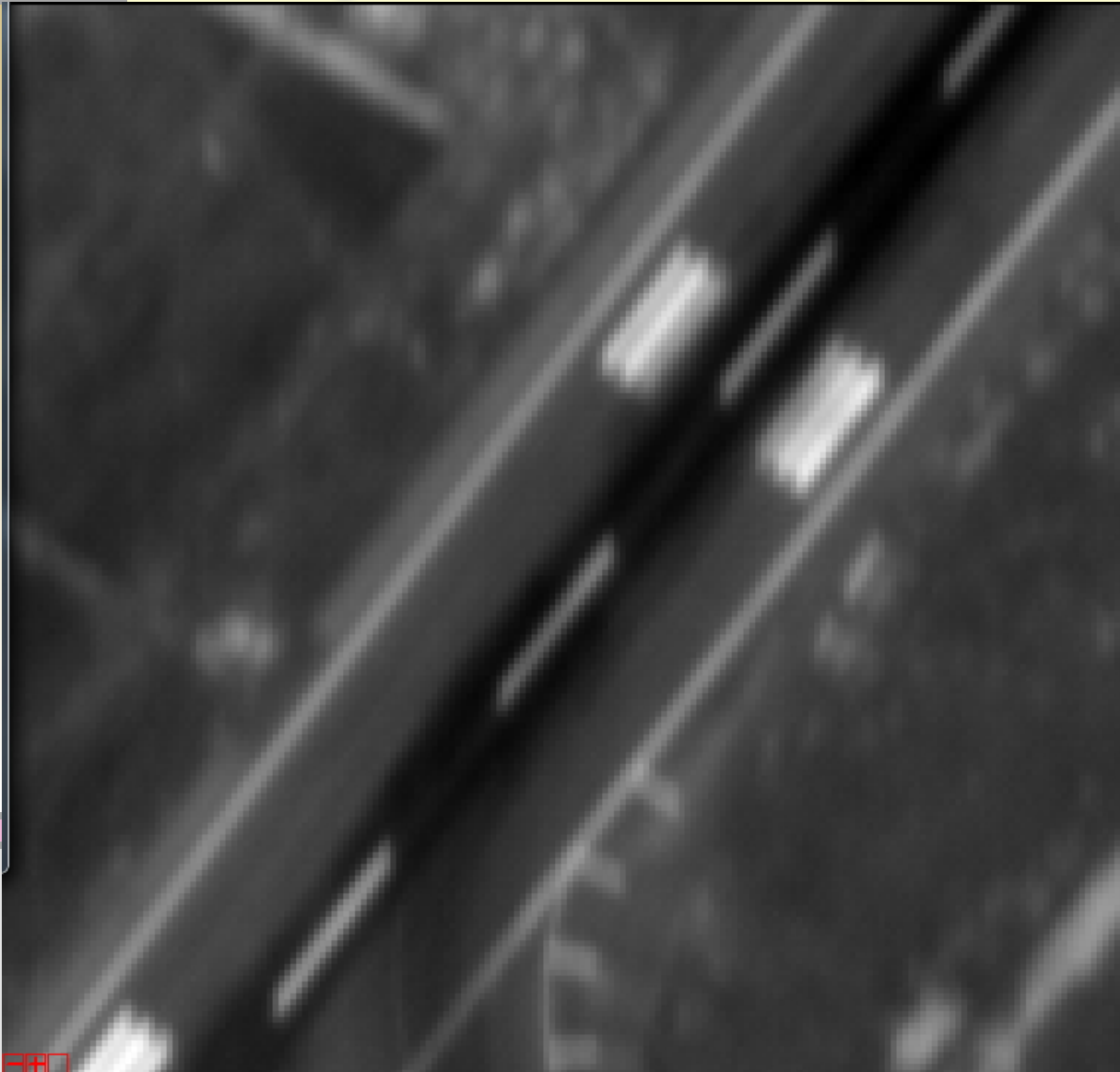
2012.05.29
Philadelphia airport
PAN_4



Initial MTF with Low Along

- Across MTF (Static MTF): . > 8% (TDI 64)
- Along MTF (Dynamic MTF): < 2~4% (TDI 64)
- Main factors for Along MTF
 - Line rate (Line time)
 - TDI CCD Blooming
- (There is a little Asymmetric LSF)
- Input factors for Line rate
 - Instantaneous Altitude
 - Roll & Pitch tilt angle
 - EFL, CCD Pixel size
- Additional factors for more accurate Line rate
 - Yaw steering angle
 - Ellipsoid
- In case of KOMPSAT-2 with 13 μ m pixel size & 32 TDI
 - the additional factors for KOMPSAT-3 are negligible.
 - And KOMPSAT-3 with 8.75 μ m & 64 TDI, those are important~!

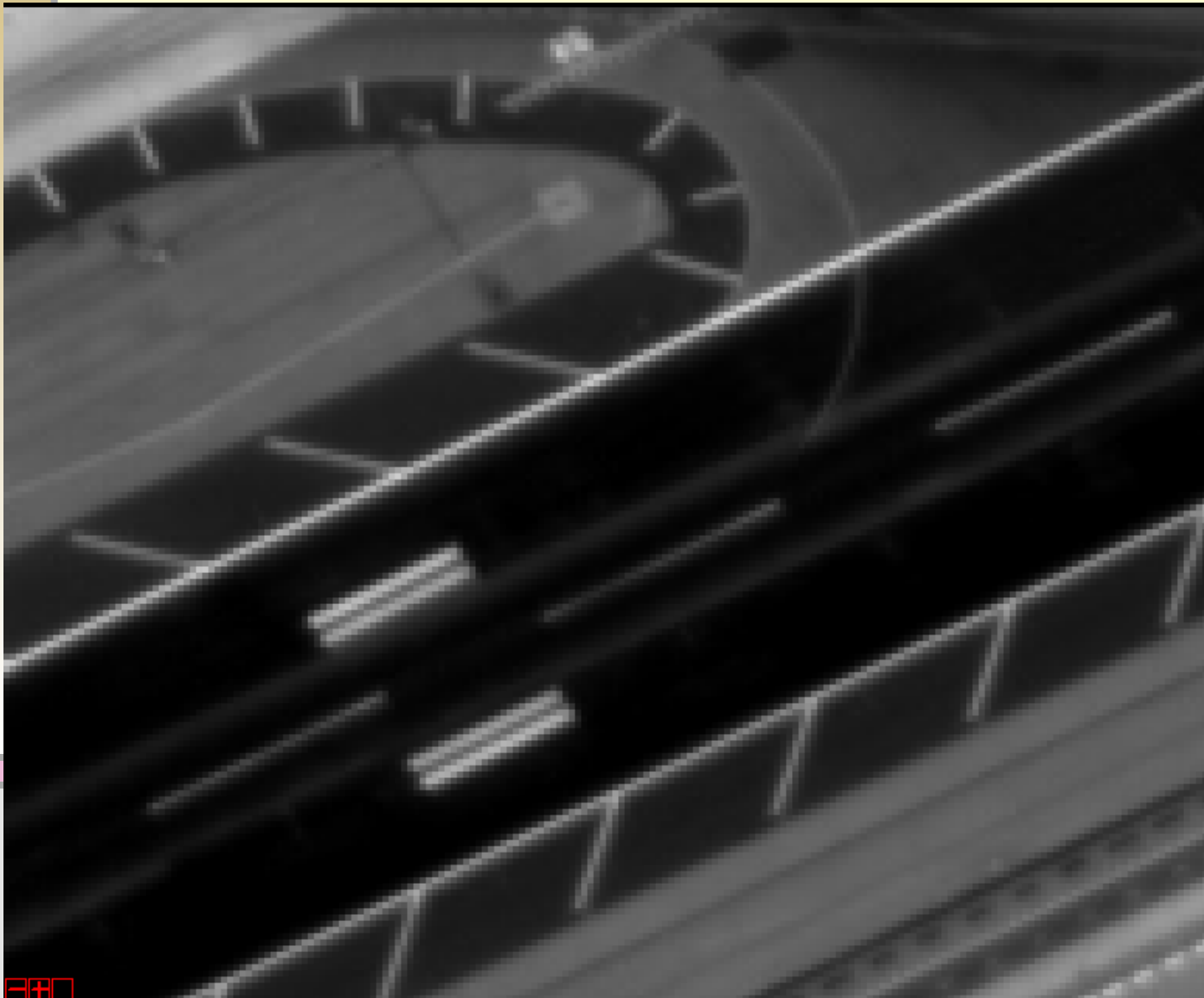
Image with Pitch tilt (-30) before Line rate



- 2012.07.08, P5
- Pitch: -30 deg
- Roll: -5 deg
- FMC Temp: -0.18
- Line rate: 7243 (OLD)
- TDI: 64

※ ARS-69

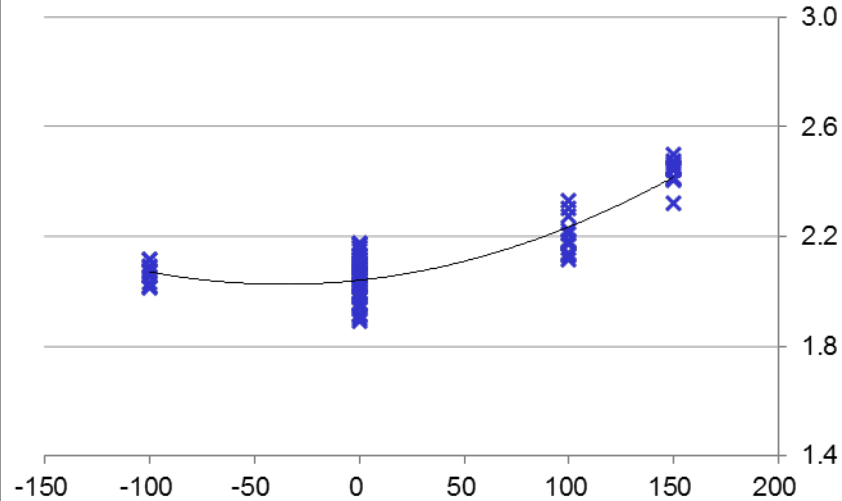
Image with Pitch tilt (+30) After Line rate



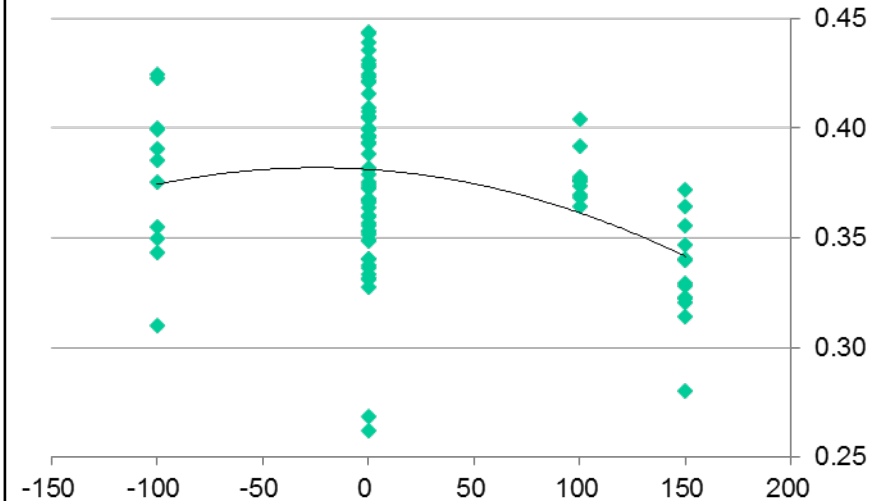
- 2012.07.26, P3
- Pitch: +30 deg
- Roll: -1 deg
- FMC Temp: 0.0
- Line rate: 6794 (NE W)
- TDI: 64

