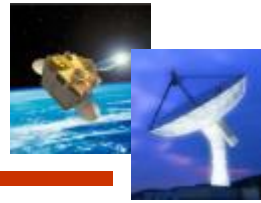


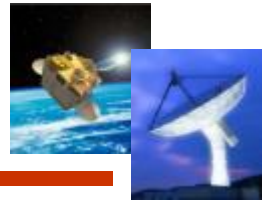
Operation and Calibration Status of GOCI

Seongick CHO

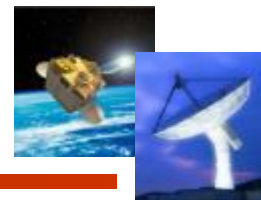
**Korea Ocean Satellite Center,
Korea Institute of Ocean Science and Technology**



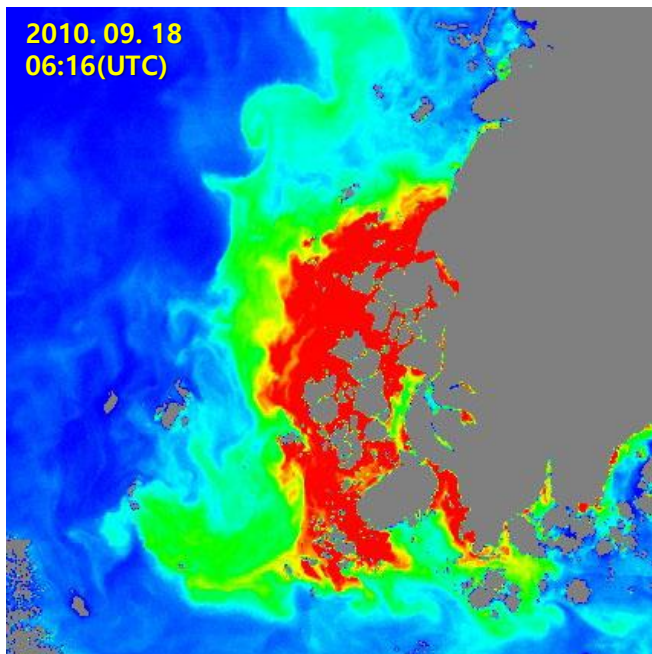
- **Introduction**
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- **Concluding Remarks**



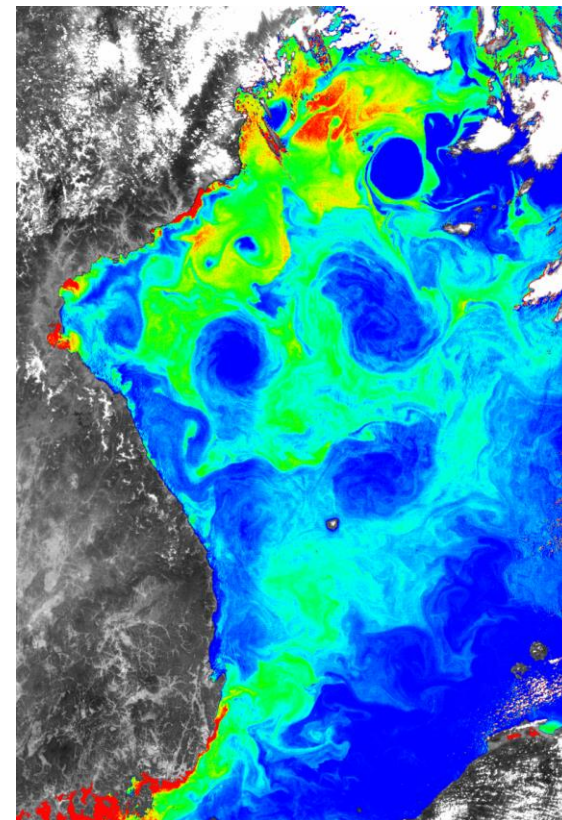
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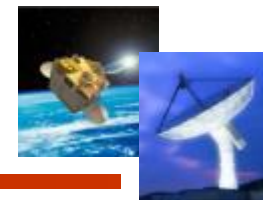


- To Monitor and Research Ocean Biophysical Phenomena with the observation of visible light from Ocean
 - CHL : Chlorophyll Concentration
 - CDOM : Colored Dissolved Organic Matter
 - TSS : Total Suspended Sediment

