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Analysis on Refinement of On-orbit MTF Measurement using Edge Target

November 20, 2019

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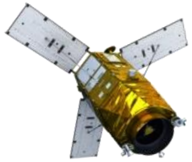
Korea Aerospace Research Institute (KARI)

Shared on JACIE 2018 & CEOS WGCV IVOS #31



References for Spatial Quality

1. [RD1] Mary Pagnutti, Slawomir Blonski, Michael Cramer, Dennis Helder, Kara Holekamp, Eija Honkavaara, and Robert Ryan, 2010, 'Targets, methods, and sites for assessing the in-flight spatial resolution of electro-optical', *Can. J. Remote Sensing*, Vol 36, No 5, 583–601
2. [RD2] Dennis Helder and Francoise Viallefont, 2012, 'A Frame for Geo/Spatial Quality', CEOS WGCV IVOS 24
3. [RD3] Françoise Viallefont-Robinet, Dennis Helder, Renaud Fraisse, Amy Newbury, Frans van den Bergh, DongHan Lee, and Sébastien Saunier, 2018, *Optics Express*, Vol 26, Issue 26, 33625-33648
4. [RD4] DaeSoon Park, HyunHo Kim, YouKyung Seo, JaeHeon Jeong, DooChun Seo, DongHan Lee, 2018, 'Analysis on Refinement of On-orbit MTF Estimation Edge Target', JACIE 2018
5. [RD5] DaeSoon Park, HyunHo Kim, YouKyung Seo, JaeHeon Jeong, DooChun Seo, DongHan Lee, 2019, 'MTF Measurement Algorithm Refining based on KOMPSAT-3 Image', CEOS WGCV IVOS 31

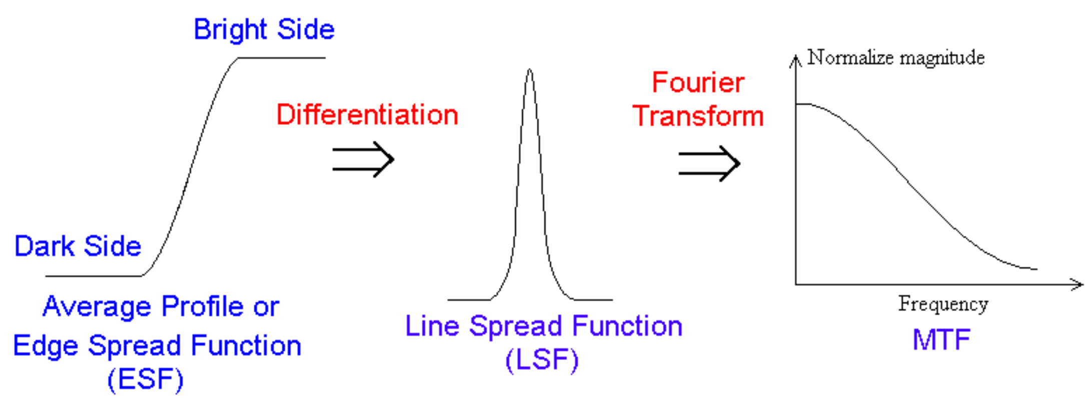
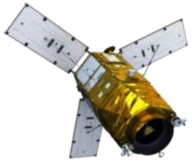
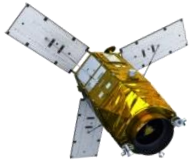


Figure. Processing Steps for Edge target to get ESF, LSF, MTF [RD2]



KARI methodology of MTF Estimation



KARI's Purpose and Works for Spatial Quality

1. **(One of Purpose) Get the reasonable quantity of Spatial quality for remote sensing satellite in *Real conditions*.**

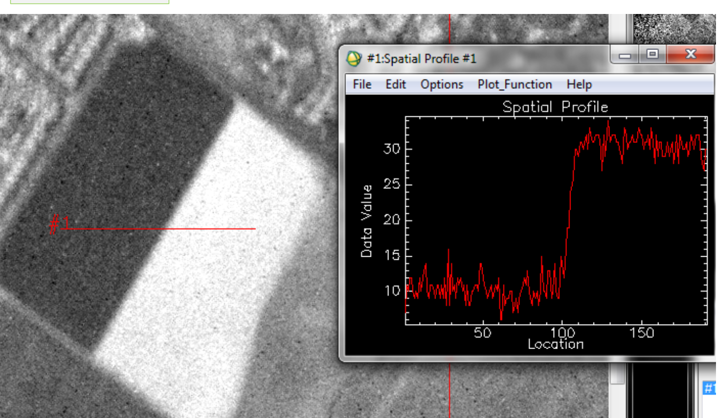
2. **Develop the Definition of the general Spatial quality Estimators**; [RD1]
   a. RER (Relative Edge Response) & Edge Response Slope
   b. FWHM (Full Width at Half Maximum)
   c. MTF curve, and MTF value at Nyquist frequency

3. **Develop the Standard process to get RER, FWHM & MTF**
   a. **Standard target from Artificial (Man-made)** & Natural target [RD1]
      ① Edge, Line (Bar), Point, Periodic target
      ② Database for Artificial & Natural target
   b. Conditions (limitations) for Target & Image data [RD1, 4, 5]
   c. Reference MTF test data
   d. **Standard Processing Step (algorithm) for Edge target** [RD3, 4, 5]
      ① Several options according to the Conditions (limitations)
      ② For target; Edge, Line, Point, Periodic
      ③ For Standard target & For Artificial & Natural target

KARI methodology of MTF Estimation (1/5)

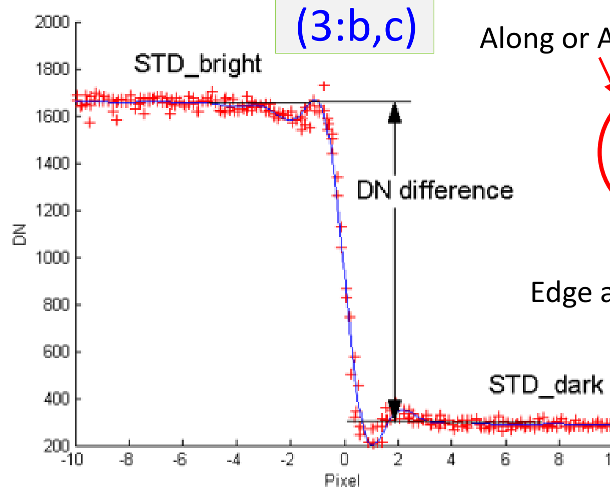
3. Check the status and health of the Edge target image data [RD2, 2.1]
   a. Straight line on Edge
      - ??? (TBD, D1)
   b. Uniformity on Bright and Dark area
      - SNR > 50 (TBR, D2) (Helder, 2002)
   c. DN difference between Bright and Dark
      - ΔDN > 50 (TBR, D3) (Helder, 2002) (Depended on SNR)
   d. Permitted Angle range between Edge and Along / Across direction
      - 0 ~ 30deg (TBR, D4) (Depended on Fitting method by No. of sample)
   e. Number of Edge line
      - > 10~20 pixels (TBR, D5) (Depended on Fitting method by No. of sample)
   f. Width of Bright and Dark area
      - > 5 pixels (TBR, D6)

(3:b,c)



Because of low SNR, it is impossible to calculate the RER, FWHM, MTF.

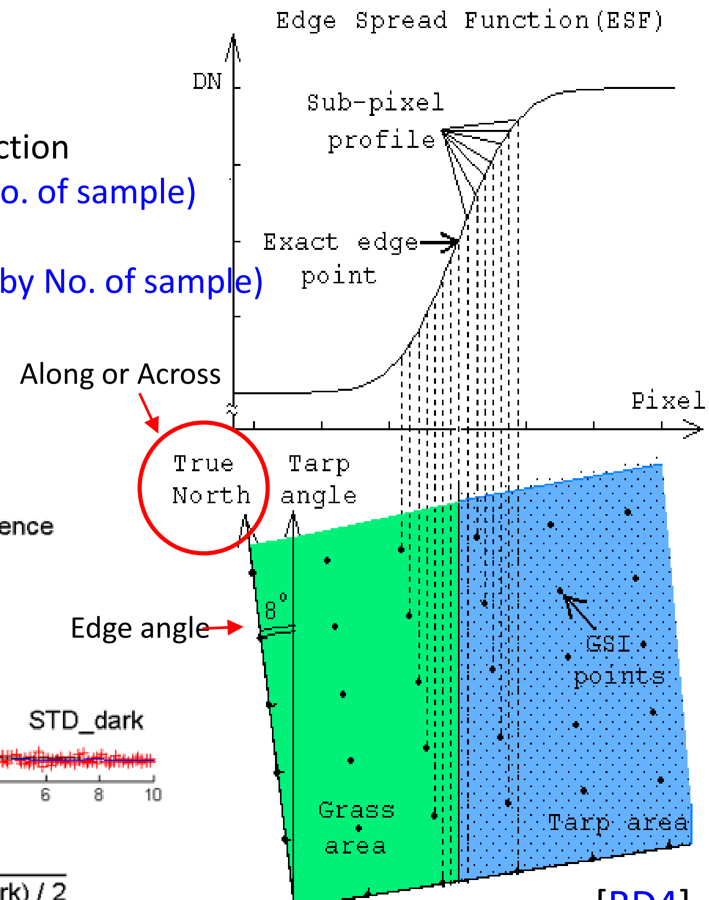
(3:b,c)



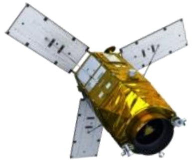
$$SNR = \frac{\text{DN difference}}{(\text{STD\_bright} + \text{STD\_dark}) / 2}$$

[RD4]

(3:d)

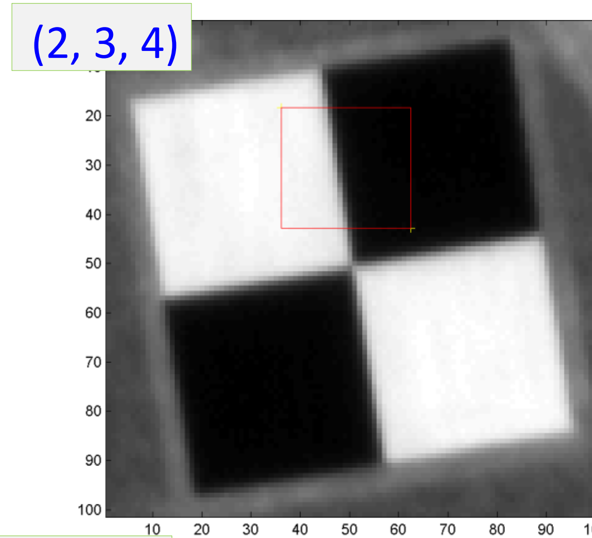


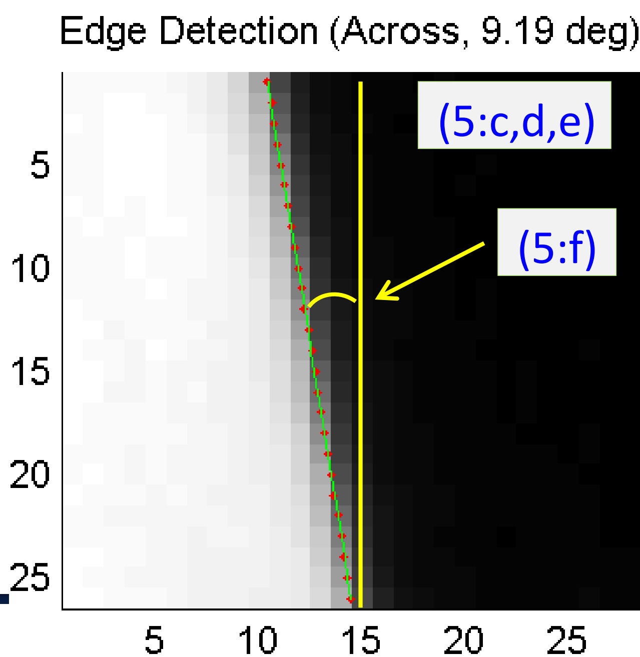
[RD4]

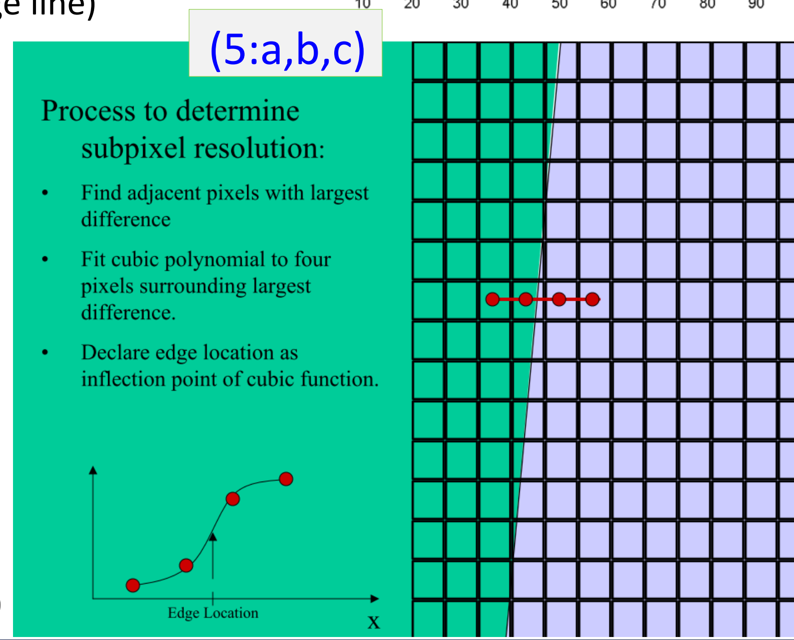


KARI methodology of MTF Estimation (2/5)

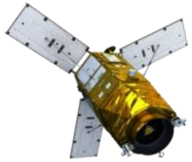
4. Select and Determine ROI of Edge on the Edge image data [RD2, 2.1]
   a. Determine Along & Across direction
   b. Determine Bright and Dark side
5. Detect the Edge line on ROI
   a. At every line, Find adjacent pixels with largest difference
   b. Fit cubic polynomial (TBC, E1) to (more than) 4 pixels (TBC, E2) surrounding largest difference
   c. Declare edge location as inflection point of cubic function (Red dot) (TBC, E3)
   d. Linear fitting with all edge locations of lines (Green line) (Fit Err.)
   e. Get the Edge line (Green line)
   f. Calculate the Angle of Edge line (ɵ; Along/Across vs. Edge line)







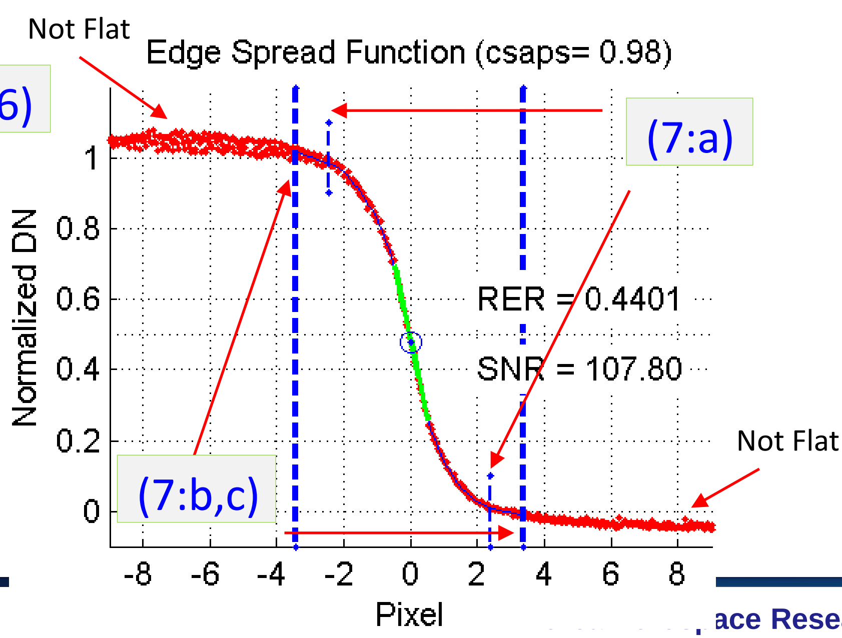
(Helder, 2001)

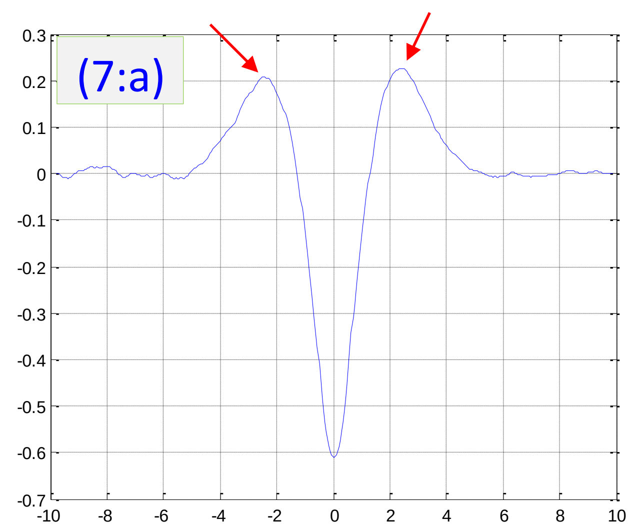


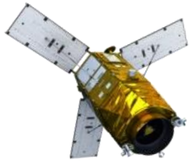
KARI methodology of MTF Estimation (3/5)

