Spatial Quality for Satellite Image data and Landsat8 OLI Lunar data

October 2, 2014

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Agenda
1. **Spatial Quality for Satellite image data**
2. Database of Standard Artificial (Man-made) Edge targets
3. Standard Processing Step (algorithm) for Edge target
4. Spatial Quality of Landsat8 OLI Lunar image data

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, pp. 583–601
2. [RD2] Philippe Blanc, 2010, 'Calibration Test Sites Selection and Characterisation – WP210', TN-WP210-001-ARMINES, Issue 0.2, ESA/ESRIN
3. [RD3] Philippe Blanc and Lucien Wald, 2008, 'Image Quality – WP224 (ARMINES)', TN-WP224-001-ARMINES, Issue 1.0, ESA/ESRIN
4. [RD4] Dennis Helder and Francoise Viallefont, 2012, 'A Frame for Geo/Spatial Quality', CEOS WGCV IVOS 24

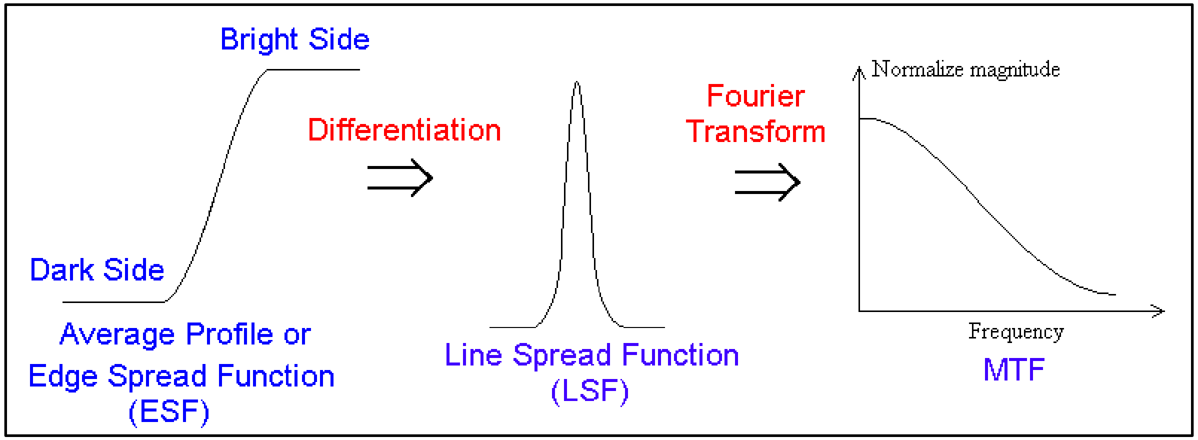


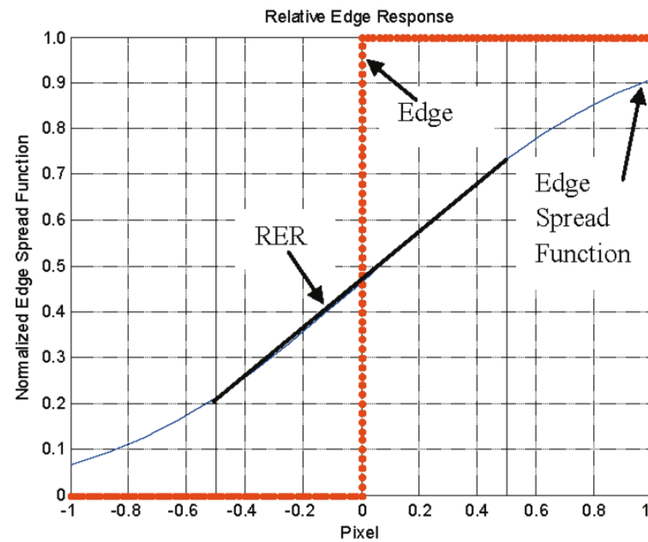
Fig. 1. Processing Steps for Edge target to get ESF, LSF, MTF [RD4]

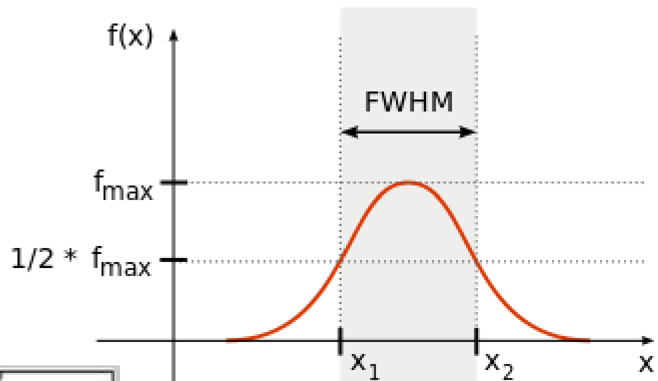
Purpose and Works for Spatial Quality in CEOS WGCV IVOS (led by Dr. Helder, SDSU)

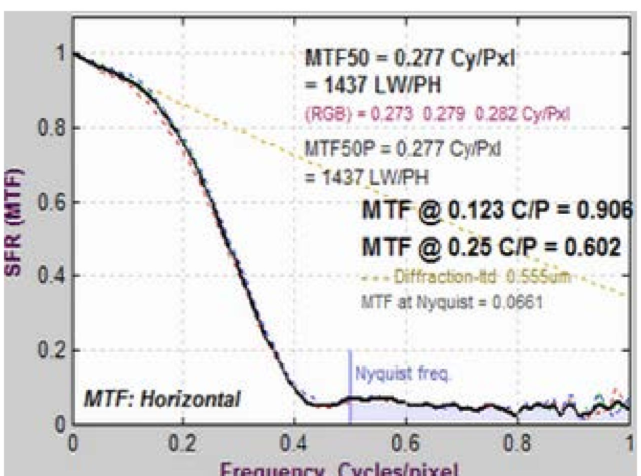
1. (One of Purpose) Get the reasonable quantity of Spatial quality for remote sensing satellite in ***Real conditions***.
2. Develop the Definition of the general Spatial quality Estimators; [RD4, p15]
   a. RER (Relative Edge Response) & Edge Response Slope
   b. FWHM (Full Width at Half Maximum)
   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** [RD4, p32]
      ① Edge, Line (Bar), Point, Periodic target
      ② Database for Artificial & Natural target [RD1, RD2]
   b. Conditions (limitations) for Target & Image data [RD4, p33?]
   c. Reference MTF test data
   d. **Standard Processing Step (algorithm) for Edge target** [RD4, p35]
      ① Several options according to the Conditions (limitations)
      ② For target; Edge, Line, Point, Periodic
      ③ For Standard target & For Artificial & Natural target

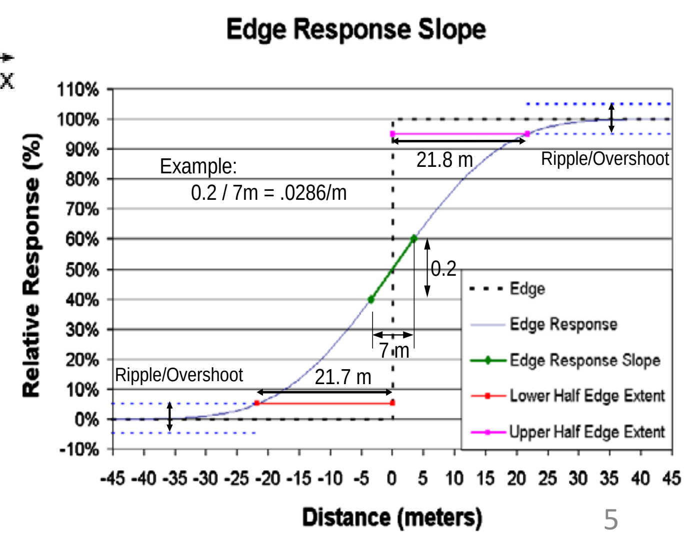
Develop the Definition of the general Spatial quality Estimators

1. RER (Relative Edge Response)
2. Edge response Slope
3. FWHM (Full Width at Half Maximum)
4. MTF (Modulation Transfer Function)
   a. MTF value at Nyquist frequency
   b. MTF curve









Comparison of each Estimator

- We need to & will fill in this table in CEOS WGCV IVOS.

Estimator	Good	Weak	Applicable Targets	Recommend	Comments
RER	High reliable	In High Quality (Landsat8) Only Edge	Edge		
Edge slope	High reliable	Need GSD each imaging Only Edge	Edge		
FWHM	High reliable		Edge, Point		50% for user; surface, 25% & 80% for Cal/Val?
MTF	MTF Curve	Low reliable MTF @ Ny.	Edge, Point, Periodic		MTF@Ny. For users; MTF curve for Cal/Val

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4. Spatial Quality of Landsat8 OLI Lunar image data

Standard Edge target Survey by Dr. Helder

South Dakota State University
SDSU

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Office of the Associate Dean for Research

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South Dakota State University
Brookings, SD 57007
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May 2, 2014

Dear CEOS IVOS Colleague:

I am writing to you to request your help in completing an action I took at the IVOS 24 meeting at USGS EROS to develop a website containing information related to image spatial quality and the estimation of PSF/MTF. Through the generosity of Greg Stensass and Jon Christopherson at USGS EROS we will be able to host this information as part of the website they already maintain (http://calval.cr.usgs.gov/rst-resources/sites_catalog/radiometric-sites/test-site-gallery/).

To begin collection of this information, we are focusing on cataloging spatial quality test sites and processing methodologies. On the second page of this document you will find a short survey requesting this information. Please fill out this survey form at your earliest convenience and as completely as possible. Then, return it to me at dennis.helder@sdstate.edu along with any attachments. If you are not the appropriate person at your organization to complete the survey, please feel free to forward it to that person. If you know of others who are not a part of CEOS IVOS but could contribute to this activity, please feel free to send it to them as well.

Thank you in advance for your help with this activity. I look forward to seeing you at the next IVOS meeting!

Sincerely,

Dennis Helder

USGS Cal/Val Portal

http://calval.cr.usgs.gov/rst-resources/sites_catalog/

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understanding the technologies needed to sense our world

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You are here: Home » RST Resources » Test Sites Catalog » Spatial Sites » Stennis, Mississippi, USA

Test Site Catalog

Site Location: Stennis, Mississippi, USA

Spatial

Stennis Spatial Targets, February 2004

30.386151° -89.628116°

Stennis Spatial Targets, March 2014

Location (City, State, Country):	Stennis, Mississippi, USA
Altitude above sea level Min/Max/Mean (meters):	TBD
Center Latitude,Longitude (Degrees):	30.386151° -89.628116°
UTM Zone:	13 N
Landsat WRS-2 Path / Row:	022039
Owner:	NASA Stennis Space Center
Points of Contact and Affiliation:	Dr. Robert Ryan, Mary Pagnutti
Purpose:	Spatial assessment of high resolution satellites
Range Layout:	Painted concrete targets on the property of NASA Stennis Space Center.
Description:	From ~1998 to ~2009 two targets, one an edge target, the other a quarter Siemens Star, were maintained to some degree. From 2010-2013 targets fell into disrepair and covered. As of 2014 new edge target has been made in location of Siemens Star.
Suitability:	Higher resolution satellites (2m or finer (??) resolution)
Limitations:	Due to proximity to Gulf of Mexico, atmosphere tends to be humid and may often have clouds, particularly in afternoons. Best months for use tend to be: (XXXXX)

Test Site Home

RADIOMETRIC SITES

Select Site

- CEOS Reference Sites
- Radiometry Test Site Gallery
- Download Google Earth KMZ

GEOMETRIC SITES

Select Site

SPATIAL SITES

Select Site

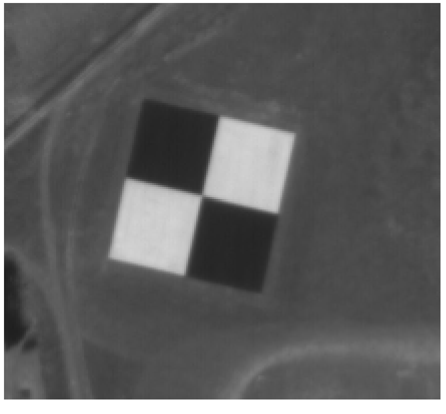
ADDITIONAL INFORMATION

- Acronyms
- References

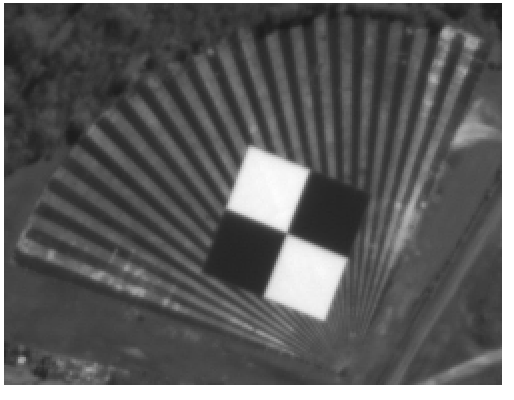
CEOS QA4EO

List of Standard Edge targets [RD1, RD2]