New Line rate algorithm Test

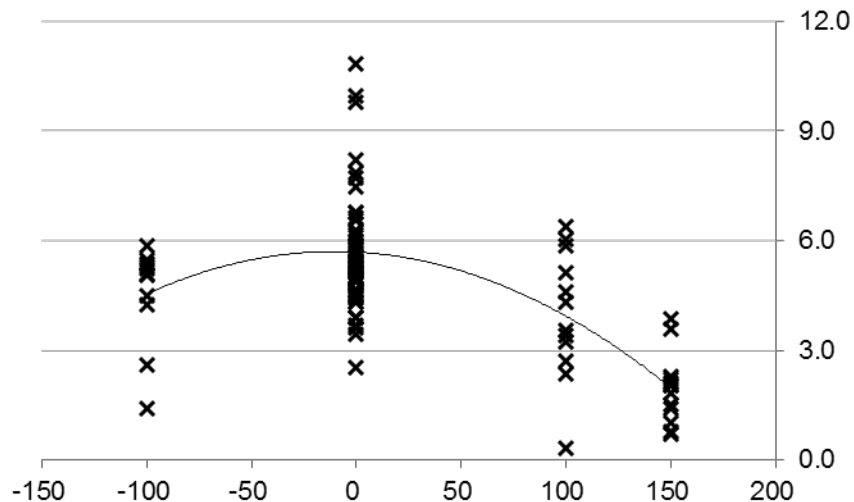
× FWHM-Along



◆ RER-Along



× MTF-Along

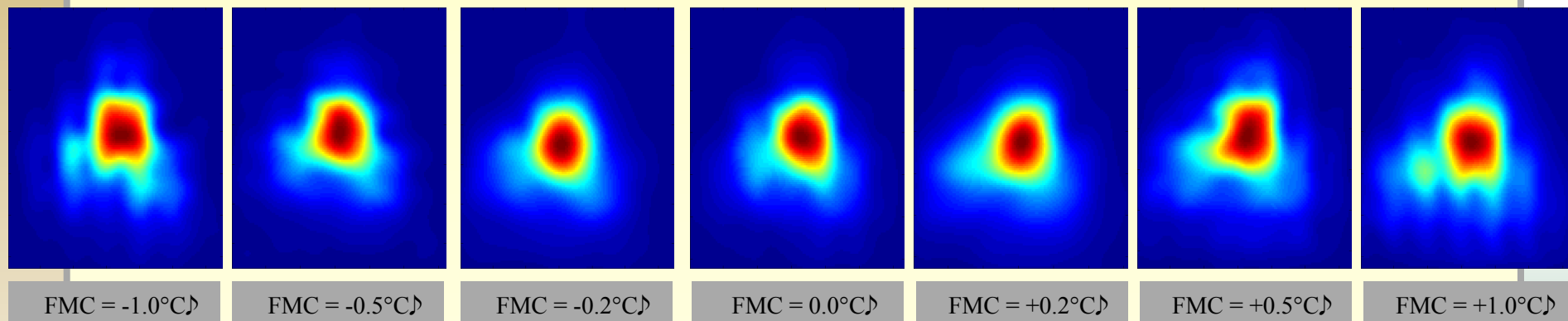


Test DATE	Line-Rate	Del_rate	FWHM	RER	MTF
2012.08.07	6831	0	2.0458	0.381	5.73
	6487	100	2.2005	0.377	3.99
2012.08.08	6325	-100	2.0583	0.376	4.75
	6794	0	2.0804	0.362	5.10
	6946	150	2.4075	0.339	2.04

FWHM is GOOD, but RER & MTF is bad~!

Why? (Please talking at 5th 16:00 with my PPT.)

Focusing with Star image data



FMC Temperature(°C)		FWHM - Across			FWHM-Along			MTF(%)	
at Star	at Ground	20%	50%	80%	20%	50%	80%	Across	Along
-1.46	-1.00	2.881	1.666	0.997	2.816	1.803	1.115	12.52	7.85
-0.96	-0.50	2.750	1.665	0.957	2.644	1.745	1.082	11.41	9.13
-0.67	-0.21	2.834	1.580	0.926	2.765	1.789	1.065	13.22	7.37
-0.46	0.00	2.907	1.650	1.000	2.458	1.587	0.901	12.44	12.69
-0.26	0.20	2.612	1.650	0.997	2.994	1.813	1.072	12.14	8.02
0.04	0.50	3.207	1.747	1.011	2.896	1.808	1.124	10.54	7.67
0.54	1.00	3.122	1.773	1.065	2.929	1.801	1.019	10.76	7.82

Concept of MTF Compensation (MTFC)

- **Purpose and Necessity of MTF Compensation**

- Restoration of the distortion of the image data from the Sensor deviation.
- Enhancement of the sharpness of the image data
- But, increase the Noise and get the other distortion; Ringing, etc.

- **Highlight the only information in Image data**

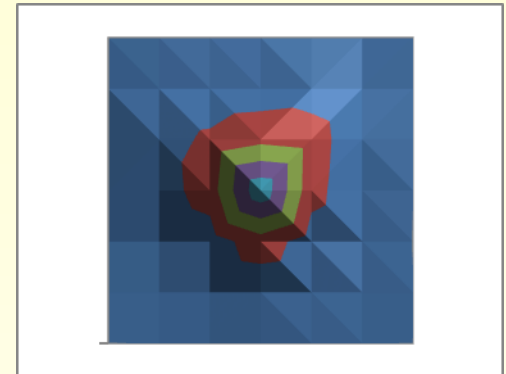
- But, must not distort the information.
- Change, Remove, Add (X)

- **Suppress the Noise against MTFC**

- Match the MTFC with the De-noising filter
- Don't read any information as the Noise.
- Don't read any noise as the Information.

- **MTFC algorithm must have the specific character of the Sensor.**

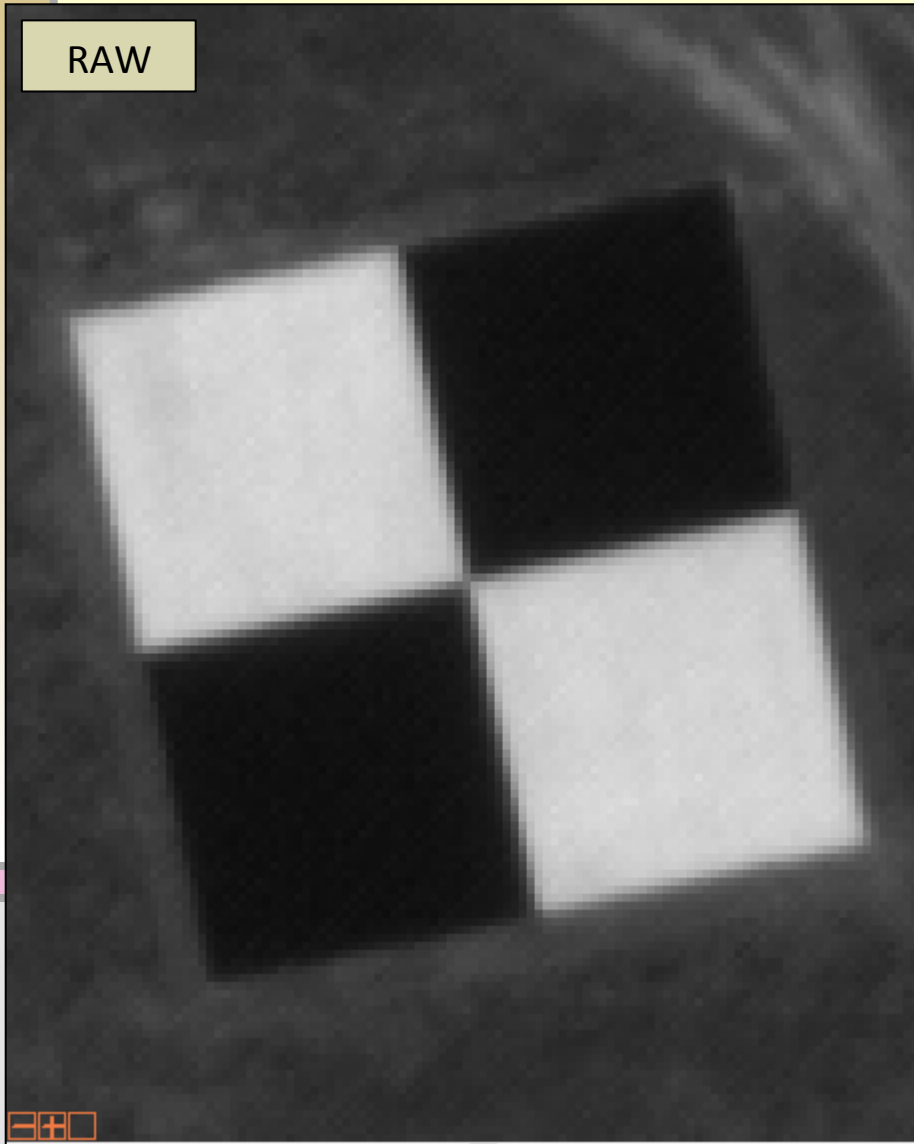
- PSF (Point Spread Function) has to be measured by the optimum method (Star).
- Optimal MTFC algorithm ([Wiener filter](#), Lucy Richardson, Sparse Prior, etc.)



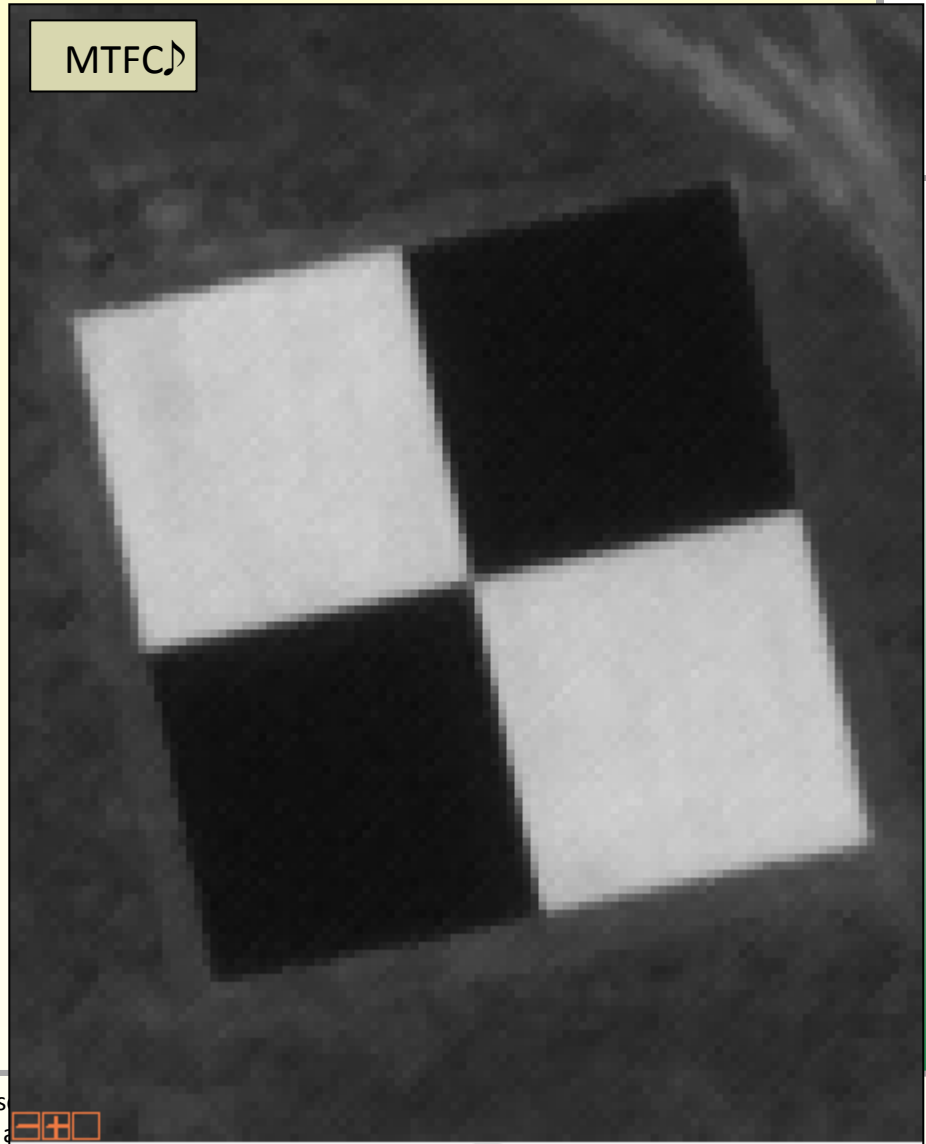
KOMPSAT-3 PSF
from Star

MTFC of KOMPSAT-3 (I like it~!)