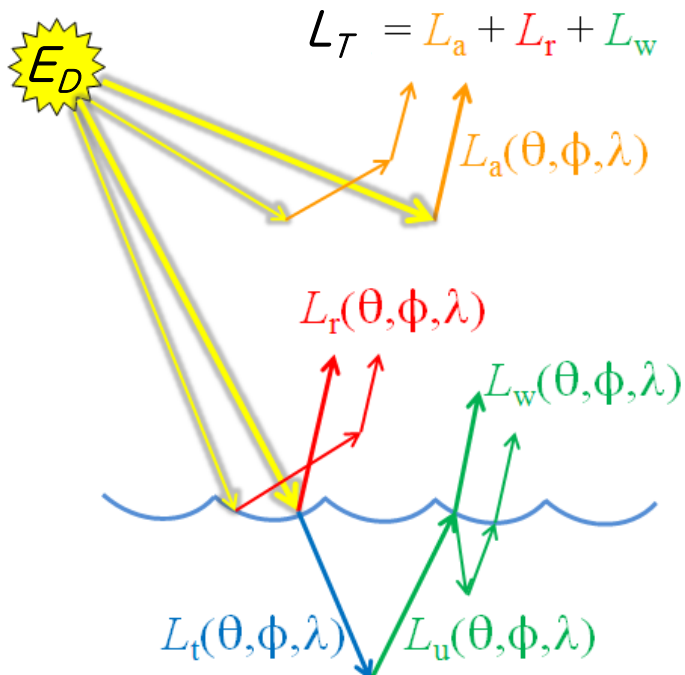


Hourly Monitoring of TSS

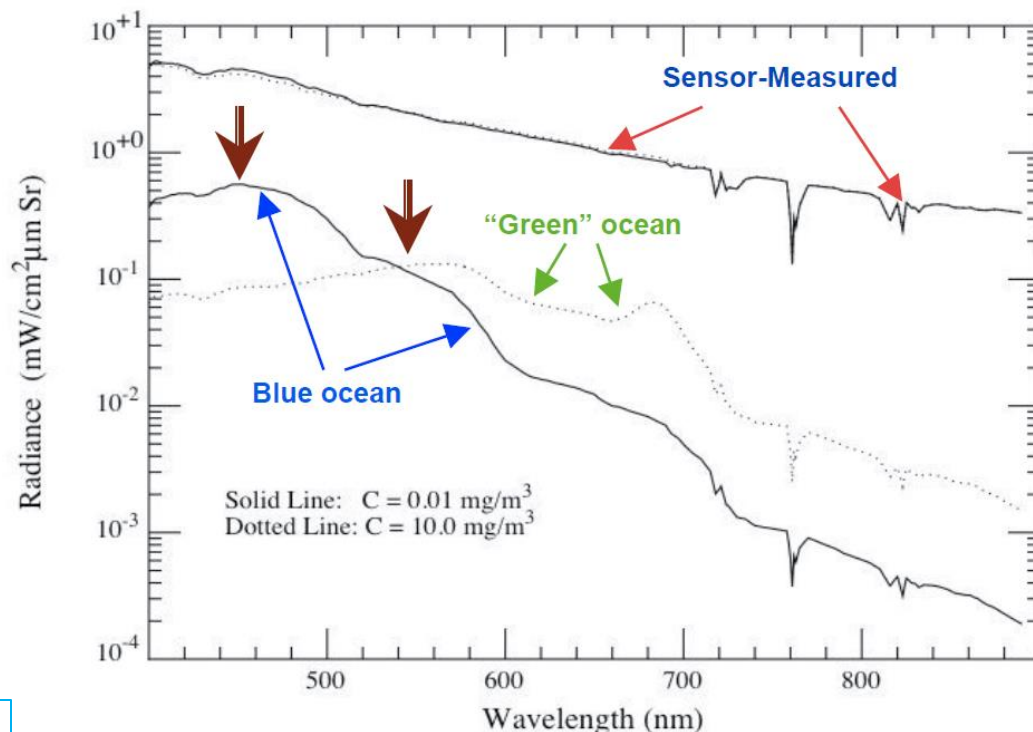




Scientific Definition : *the derivation from the top-of-atmosphere radiance at a certain wavelength λ , $L_T(\lambda)$, reaching a space sensor, of the spectral upward radiance, $L_w(\lambda)$, leaving the water surface in the direction of the sensor* (Ref. Jean-François Berthon, et. al., 2008)

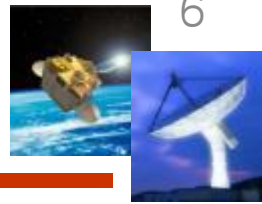


E_D : Downward Solar Irradiance
 L_T : Top-of-atmosphere Radiance
 L_w : Water Leaving Radiance (10~20% of L_T)
 L_a : Atmosphere Path Radiance (80~90% of L_T)
 L_r : Surface-Reflected Radiance



Spectral Response Comparison between L_T and L_w

(Ref. <http://www.ioccg.org/training/SLS-2012/Wang-Sections1-4.pdf>)