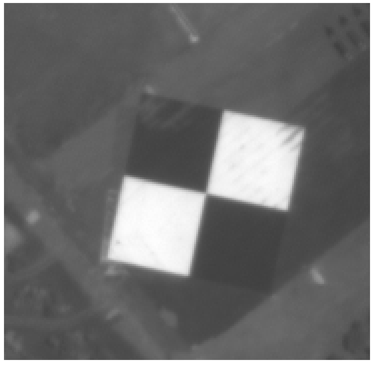
Target	Description and Dimensions	Orientation (to true north)	Lat / Long	Status
Salon de Provence, France	60m x 60m, 2x2 checkerboard, painted tar pad	~-3º / 87º	43º36’21”N / 05º07’13”E	Good
Stennis Space Center, USA	45m x 45m (?), 2x2 checkerboard		23º31’11”N / 119º35’00”W	Good (New)
Penghu, Taiwan	60m x 60m, 2x2 checkerboard, painted surface	0º / 90º	30º23’12”N / 89º37’43”E	Good
Big Spring, USA	40m x 40m, 2x2 checkerboard, painted concreted			
Baotou city, China	48m x 48m for a single panel, contrast (W/B) > 5:1	5º	40º51’06”N / 109º37’44”E	New
Mongol & GoHeung, Korea				in Construction



Salon de Provence



Stennis Space Center

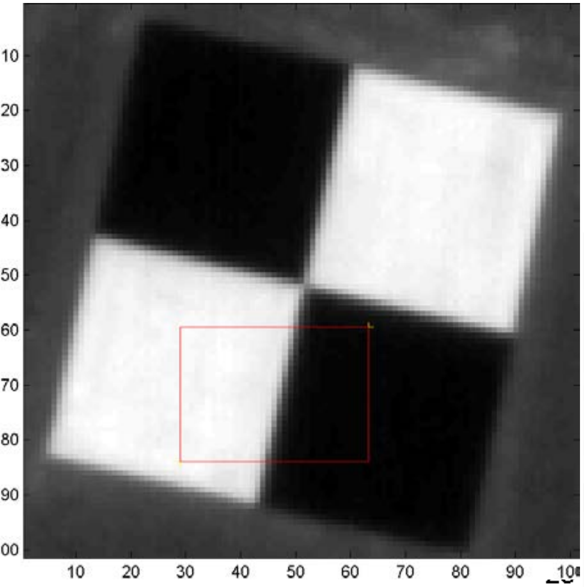


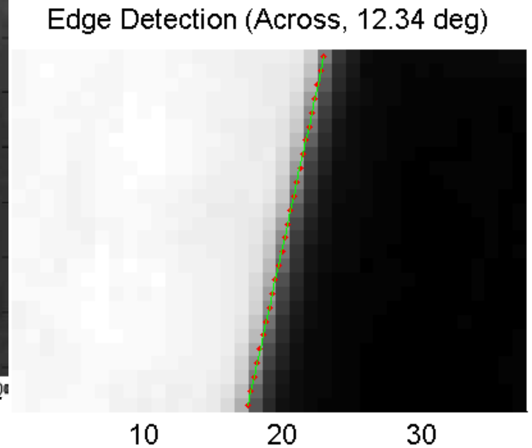
Penghu

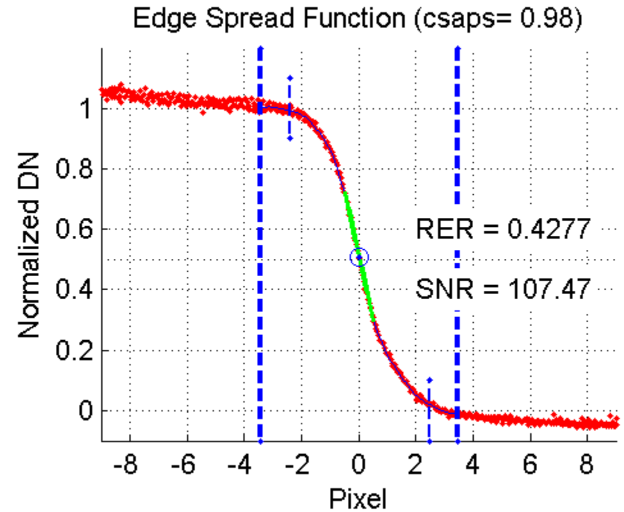
Imaged by KOMPSAT-3
GSD (0.7m)

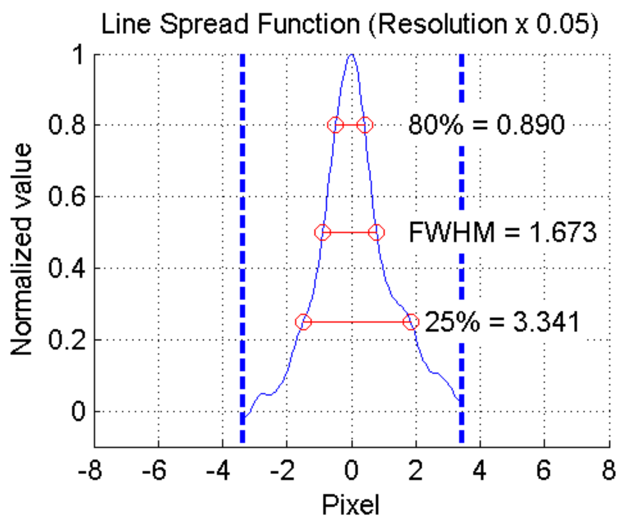
Salon de Provence, France

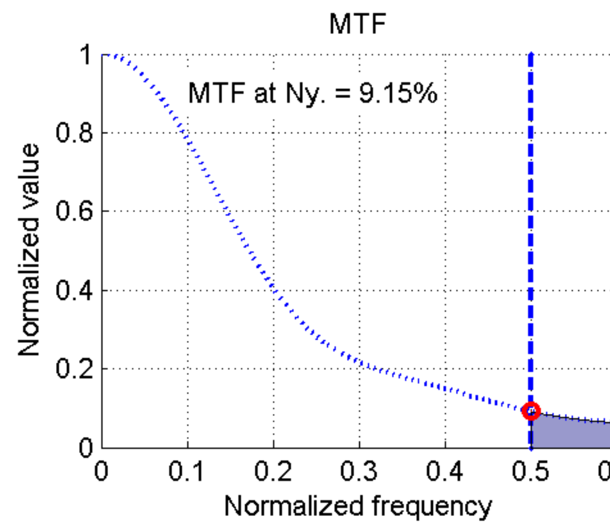
- Imaging date: 03.05.2014
- Tilt angle: -14.94deg







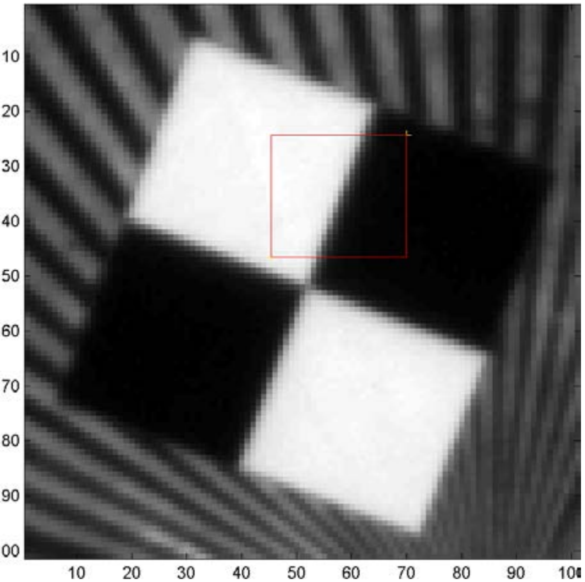


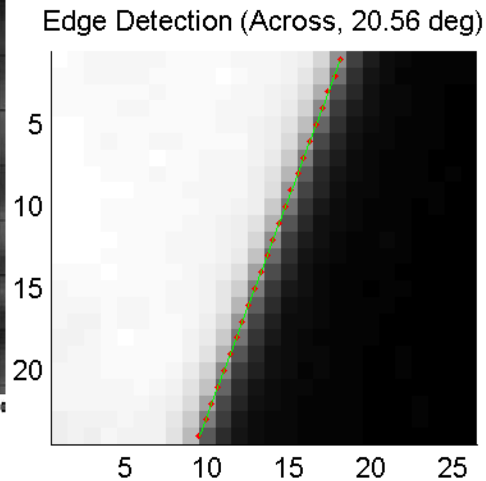


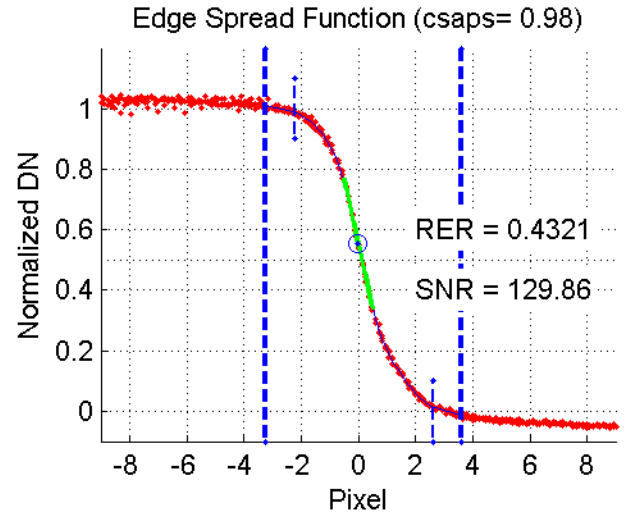
Imaged by KOMPSAT-3
(GSD: 0.7m)

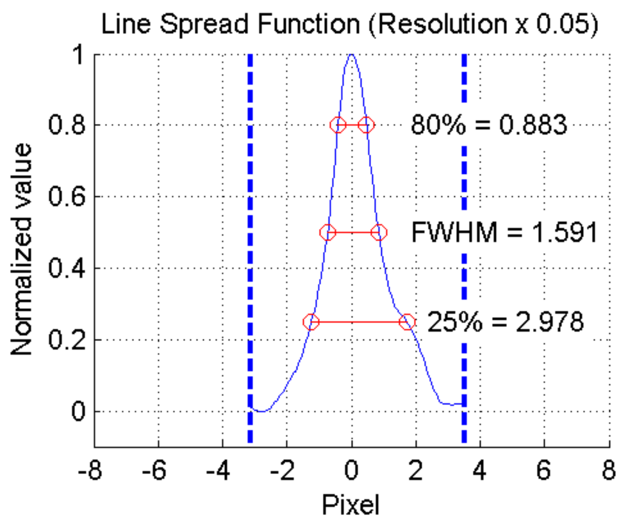
Stennis Space Center, USA

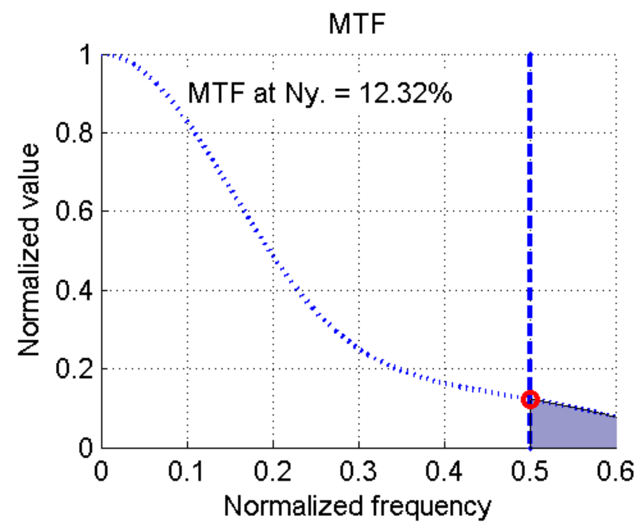
- Imaging date: 04.30.2014
- Tilt angle: 2.11deg







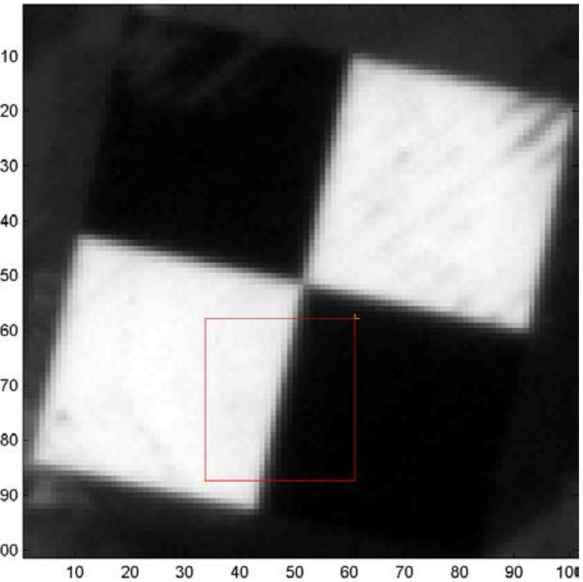


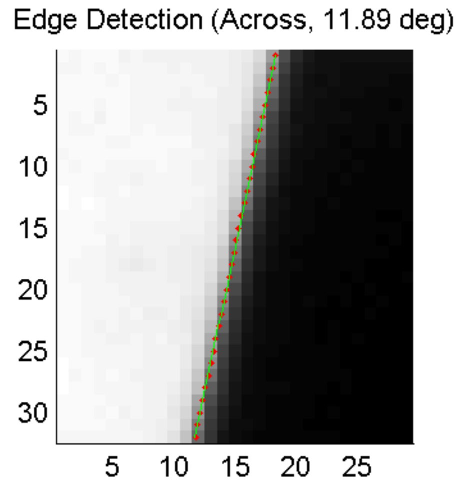


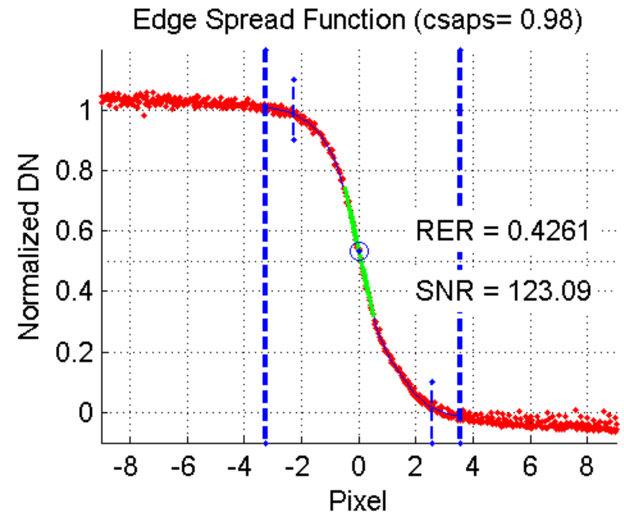
Imaged by KOMPSAT-3
(GSD: 0.7m)