6. Get & Plot Edge Spread Function (ESF) with Pixel data
   a. Divide 'the Relative distance of every pixel' by 'cos(ɵ); Edge angle, Along/Across vs. Edge line'
   b. (X-axis) Relative distance of every pixel from the Edge line on the each line by pixel unit
   c. (Y-axis) DN value of each pixel (Red dot)

7. Decide the Starting point of the Bright & Dark area (Because Bright & Dark area are not Flat~!)
   a. Inflection point on LSF for the Starting point (TBR, F1)
      I. Fitting (Cubic Smoothing Spline; TBR, F2) with Pixel data
      II. Differential Fitted ESF to LSF
      III. 2 more Differential LSF for the Inflection point
   b. The width of Bright / Dark area; 1 pixel (TBR, F3)
   c. Trim ESF with Pixel data with Bright / Dark area (Blue dot Line)

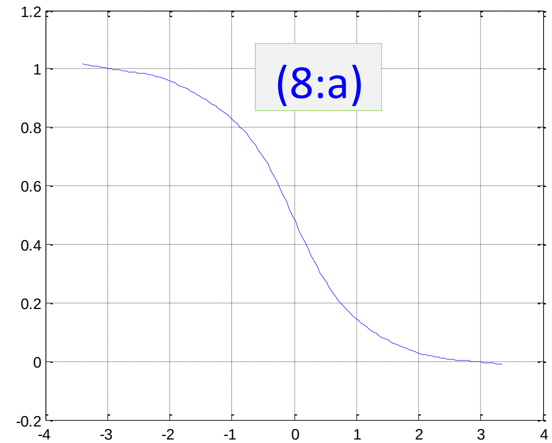


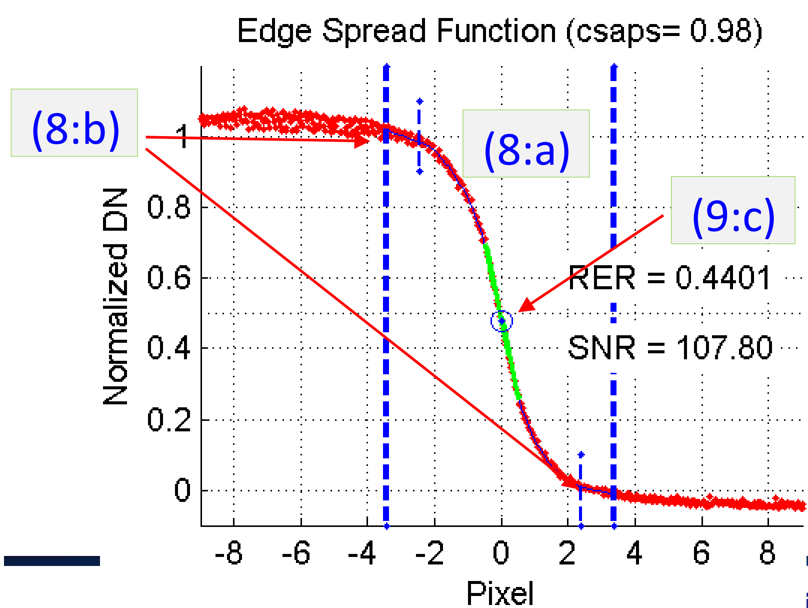


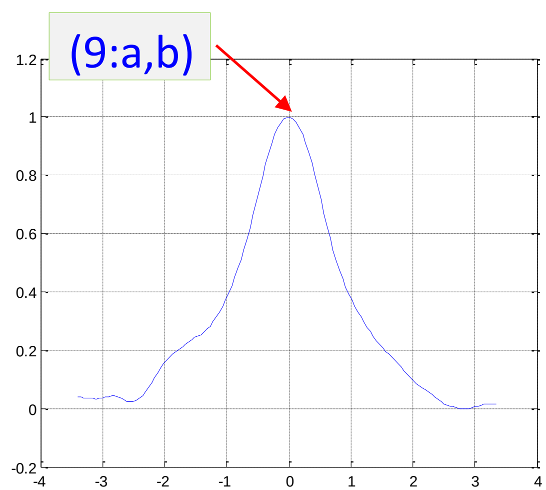


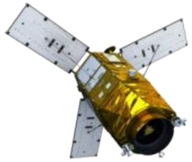
KARI methodology of MTF Estimation (4/5)

8. Calculate and Plot ESF by Fitting from the Trimmed ESF pixel data
   a. Fitting by the next (according to the Asymmetric LSF) (TBD, B1);
      I. Parametric (Fermi-Dirac)
      II. Non-parametric (Cubic Smoothing Spline, Savitzky-Golay)
         • KARI: 'CSAPS (0.98)' in Matlab
   b. Normalization by fitted ESF, and Plot
9. Calculate Relative Edge Response (RER) (by one pixel)
   a. Differential ESF and get LSF ('8')
   b. The Inflection point (Top) is the Center of RER (TBR, H1)
      • Because of Asymmetric LSF
   c. Calculate RER by one pixel (Green line)
   d. If Parametric fitted ESF,
      • The Center of RER is '0.5' on Normalized DN







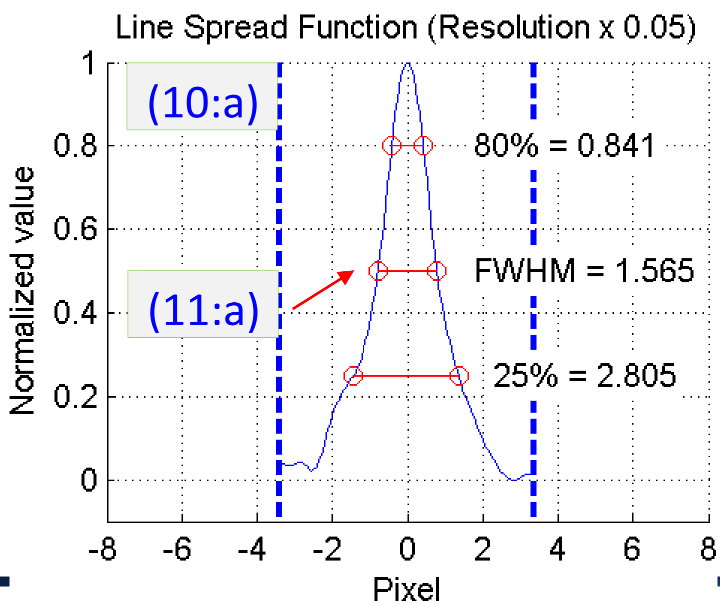


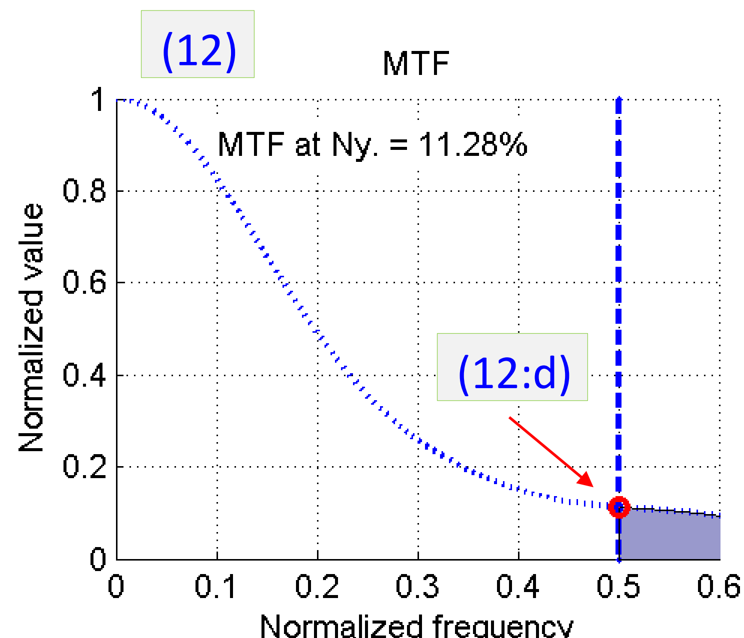
KARI methodology of MTF Estimation (5/5)

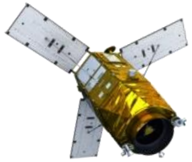
10. Calculate and Plot Line Spread Function (LSF)
    a. Differential ESF and get LSF ('8')

11. Calculate Full Width at Half Maximum (FWHM)
    a. FWHM (50%)
    b. 80%, 25% (if Parametric Fitting, and in Optional)

12. Calculate and Plot MTF (Modulation Transfer Function)
    a. Calculate Nyquist frequency
    b. FFT apply to LSF
    c. Plot MTF
    d. Get MTF value at Nyquist frequency (Red dot)





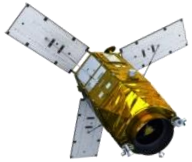


TBD, TBR, TBC on KARI's MTF Estimation

No.		Item	Content	Link	TB.
A	1	**Reference target**	Status of Reference target		TBD
	2	**Natural target**	What is Requirements of Natural target?		TBR
	3	**Satellite Resolution**	(Loosely) Link to Satellite Resolution	D1	TBR
B	1	**Asymmetric PSF & LSF**	How to reflect and handle Asymmetric PSF & LSF	H1	TBD
C	1	**RER, FWHM, MTF**	What is the best Reasonable (Representative) Estimator?	H1	TBD
D	1	**Straight Line on Edge**	Limitation of Straight line by One pixel	A3	TBD
	2	**Uniformity on Bright & Dark area**	Limitation of Uniformity on Bright and Dark area by SNR (> 50)		TBR
	3	**DN Difference between Bright and Dark area**	Limitation of DN Difference between Bright and Dark area by SNR (> 50)		TBR
	4	**Angle between Edge and Along / Across direction**	Permitted Angle range between the Edge and Along / Across direction (0~30deg) (Depended on Fitting method by No. of sample)	G1	TBR
	5	**Number of Pixel on Edge line**	Limitation of Number of Pixel on Edge line (> 10~20 pixels) (Depended on Fitting method by No. of sample)	G1	TBR
	6	**Width of Bright & Dark area**	Width (pixel) of Bright and Dark area (> 5 pixels)		TBR
E	1	**Fitting Cubic polynomial**	Fitting Cubic polynomial for Detecting the Edge line on ROI		TBC
	2	**4 pixels for Edge detecting**	4 pixels for Detecting the Edge line on ROI		TBC
	3	**Edge location as Inflection point of Cubic function**	Edge location as Inflection point of Cubic function for Detecting the Edge line on ROI		TBC
F	1	**Inflection point on LSF for Starting point**	What is Starting point of Bright & Dark area		TBD
	2	**Fitting (Cubic Smoothing Spline) for 'F1'**	Fitting method (Cubic Smoothing Spline) for Inflection point on LSF for Starting point, and Weight value of Cubic Smoothing Spline	F1	TBR
	3	**Width of Bright / Dark area**	Width of the Bright & Dark area from the Starting point (1 pixel)		TBR
G	1	**Fitting method on ESF**	What it the optimal fitting method on ESF?		TBD
H	1	**Inflection point as RER Center**	What is Center of RER; Inflection point (Top) on LSF or Half DN	B1,C1	TBR

Analysis on Refinement of On-orbit MTF Measurement using Edge Target

(TBD, TBR in Previous Table)



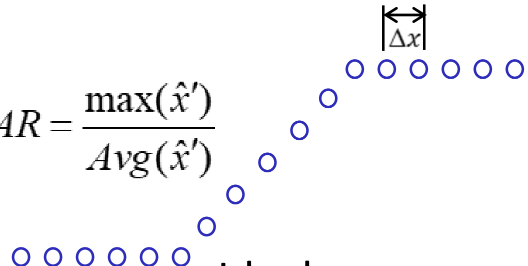
(D4, D5) Optimal Angle & No. of Edge line

- **at CEOS WGCV IVOS #30 – GeoSpatial W/G (March 27, 2018)**
  - DaeSoon Park, JaeHeon Jung, DooCheon Seo, YouKyung Seo, DongHan Lee
  - 'Validation of MTF Measurement method by Edge Target' (Optimum angle versus sample of lines for slant-edge method)

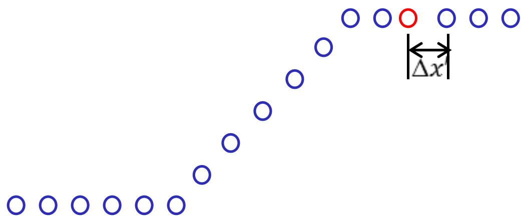
No.		Item	Content	Link	TB.
D	4	**Angle between Edge and Along / Across direction**	Permitted Angle range between the Edge and Along / Across direction (0~30deg) (Depended on Fitting method by No. of sample)	G1	TBR
	5	**Number of Pixel on Edge line**	Limitation of Number of Pixel on Edge line (> 10~20 pixels) (Depended on Fitting method by No. of sample)	G1	TBR

- **SDPAR(Subpixel Distance Peak to Average Ratio)**
  - For ideal
    - SDPAR = 1
  - For non-ideal(real)
    - SDPAR > 1

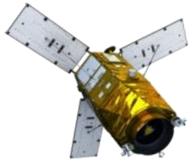
$$SDPAR = \frac{\max(\hat{x}')}{Avg(\hat{x}')}$$



Ideal case

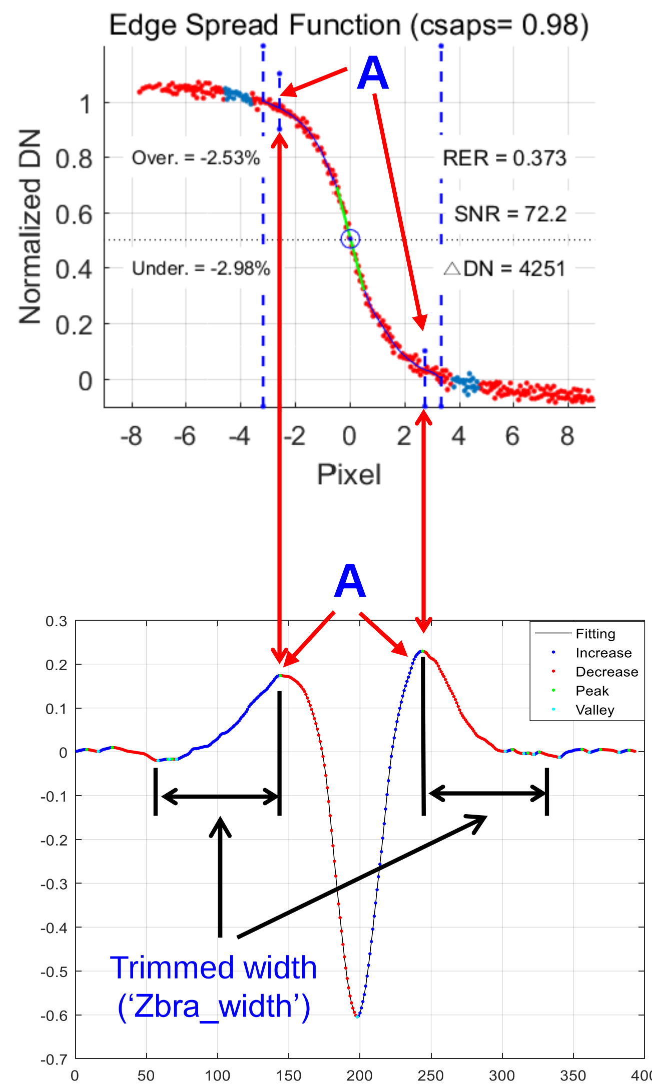


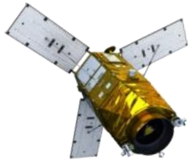
Non-ideal case



(D6, F1, F3) Trimmed width on ESF

- **(D6) Width of Bright & Dark area**
  - Width (pixel) of Bright and Dark area on Edge target image (> 5 pixels)
- **(F1) Inflection point on LSF for Starting point**
  - Starting point of Bright & Dark area
- **(F3) Edge location as Inflection point of Cubic function**
  - Width of the Bright & Dark area from the Starting point (1 pixel)
- **Inflection point (because Asymmetric PSF)**
  - Peak points comes out by Laplacian operation(▽) of ESF
- **Trimmed point**
  - Inflection point ± Trimmed width ('Zbra_width')
- **Trimmed width (1 pixel, Now)**
  - 'Zbra_width': Parameter in KARI MTF Code
  - Trimmed pixels from Inflection point (A)