Meteorological Imager

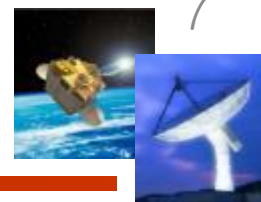
Geostationary Ocean Color Imager

L-band antenna

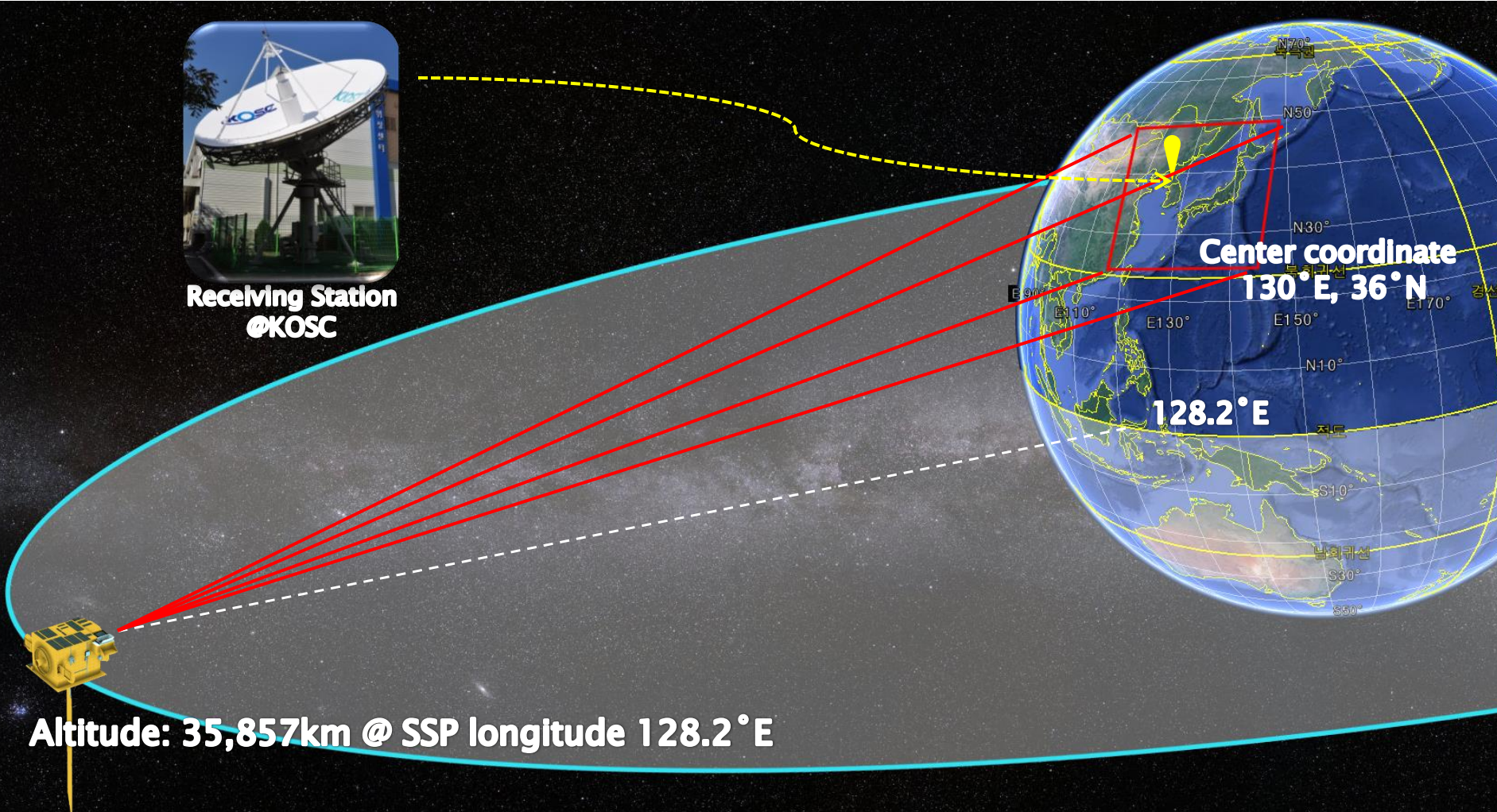
Ka-band antenna

- ◆ COMS : Communication, Ocean & Meteorological Satellite (aka Chollian)
 - Developments of COMS(H/W) and GDPS(S/W) : 2003
 - Establishment of KOSC (Ground System) : 2005
 - The first Korean Geostationary multipurpose Satellite
 - Launch date : June 27 2010
 - Lifetime : 7 years
 - Payloads (3 Missions)
 - Geostationary Ocean Color Imager (GOCI)
 - Meteorological Imager
 - Ka-band Communication