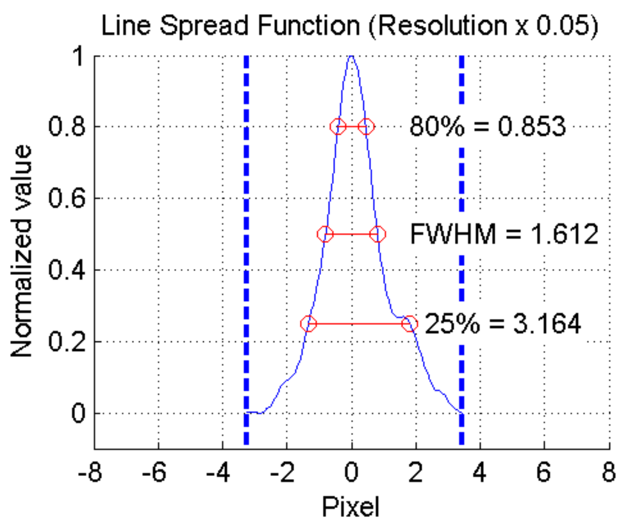
Penghu, Taiwan

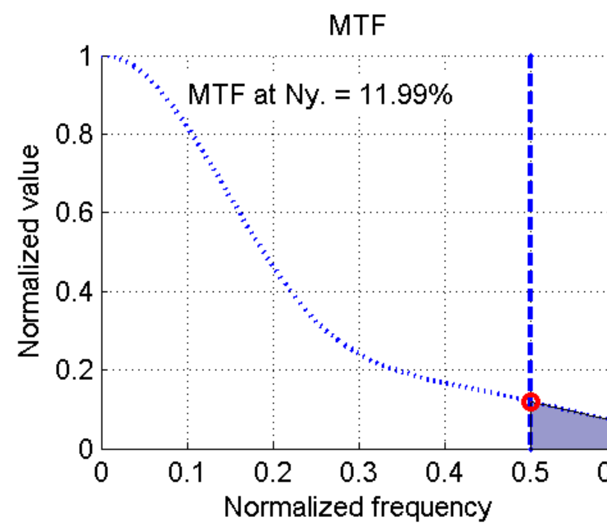
- Imaging date: 04.29.2014
- Tilt angle: 7.29deg











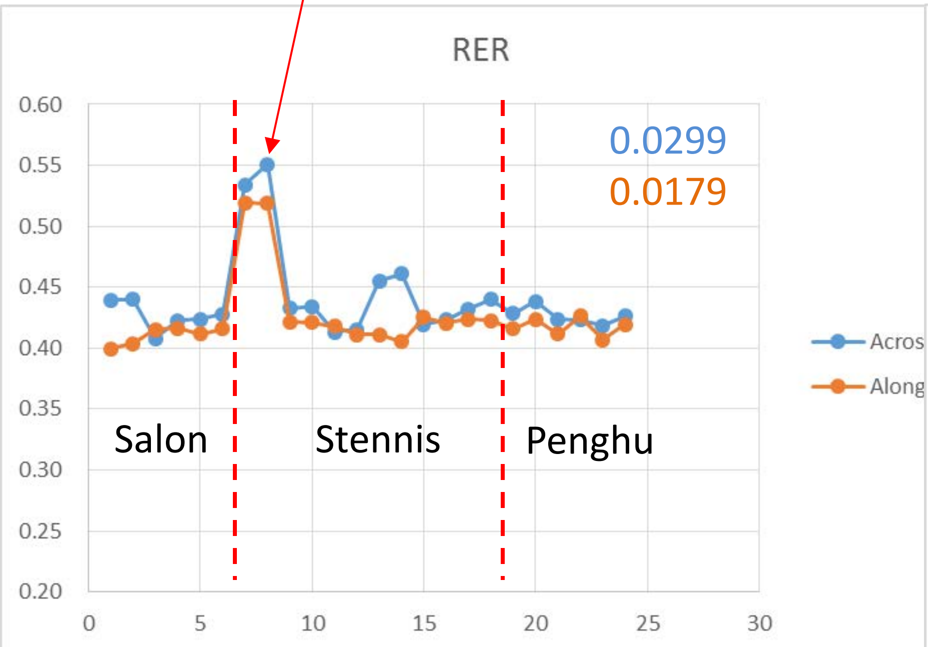
Imaged by KOMPSAT-3
(GSD: 0.7m)

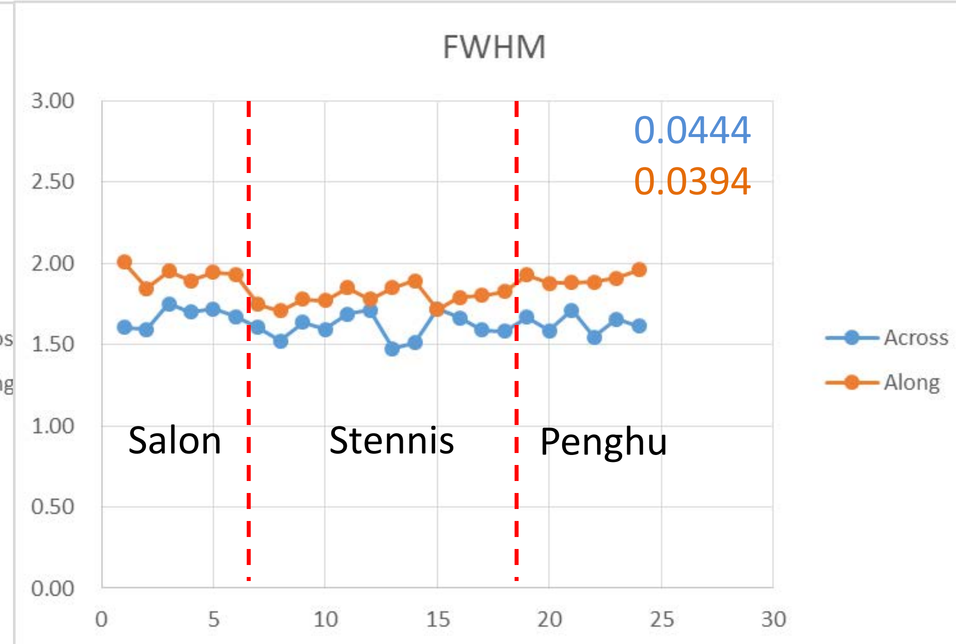
Results from Edge targets with KOMPSAT-3

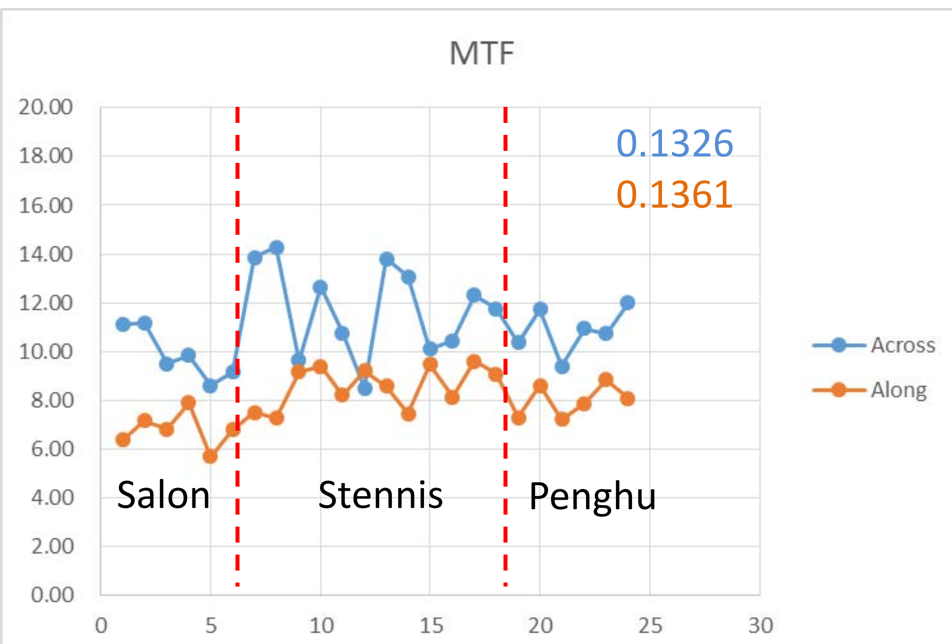
Target	Date	Roll / Pitch	Across RER	Across FWHM	Across MTF	Along RER	Along FWHM	Along MTF
Salon, France	2013.06.25	5.487	0.4393	1.605	11.09	0.3993	2.008	6.37
		0.434	0.4401	1.593	11.17	0.4036	1.845	7.15
	2014.02.13	-1.725	0.4081	1.750	9.49	0.4151	1.954	6.82
		0.086	0.4225	1.702	9.83	0.4162	1.893	7.89
	2014.03.05	-14.935	0.4236	1.718	8.59	0.4115	1.945	5.68
		-0.513	0.4277	1.673	9.15	0.4158	1.931	6.80
	Average		0.4269	1.674	9.89	0.4103	1.929	6.79
Stennis, USA	2014.01.17	-19.071	0.5341	1.606	13.86	0.5192	1.746	7.51
		-0.874	0.5506	1.523	14.27	0.5186	1.710	7.25
	2014.02.14	-2.431	0.4328	1.638	9.63	0.4217	1.781	9.15
		0.007	0.4341	1.594	12.65	0.4211	1.772	9.40
	2014.02.17	29.690	0.4132	1.690	10.77	0.4177	1.849	8.20
		1.533	0.4151	1.713	8.50	0.4109	1.779	9.20
	2014.03.01	-14.124	0.4554	1.477	13.80	0.4110	1.849	8.58
		-0.629	0.4608	1.512	13.07	0.4051	1.895	7.44
	2014.03.11	-21.903	0.4197	1.721	10.10	0.4251	1.715	9.47
		-0.972	0.4232	1.665	10.44	0.4205	1.792	8.13
	2014.04.30	2.112	0.4321	1.591	12.32	0.4237	1.803	9.61
		0.272	0.4400	1.584	11.76	0.4226	1.827	9.07
	Average		0.4509	1.610	11.76	0.4348	1.793	8.58
PengHu, Taiwan	2014.02.17	-2.236	0.4286	1.670	10.37	0.4159	1.929	7.30
		-0.013	0.4383	1.585	11.72	0.4235	1.879	8.60
	2014.03.19	-27.142	0.4237	1.713	9.38	0.4118	1.882	7.20
		-1.255	0.4231	1.548	10.93	0.4262	1.884	7.88
	2014.04.29	7.293	0.4182	1.658	10.73	0.4070	1.909	8.85
		0.568	0.4261	1.612	11.99	0.4197	1.961	8.09
	Average		0.4263	1.631	10.85	0.4174	1.907	7.99
Total Average			0.4388	1.631	11.07	0.4243	1.856	7.99

RER, FWHM, MTF

Stennis, (01.17.2014)







- RER & FWHM is stable.
- MTF @ Ny as estimator is worst.
- Stennis, 01.17.2014
  - ✓ We need to look for the reason.
  - ✓ Imaging conditions
  - ✓ Status of target
  - ✓ MTF measuring code
  - ✓ Relation between RER and FWHM

(Across) Std.Dev / Average

(Along) Std.Dev / Average

Issues and Future works

1. Database for the Standard Edge target in Worldwide [RD1, RD2]
    a. Need to keep and share the Information of Every Edge target [RD4]
    b. On USGS Cal/Val portal (http://calval.cr.usgs.gov/rst-resources/sites_catalog/)

1. USGS EROS Cal/Val Portal (http://calval.cr.usgs.gov/rst-resources/sites_catalog/)
    a. Database for the Standard Edge targets
    b. Status of Every edge target (TBD)

2. Maintenance and Monitoring be Needed to;
    a. Keep and Share the status of the Edge target [RD4]
    b. CCTV in Web site
    c. Keep and Share the standard MTF measuring code

3. Maintenance and Monitoring of the Status of Targets and Sites
    a. Acquire quarterly to monitor status of test sites
    b. Imaging by the several satellites
    c. KOMPSAT-3, Pleiades & SPOT, Worldview, GeoEye, etc.