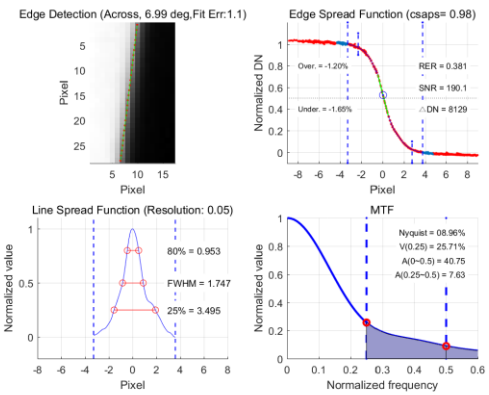




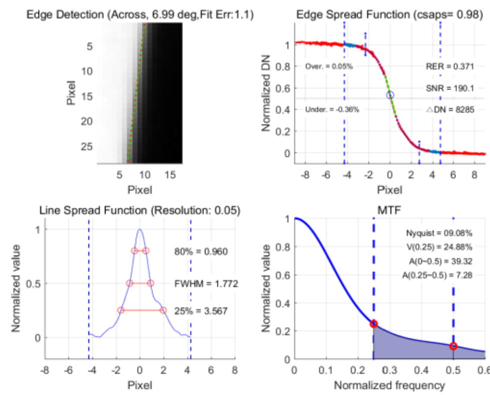
(D6, F1, F3) Trimmed width: 'Zbra_width'

- **Trimmed width: 'Zbra_width'**
  - Selected uniform width from Inflection point: 1 → 2 → 3 → 4 → 5

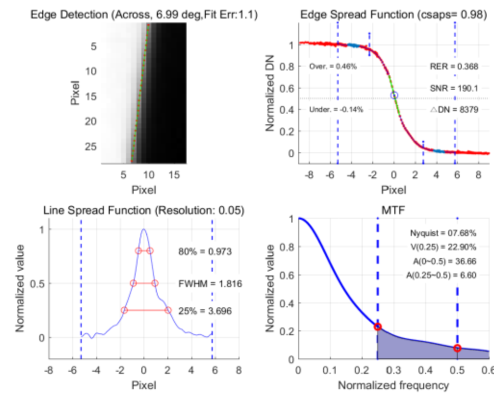
Zbra_width = 1



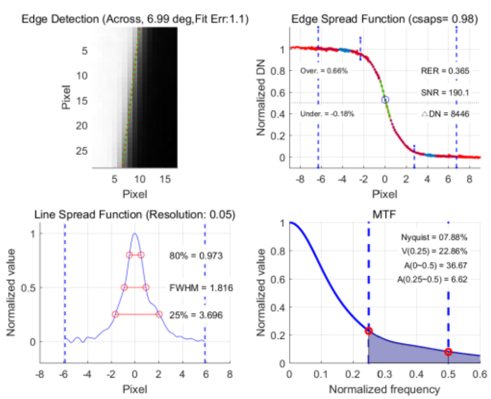
Zbra_width = 2



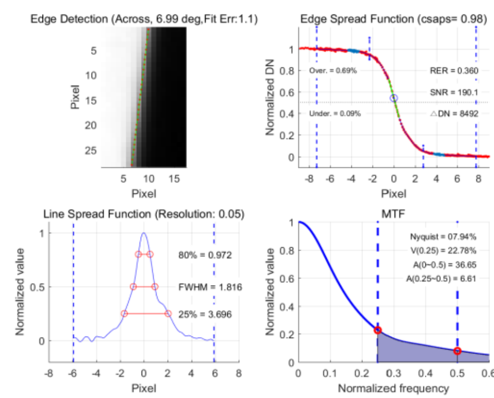
Zbra_width = 3

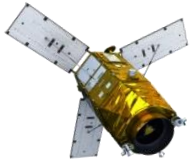


Zbra_width = 4



Zbra_width = 5

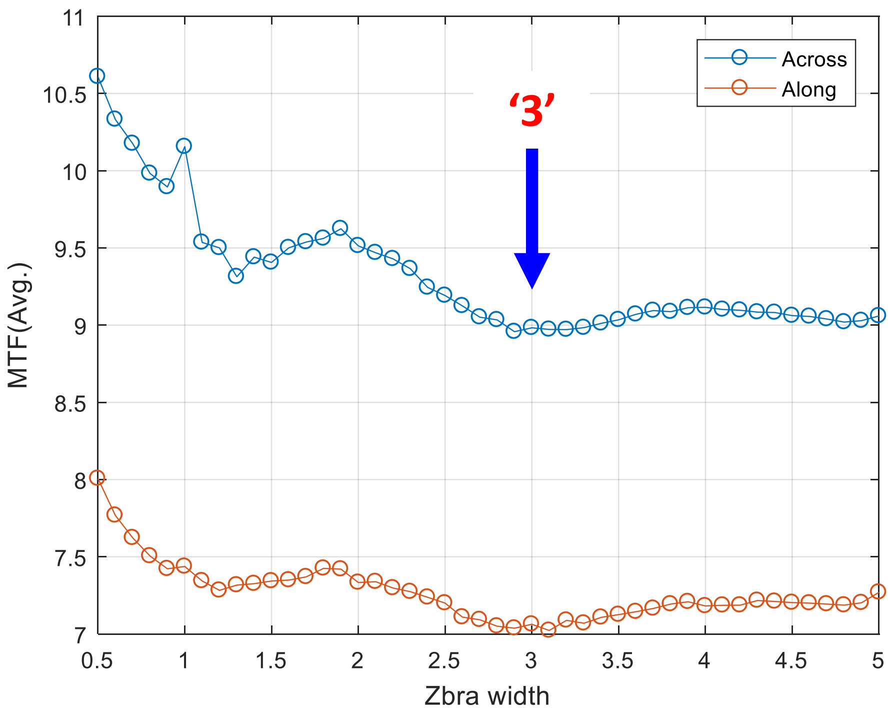




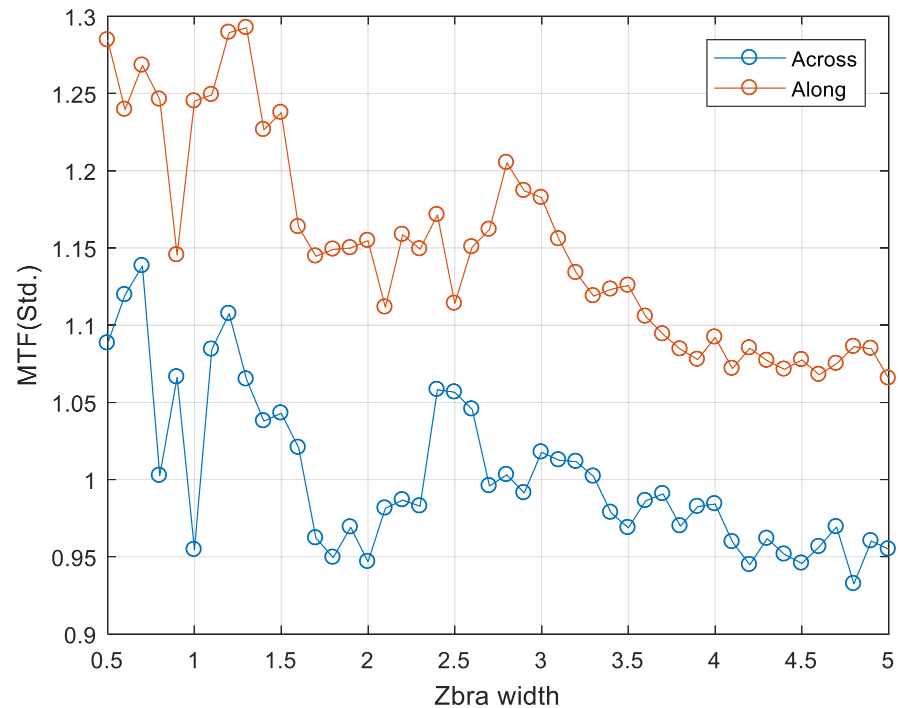
(D6, F1, F3) Trimmed width Analysis

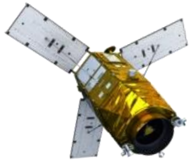
- **MTF vs. Trimmed width**
  - MTF value goes 'zero’ with 'Zbra_width = 3’

MTF (Average)



MTF (Std.Dev)

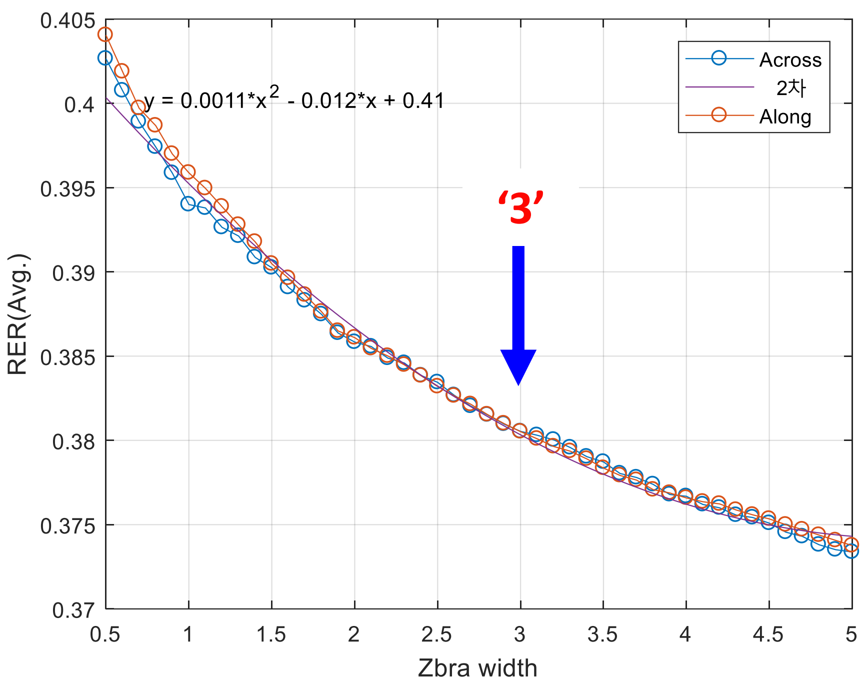




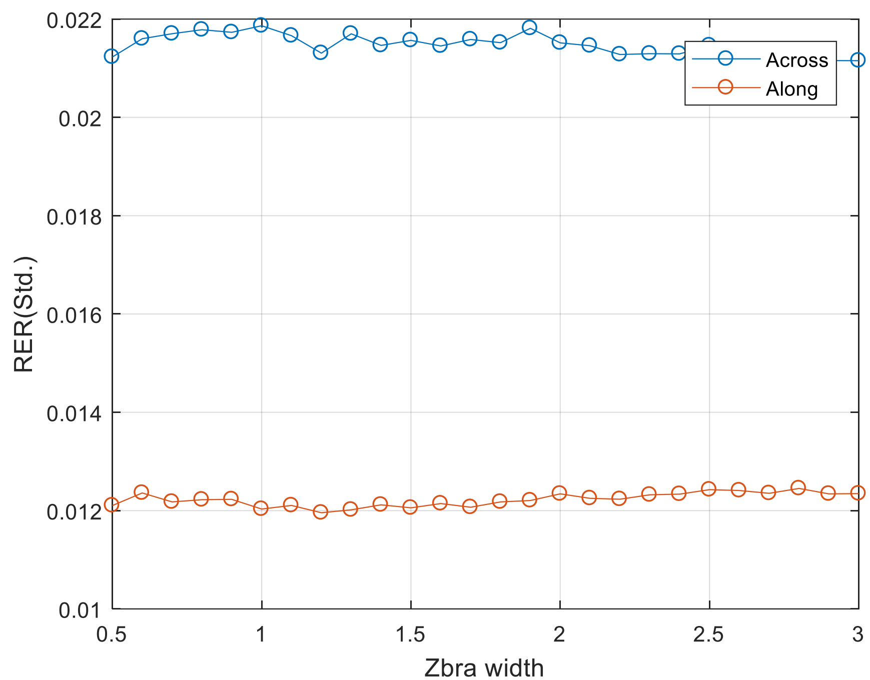
(D6, F1, F3) Trimmed width Analysis

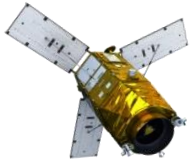
- **RER vs. Trimmed width**
  - RER value is inversely proportional to the trimmed width clearly.
  - RER doesn’t go 'zero’ with 'Zbra_width = 3’ (????)

RER (Average)



RER (Std.Dev)

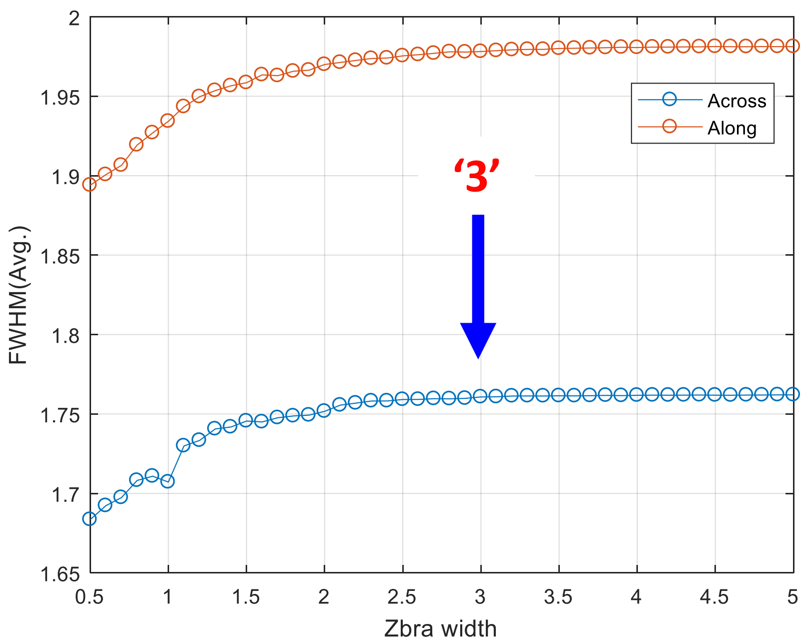




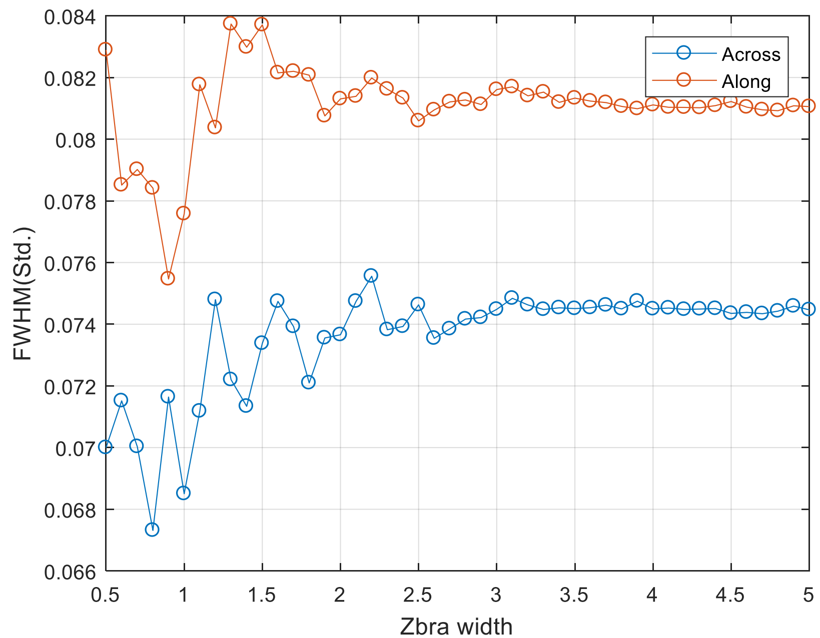
(D6, F1, F3) Trimmed width Analysis

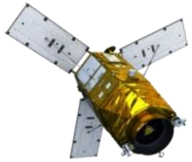
- **FWHM vs. Trimmed width**
  - FWHM goes 'zero’ with 'Zbra_width = 3’
  - FWHM shows a proportional dependency to Trimmed width

FWHM (Average)



FWHM (Std.Dev)