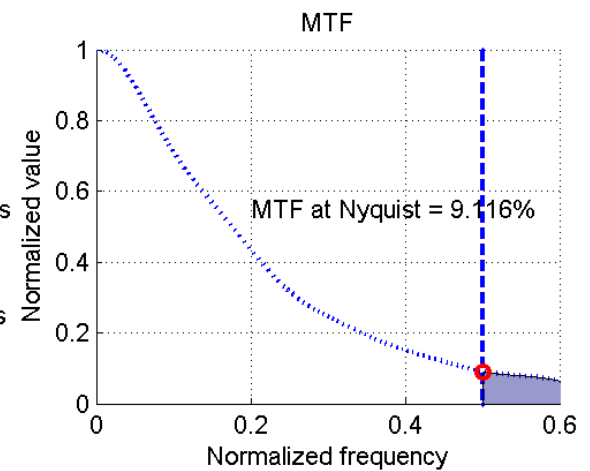
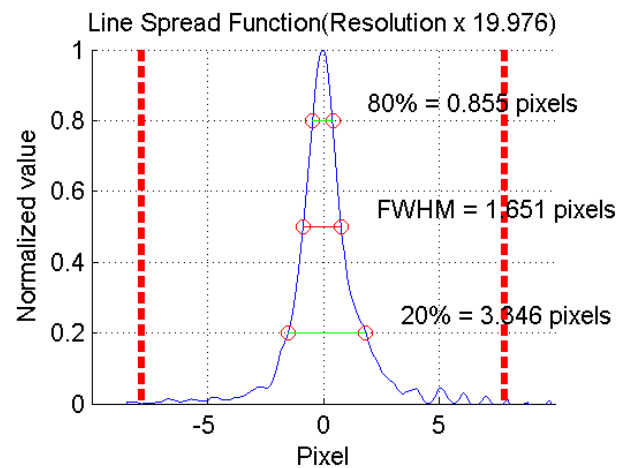
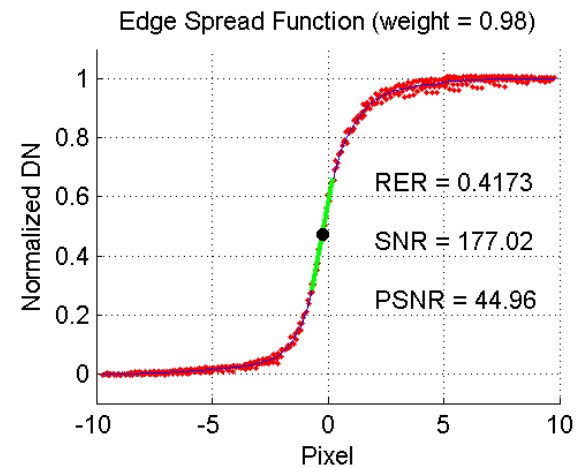
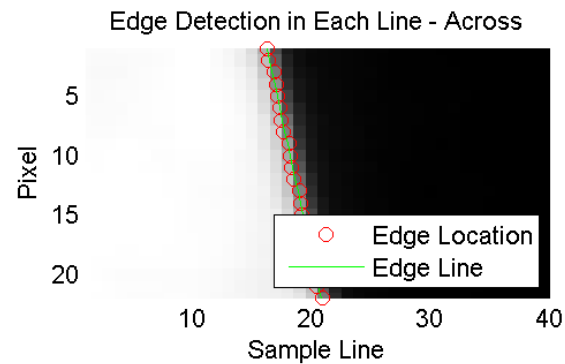
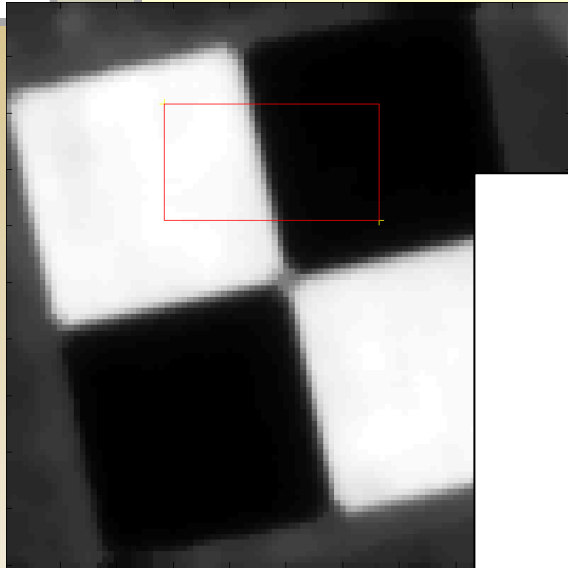
RAW



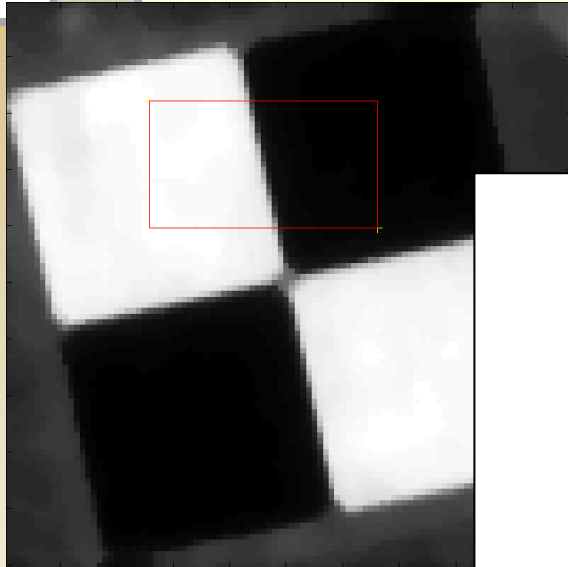
MTFC♪



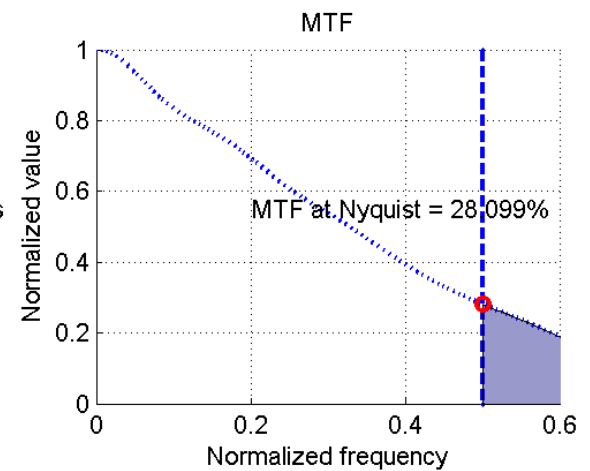
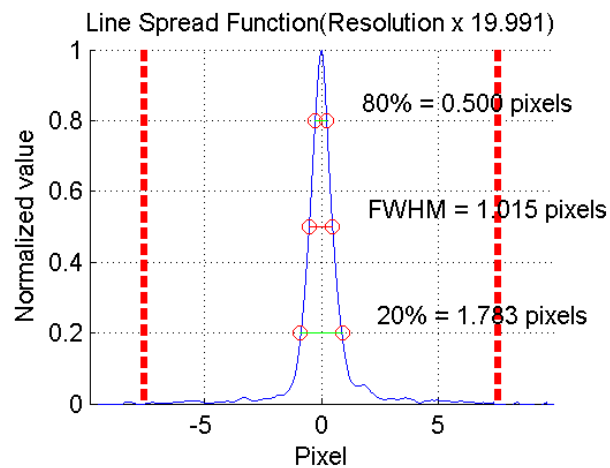
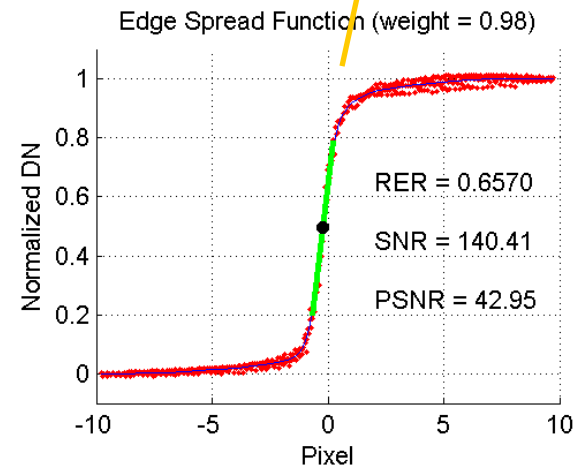
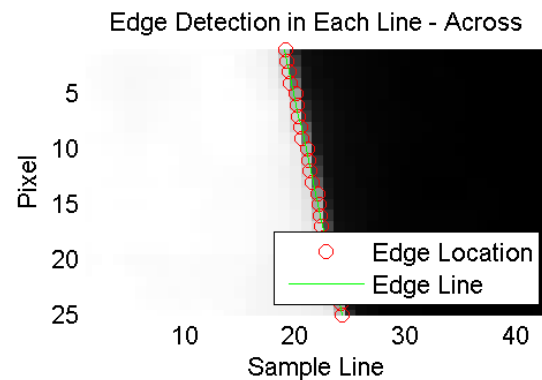
RAW image (Across)



MTFC image (Across)



No Ringing~!