4. Point, Bar, Periodic (Radial, Siemens) target

5. Natural target (TBD)
    a. Various Situation of the Natural edge target
        i. Clear sky, Dry, Broad building, Dam, Artificial lake, Airstrip, etc.
    b. Database of recommended cities of the Natural edge target
        i. Phoenix, Dallas, Las Vegas, Los Angels, Denver, etc. (Cities in USA)
        ii. Airports in the world

Agenda
1. Spatial Quality for Satellite image data
2. Database of Standard Artificial (Man-made) Edge targets
3. Standard Processing Step (algorithm) for Edge target
4. Spatial Quality of Landsat8 OLI Lunar image data

Processing Steps (Recommended)

1. Imaging by the Satellite
2. Read & Select ROI of the Edge target on the image data
3. Check the status and health of the Edge target image data
4. Select and Determine ROI of Edge on the Edge image data
5. Detect the Edge line on ROI
6. Get & Plot Edge Spread Function (ESF) with Pixel data
7. Decide the Staring point of the Bright & Dark area
8. Calculate and Plot ESF by Fitting from the Trimmed ESF pixel data
9. Calculate Relative Edge Response (RER) (by one pixel)
10. Calculate and Plot Line Spread Function (LSF)
11. Calculate Full Width at Half Maximum (FWHM)
12. Calculate and Plot MTF (Modulation Transfer Function)

Processing Steps in Detail (1/7)

1. Imaging by the Satellite
   a. Edge target on Ground [RD1] [RD2] [RD4]
      I. Standard (Artificial) target (Salon, Stennis, etc. by USGS CalVal Portal)
      II. Natural target (Edge of Building, Airstrip, etc.)
   b. Condition of Imaging & Image data
      I. Cloud, Noise, etc.
      II. Product Processing Level (resampling, with / without MTFC, etc.)
      III. Along (Flight) & Across direction on the image data (if with asymmetric PSF)
      IV. Storage format (TIFF, HDF, raw, etc.)
   c. (Loosely) link to the satellite Resolution

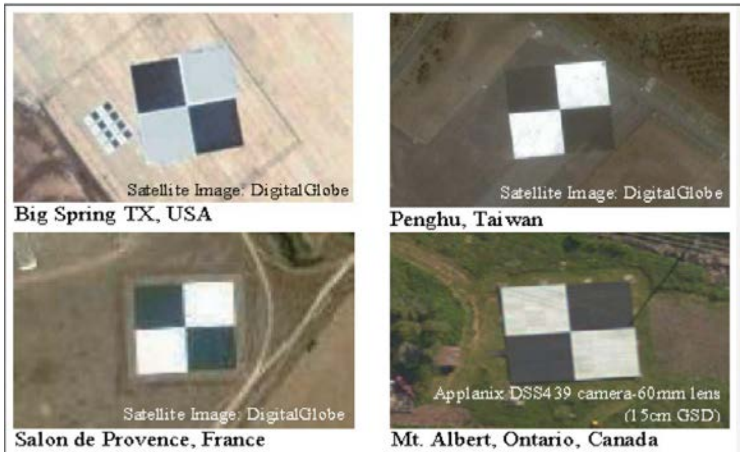
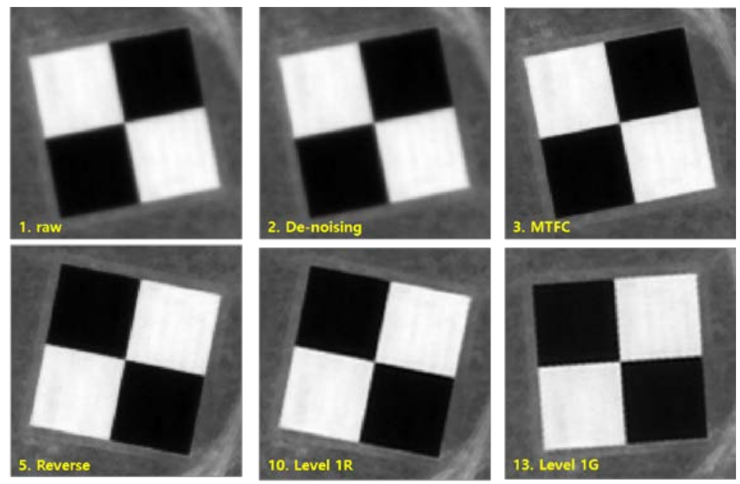
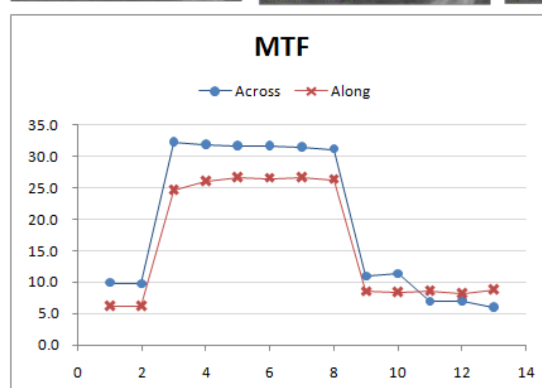


Figure 9. Painted 2 × 2 checkerboard edge targets.

(1:a:i)

[RD1]



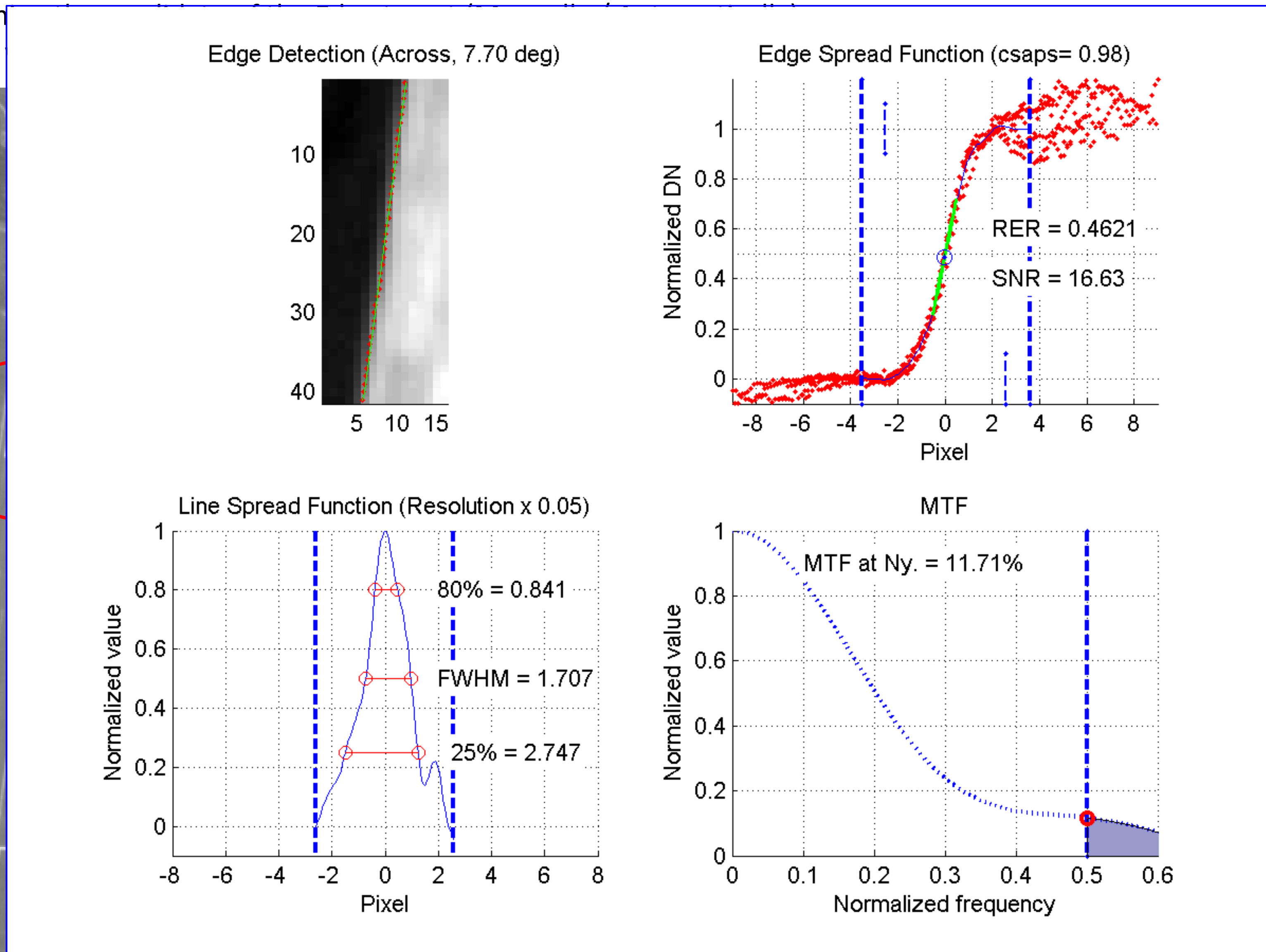


(1:b:ii)

MTF according to KOMPSAT-3 Steps

Processing Steps in Detail (2/7)

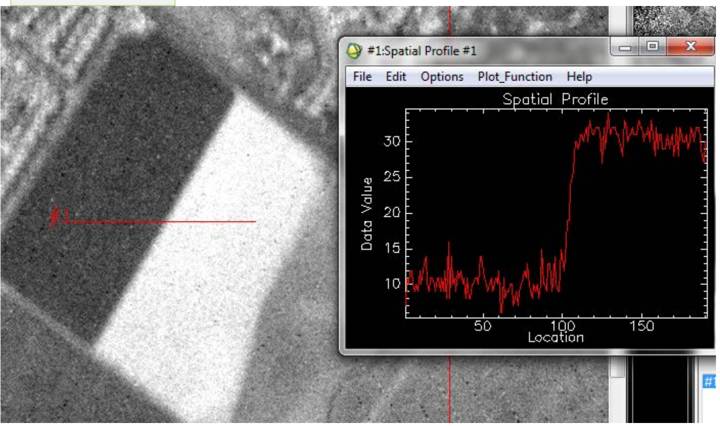
2. Read & Select ROI of the Edge target on the image data
   a. Reading the image data according to the storage format
   b. Search
      •



Processing Steps in Detail (3/7)

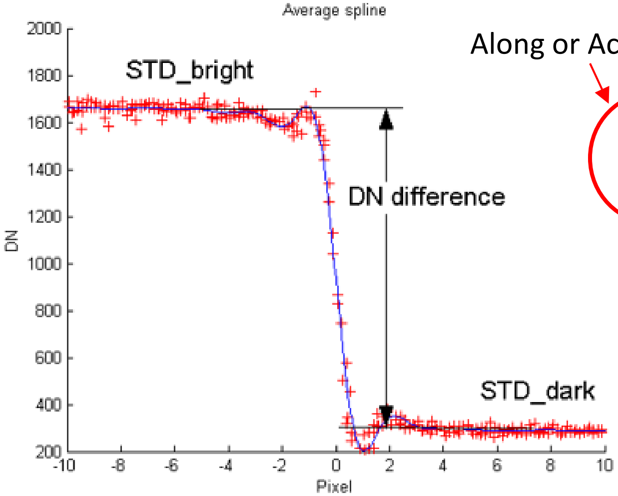
3. Check the status and health of the Edge target image data [RD2, 2.1]
   a. Straight line on Edge
      - ??? (TBD)
   b. Uniformity on Bright and Dark area
      - SNR > 50 (TBR) (Helder, 2002)
   c. DN difference between Bright and Dark
      - ΔDN > 50 (TBR) (Helder, 2002)
   d. Permitted Angle range between Edge and Along / Across direction
      - 0 ~ 30deg (TBR)
   e. Number of Pixel on Edge line
      - > 10~20 pixels (TBR)
   f. Width of Bright and Dark area
      - > 5 pixels (TBR)

(3:b,c)



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

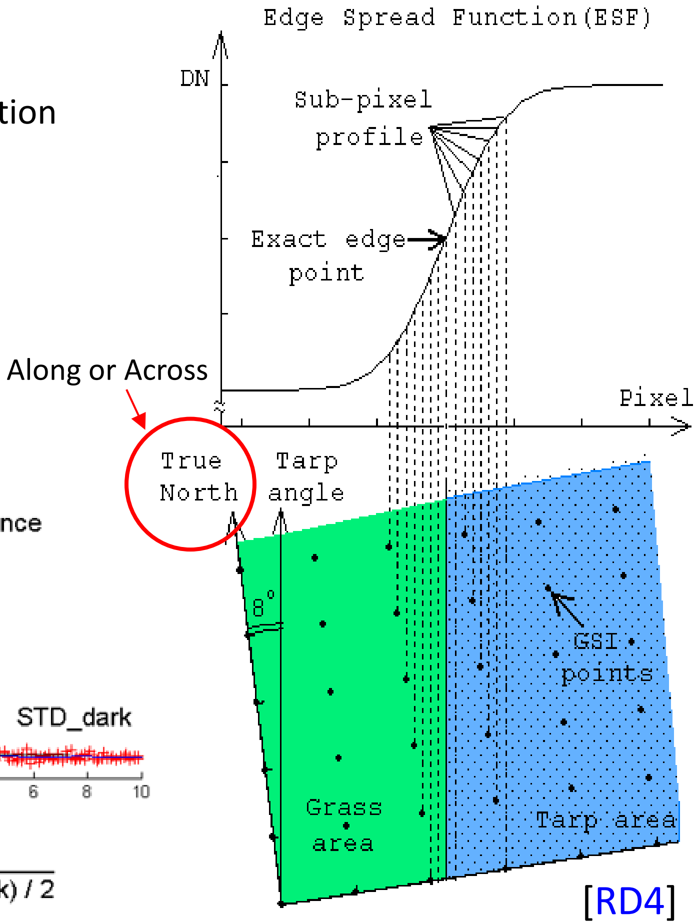
(3:b,c)



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

[RD4]

(3:d)



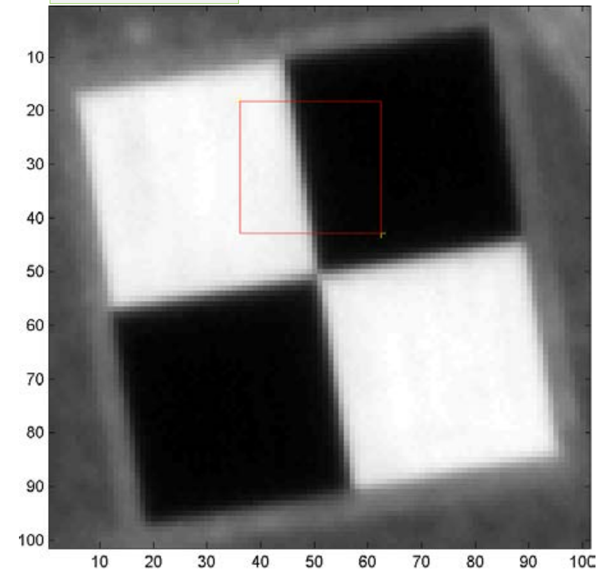
[RD4]