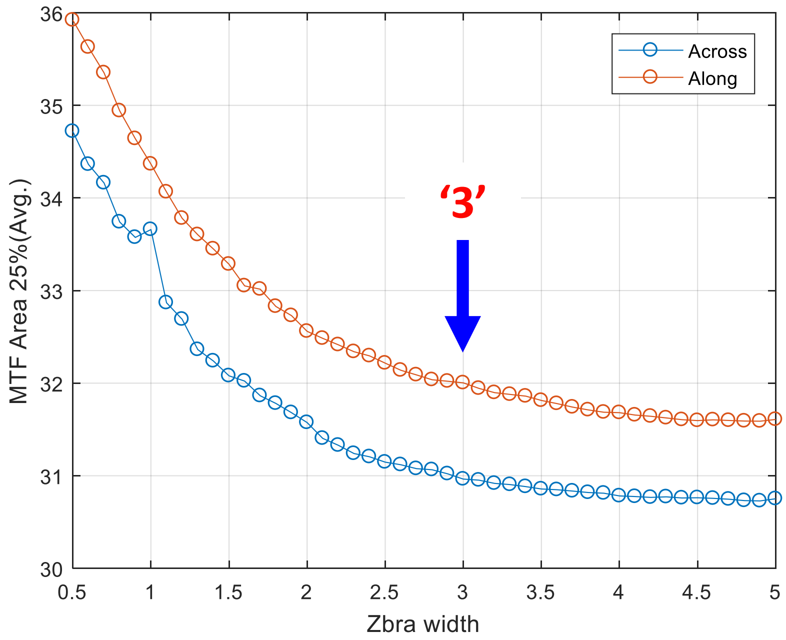




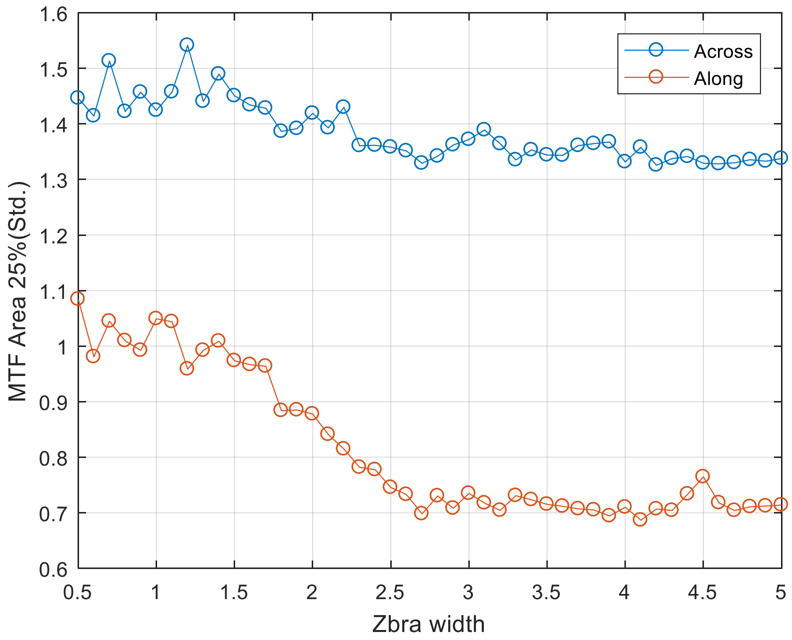
(D6, F1, F3) MTF Curve

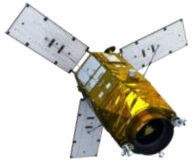
- **MTF area(25%) is shrinking and tends to converge**

MTF area(25%) (Average)



MTF area(25%) (Std.Dev)



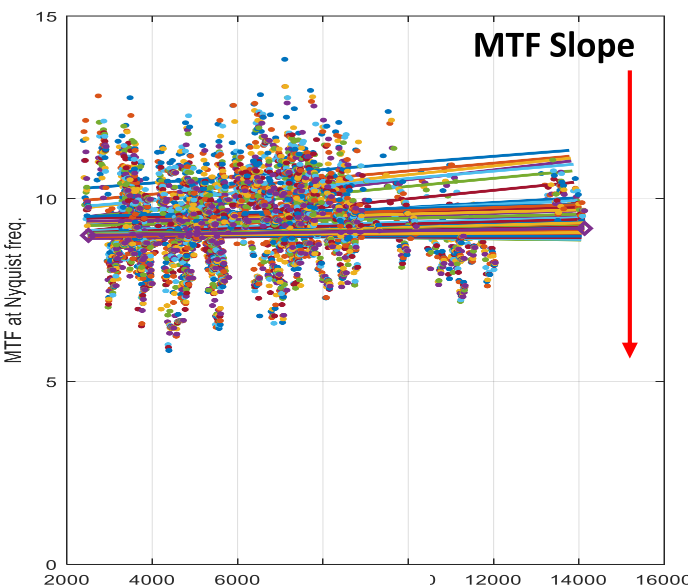


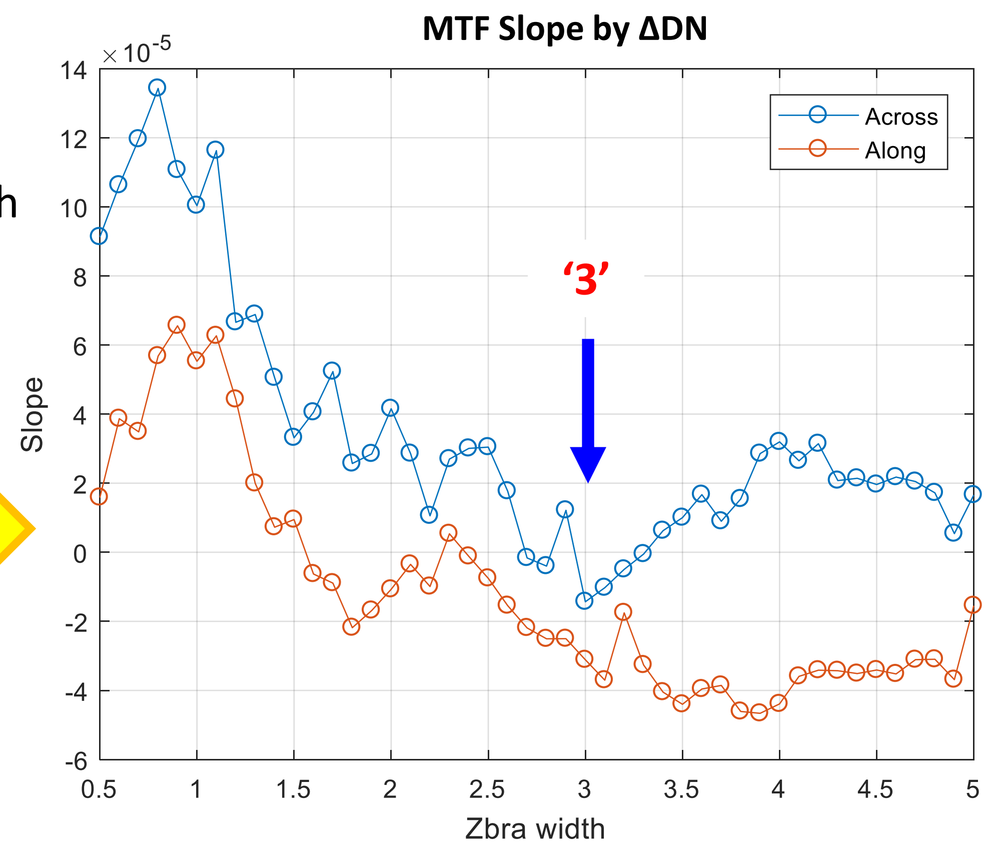
(D3, D6, F1, F3) Trimmed width Analysis

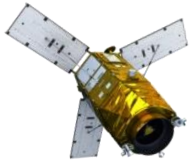
- **(D3) DN Difference between Bright and Dark area**
  - Limitation of DN Difference between Bright and Dark area by SNR (> 50)
- **(Oct.03, 2015 ~ Mar.16, 2017) Edge target at Baotou, Mongol, Salon (123 EA)**

- **MTF vs. ΔDN with Zbra_width**
  - 'Slope' goes 'zero' with 'Zbra_width = 3'

※ 'Zbra_width' denoted trimmed width

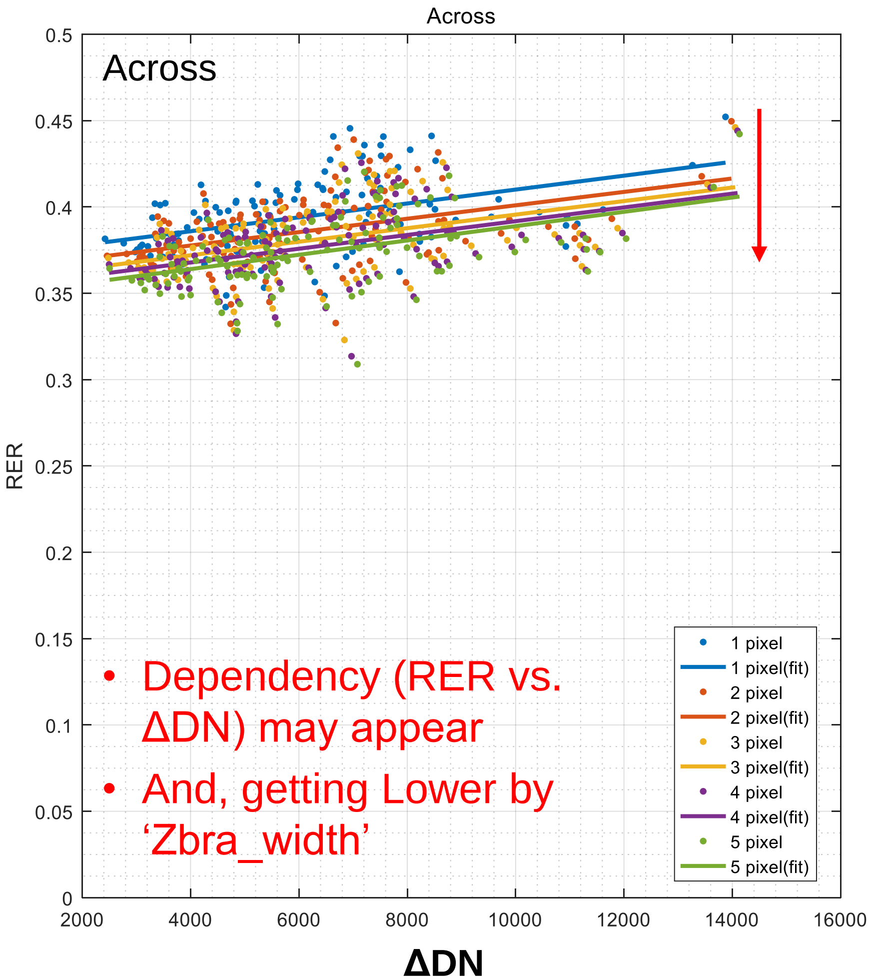


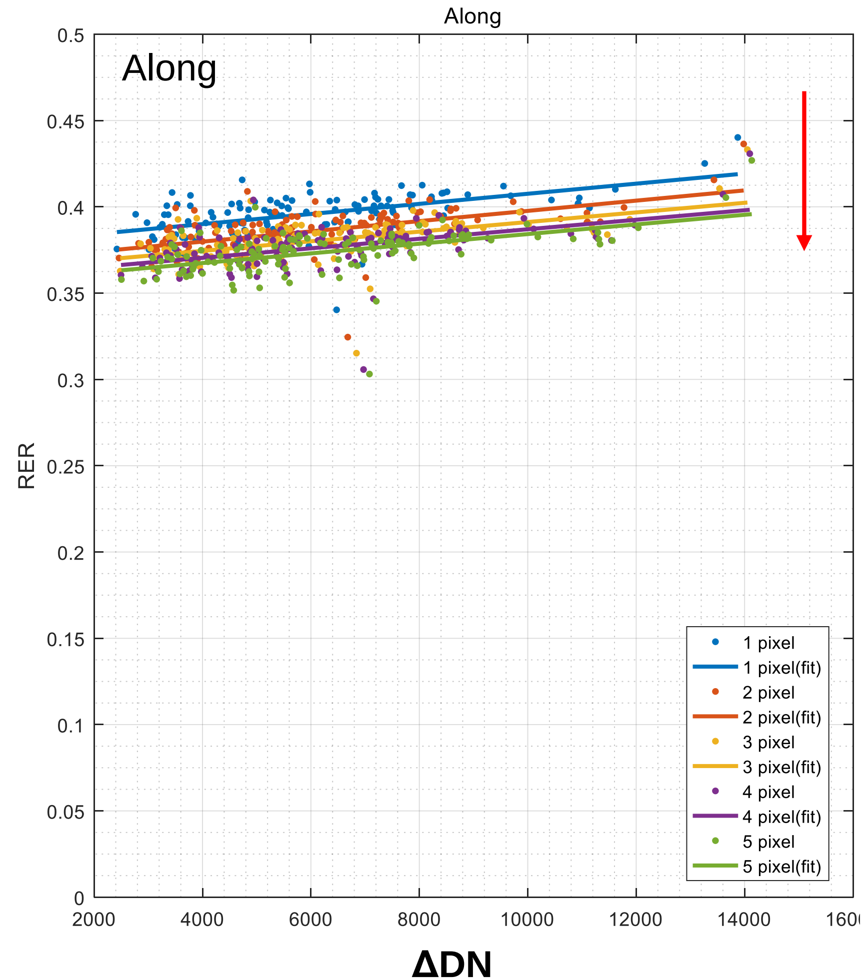


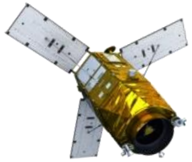


(D3, D6, F1, F3) RER vs. ΔDN with Zbra_width

- (Oct.03, 2015 ~ Mar.16, 2017) Edge target at Baotou, Mongol, Salon (123 EA)