De-Noised



MTFC & No De-Noised



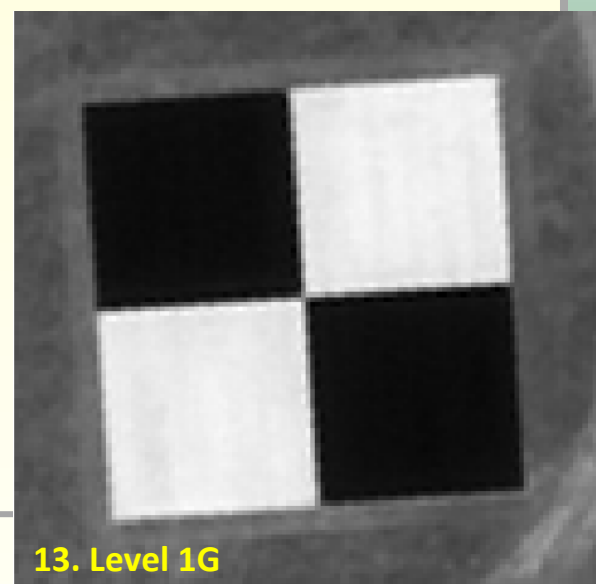
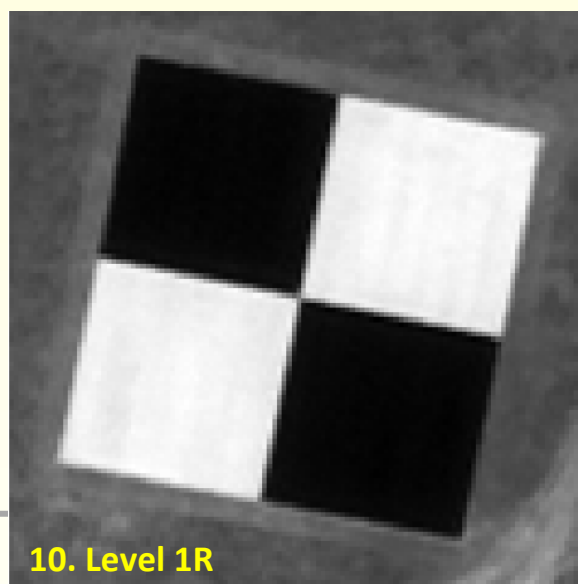
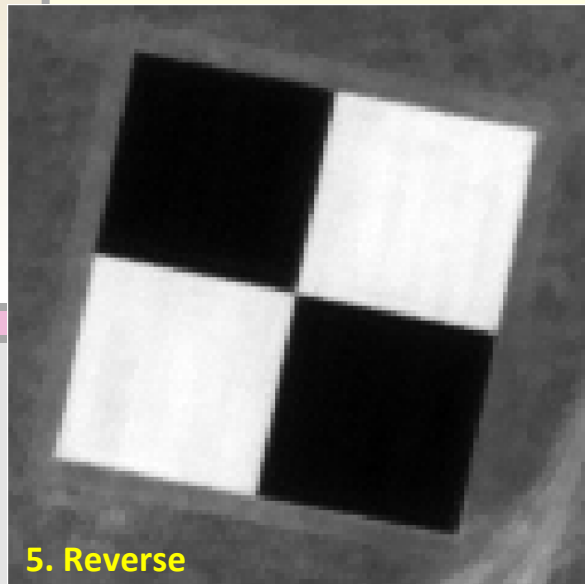
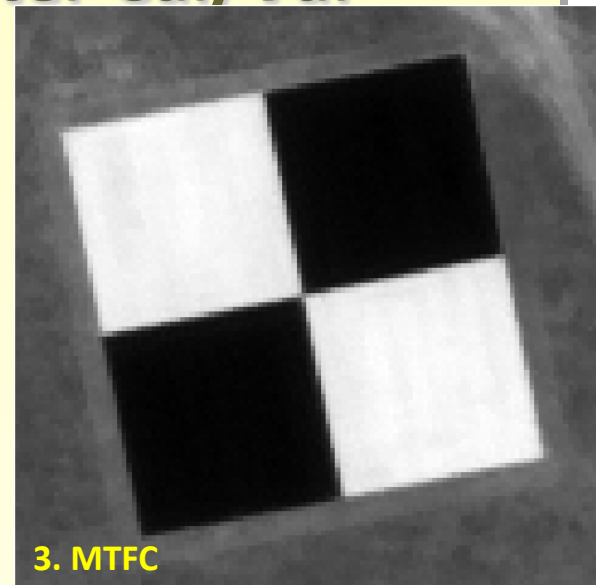
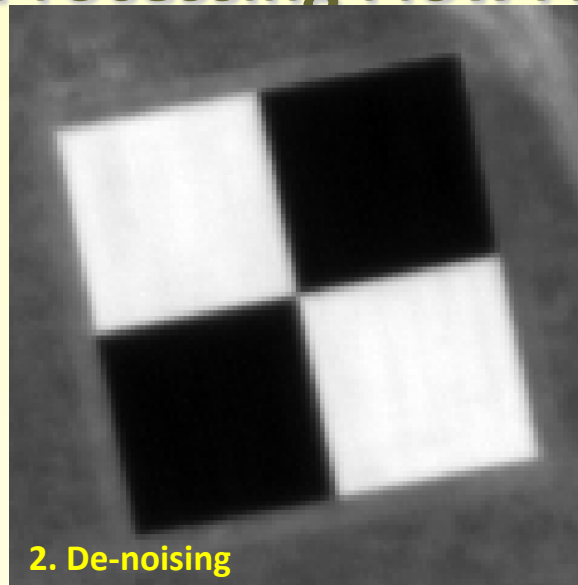
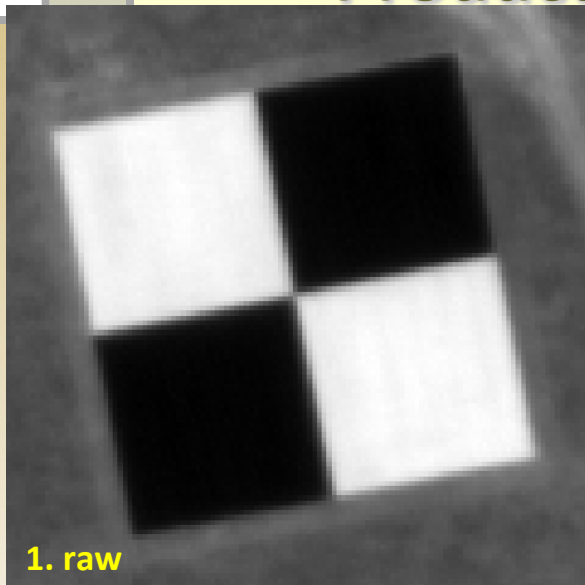
<Dynamic Range=2405(732,~137)DN, impulsive range=127 DN, PSNR=25.54dB>

MTFC & De-Noised



< Dynamic Range=2405(732~3137)DN, impulsive range=20 DN, PSNR=41.60dB >

Product Processing Flow After Cal/Val



MTFC image

RAW

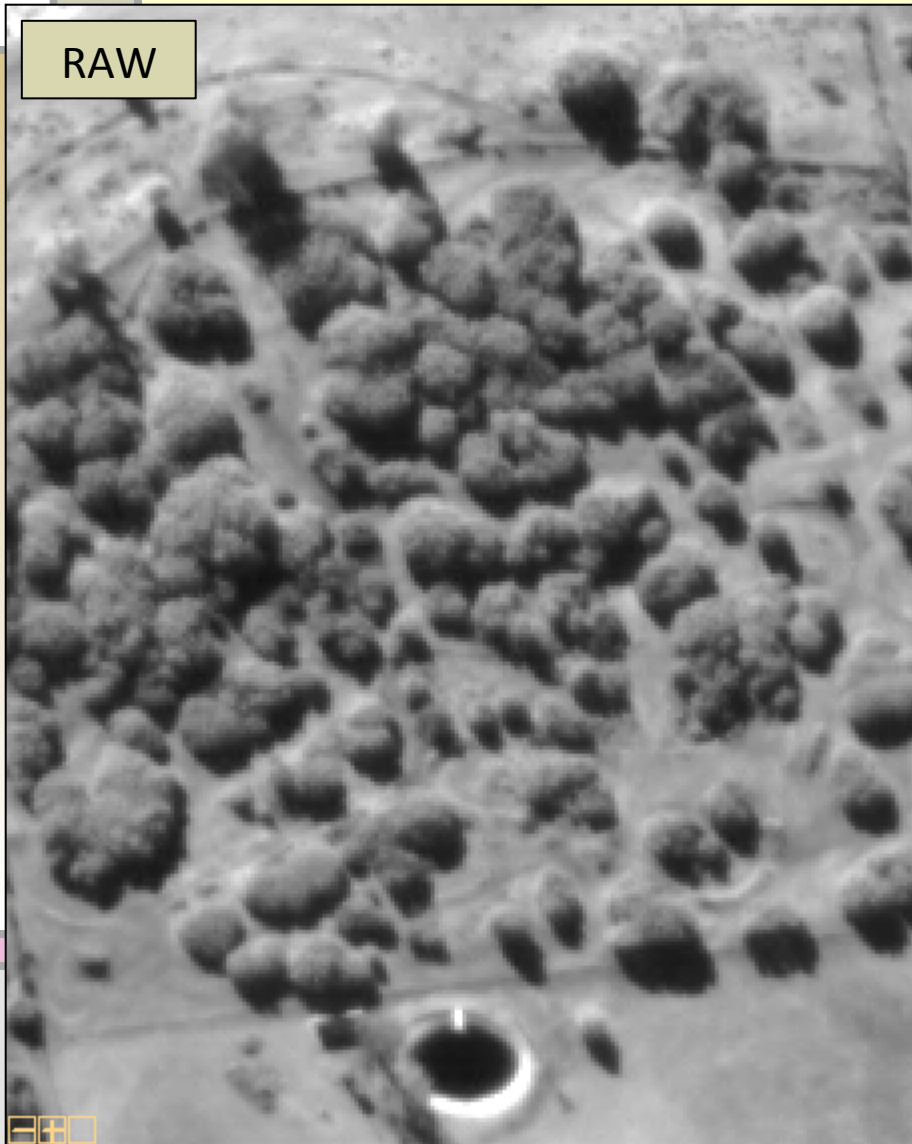


MTFC



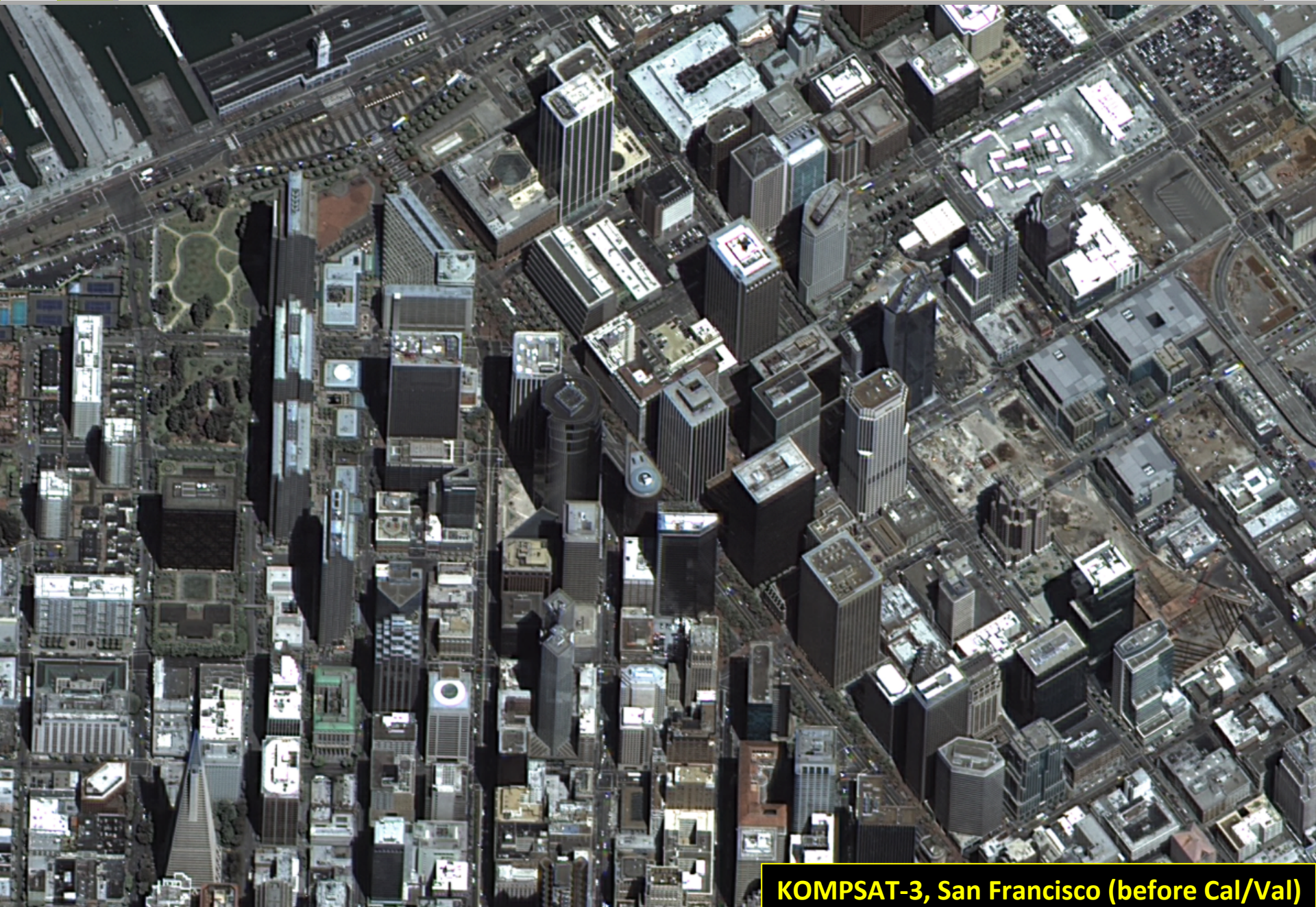
MTFC image

RAW



MTFC





KOMPSAT-3, San Francisco (before Cal/Val)



KOMPSAT-3, Dubai, UAE (After Cal/Val)

**Tornado, KOMPSAT-3, Louisville Mississippi USA, i
maging date: 2014.05.05**

Google Map

KOMPSAT-3



Geometric Cal/Val for KOMPSAT-3

KOMPSAT-3 Geometric Sensor Model

• KOMPSAT-3 Direct Geo-Referencing Model & Geometric Cal/Val

– Backward model

$$\begin{bmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{bmatrix}_{ECEF} = \frac{1}{\lambda} \cdot M_{ECI}^{ECEF} \cdot M_{Sensor}^{ECI} \begin{bmatrix} -y \\ -x \\ f \end{bmatrix}_{Sensor}$$