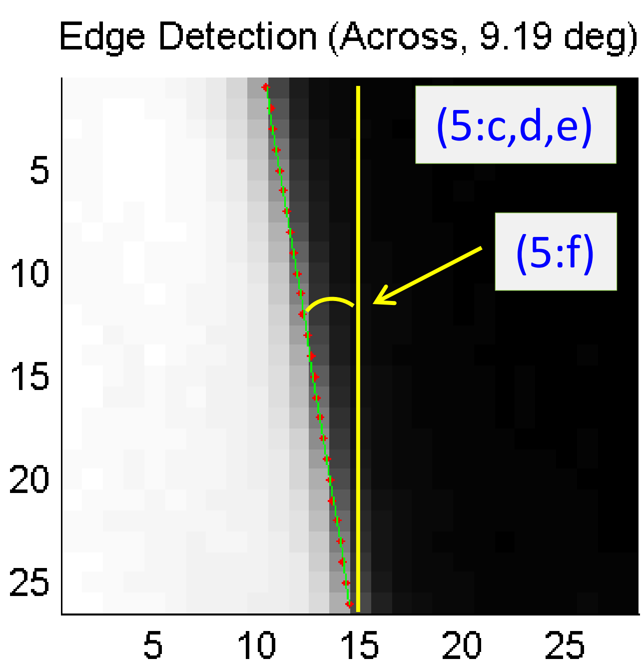
Processing Steps in Detail (4/7)

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

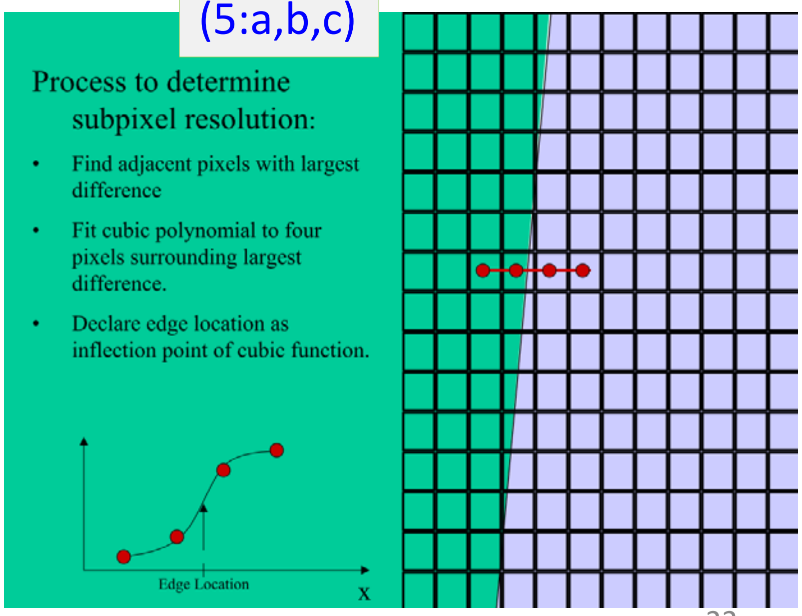
5. Detect the Edge line on ROI
    a. At every line, Find adjacent pixels with largest difference
    b. Fit cubic polynomial (TBC) to (more than) 4 pixels (TBC) surrounding largest difference
    c. Declare edge location as inflection point of cubic function (Red dot) (TBC)
    d. Linear fitting with all edge locations of lines (Green line)
    e. Get the Edge line (Green line)
    f. Calculate the Angle of Edge line (ɵ; Along/Across vs. Edge line)

(2, 3, 4)





(5:a,b,c)

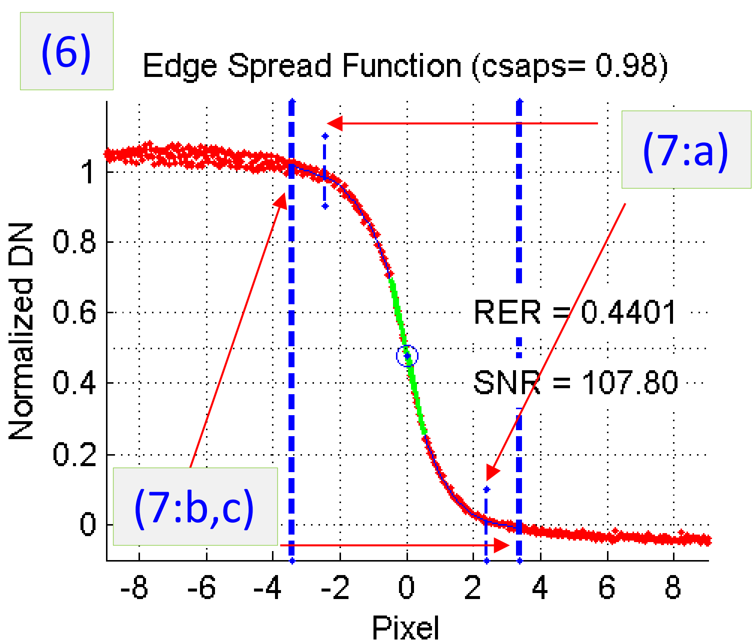


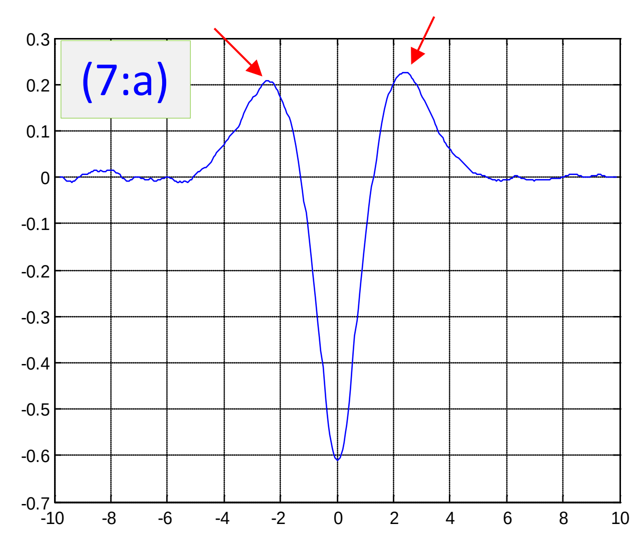
(Helder, 2001)

Processing Steps in Detail (5/7)

6. Get & Plot Edge Spread Function (ESF) with Pixel data
   a. Divide 'the Relative distance of every pixel' by 'cos(ɵ); 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 Staring point of the Bright & Dark area
   a. Inflection point on LSF for the Starting point (TBR)
      I. Fitting (Cubic Smoothing Spline; TBR) 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)
   c. Trim ESF with Pixel data with Bright / Dark area (Blue dot Line)

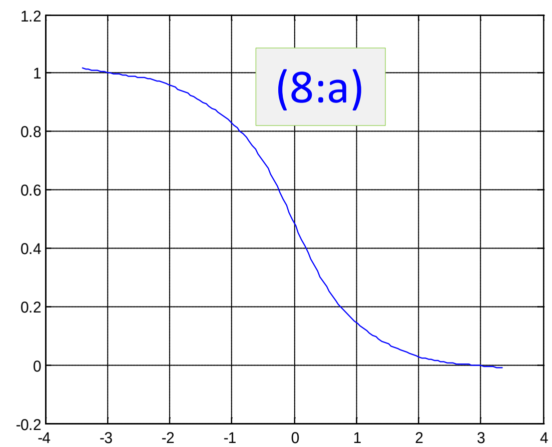


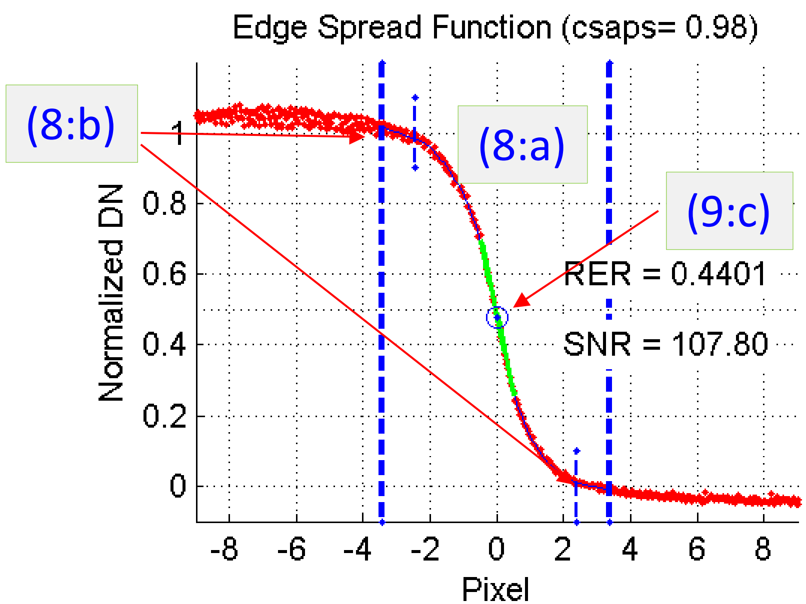


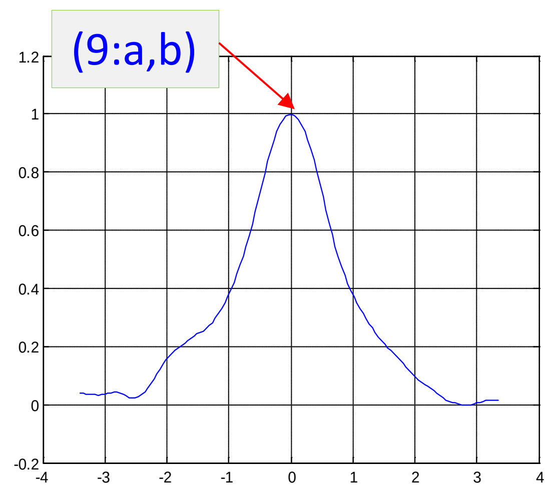
Processing Steps in Detail (6/7)

8. Calculate and Plot ESF by Fitting from the Trimmed ESF pixel data
   a. Fitting by the next (according to the asymmetric LSF) (TBD);
      I. Parametric (Fermi-Dirac)
      II. Non-parametric (Cubic Smoothing Spline, Savitzky-Golay)
   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)
   c. Calculate RER by one pixel (Green line)
   d. If Parametric fitted ESF,
      - The Center of RER is ‘0.5’ on Normalized DN





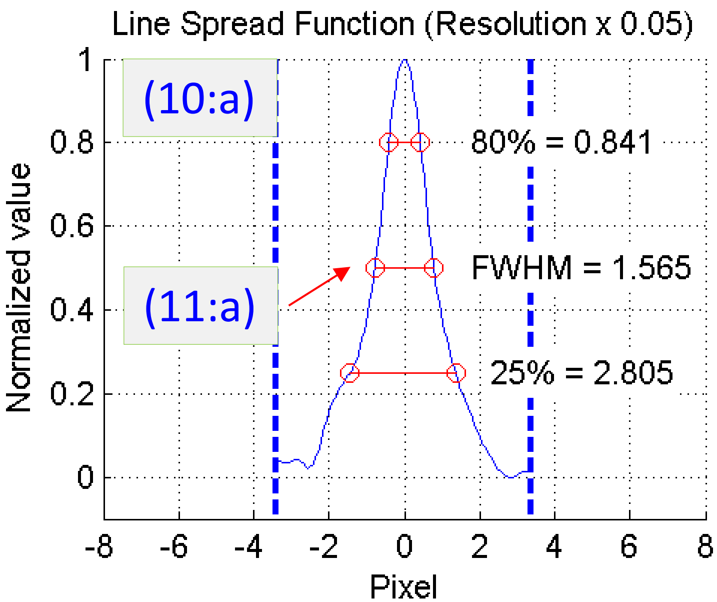


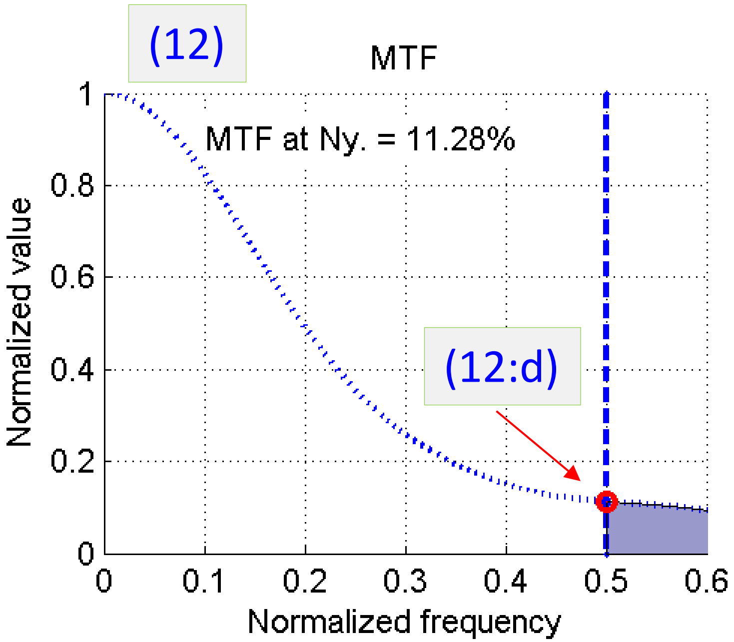
Processing Steps in Detail (7/7)

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 (Draft)

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)		TBR
	5	**Number of Pixel on Edge line**	Limitation of Number of Pixel on Edge line (> 10~20 pixels)		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		TBR
	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 of RER Center**	What is Center of RER; Inflection point (Top) on LSF or Half DN	B1,C1	TBR

Contents

Purpose

- **Measuring the Spatial Characteristics from Landsat-8 OLI Lunar data (Level 1R)**
  - ✓ Edge Slope, RER, FWHM, MTF

- **Major Initial Considerations**
  1. Not Geometric Corrected
     a. CCD Geometry
  2. Not Circle (Level 1R)
  3. Not Uniform Brightness
  4. Shadow area

LO800U0006422013175LGN00
Level 1R, Band_8, PAN, SCA_8

I'm not Dog~!, and just Wolf~!