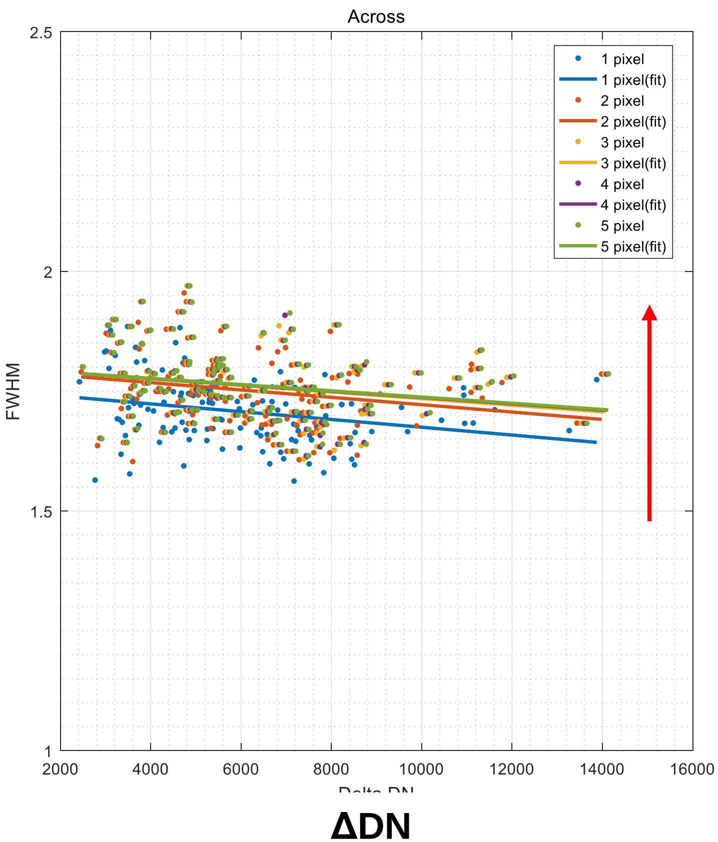


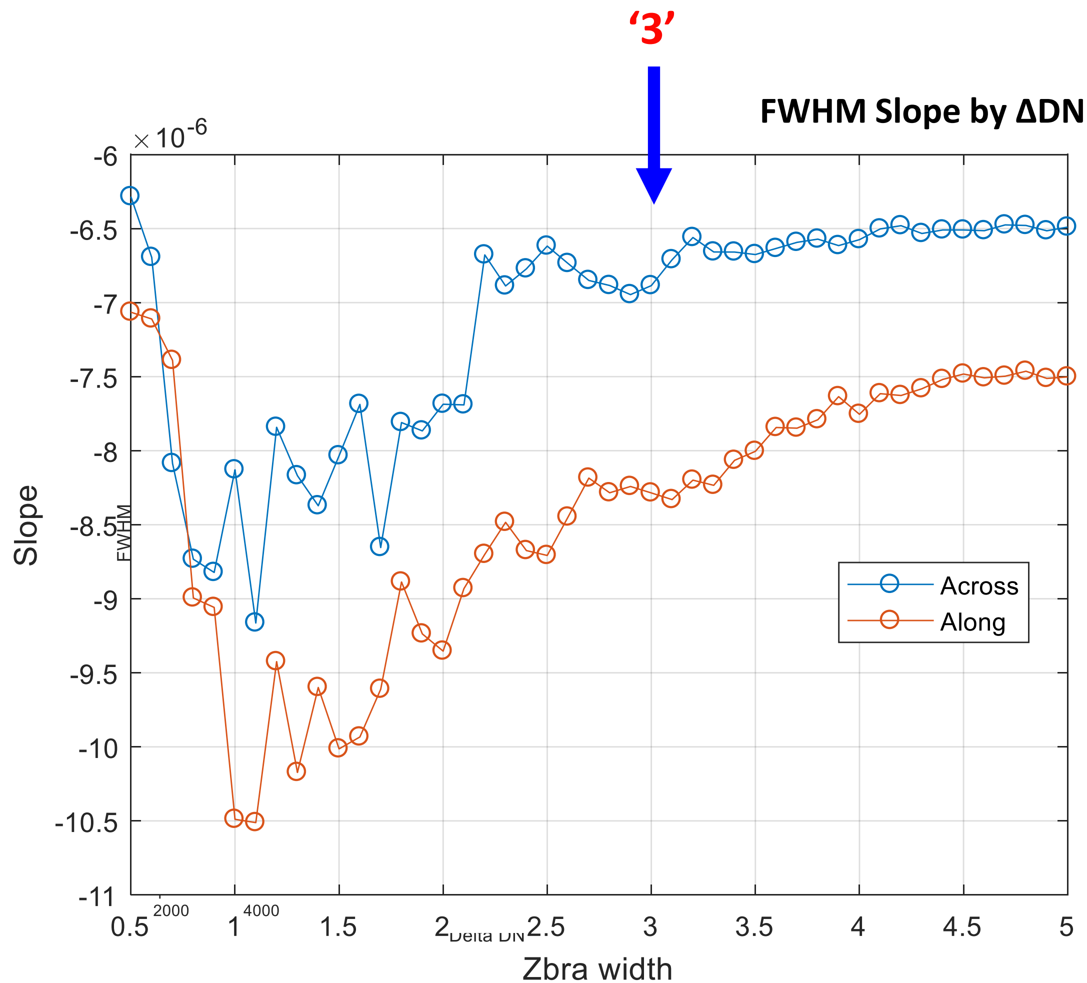




(D3, D6, F1, F3) FWHM vs. ΔDN with Zbra_width

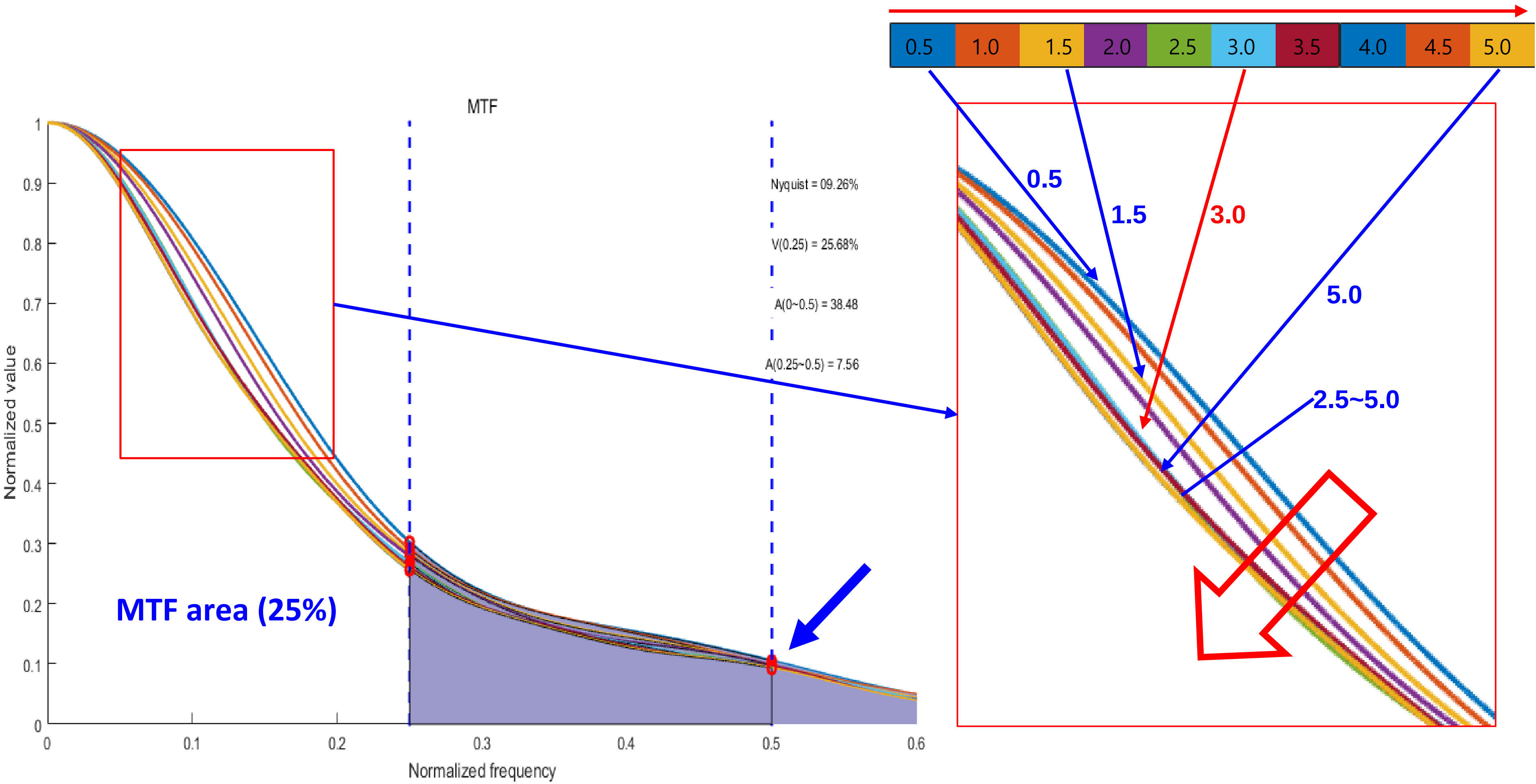
- **(Oct.03, 2015 ~ Mar.16, 2017) Edge target at Baotou, Mongol, Salon (123 EA)**
  - ‘Slope’ goes 'zero’ with 'Zbra_width = 3’

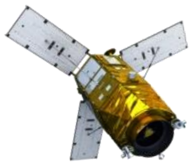




(D6, F1, F3) MTF Curve

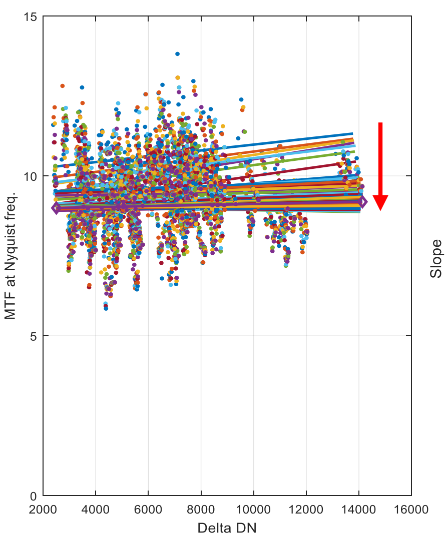
- **Normalized area is shrinking by Trimmed width**
  - More stabilized value at Nyquist Freq.

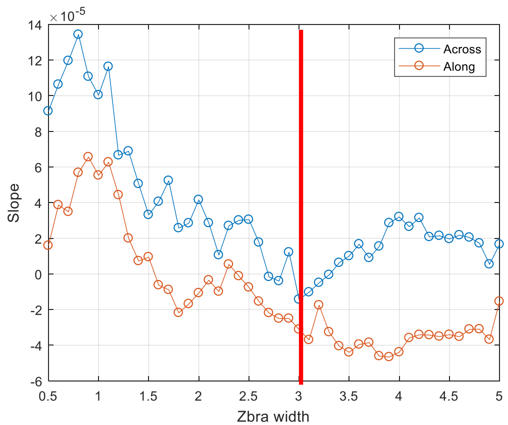


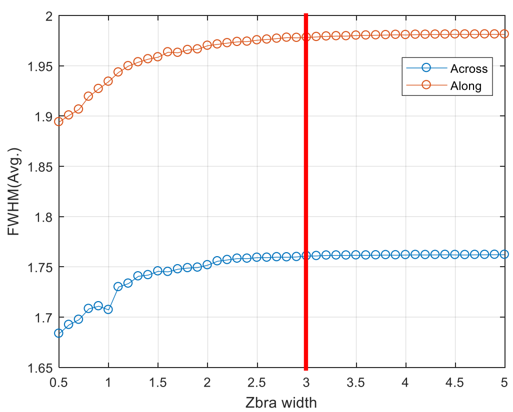


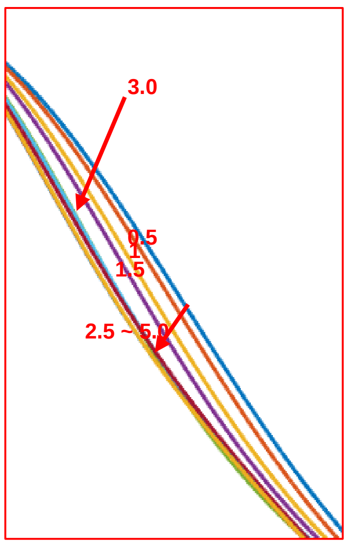
(D3, D6, F1, F3) Summary of 'Zbra_width'

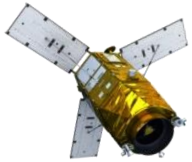
- **Trimmed(Zbra_width) width: 1 → '3' (from Inflection point)**
  - RER dependency for ΔDN appears
    - But, Need to decide the recommended ΔDN value
  - FWHM converges
  - MTF curve and area converges









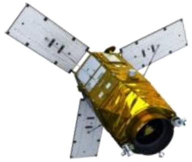


(D6, F1, F3) Result of ‘Zbra_width’

- ‘Edge target at Baotou, Mongol, Salon (212 EA) (KOMPSAT-3A)
- Getting Lower Spatial quality by ‘Zbra_width’ = ‘3’
  - But, More Reliable~!

Total (212EA)

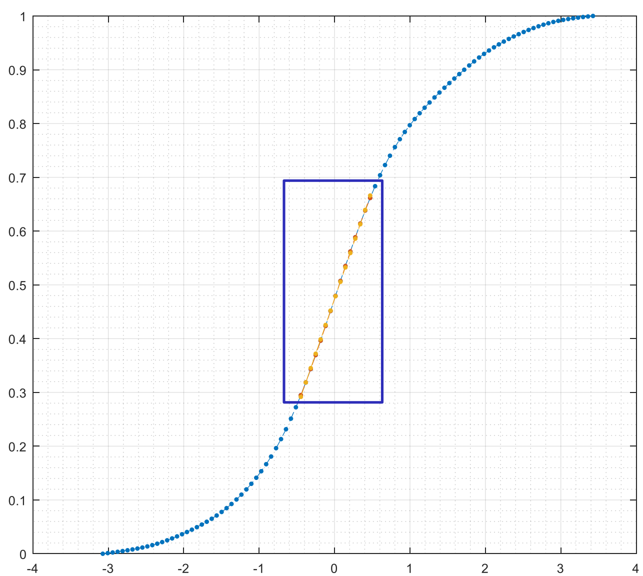
Zbra_width		Across				Along			
		Avg	Std.	Std/Avg	RMSE/Avg	Avg	Std.	Std/Avg	RMSE/Avg
1	RER	0.3837	0.0209	0.0544	0.0409	0.3858	0.0120	0.0312	0.0298
	FWHM	1.7545	0.0823	0.0469	0.0406	1.9730	0.0845	0.0428	0.0414
	MTF	9.7302	1.0060	0.1034	0.0965	7.2493	1.1242	0.1551	0.1513
Zbra_width		Across				Along			
		Avg	Std.	Std/Avg	RMSE/Avg	Avg	Std.	Std/Avg	RMSE/Avg
3	RER	0.3747	0.0203	0.0542	0.0412	0.3758	0.0121	0.0321	0.0311
	FWHM	1.7709	0.0824	0.0465	0.0410	1.9865	0.0840	0.0423	0.0410
	MTF	9.1192	0.9231	0.1012	0.0966	7.0840	1.0941	0.1544	0.1482
Diff.	RER	**-0.0090**	**-0.0006**	**-0.0002**	**0.0003**	**-0.0100**	**0.0001**	**0.0009**	**0.0013**
	FWHM	**0.0164**	**0.0001**	**-0.0004**	**0.0004**	**0.0135**	**-0.0005**	**-0.0005**	**-0.0004**
	MTF	**-0.6110**	**-0.0829**	**-0.0022**	**0.0001**	**-0.1653**	**-0.0301**	**-0.0007**	**-0.0031**

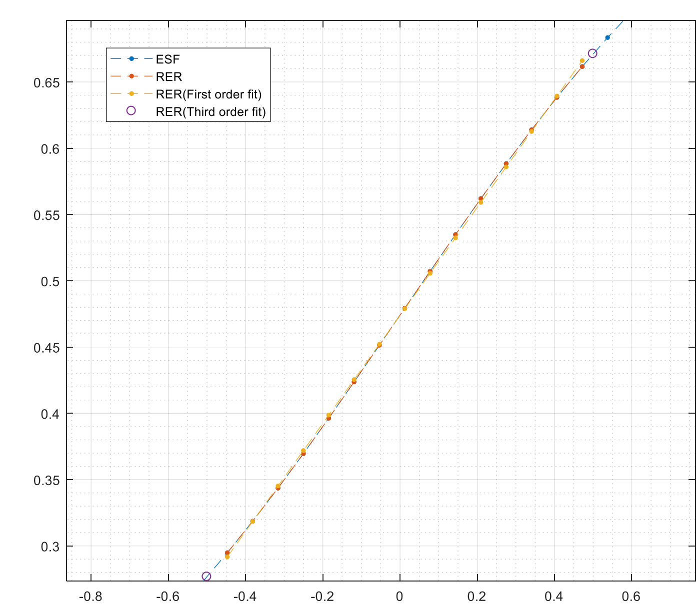


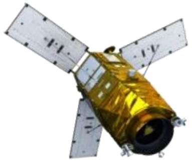
(H1) RER Center Analysis

- **(H1) Inflection point as RER Center (because Asymmetric PSF)**
  - What is Center of RER; Inflection point (Top) on LSF or Half DN
- **Case 1 (‘C1’, Now)**
  - First order fitting using samples within <u>slope at Inflection point</u> ±0.5 pixel
- **Case 2 (‘C2’)**
  - Third order fitting using samples within <u>slope at Inflection point</u> ±0.5 pixel

RER = | ESF(+0.5) - ESF(-0.5) |

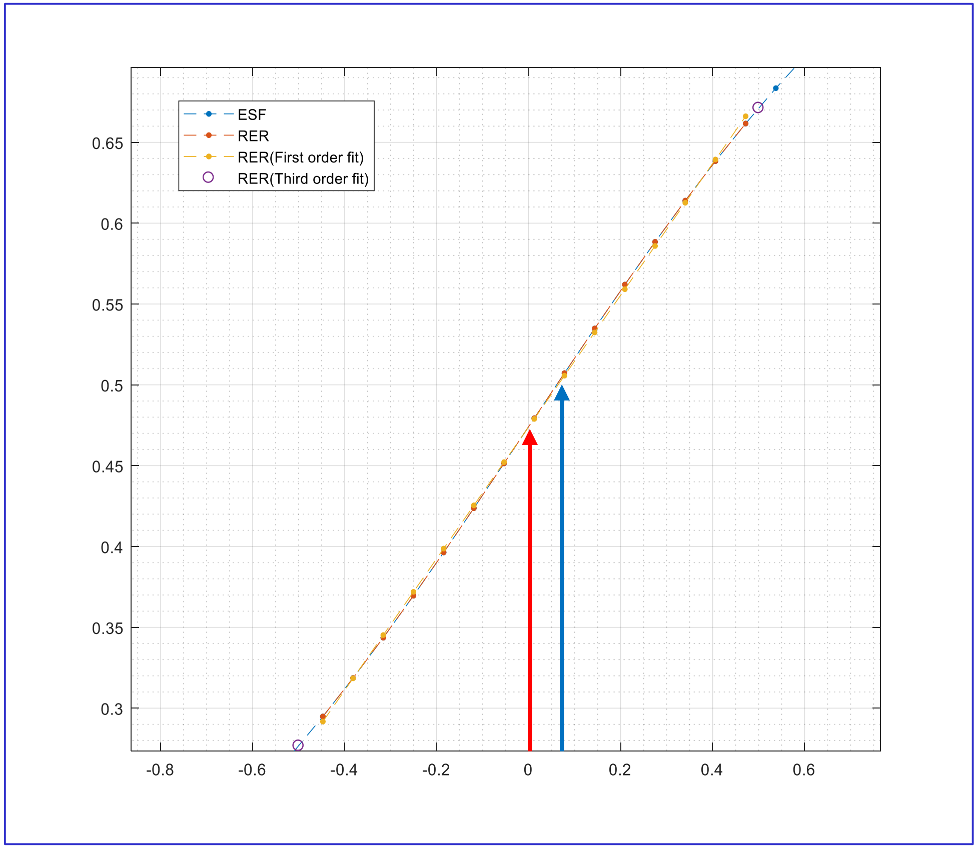






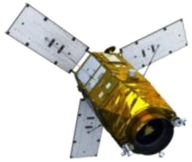
(H1) RER Center Analysis

- **Case 3 ('C2')**
  - First order fitting using samples within half DN point ±0.5 pixel
- **Case 4 ('C3')**
  - Third order fitting using samples within half DN point ±0.5 pixel