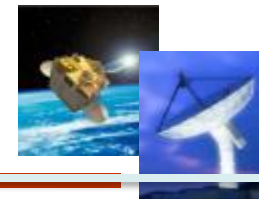
COMS geostationary orbit



Receiving Station
@KOSC



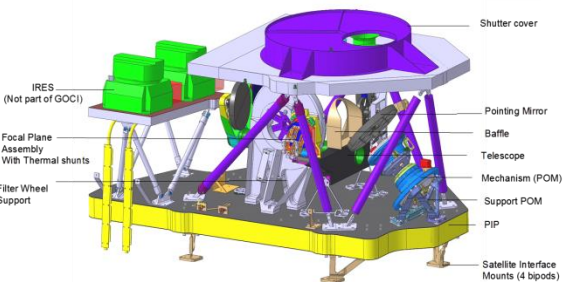
Altitude: 35,857km @ SSP longitude 128.2°E



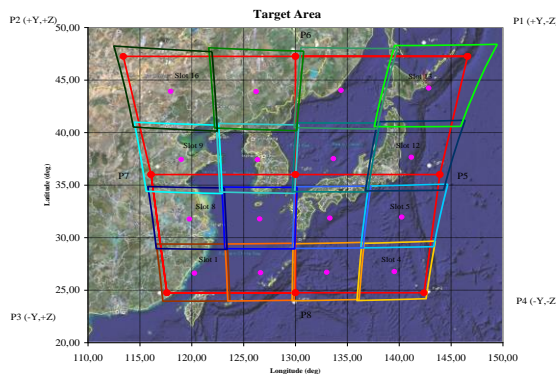
◆ Geostationary Ocean Color Imager

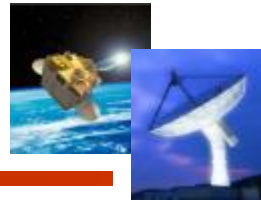
- VIS/NIR Multispectral Imager for Ocean Monitoring