Cal/Val Phase I

Exterior Orientation

- Satellite Position
- Satellite Attitude

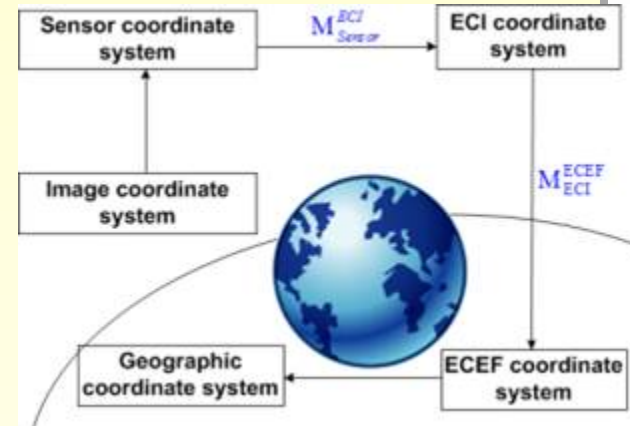
Time Sync

- Satellite Position
- Satellite Attitude
- Image Line Time

Cal/Val Phase II

Interior Orientation

- Focal Length
- CCD Alignment
- CCD Distortion



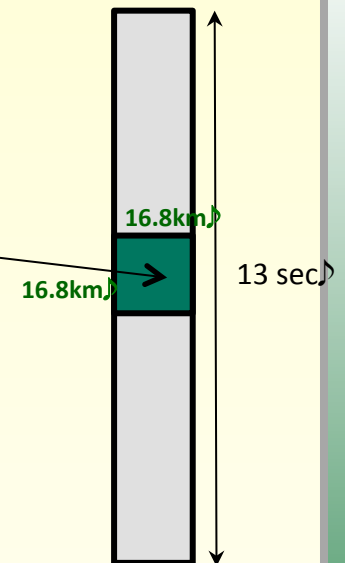
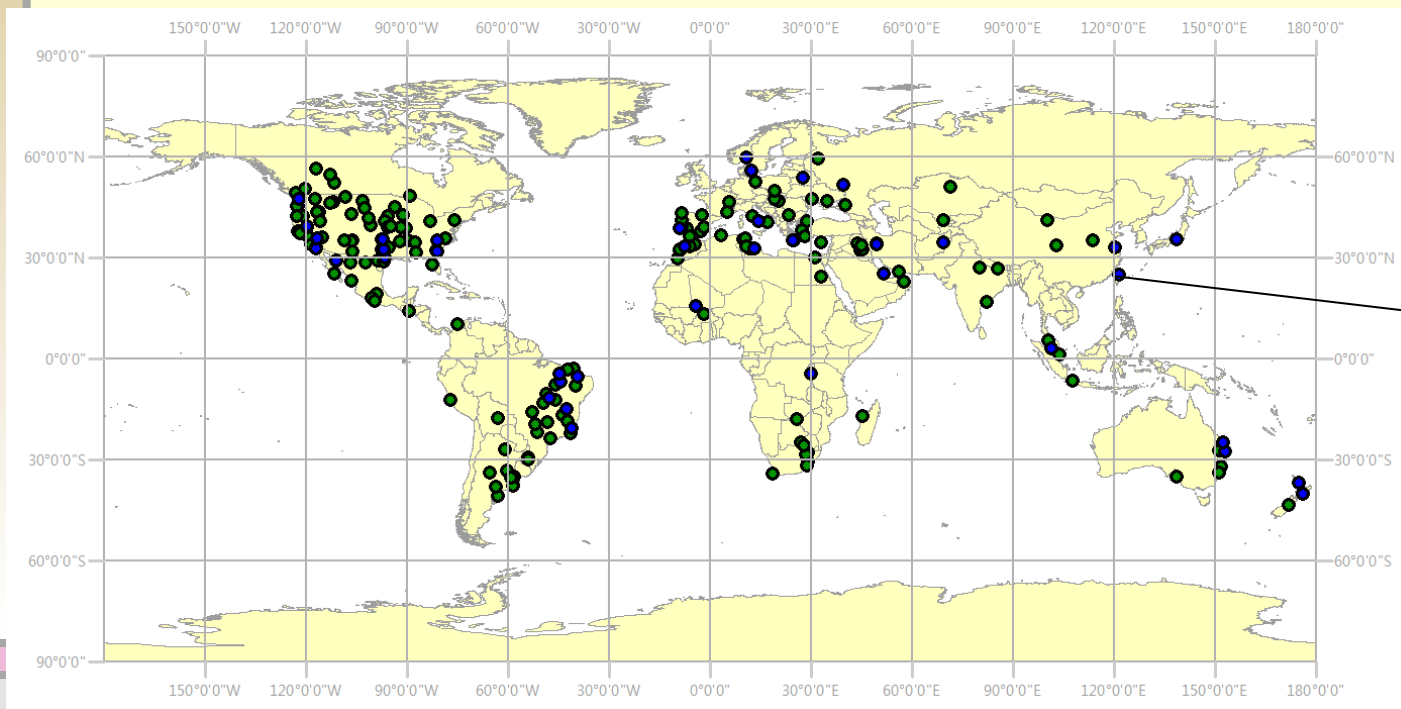
– Foreword Model

$$\begin{bmatrix} -y \\ -x \\ f \end{bmatrix}_{Sensor} = \frac{1}{\lambda} \cdot M_{ECI}^{Sensor} \cdot M_{ECEF}^{ECI} \cdot \begin{bmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{bmatrix}_{ECEF}$$

Location accuracy Check

- **Location Accuracy test data**

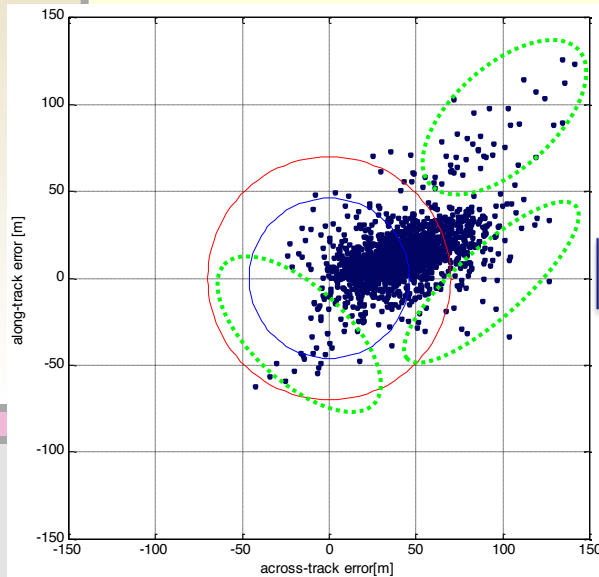
- Imaging date: 2012.07.12 ~ 2012.07.30 (239 imaging)
- Latitude range: $-43.5^{\circ} \sim 59.8^{\circ}$



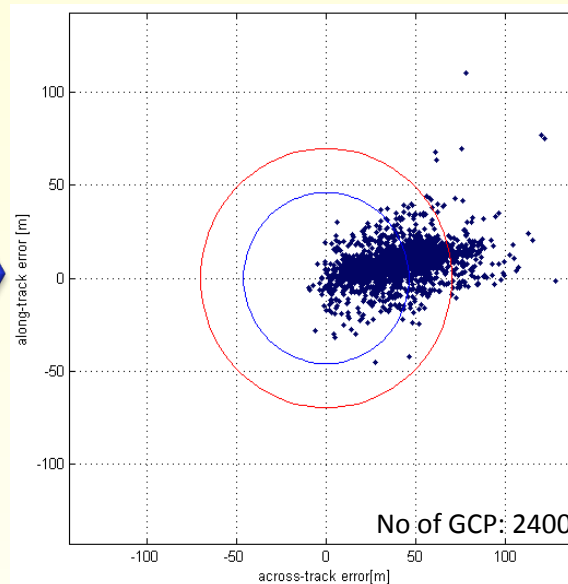
Location accuracy Check (after KPADS Tuning & Alignment)

Date ♪	Activity
2012.07.30 ♪	POD/PAD Accuracy report♪
2012.08.07♪	STA meas. Cov. Tuning version
	STA meas. + Gyro meas. Cov Tuning version♪
2012.08.12♪	KPADS Sensor Alignment Adjustment ♪

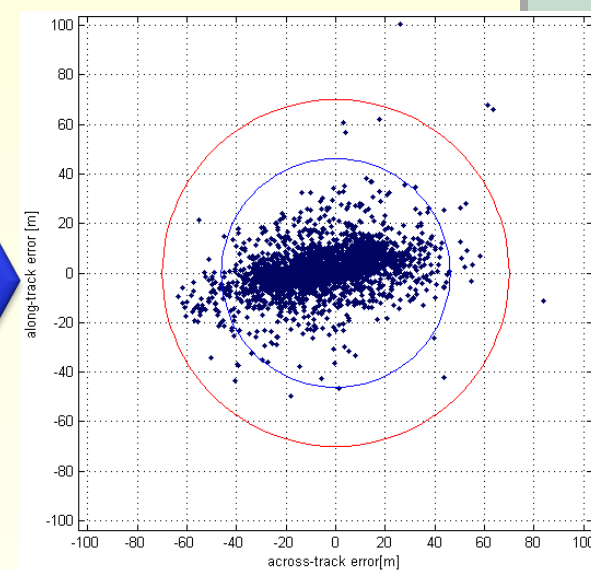
2012.07.30
After AOCS Cal. ♪



2012.08.07
After KPADS Tuning♪

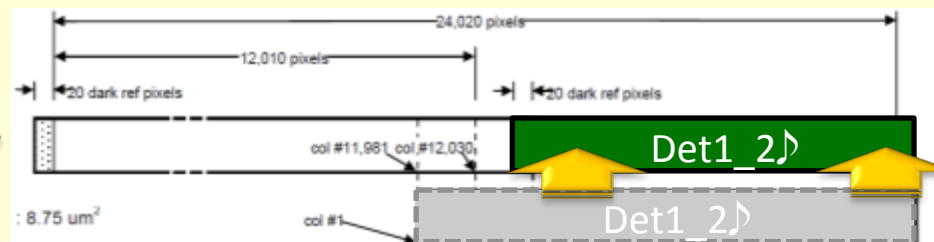
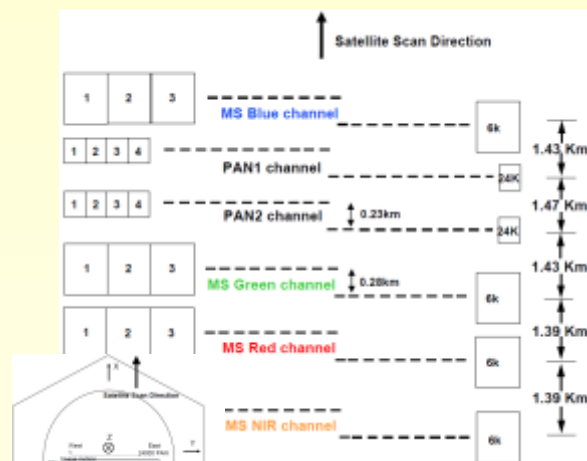


2012.08.12
After KPADS Alignment♪

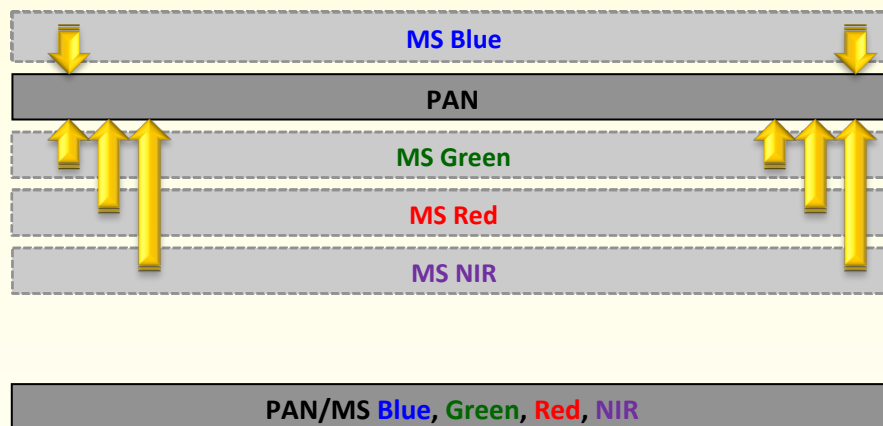


Overlap zone (Registration)