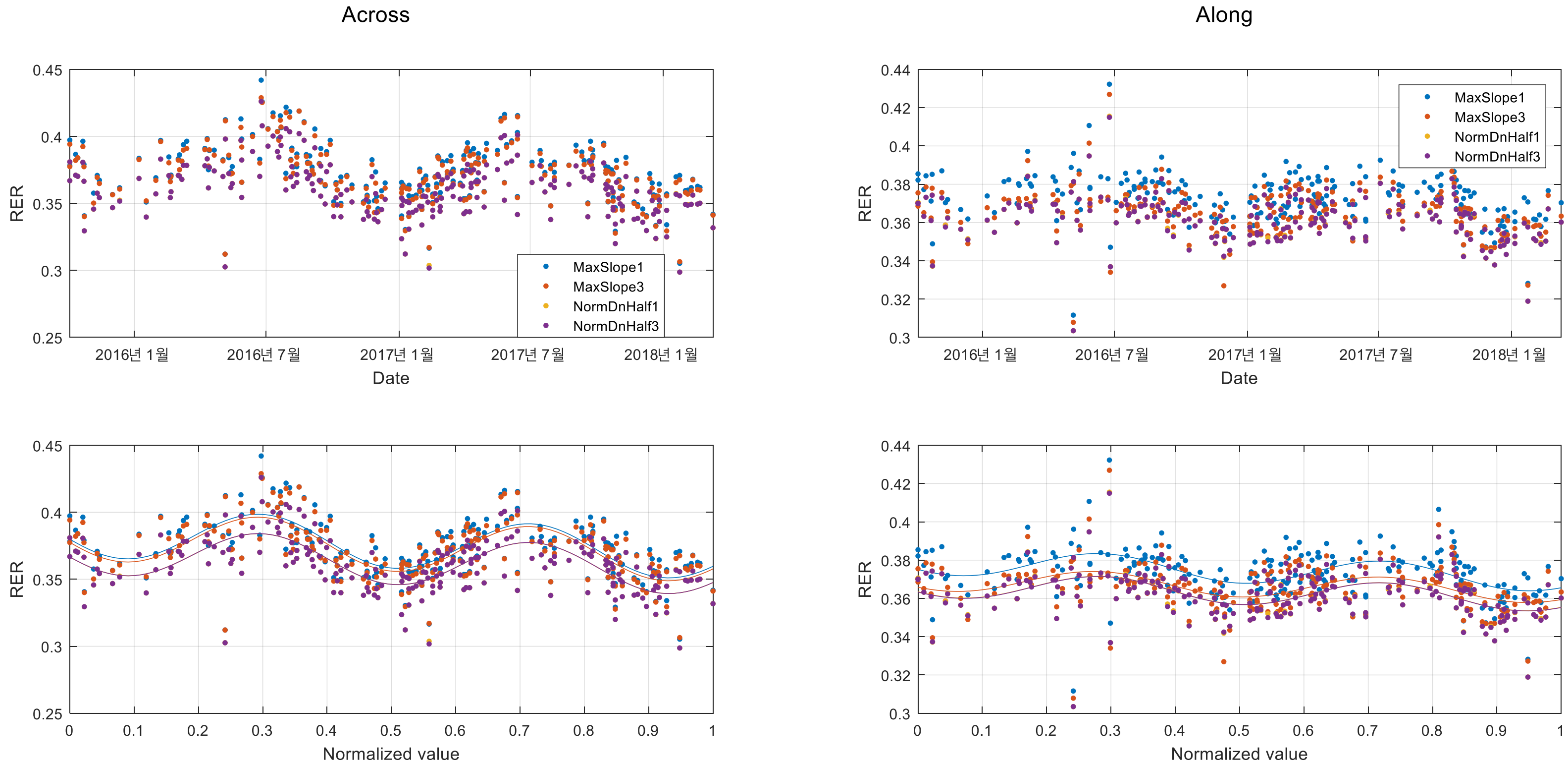
Inflection (C1, C2)

Half DN (C3, C4)

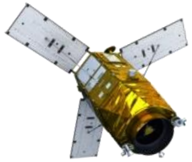


(H1) RER Center Analysis

- **Slope of Inflection point(1st) is promising for sensitivity**

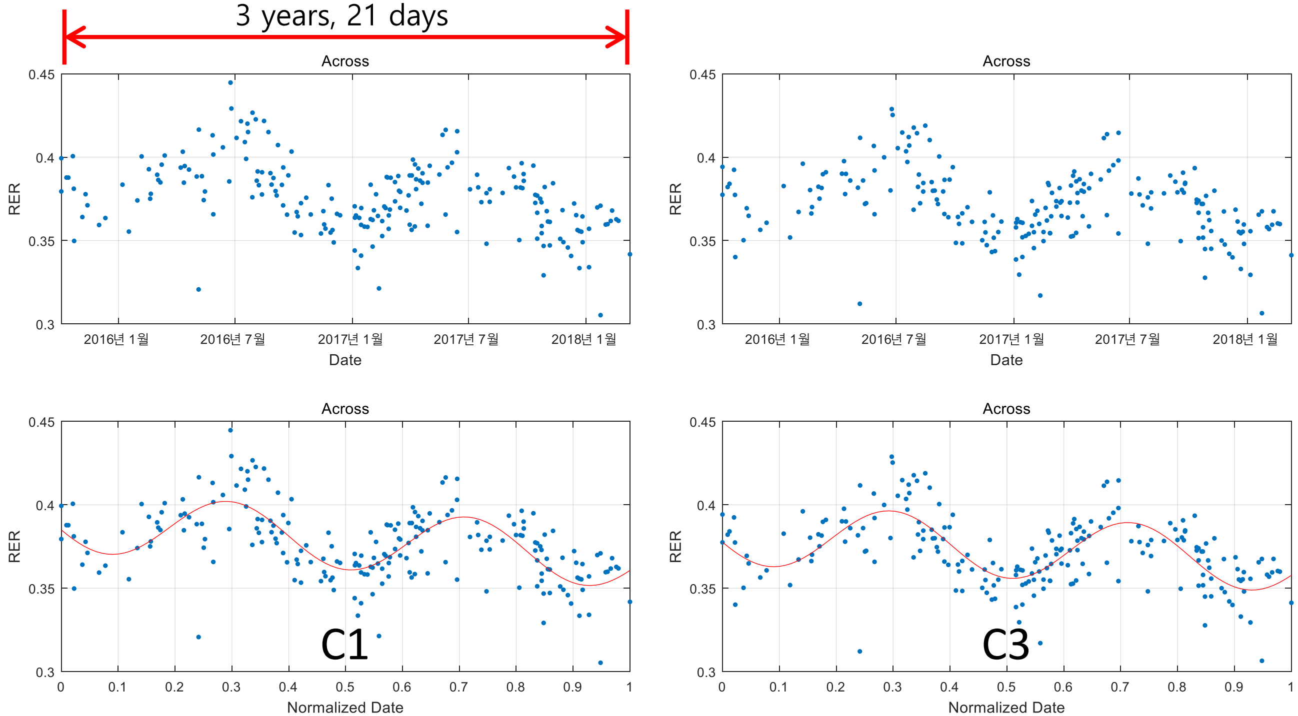


RER Method	Across				Along			
	Avg	Std.	Std./Avg	RMSE/Avg	Avg	Std.	Std./Avg	RMSE/Avg
(C1) Inflection point (1st)	0.3736	0.0211	0.0564	**0.0426**	0.3736	0.0124	0.03319	**0.0299**
(C2) Inflection point (3rd)	0.3714	0.0206	0.0554	0.0429	0.3657	0.0122	0.03342	0.0305
(C3) Half DN (1st)	0.3606	0.0197	0.0547	0.0442	0.3623	0.0116	0.03208	0.0308
(C4) Half DN (3rd)	0.3606	0.0198	0.0548	0.0442	0.3622	0.0116	0.03209	0.0308



(H1) Sinusoidal Fitting of RER (212 Edges)

- **Inflection Slope(1st fit) – C1** → $a * \sin(\omega t + \theta) + bt + c$
  - Estimated Period: 2.438
  - Std.Dev: 0.0230 → RMSE: 0.0158
- **Half DN(1st fit) – C3**
  - Estimated Period: 2.471
  - Std.Dev: 0.0227 → RMSE: 0.0154



- Yearly Cycle
- Aging factor

< For C1 >

a = 0.0184

ω = 0.4205

θ = -2.200

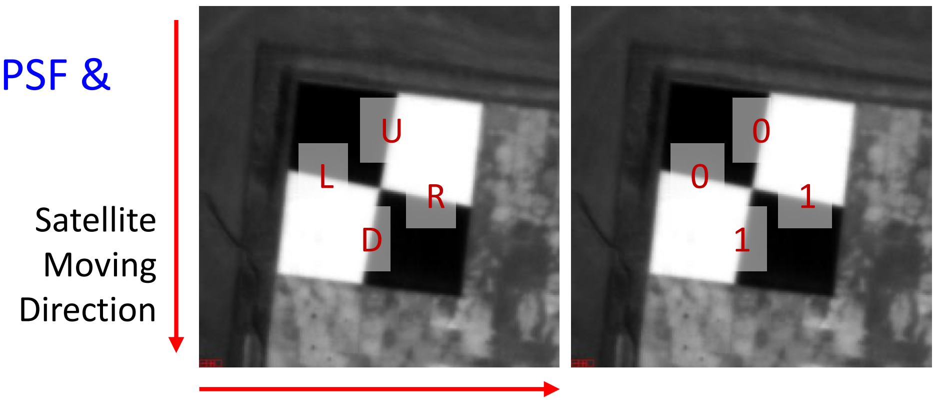
b = -0.0213

c = 0.3840

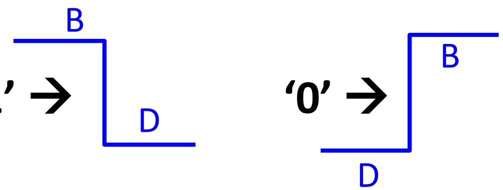
Aging : -0.0104/year

(B1) Asymmetric ESF: Parameter Definition

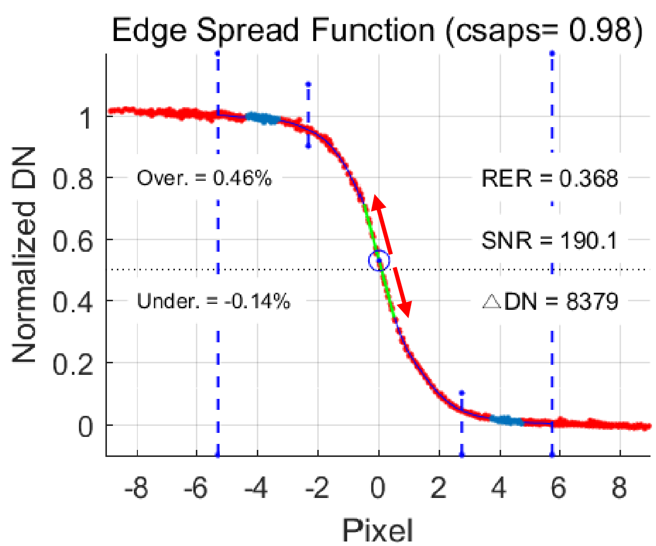
- **(B1) Asymmetric PSF & LSF**
  - How to reflect and handle Asymmetric PSF & LSF

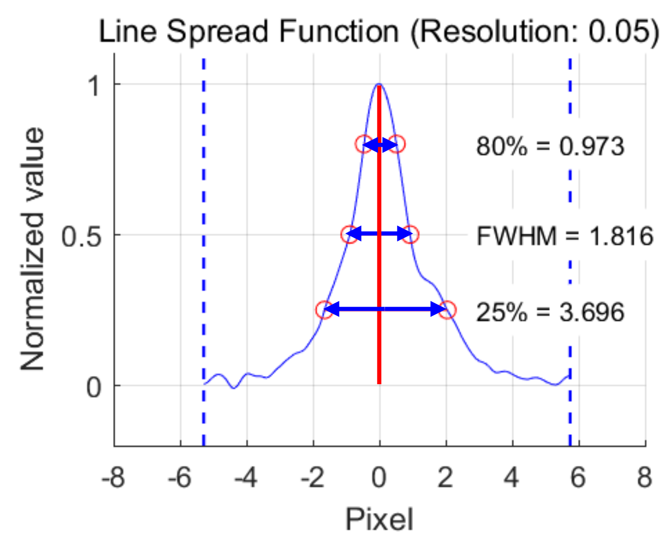


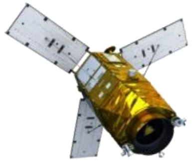
- **Flag-BD :** ‘1’ → ‘0’ →



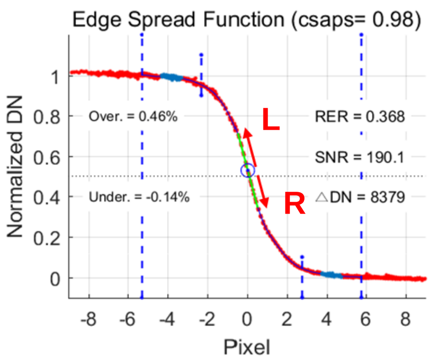
- **RER-L**
- **RER-R**
- **FWHM-L**
- **FWHM-R**
- **FWHM(25%)-L**
- **FWHM(25%)-R**

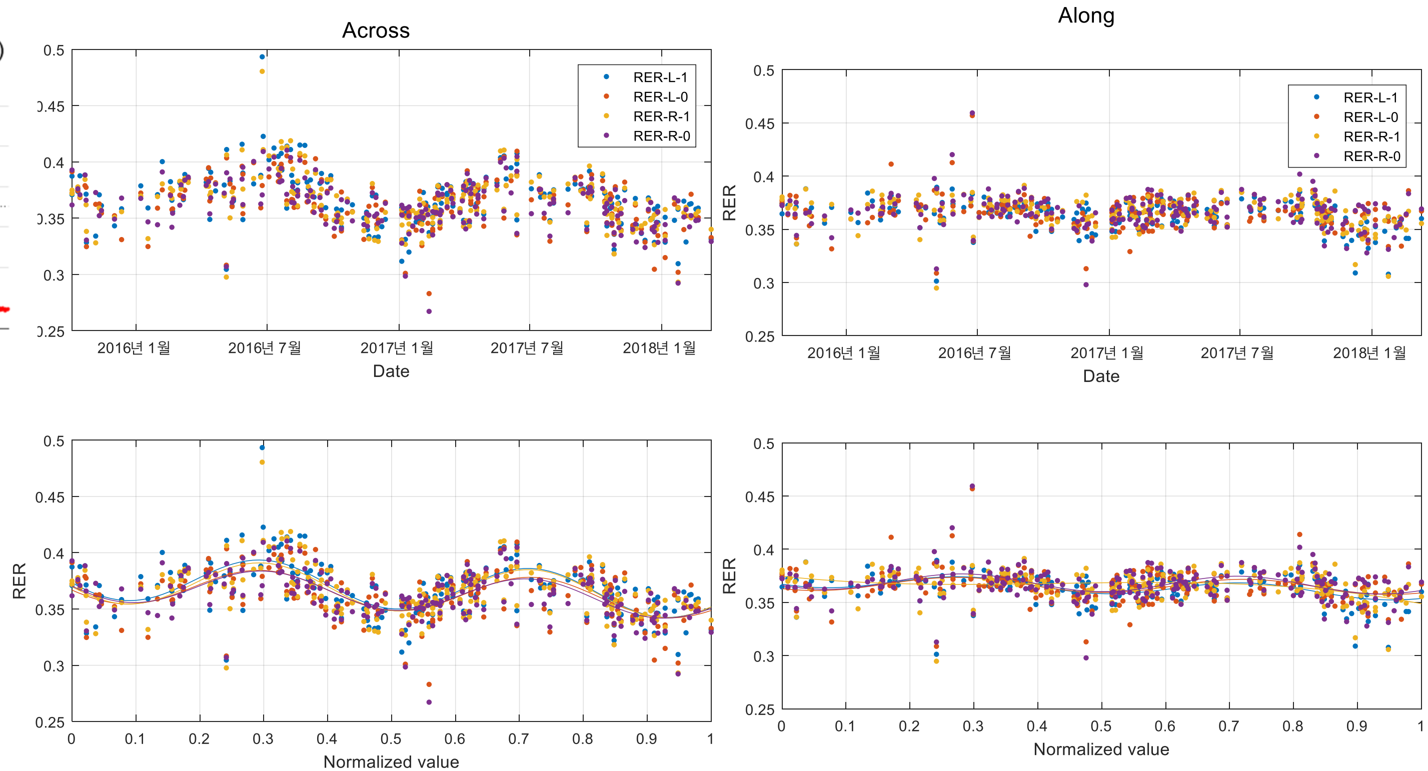






(B1) Asymmetric RER Analysis

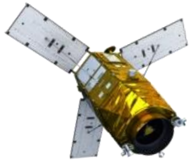




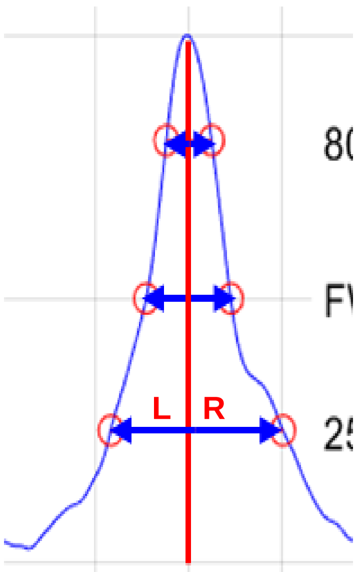
RER shows no difference between 'R' and 'L'.