- GSD(Ground Sampling Distance) : 500m@130°E 36°N, ~370m@nadir
- Target Area : 2,500km * 2,500km
(Center : 130°E 36°N; Pohang-Si, Korea)
- Temporal Resolution : 1 hour (8 times at 1 day)

◆ Spectral Bands Characteristics of GOCI

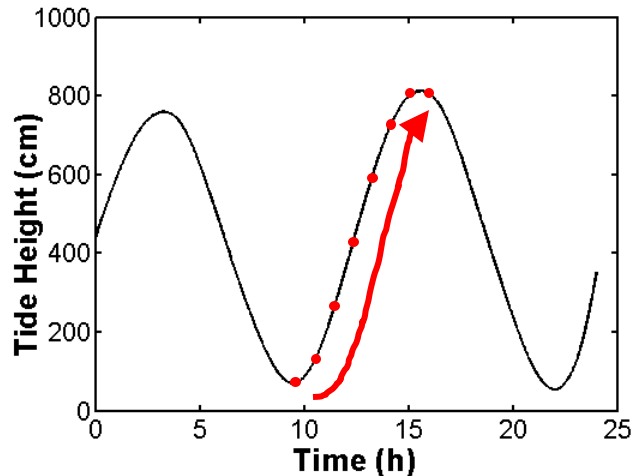
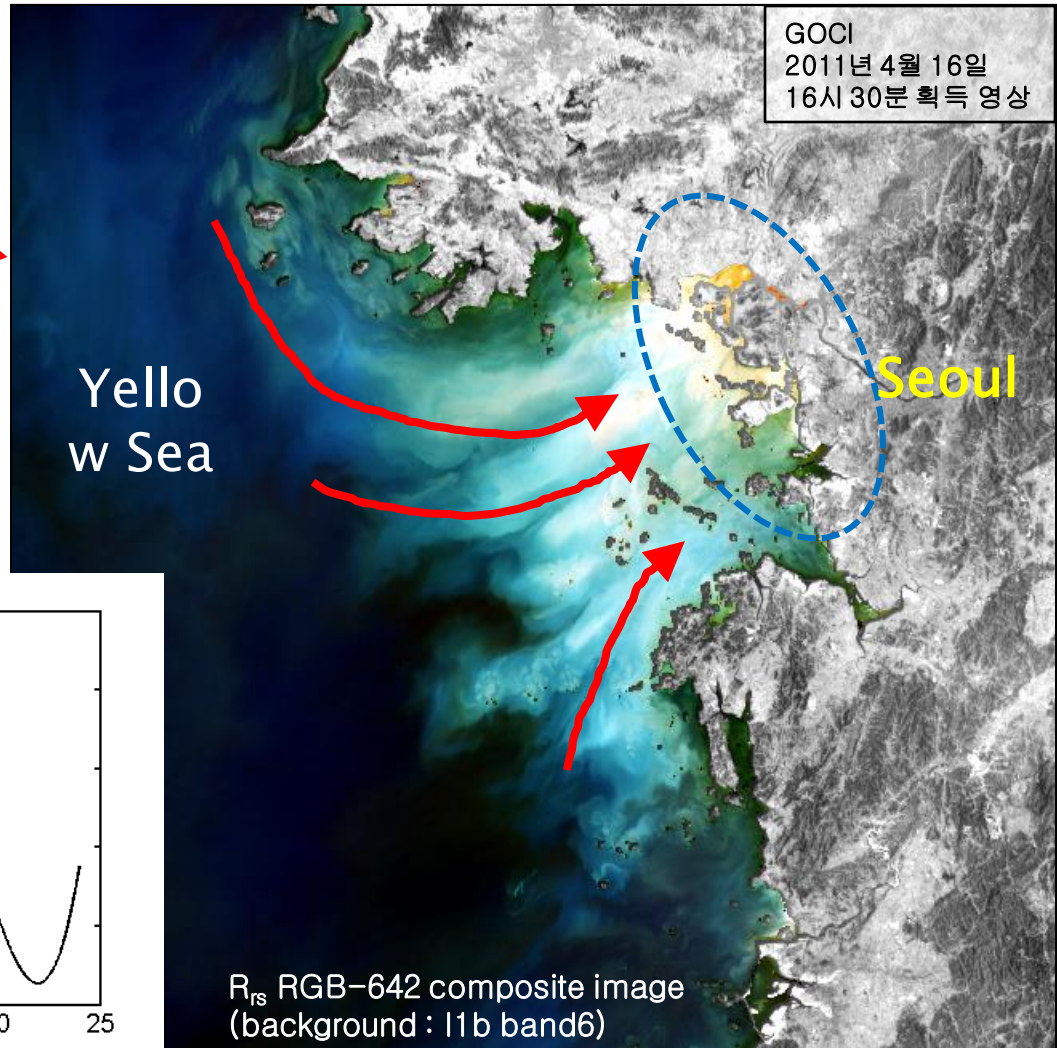
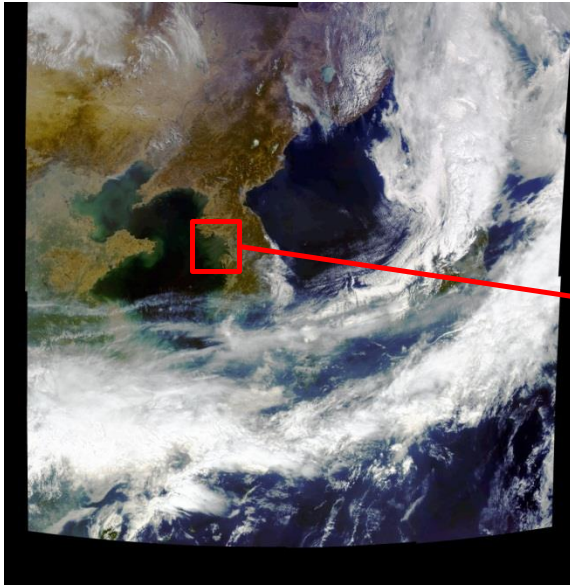
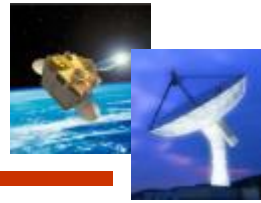