- KOMPSAT-3 : Swath-width (15km)
 - AEISS Detector 구조 특성

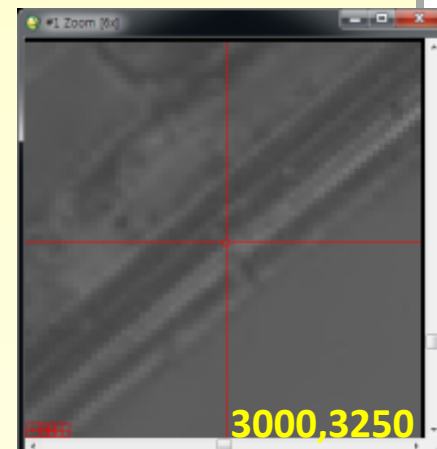
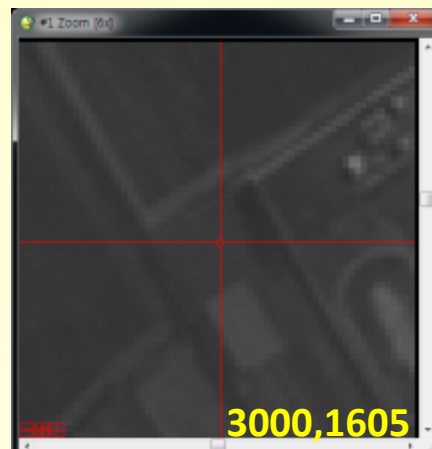
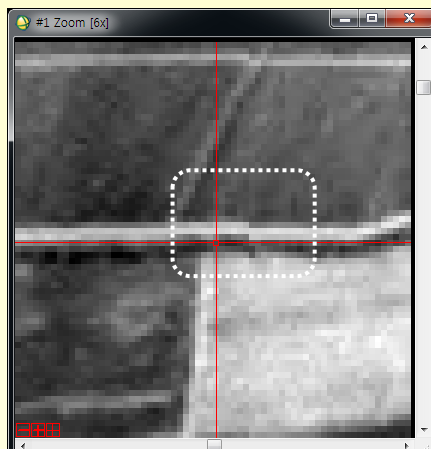
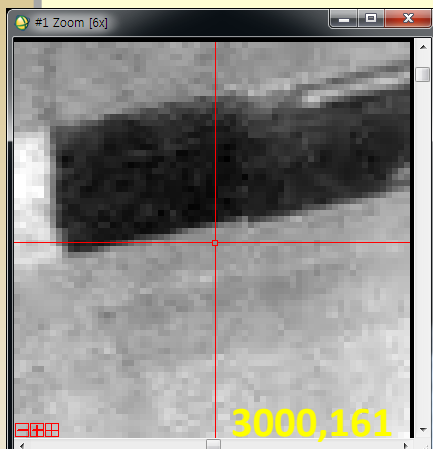


Band-to-Band Registration

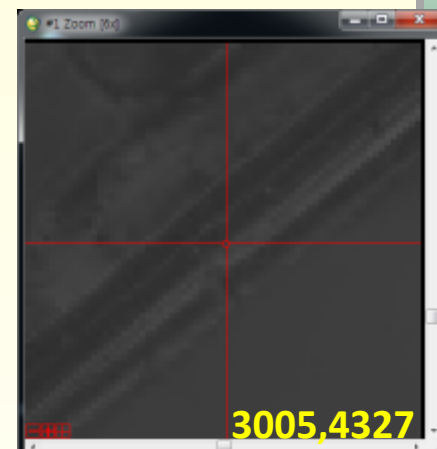
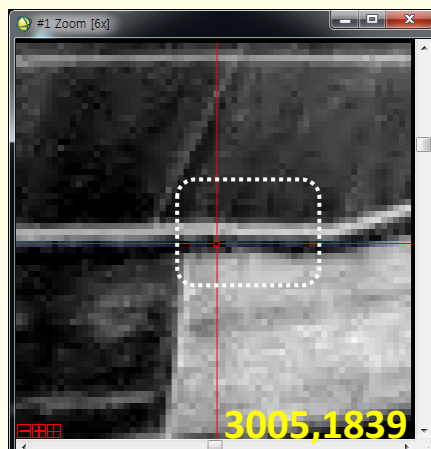


Overlap zone (Registration)

- Before

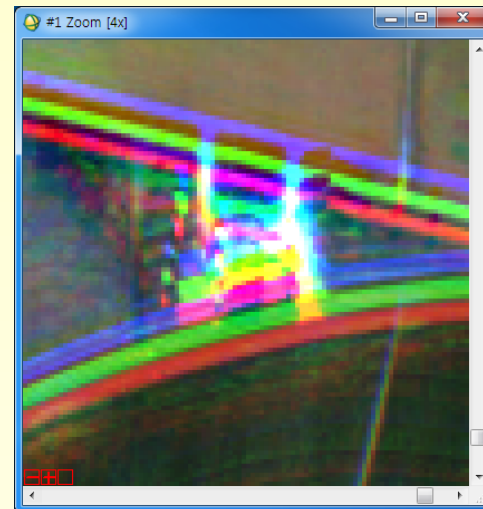
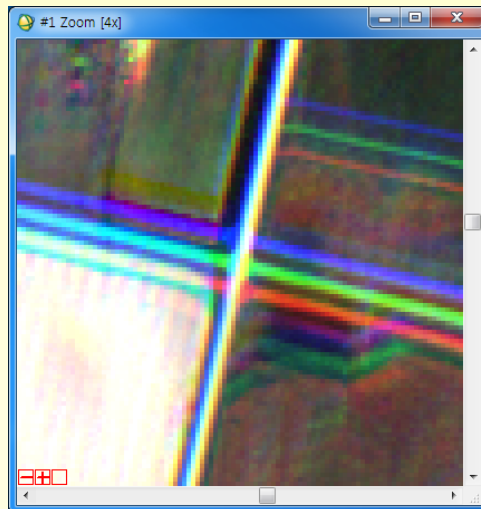
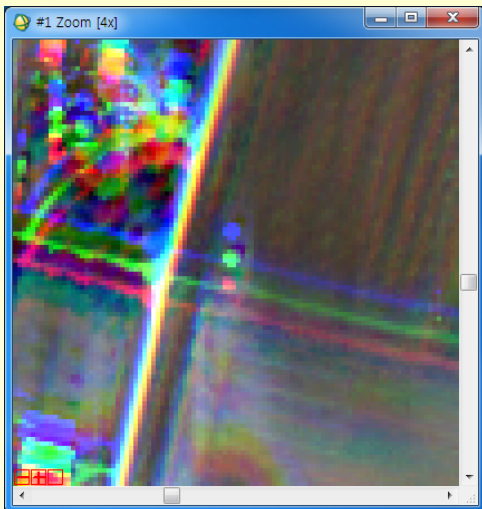


- After

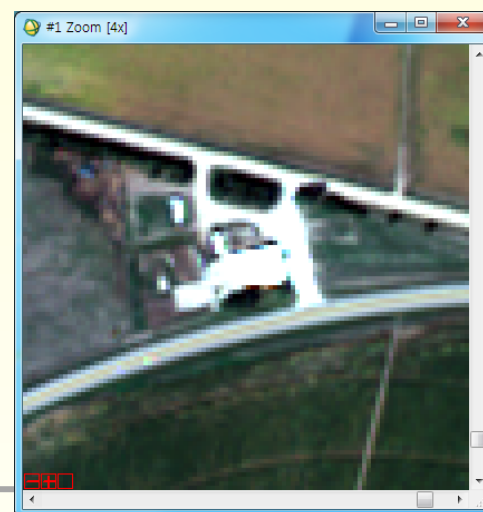
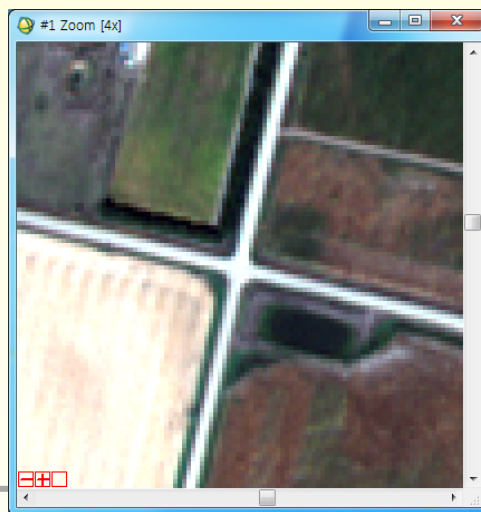
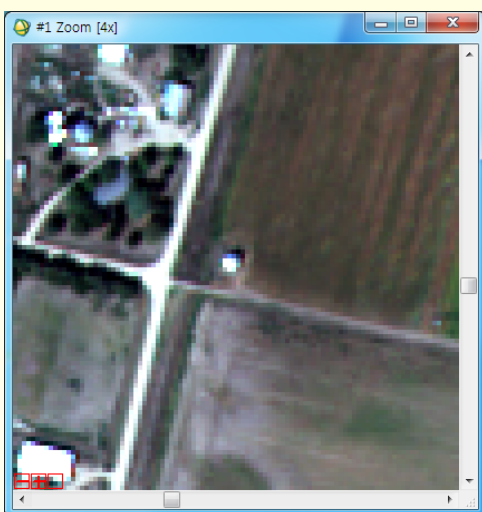


Band-to-Band Registration

- Before



- After



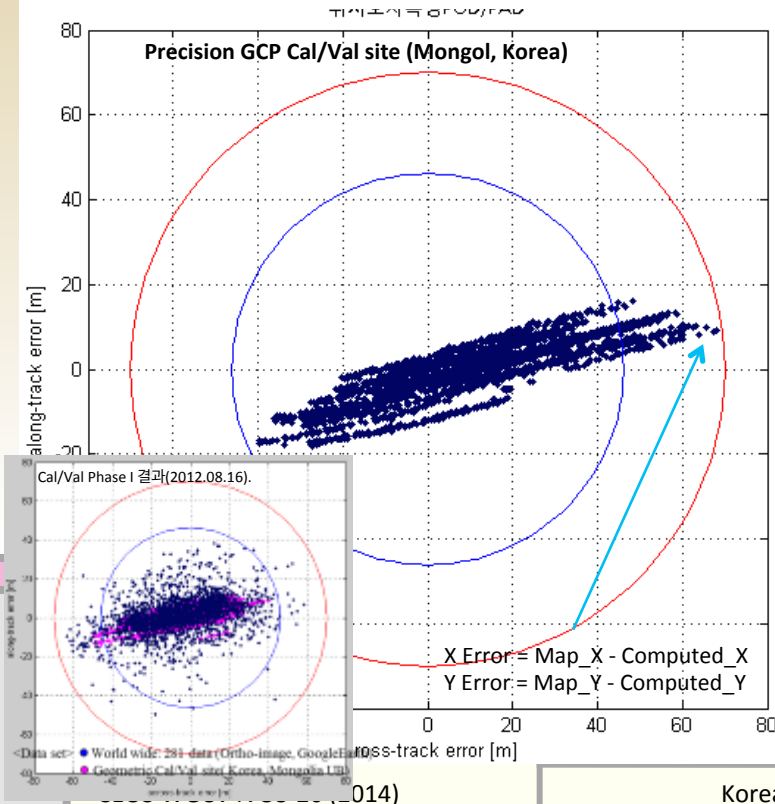
CLOS WDCV IVOS-20 (2014)

Korea Aerospace Research Institute (KARI)
Satellite data Calibration and Validation team (SCV)