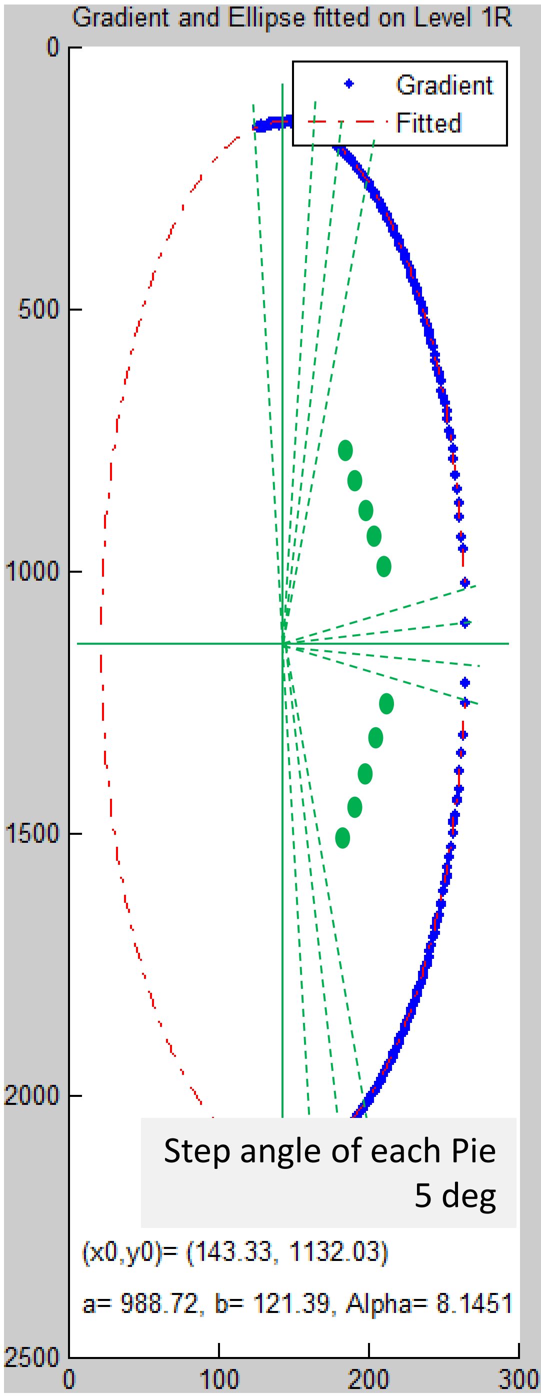
Assumption & Uncertainty

1. **Minor initial effects**
   a. Almost circle of Lunar data after Geometric corrected (Level 1R)
   b. Symmetric LSF each direction of Landsat-8 OLI
   c. Outer line of Lunar data is almost circle line at the Landsat 8 resolution (30m)
   d. Brightness variation in one Step angle (Pie)
   e. Inflection point on LSF may be the starting point of Bright & Dark area

2. **Geometric Correction with CCD Geometry (Minor initial effect)**
   a. Scanning rate on Pitch for imaging the Moon may be Constant.

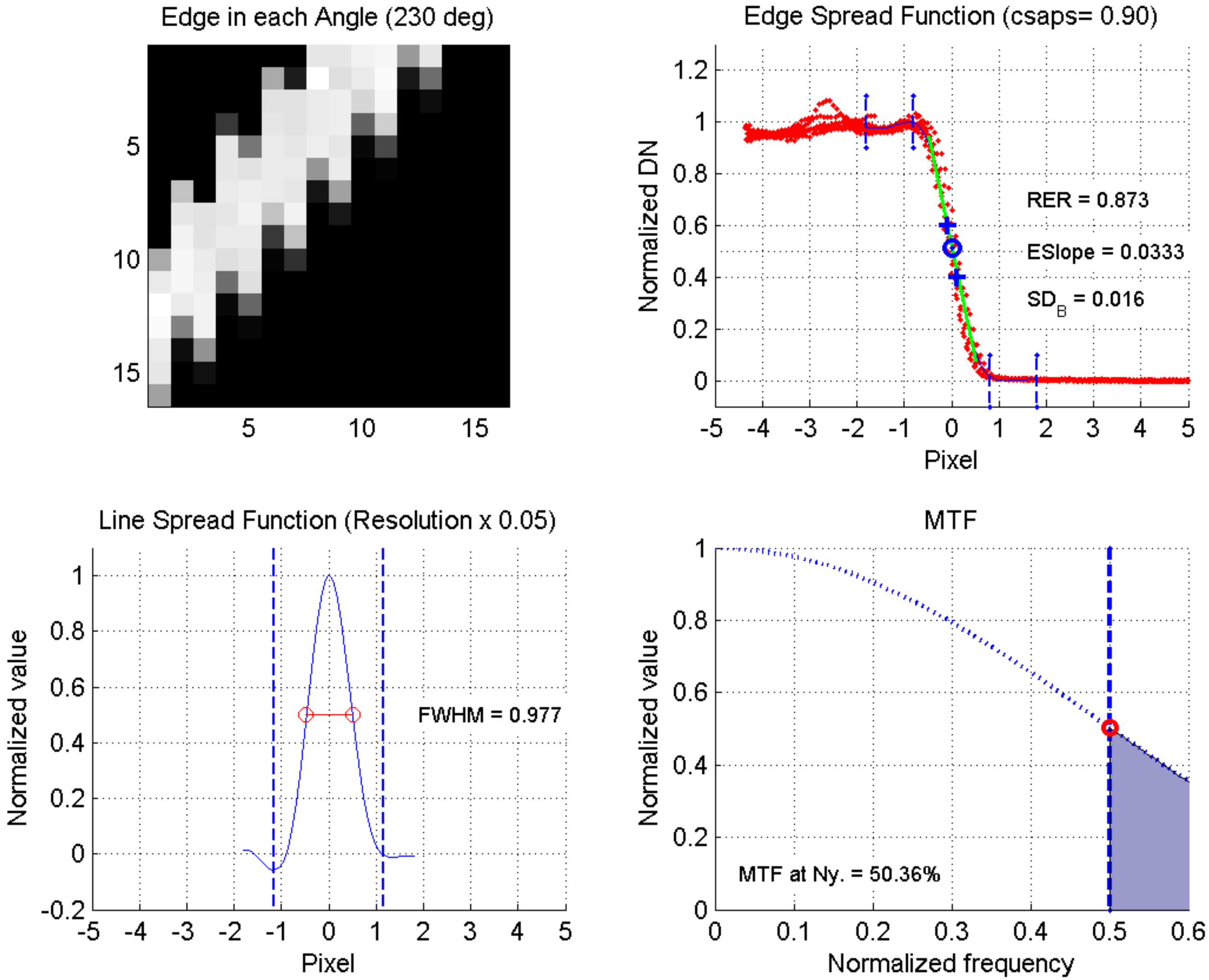
3. **Drop out the low reliable angle values**
   a. Big Brightness variation in one Step angle (StdDev_B_Y) (> 0.065)
   b. Angle: 0, 90, 180, 270, 330deg
   c. etc.

Unprocessed
Level 1R



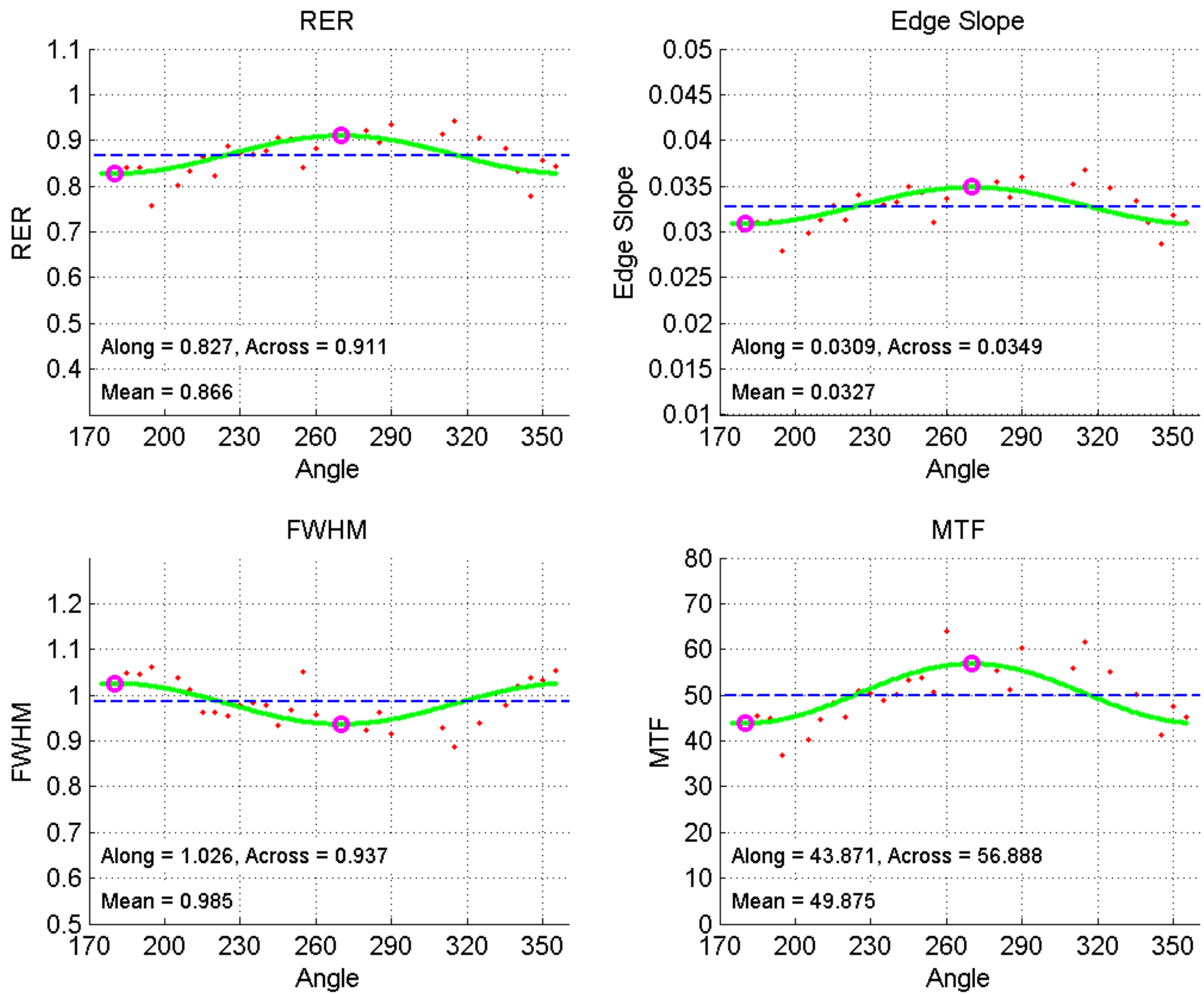
ESF, LSF, MTF (Band_1, Angle: 230deg)

Imaging date: 2013.116, I37900, SCA: 4



RER, Edge Slope, FWHM, MTF (Band_1)

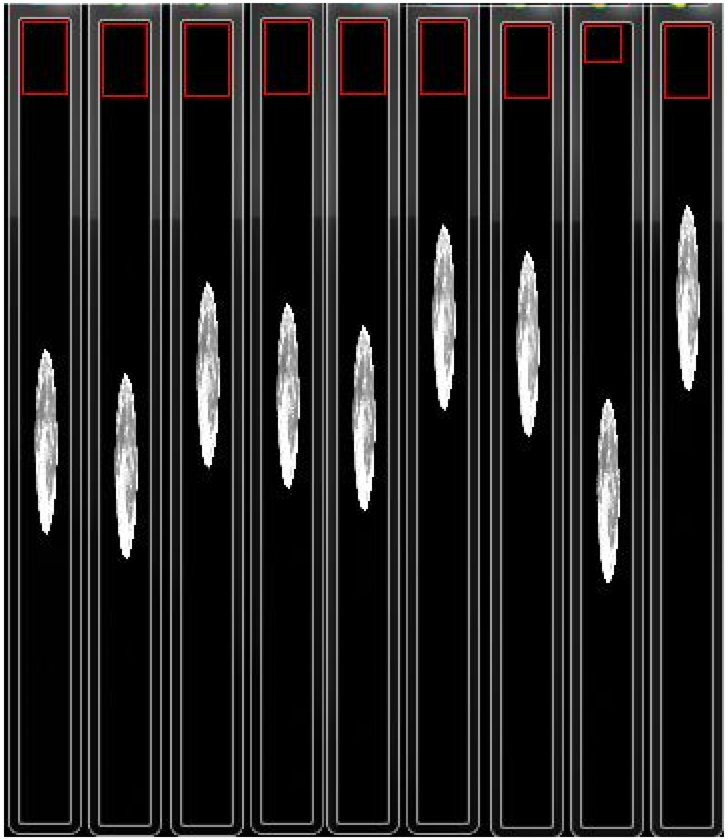
Imaging date: 2013.116, I37900, SCA: 4



Dataset of Level 1R Lunar data

Date	No.
2013.085	15
2013.086	15
2013.115	15
2013.116	15
2013.145	6
2013.175	1
2013.351	15
2014.076	1
2014.164	1
2014.193	5
Total	89