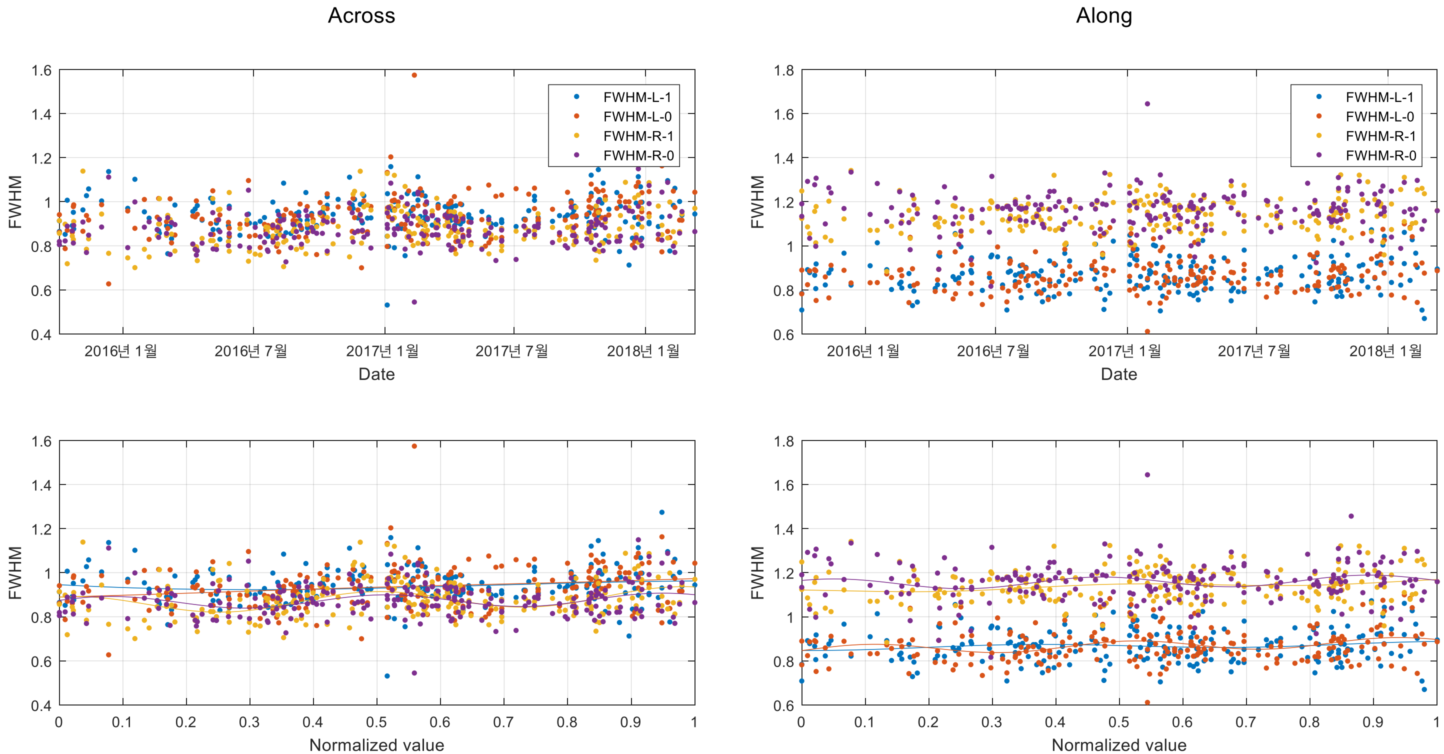
- Because RER use half of the center part.

RER Parameter	Across				Along			
	Avg	Std.	Std/Avg	RMSE/Avg	Avg	Std.	Std/Avg	RMSE/Avg
RER-L-1(BD)	**0.3668**	0.0232	0.0632	0.0487	0.3635	0.0131	0.0360	0.0492
RER-L-0(DB)	0.3623	0.0213	0.0589	0.0482	0.3651	0.0149	0.0408	0.0478
RER-R-1(BD)	**0.3652**	0.0223	0.0612	0.0469	0.3661	0.0134	0.0367	0.0468
RER-R-0(DB)	0.3619	0.0207	0.0571	0.0463	0.3668	0.0154	0.0420	0.0457



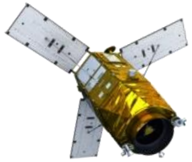
(B1) Asymmetric FWHM Analysis



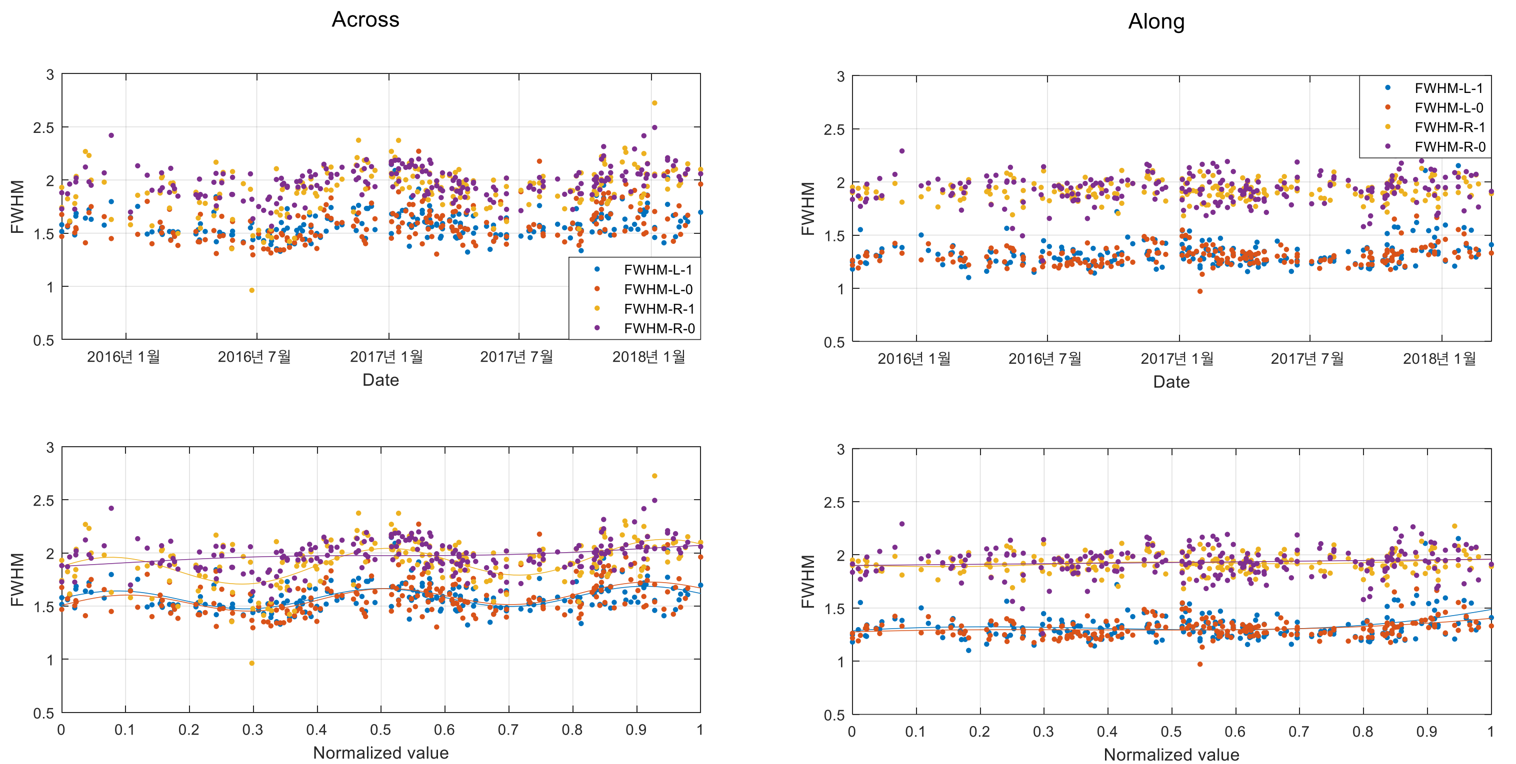


FWHM shows a difference between 'R' and 'L'.

FWHM	Across				Along			
	Avg	Std.	Std/Avg	RMSE/Avg	Avg	Std.	Std/Avg	RMSE/Avg
FWHM-L-1(BD)	0.9382	0.0826	0.0880	0.0867	0.8682	0.0763	0.0878	0.0937
FWHM-L-0(DB)	0.9359	0.0935	0.0999	0.0869	0.8714	0.0784	0.0900	0.0934
FWHM-R-1(BD)	0.8785	0.0832	0.0948	0.0926	1.1399	0.0741	0.0650	0.0714
FWHM-R-0(DB)	0.8751	0.0763	0.0872	0.0930	1.1605	0.0907	0.0781	0.0701

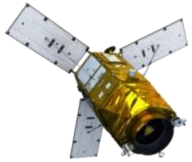


(B1) Asymmetric FWHM(25%) Analysis



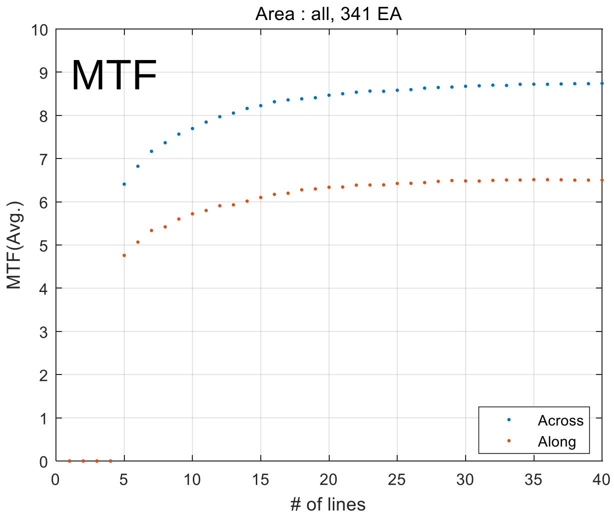
FWHM(25%) shows a difference between ‘R’ and ‘L’.

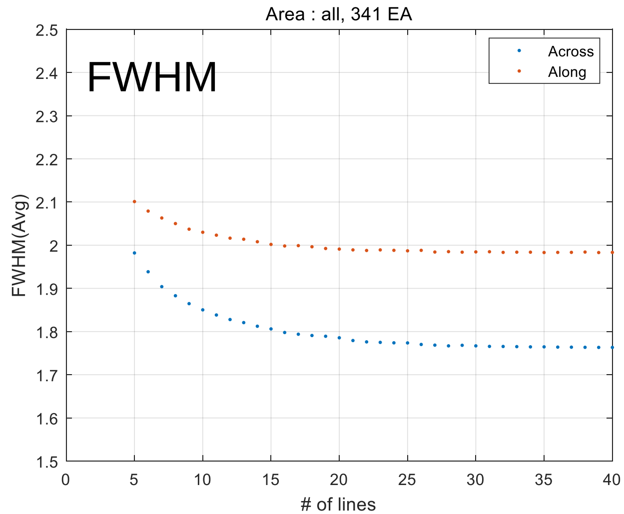
FWHM(25%)	Across				Along			
	Avg	Std.	Std/Avg	RMSE/Avg	Avg	Std.	Std/Avg	RMSE/Avg
FWHM-L-1(BD)	1.5887	0.1336	0.0841	0.0737	1.3254	0.1292	0.0974	0.0884
FWHM-L-0(DB)	1.5917	0.1711	0.1075	0.0736	1.3088	0.0901	0.0688	0.0895
FWHM-R-1(BD)	1.9209	0.2097	0.1092	0.0610	1.9223	0.0901	0.0469	0.0609
FWHM-R-0(DB)	1.9791	0.1435	0.0725	0.0592	1.9309	0.1391	0.0721	0.0607

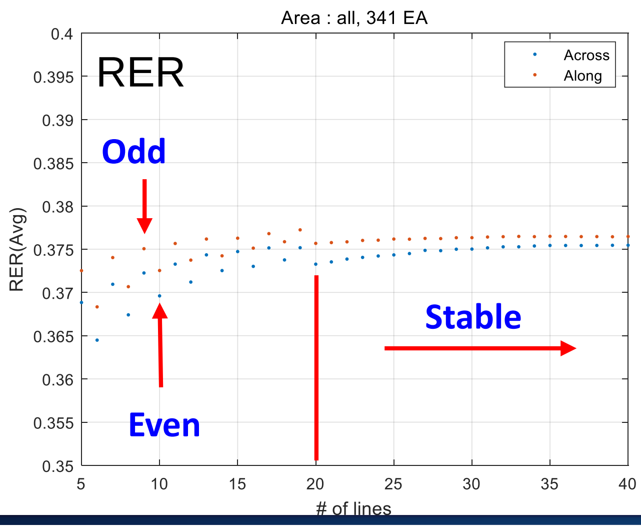


(D5, E2) Spatial Performance Trend (K3)

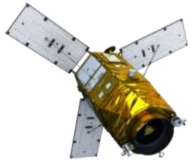
- **MTF, FWHM converge versus number of line, but RER**







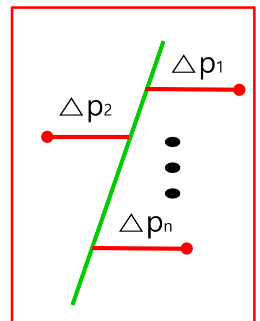
❖ Dependency is shown versus even/odd under 20 lines



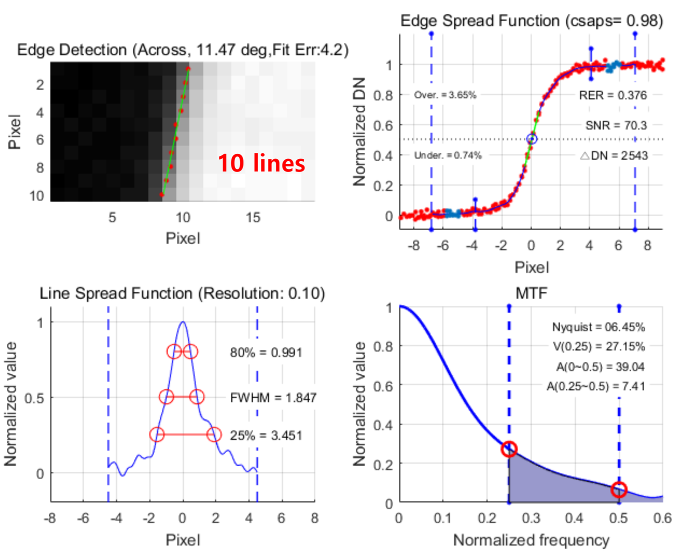
(D5, E2) RER versus lines

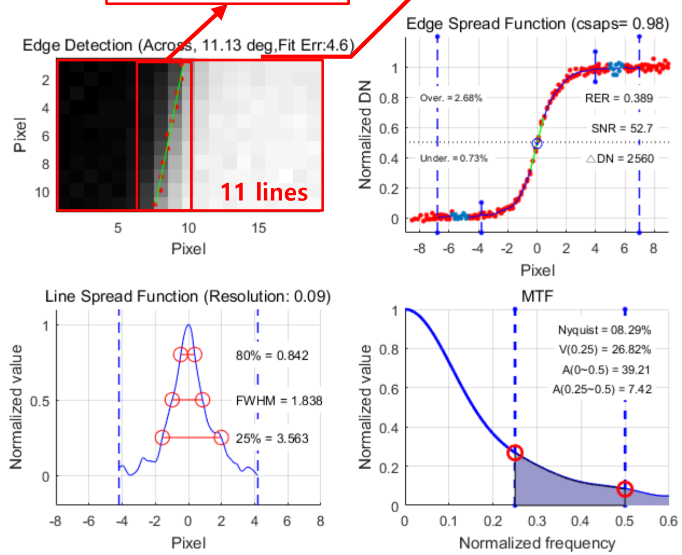
- **RER have dependency on number of lines**
  - For same edge image
  - It's affected by adding new line

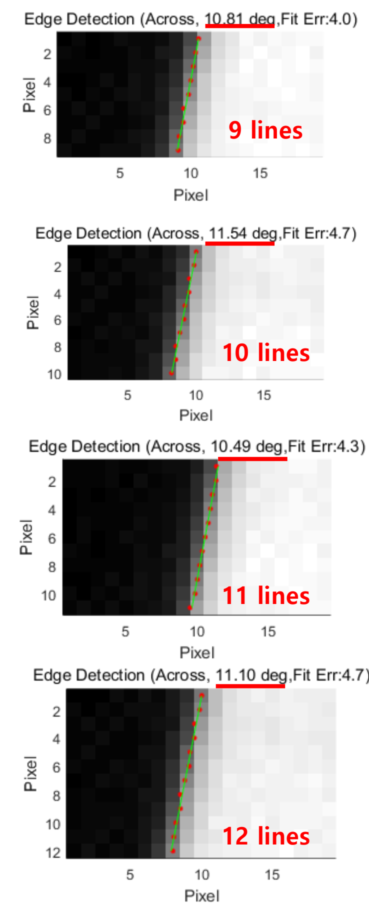
- **Edge point detection (E2)**

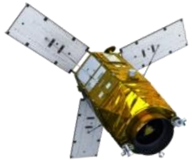


$$\sigma_p = \sqrt{E(p^2) - (E(\mathrm{p}))^2}$$







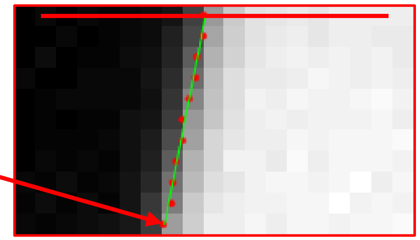


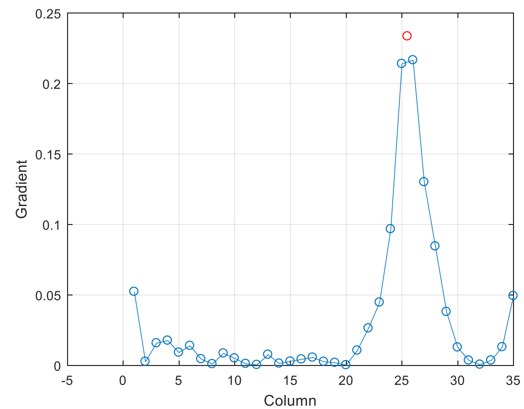
(D5, E2) Edge Point Detection Method

- **Method 1 : KARI customized function**
  - Iteration till get small error(ε)