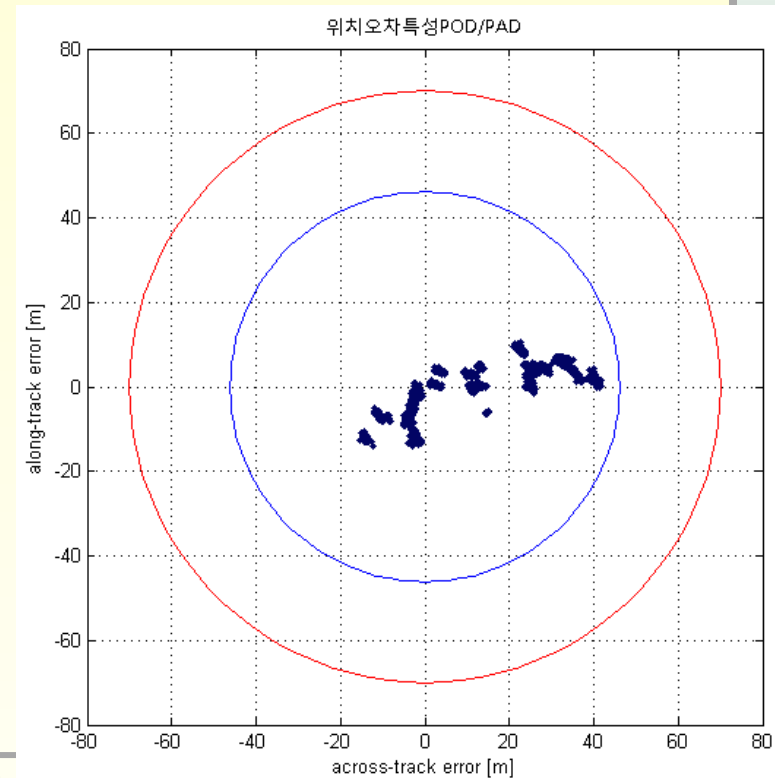
Location accuracy (after LOS/LOD)

- PAN LOS/LOD Distortion Model & Coefficient (2012.12.07) → Validated
 - Focal length: 8.561809 m
 - CCD Alignment: $a_0 = -1.056E-01$ m, $a_1 = 8.779E-06$ m, $a_2 = -9.922E-14$ m
 $b_0 = 5.004E-06$ m, $b_1 = -3.829E-10$ m, $b_2 = 1.530E-15$ m

Cal/Val Phase I, Location accuracy



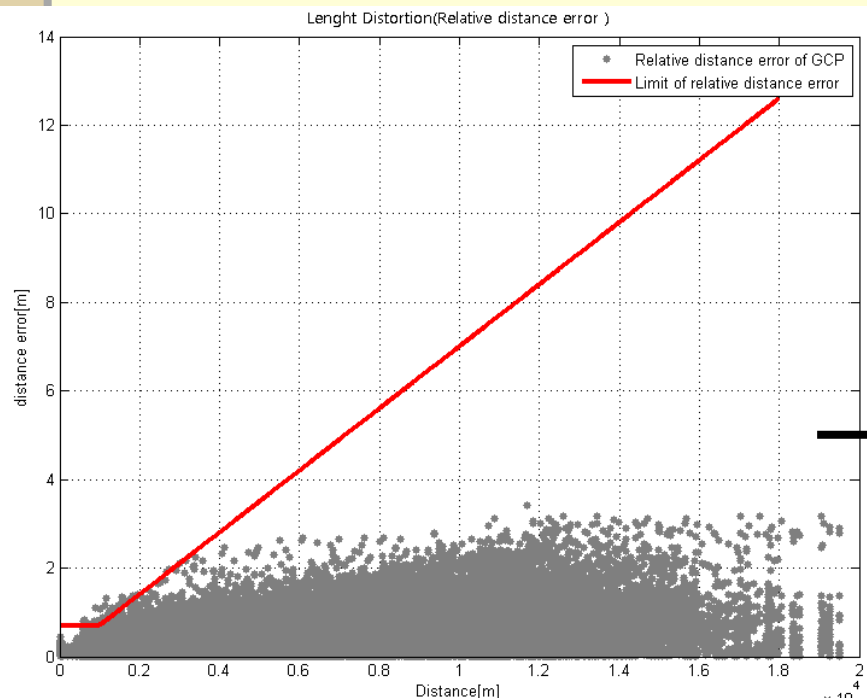
Location accuracy
After
Abs. LOS/LOD



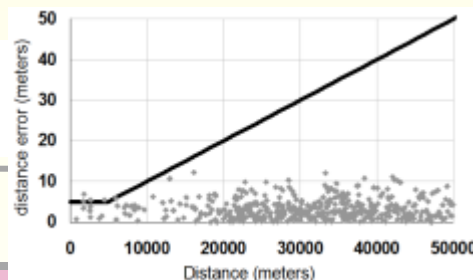
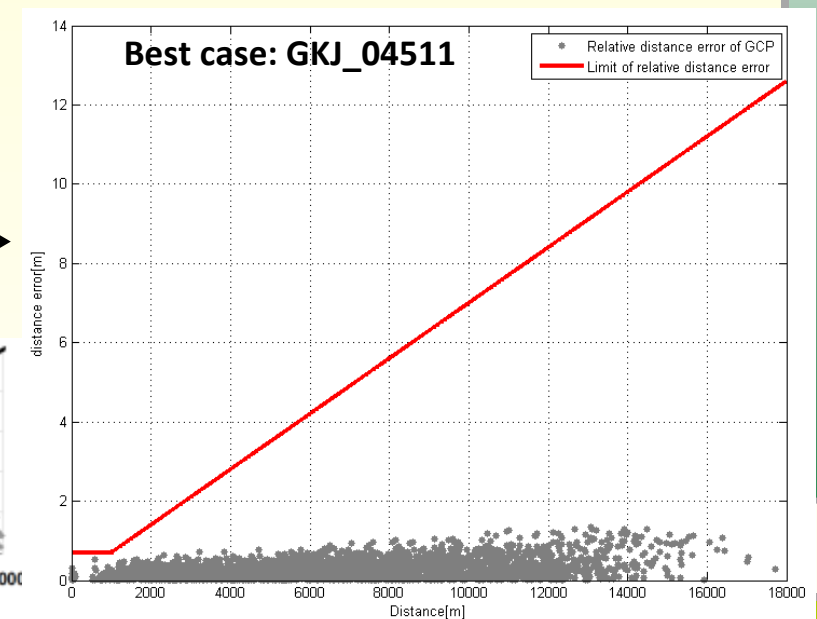
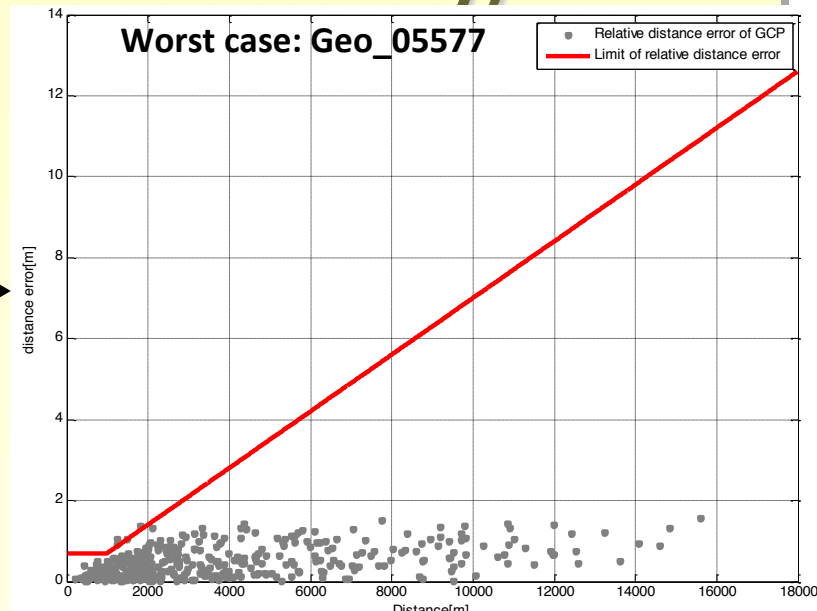
Length distortion (Relative accuracy)

- **Relative pixel distance accuracy**

- $\text{Abs}[\text{Reference Distance} - \text{Image Distance}(\text{K3 Direct Geo-referencing model})]$



전체 32개 Test data에 대한 상대적 거리 정확도 분포
Red line : $|d-d'| = [\text{Distance} \times 0.0007]$



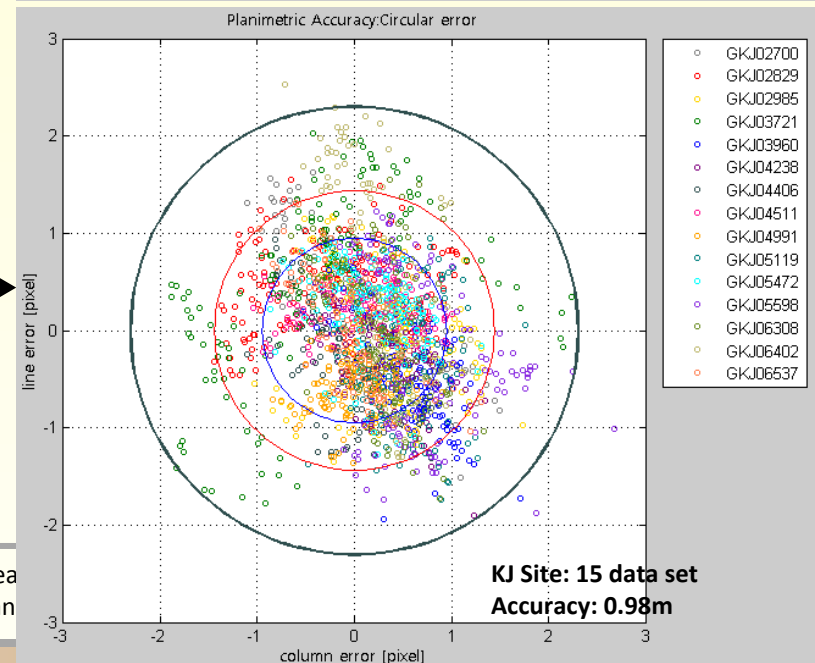
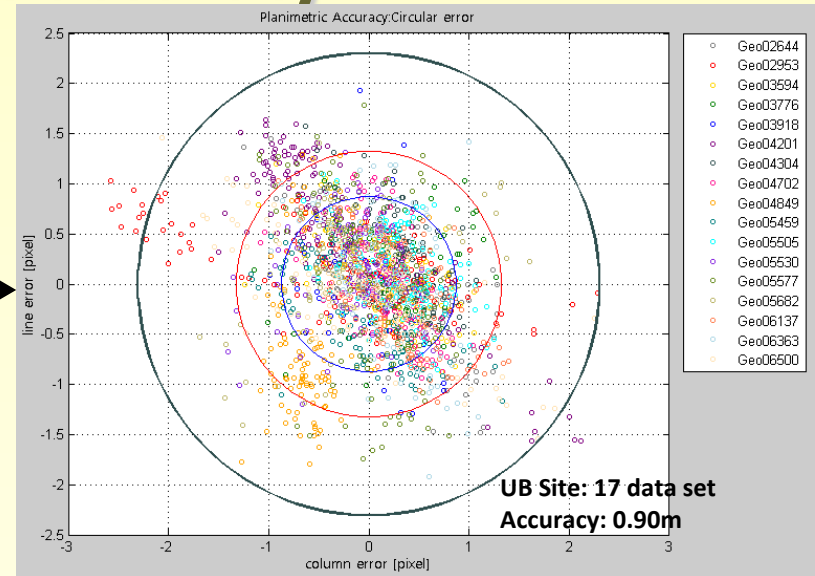
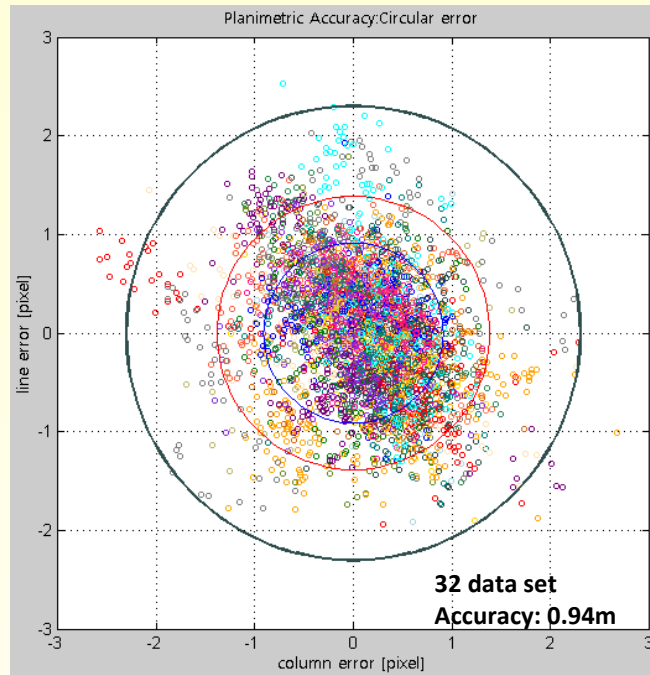
- **Accuracy of Length distortion**