SCA	No.
1	5
2	5
3	5
4	5
5	5
6	5
7	10
8	13
9	6
10	7
11	7
12	6
13	5
14	5
Total	89



LO800U1631352013145LGN00, Level 1R
Band 1, 2, 3, 4, 5, 6, 7, 8, 9

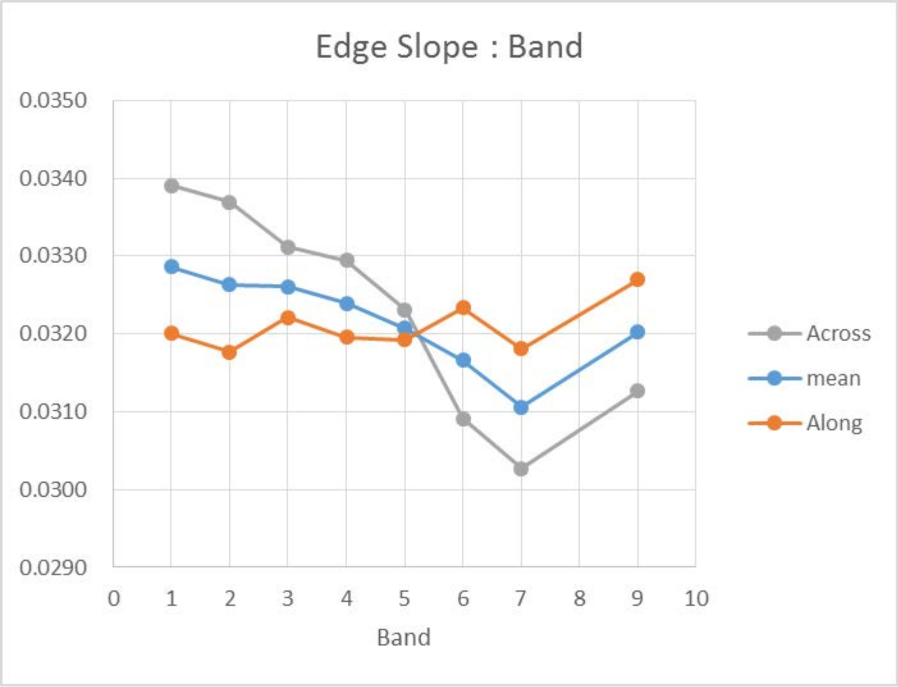
Compare and Result of Edge Slope, RER, FHWM, MTF

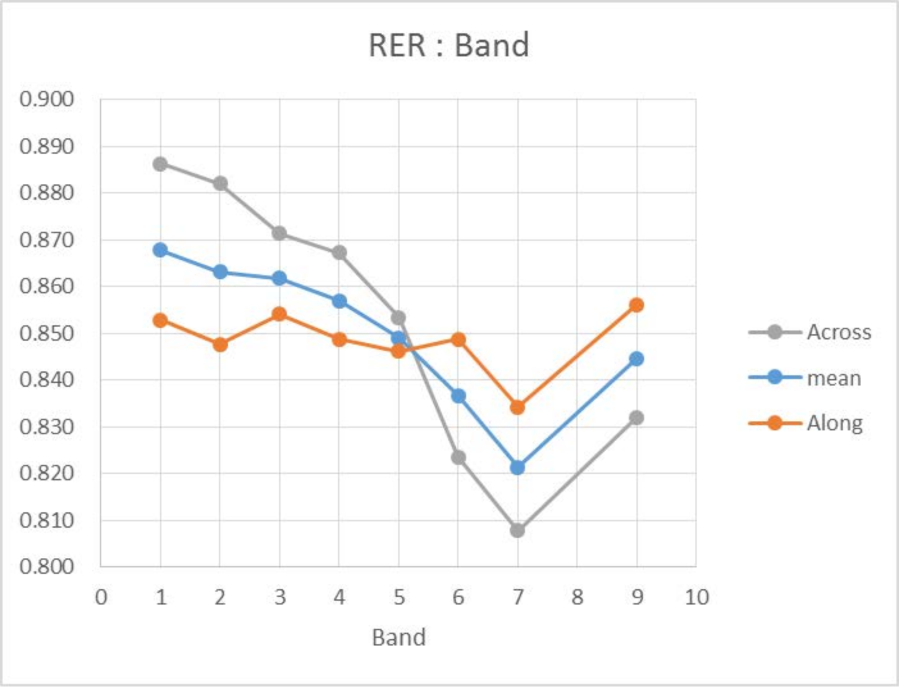
OLI	Edge Slope	GSD		RER	
		MS	PAN	MS	PAN
Specification	0.027	30	15	0.81	0.405
Measured (Jim Storey at TIM, 2013.12)	0.03054	29.934	14.932	0.914184	0.456023
Measured (Jim Storey at TIM, 2014.04)	0.02966	29.934	14.932	0.887842	0.442883

Band	Edge Slope		RER		FWHM		MTF	
	Spline	Fermi	Spline	Fermi	Spline	Fermi	Spline	Fermi
1	0.0329	0.0404	0.868	0.950	0.985	0.726	49.25	54.70
2	0.0326	0.0399	0.863	0.943	0.991	0.735	48.61	53.96
3	0.0326	0.0399	0.862	0.942	0.988	0.737	48.33	53.84
4	0.0324	0.0393	0.857	0.933	0.994	0.749	47.70	52.90
5	0.0321	0.0386	0.849	0.923	0.998	0.761	46.62	51.85
6	0.0317	0.0374	0.837	0.904	0.998	0.787	45.03	49.89
7	0.0311	0.0363	0.821	0.886	1.003	0.811	43.27	48.04
8 (PAN)	0.0593	0.0657	0.793	0.825	1.046	0.902	40.30	41.51
9	0.0320	0.0381	0.845	0.914	0.991	0.773	45.85	50.98

Edge Slope & RER vs. Band

- The trend of Edge Slope and RER is same.
- Along Edge Slope is not depended on the Bands.
  - ✓ (Issues) Along Edge Slope may be affected from any scanning work of Landsat 8.

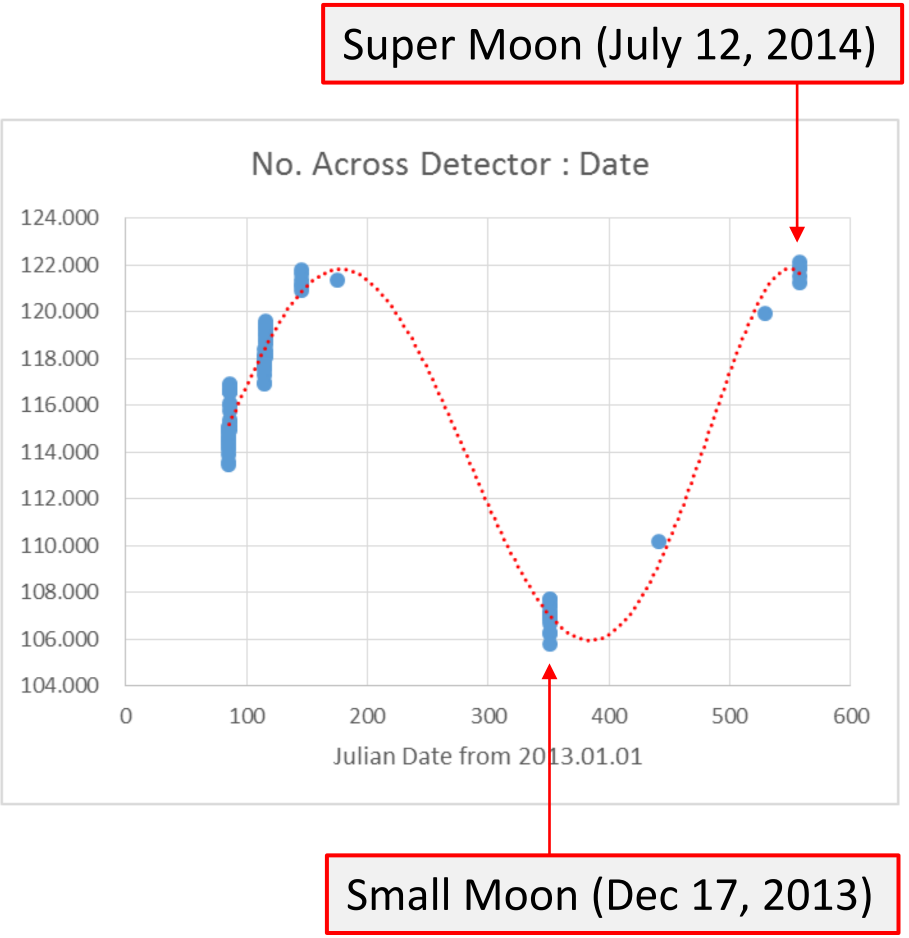




No. of Across Detector (‘b’) vs. Date

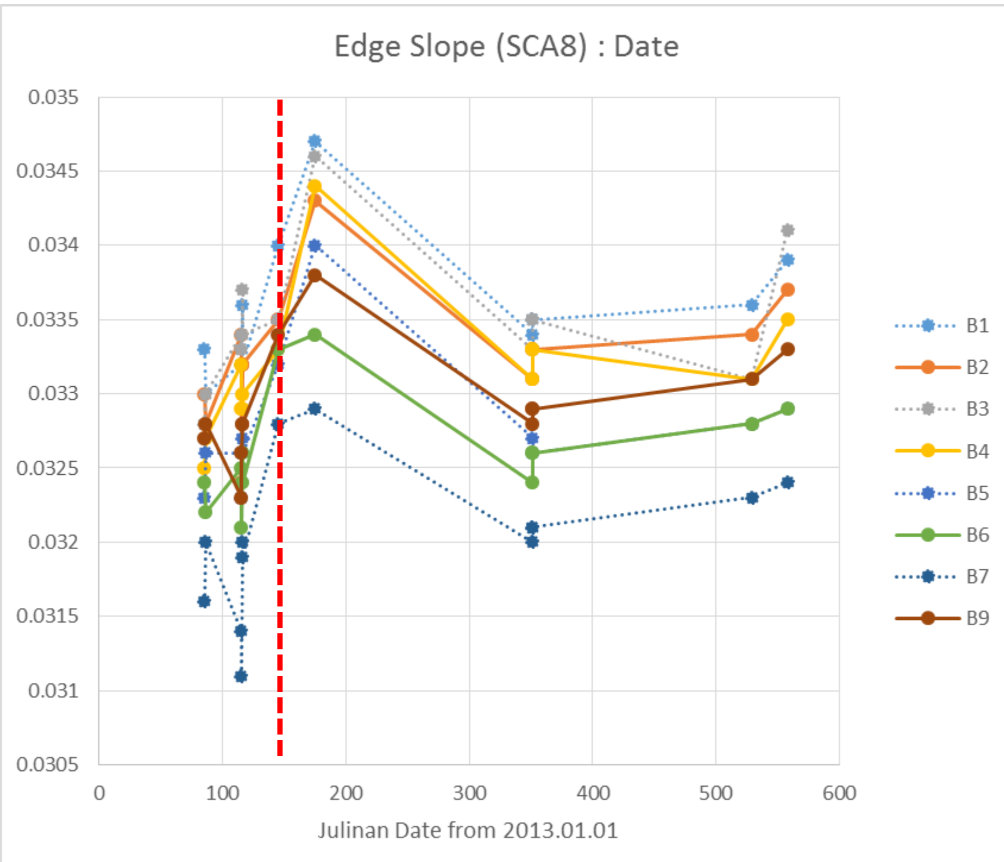
- No. of Across Detector (‘b’ from Ellipse fitting).