△Grad.

$$\min_{x} f(x)$$



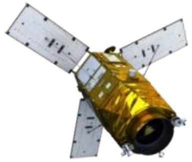


$f(x)$: Spline Interpolation

- **Method 2 : Polynomial + Noise Robust + least absolute residual method.**
- **Method 3 : Polynomial fitting 3rd**

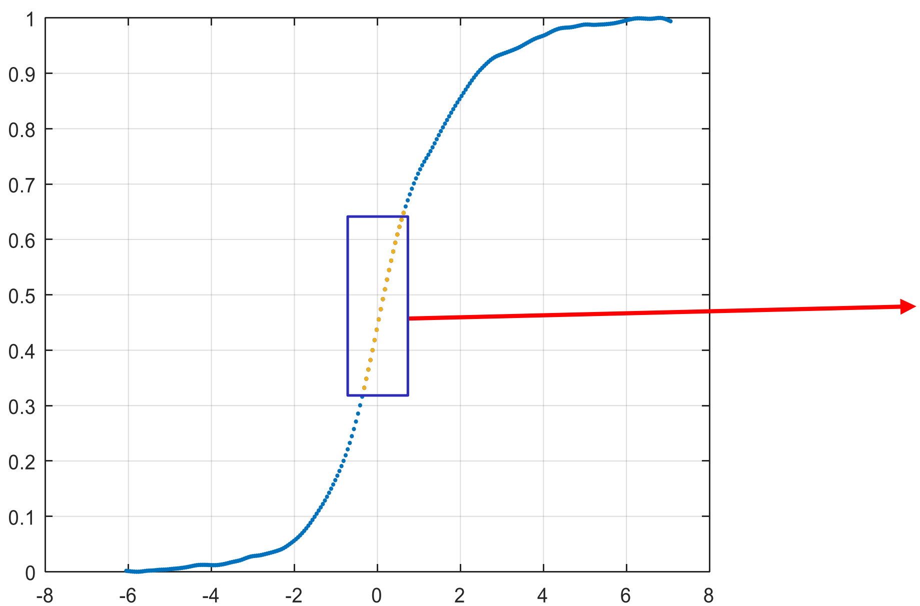
K3	Fit Error			RER		
	avg.	std.	std./avg.	avg.	std.	std./avg.
Method 1	2.02	1.9133	0.949	0.3719	0.0188	0.0505
Method 2	6.17	2.0169	0.327	0.3730	0.0190	0.0510
Method 3	4.41	1.7681	0.401	0.3731	0.0189	0.0505

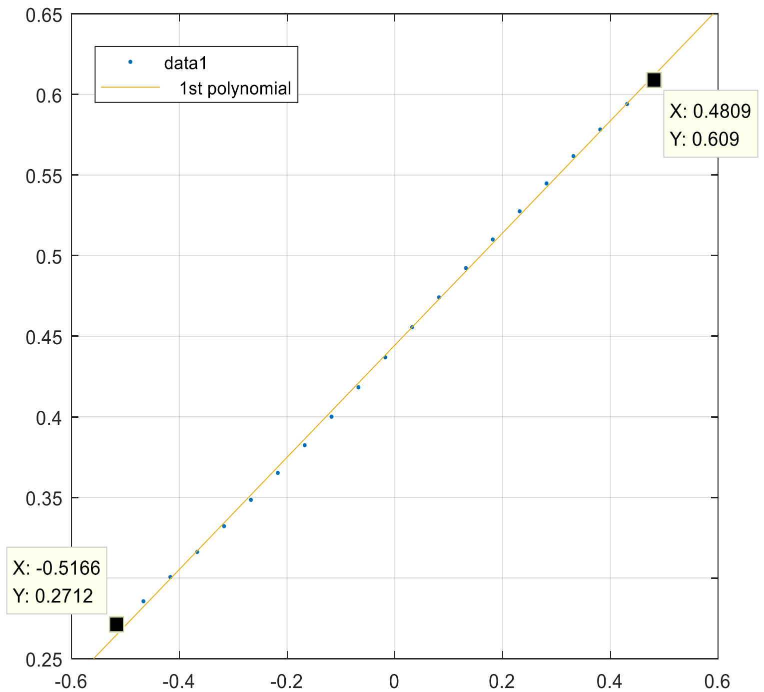
K3A	Fit Error			RER		
	avg.	std.	std./avg.	avg.	std.	std./avg.
Method 1	3.12	3.1498	1.009	0.3651	0.0304	0.0834
Method 2	6.75	18.4195	2.729	0.3662	0.0305	0.0832
Method 3	4.89	2.9673	0.607	0.3664	0.0303	0.0828

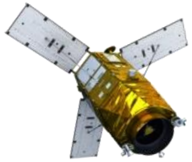


(D5, E2) Current RER calculation

- **First order fitting(Current)**
  - Using samples within slope at Inflection point ±0.5 pixel





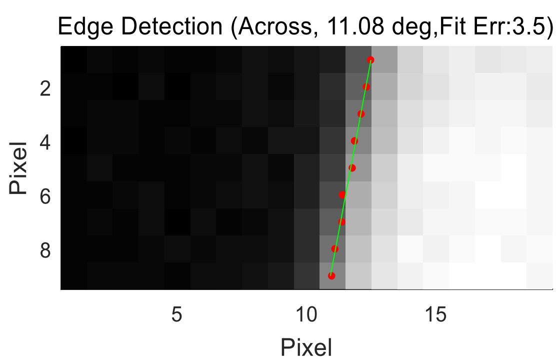


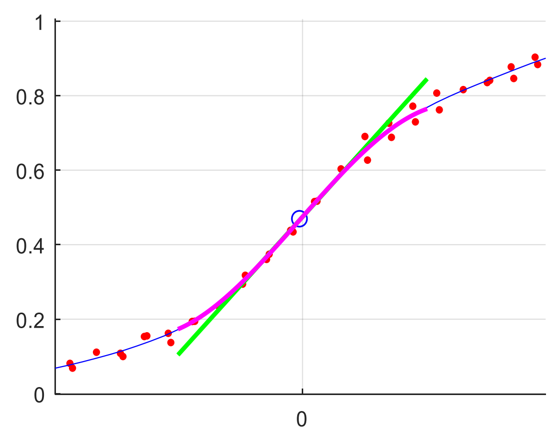
(D5, E2) Proposed RER calculation

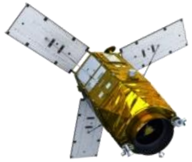
- **Robust on adding new line that status of surface is bad**
- **Pseudo instant slope at 0**
  - Input data fitting : Cubic Smoothing Spline(0.98)
  - Fit range : ±1 pixel
  - Fit method : polynomial 3^{rd}
  - Resolution : 0.00001
  - slope at 0 ± 0.000005

: Earlier method

: Proposed method

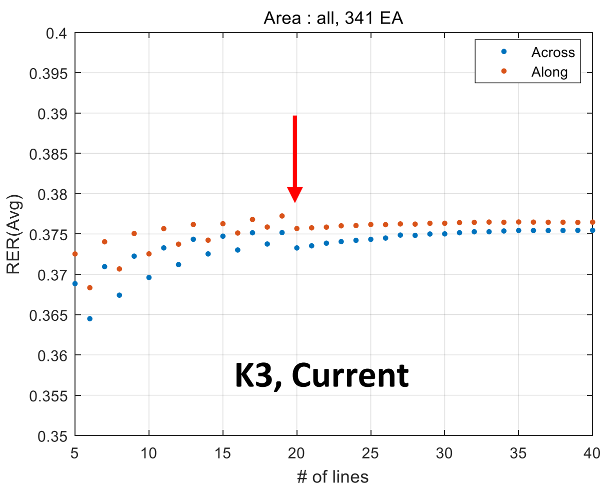


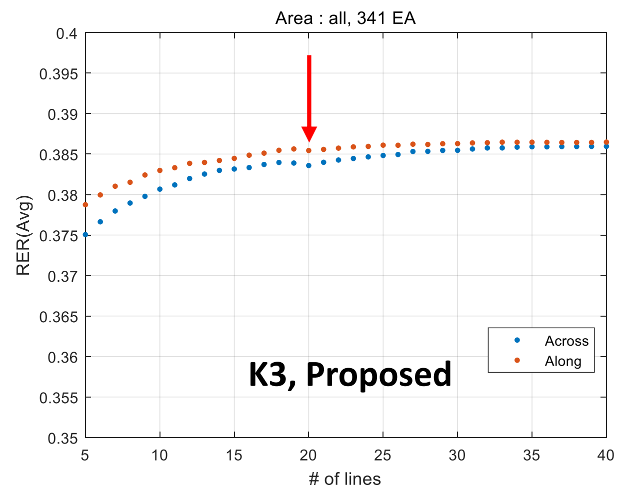




(D5, E2) RER versus lines

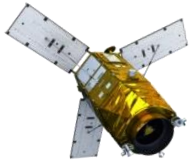
- **Even/Odd dependency is gone, but still remain little fluctuation**



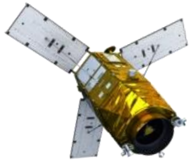


K3	Across			Along		
	avg.	std.	std./avg.	avg.	std.	std./avg.
Current	0.3736	0.002527	0.0068	0.3754	0.001841	0.0049
Proposed	0.3846	0.001324	0.0034	0.3857	0.000912	0.0024

TBD, TBR, TBC on KARI's MTF Estimation

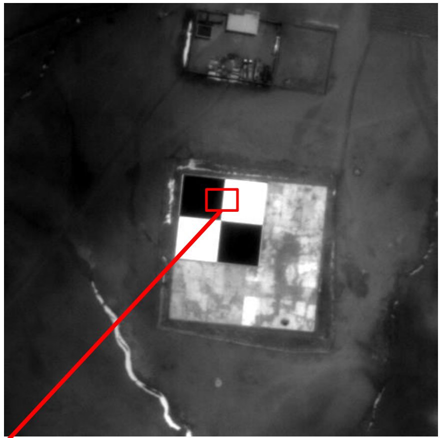


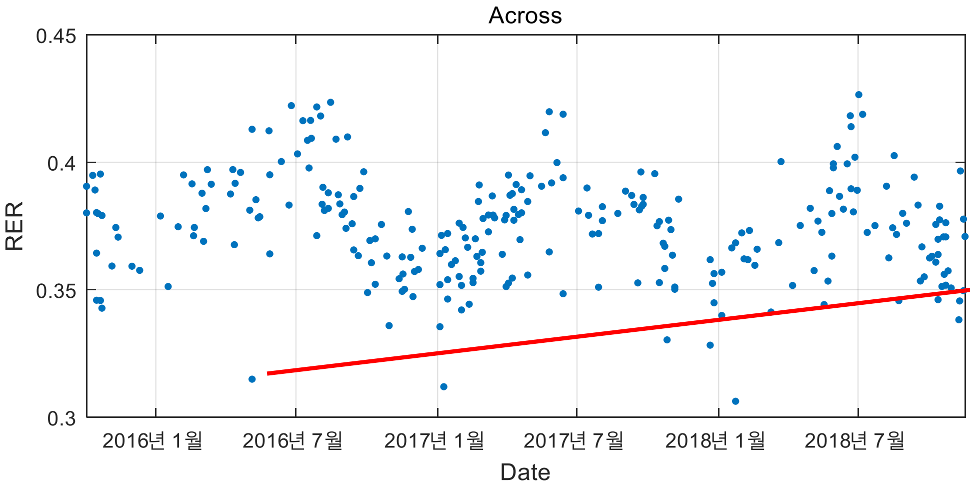
No.		Item	Content	Link	TB.
A	1	**Reference target**	Status of Reference target		TBD
	2	**Natural target**	What is Requirements of Natural target?		TBR
	3	**Satellite Resolution**	(Loosely) Link to Satellite Resolution	D1	TBR
B	1	**Asymmetric PSF & LSF**	How to reflect and handle Asymmetric PSF & LSF	H1	TBD
C	1	**RER, FWHM, MTF**	What is the best Reasonable (Representative) Estimator?	H1	TBD
D	1	**Straight Line on Edge**	Limitation of Straight line by One pixel	A3	TBD
	2	**Uniformity on Bright & Dark area**	Limitation of Uniformity on Bright and Dark area by SNR (> 50)		TBR
	3	**DN Difference between Bright and Dark area**	Limitation of DN Difference between Bright and Dark area by SNR (> 50)		TBR
	4	**Angle between Edge and Along / Across direction**	Permitted Angle range between the Edge and Along / Across direction (0~30deg) (Depended on Fitting method by No. of sample)	G1	TBR
	5	**Number of Pixel on Edge line**	Limitation of Number of Pixel on Edge line (> 10~20 pixels) (Depended on Fitting method by No. of sample)	G1	TBR
	6	**Width of Bright & Dark area**	Width (pixel) of Bright and Dark area (> 5 pixels)		TBR
E	1	**Fitting Cubic polynomial**	Fitting Cubic polynomial for Detecting the Edge line on ROI		TBC
	2	**4 pixels for Edge detecting**	4 pixels for Detecting the Edge line on ROI		TBC
	3	**Edge location as Inflection point of Cubic function**	Edge location as Inflection point of Cubic function for Detecting the Edge line on ROI		TBC
F	1	**Inflection point on LSF for Starting point**	What is Starting point of Bright & Dark area		TBD
	2	**Fitting (Cubic Smoothing Spline) for 'F1'**	Fitting method (Cubic Smoothing Spline) for Inflection point on LSF for Starting point, and Weight value of Cubic Smoothing Spline	F1	TBR
	3	Next **Width of Bright / Dark area**	Width of the Bright & Dark area from the Starting point (1 pixel)		TBR
G	1	**Fitting method on ESF**	What it the optimal fitting method on ESF?		TBD
H	1	**Inflection point as RER Center**	What is Center of RER; Inflection point (Top) on LSF or Half DN	B1,C1	TBR

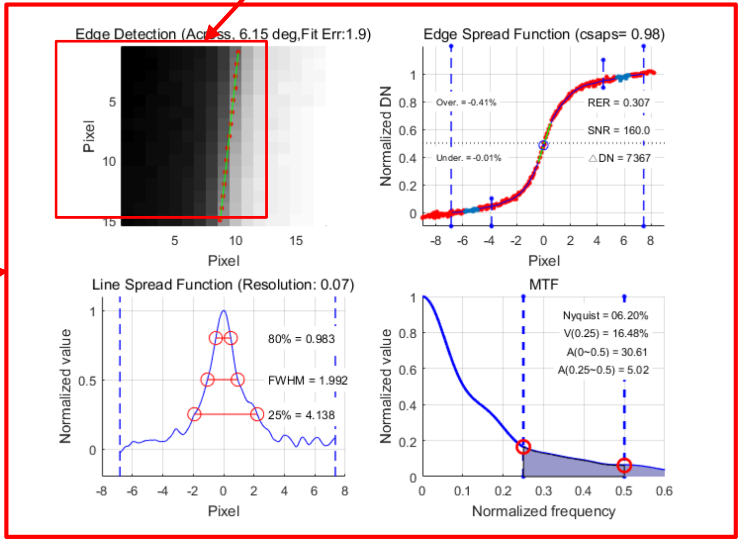


Next Work

- **Setting up constraints of edge samples**
- **Relationship among spatial parameter**
- **Tracking odd results as below**







Summary & Next Job

- **Trimmed width('Zbra_width') (1 → 3) changed for more reliable**
  - But, RER, FWHM & MTF: go Down
  - (D6) Width of Bright & Dark area
  - (F1) Inflection point on LSF for Starting point
  - (F3) Edge location as Inflection point of Cubic function
- **Dependency (RER & FWHM vs. ΔDN) may Appear**
  - (D3) DN Difference between Bright and Dark area
  - (D3) But, Need to decide the recommended ΔDN value
- **'Inflection point of RER Center' gets Better than 'Normalized Half DN'**
  - (H1) Inflection point of RER Center
- **(B1) Asymmetric PSF & LSF**

- **(Next Job) (G1) Fitting method on ESF**
  - What it the optimal fitting method on ESF?

- **CEOS WGCV IVOS – GeoSpatial W/G**