<i>Band</i>	<i>Band Center</i>	<i>Band Width</i>	<i>SNR</i>	<i>Type</i>	<i>Primary Application</i>
B1	412 nm	20 nm	1,000	Visible	Yellow substance and turbidity
B2	443 nm	20 nm	1,090	Visible	Chlorophyll absorption maximum
B3	490 nm	20 nm	1,170	Visible	Chlorophyll and other pigments
B4	555 nm	20 nm	1,070	Visible	Turbidity, suspended sediment
B5	660 nm	20 nm	1,010	Visible	Baseline of fluorescence signal, Chlorophyll, suspended sediment
B6	680 nm	10 nm	870	Visible	Atmospheric correction and fluorescence signal
B7	745 nm	20 nm	860	NIR	Atmospheric correction and baseline of fluorescence signal
B8	865 nm	40 nm	750	NIR	Aerosol optical thickness, vegetation, water vapor reference over the ocean



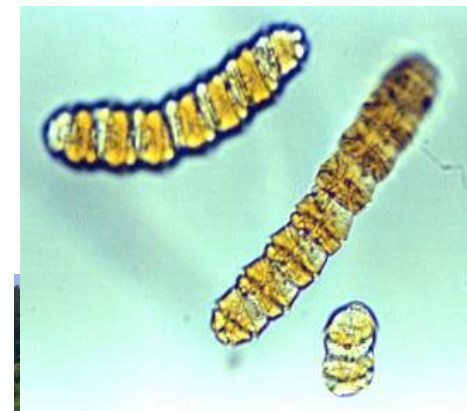


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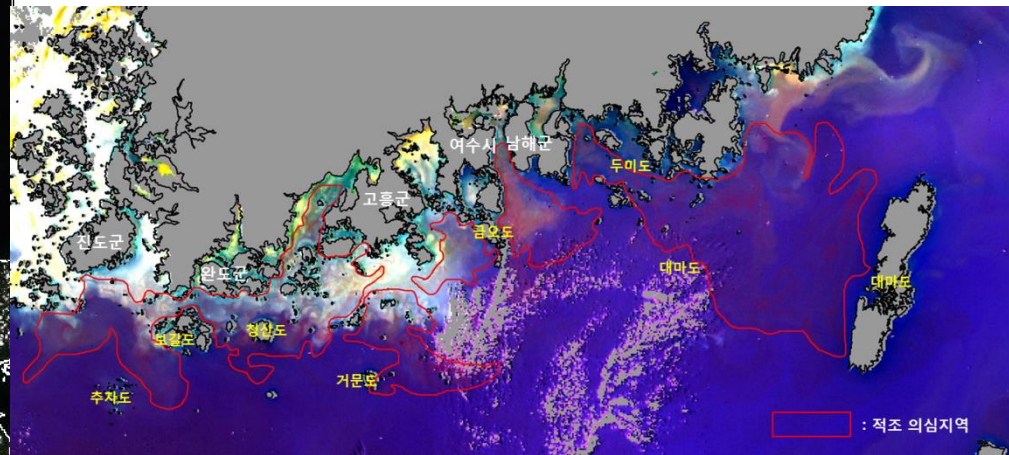
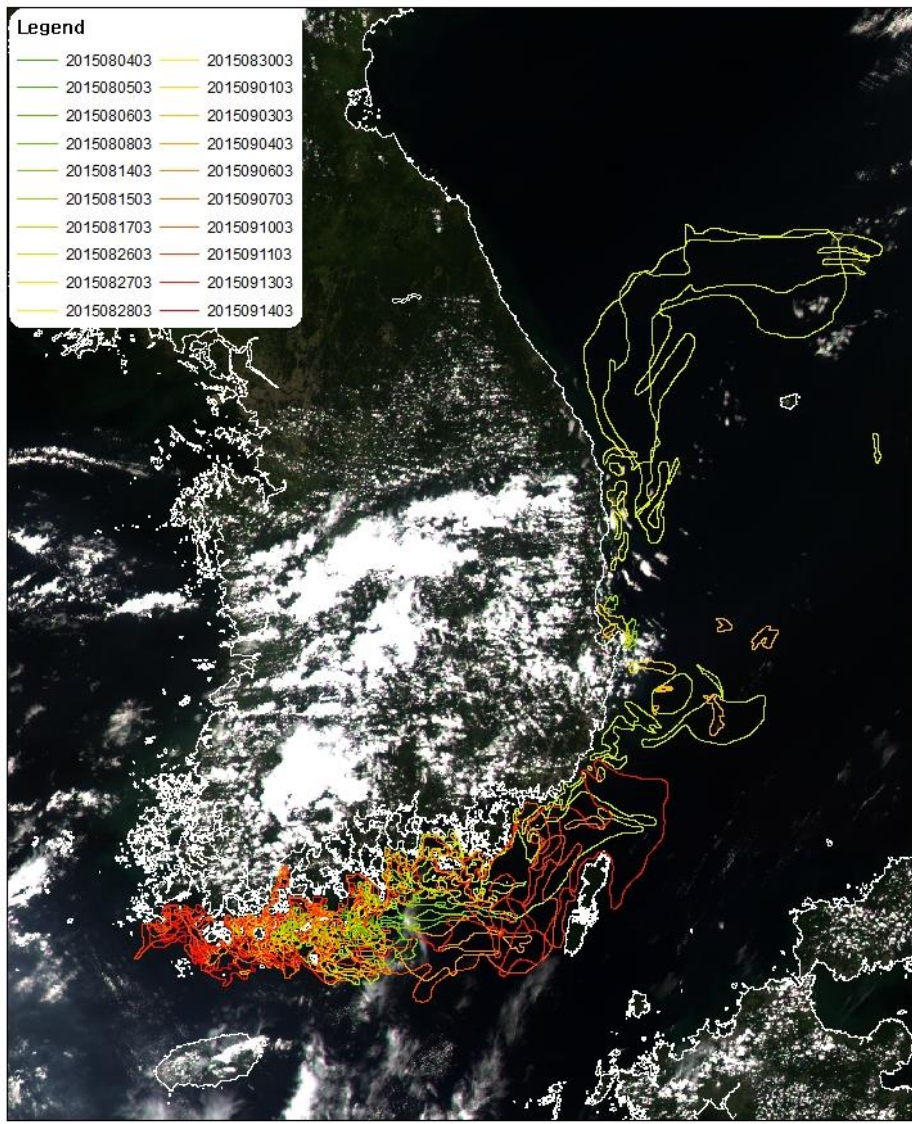
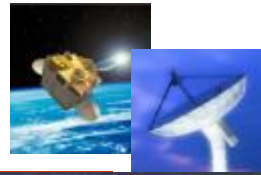


Massive outbreak of harmful algae (*C. polykrikoides*) occurred in the south coast of Korea (red-color patches in GOCI image) and was expanded to eastern coastal waters in Aug-Sep, 2014. GOCI image was useful to identify the spatial coverage of the HAB event, which was difficult with *in situ* observations only.