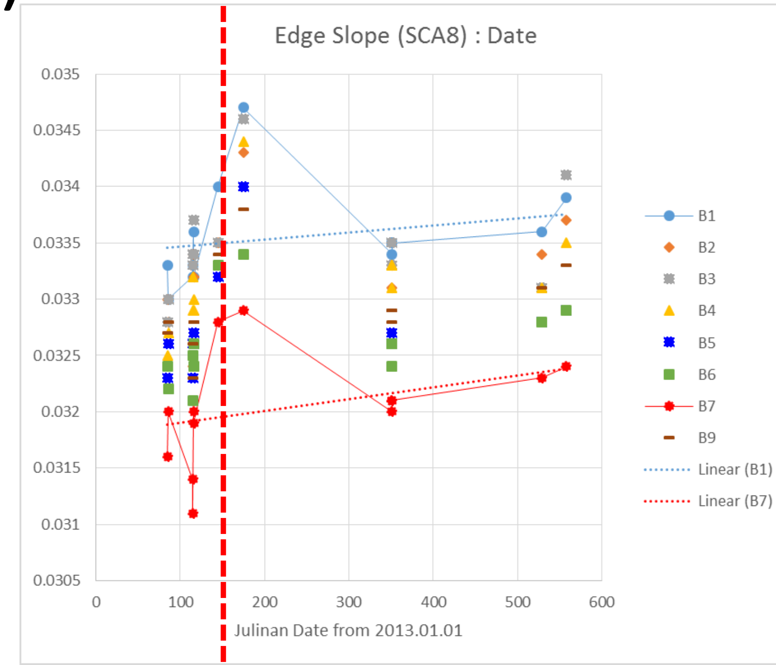
Date	No.
2013.351 (Dec. 17, 2013)	214.24
2014.193 (Jul. 12, 2014)	242.70

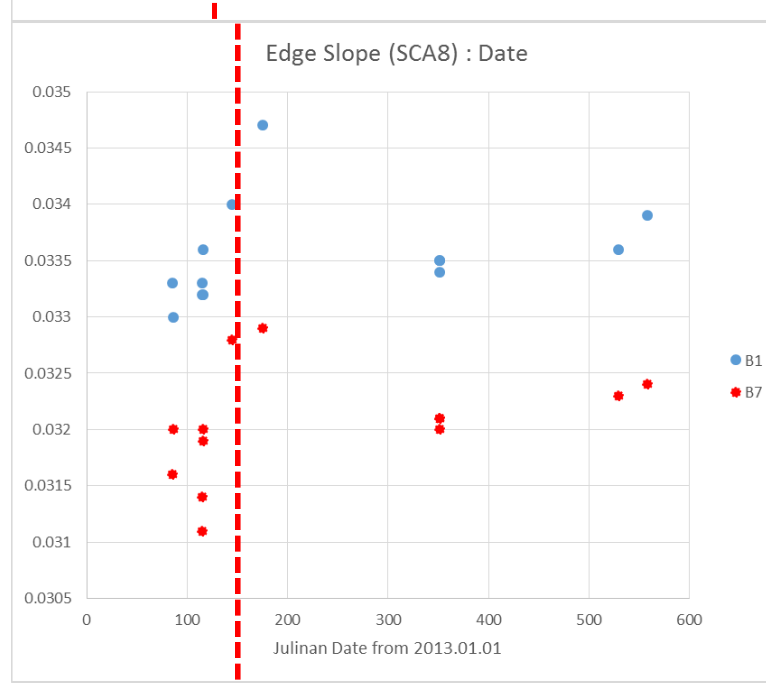


Edge Slope (SCA8) vs. Date

- Landsat 8 OLI may be stable on time (?)
  - ✓ Need more Lunar data

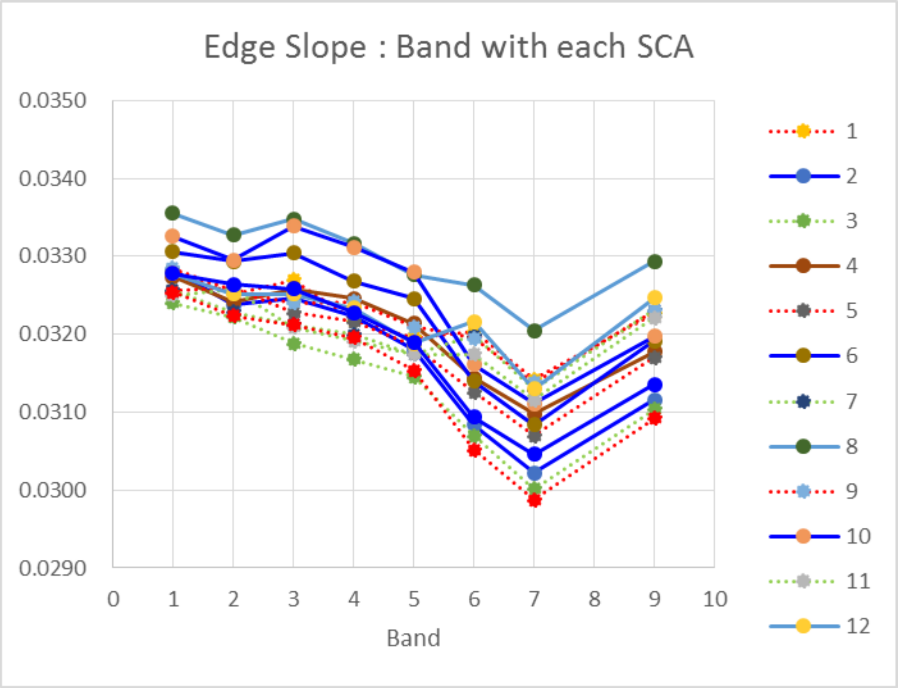


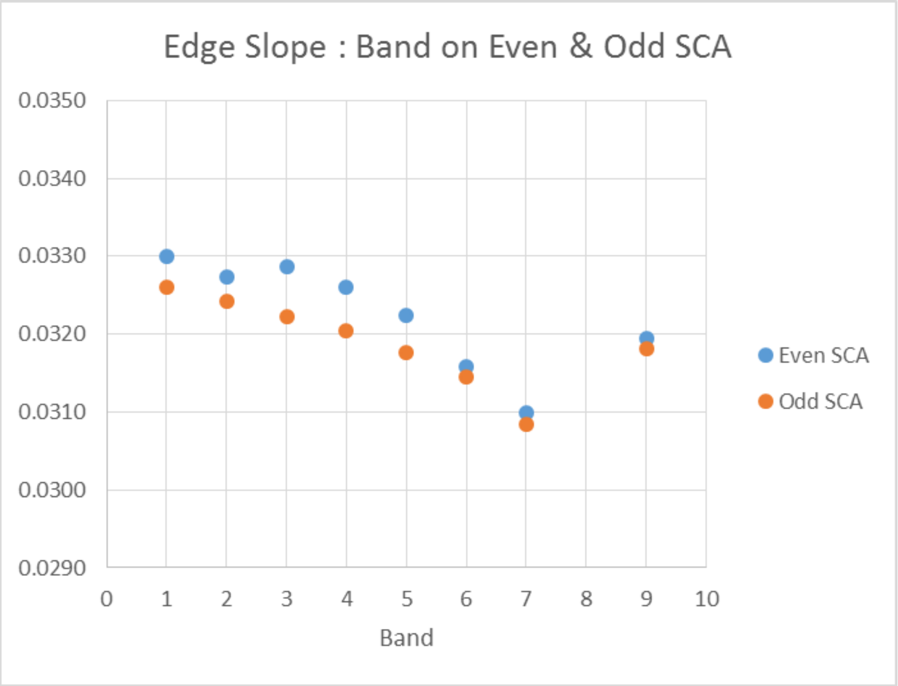




Edge Slope vs. SCA

- Edge Slope of each SCA may be a little different.
- Edge Slope of Even SCA is more than Odd's.

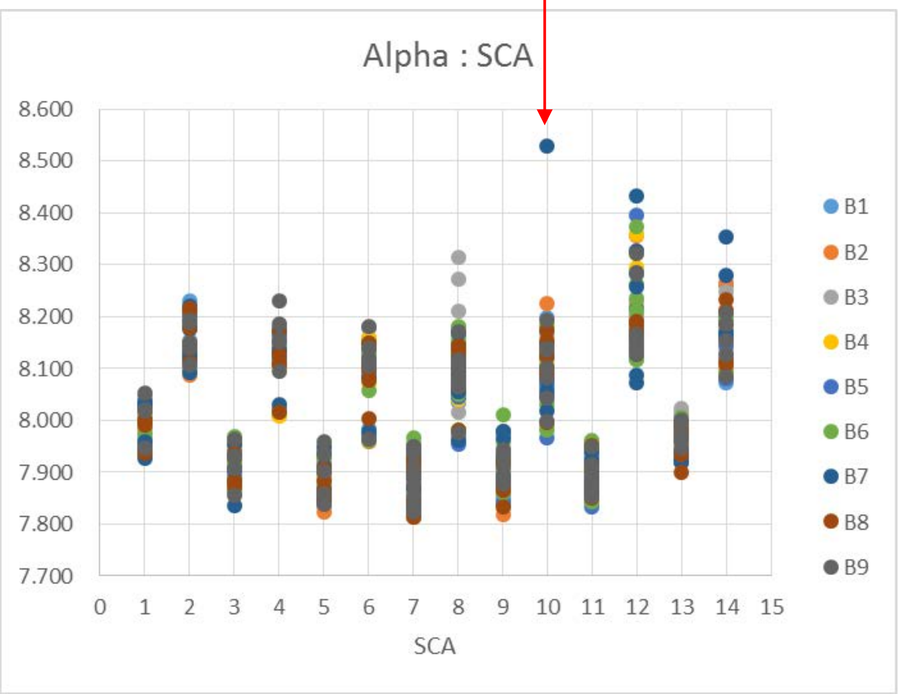


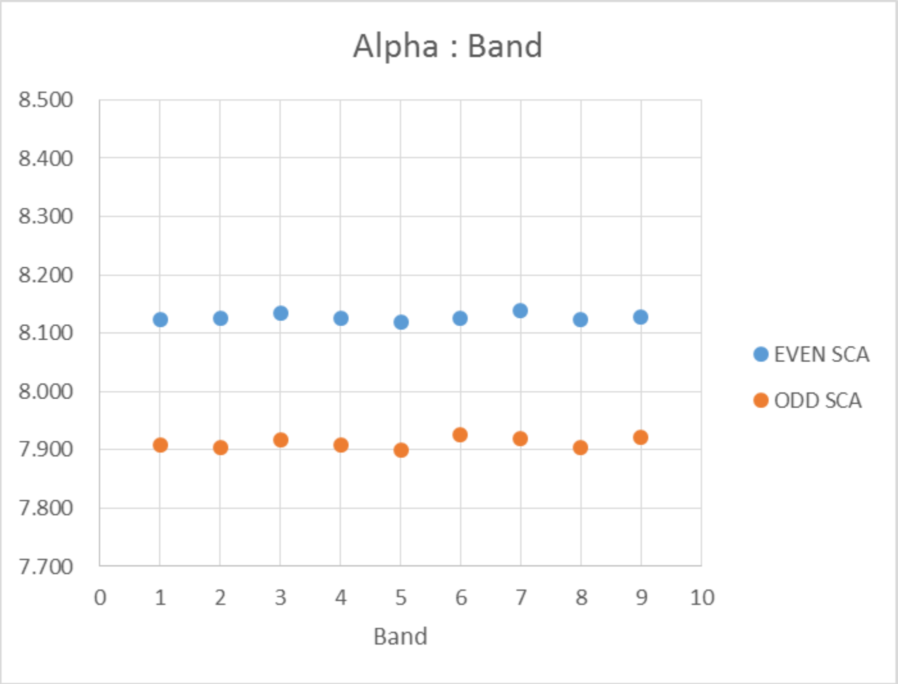


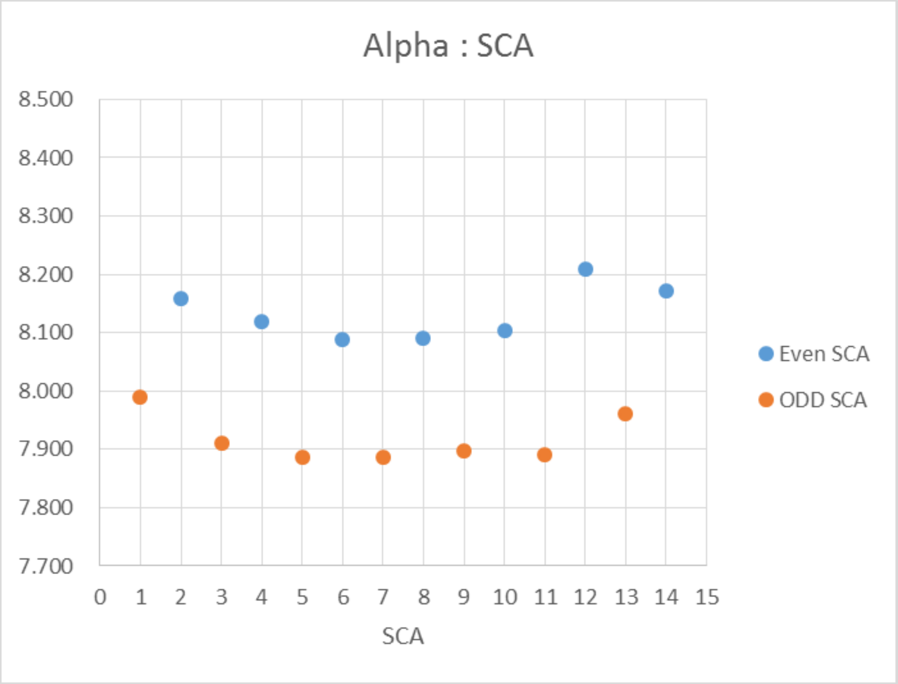
Alpha vs. SCA & Band

- Alpha (a/b from Ellipse fitting) depends on SCA.
- Even SCA is bigger than Odd's.
- Band7, SCA10, 2013 116
  - ✓ Alpha: 8.530
  - ✓ Need more checking

Band7, SCA10, 2013 116 (8.530)







Issues & Concerns

1. This Edge Slope is a little more than Jim's
   a. Atmosphere or Not
   b. Fermi-Dirac fitting on ESF may make the bigger values.
      - ✓ The result of Spline (CSAPS in Matlab) is a little bigger than Jim's; '0.002'
      - ✓ What is Optimal fitting method on ESF?

2. Edge Slope of B8 (PAN) is almost double than MS, but RER of B8 (PAN) is not double.
   a. FWHM & MTF is same with RER
   b. Edge Slope is more stable and reliable for Landsat 8 OLI that has the very high spatial quality.

3. Landsat 8 OLI may be stable on time (?)
   a. Need more Lunar image data

4. Along Edge Slope is not depended on the Bands.
   a. Along Edge Slope may be affected from any scanning work of Landsat 8

5. Edge Slope of each SCA may be a little different.
   a. Edge Slope of Even SCA is more than Odd's.

6. Alpha (a/b from Ellipse fitting) depends on SCA.
   a. Even SCA is more than Odd's.
   b. Band7, SCA10, 2013 116
      - ✓ Alpha: 8.530
      - ✓ Need more checking