– CE90 = 0.218m

CEOS WGCV IVOS-26 (2014)

Planimetric accuracy

- Circular error of Planimetric Accuracy
 - CE90 : 1.34 pixel (0.94m)



Ortho-image accuracy

- Overlay : 1:5,000 digital map + Generated ortho-image map

Road

Geo_04702
✓ Planimetric accuracy
: 0.66 pixel/0.46m



Downtown

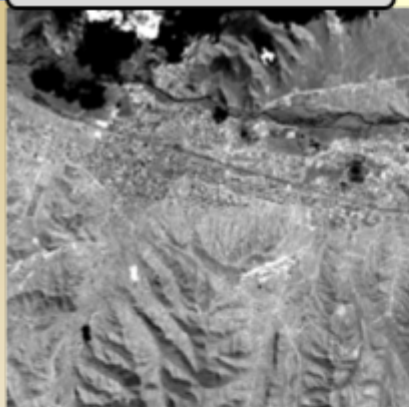


Mountain

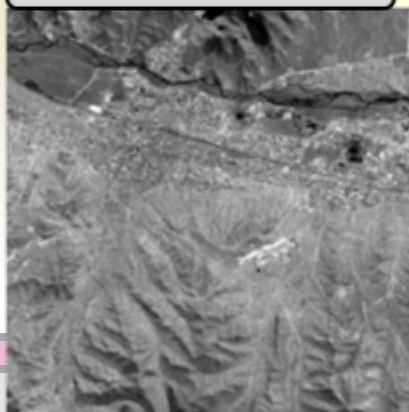


DEM Extraction

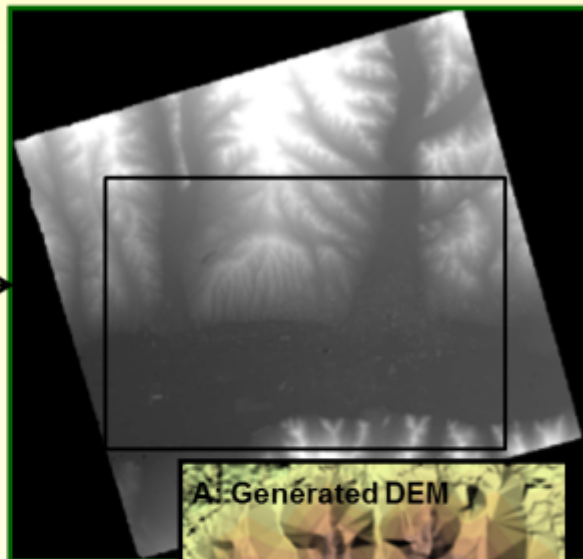
Geo_04702: -4.7 deg



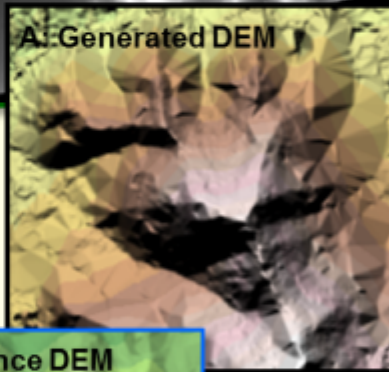
Geo_04201: +5.4deg



DEM



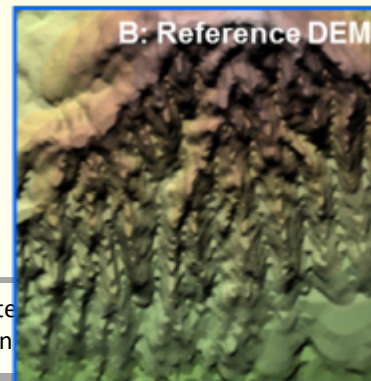
A: Generated DEM



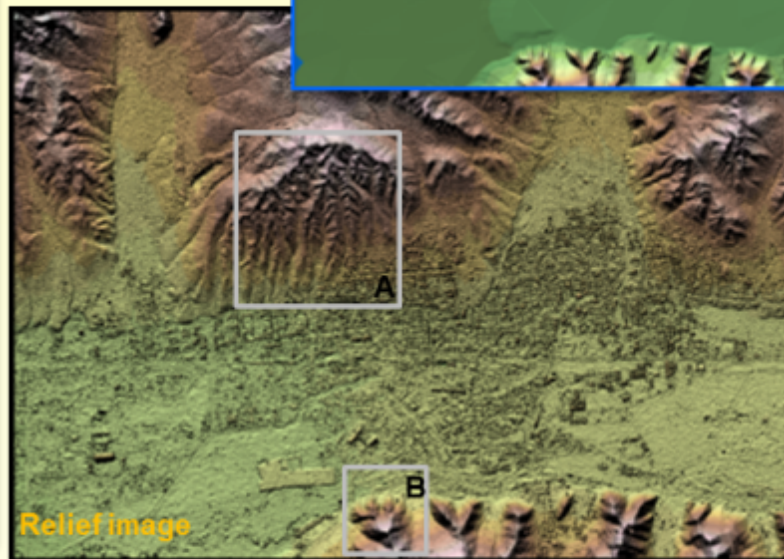
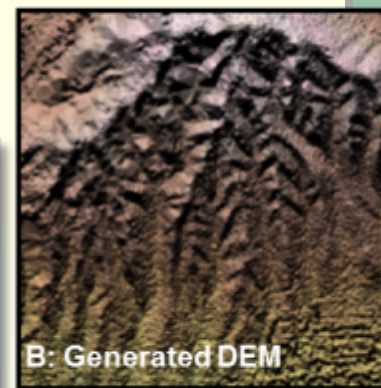
A: Reference DEM



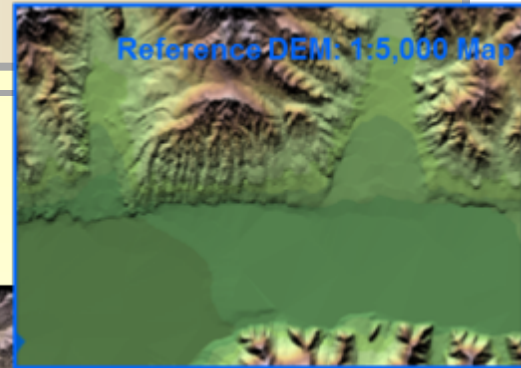
B: Reference DEM



B: Generated DEM



Reference DEM: 1:5,000 Map



KOMPSAT-2 vs. KOMPSAT-3

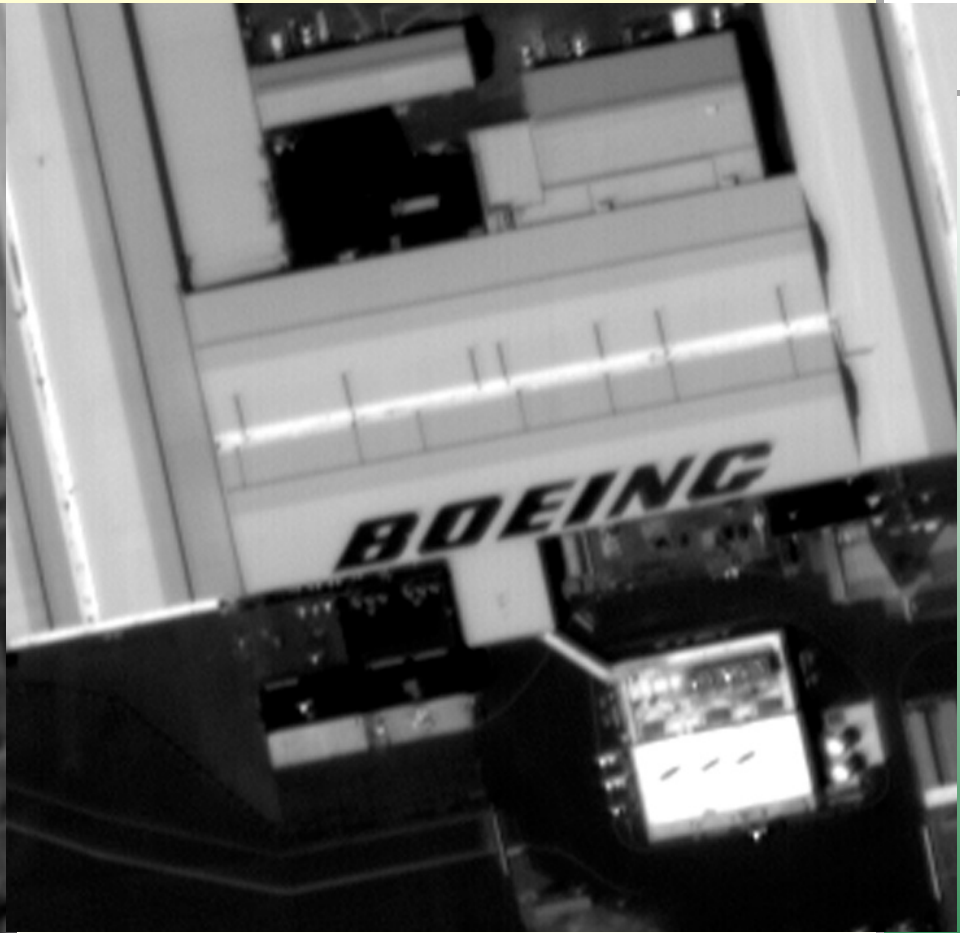
K2 & K3 image data Quality

	KOMPSAT-2 Design	Requirement from user	KOMPSAT-2 (Now)	KOMPSAT-3 after Cal/Val
GSD (PAN)	1m	1m	1m	0.7m
MTF	8%	8%	6%	(8)~10%
MTFC			10~12%	13~20%
SNR (Noise)	>100 (<1%)	>100 (<0.2%)	>100 (<0.2%)	> 200
Radiometric resolution	10bit (1024)	10bit (1024)	10bit (1024)	14bit (16384)
Dynamic range		200	200	
Linearity	4% (10~90%)	<1%	1% (15~90%)	< 1% (5~95%)
Location without GCP	80m CE90	80m CE90	< 80m CE90	< 70m CE90
Mapping (Ortho)	25.4m CE90	5m CE90 (Planimetric)	1:5,000~10,000	1:5,000
Length distortion	< 2% (300pixel)	< 2pixel	< 2pixel	< 2pixel
Registration	±0.3pixel 2σ	0.5pixel 3σ	0.5 pixel 2σ	0.5 pixel 2σ
Imaging mode	Strip		Strip	Strip+Multi+...

Compare of Design for image: K2 & K3

	KOMPSAT-2	KOMPSAT-3	Image data Quality
Star Tracker Location	BUS Frame	Optical Bench	Geometric
Solar Panel	Driving Wing (2)	Static (3)	Geometric
Time Sync.	GPS receiver Local time	UTC	Geometric
Compression	Jpeg like	Wavelet	Radiometric (Noise)
Imaging mode	Strip	Strip+Multi+Stereo	Geometric
CCD	Butting zone	Overlap zone	Geo & Radio
Focal length	Bi-Focal	Uni-Focal	Geometric
PAN : MS	On Each frame	On One frame	Geometric
Radiometric resolution	10bit	14bit	Radiometric
X-band Trans Ant.	9°	15°	Geometric
Spectral band (PAN)	510 ~ 900nm	450 ~ 900nm	Application
NUC table loading	HDD	Memory	Operation
NUC	Analog	Digital	Radiometric

KOMPSAT-2 vs. KOMPSAT-3





KOMPSAT-2,1m PAN sharpened



KOMPSAT-3, 0.7m PAN sharpened

Thank you for KOMPSAT~!