Korean Media reporting that satellite captured a huge red-tide patch in the south coast of Korea in 2014.

HAB in 2015



<2015년 9월 11일 12:15
GOCI 순수해수신호 합성영상(R:B6,G:B4,B:B2)>

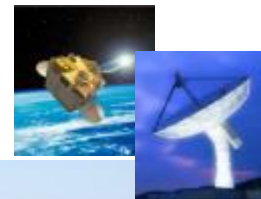
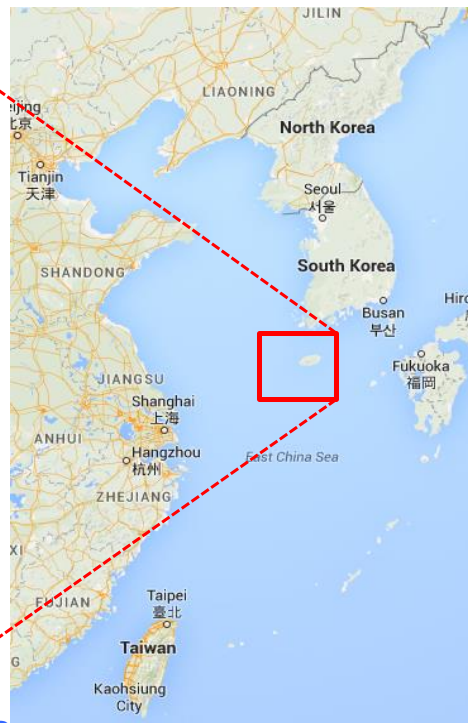
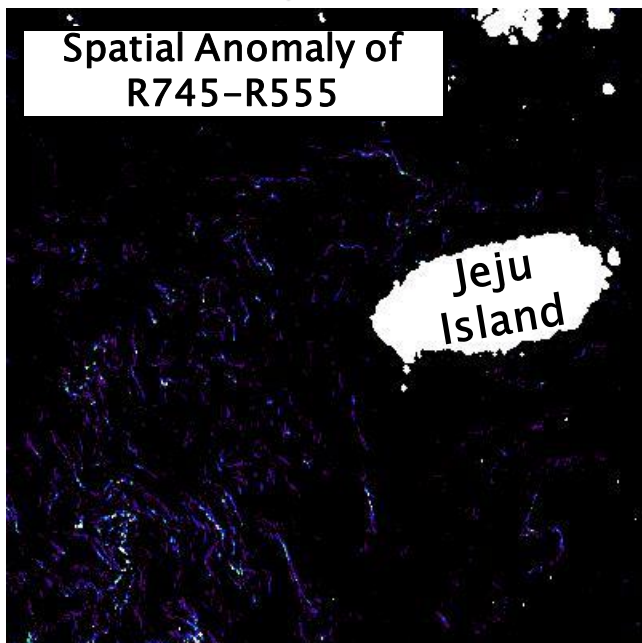
HAB area (2015/08/04~09/14)

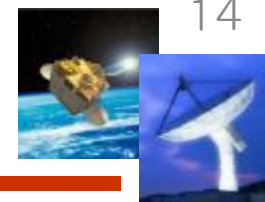
Floating algae (*Sargassum horneri*)

In Jan–Feb 2015, accumulated patches of ‘*Sargassum horneri*’ were found in coastal areas of Jeju island and southwest of Korea. GOCI image (bottom–left image) revealed that the floating algae patches were widely spread in the northern East China Sea.

Spectral signature of *Sargassum* patch is weak and barely visible using contrast in 745nm before atmospheric correction.)

22 April 2015



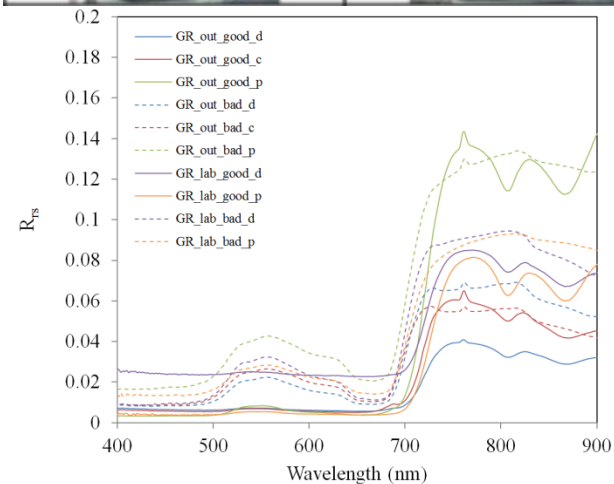
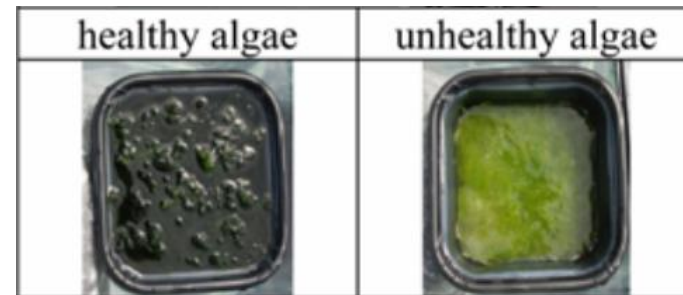


- Qingdao sailing venue



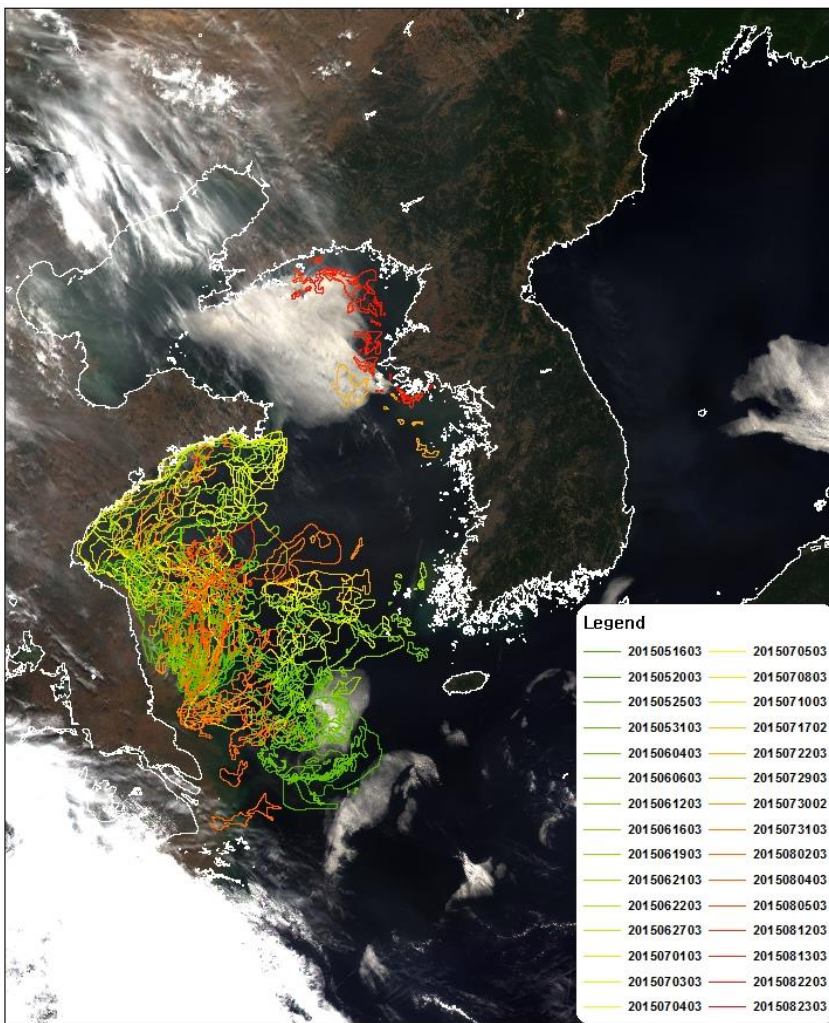
Photo by Victor Kovalenko | YachtPals.com

Boats racing on green meadow??

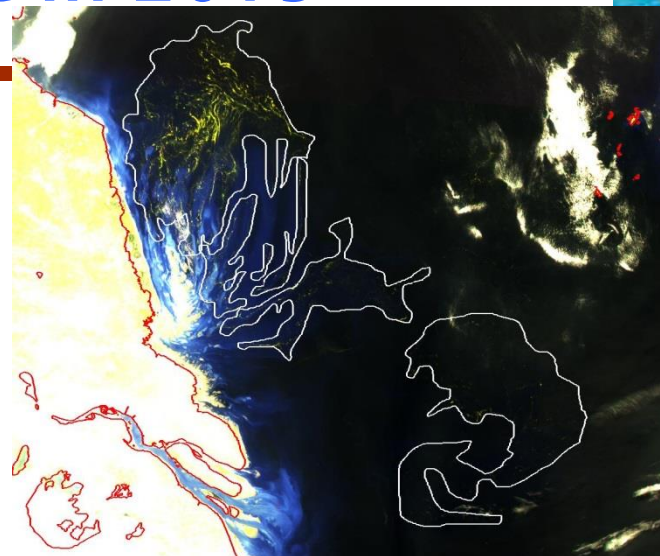


(Reflectance spectra)

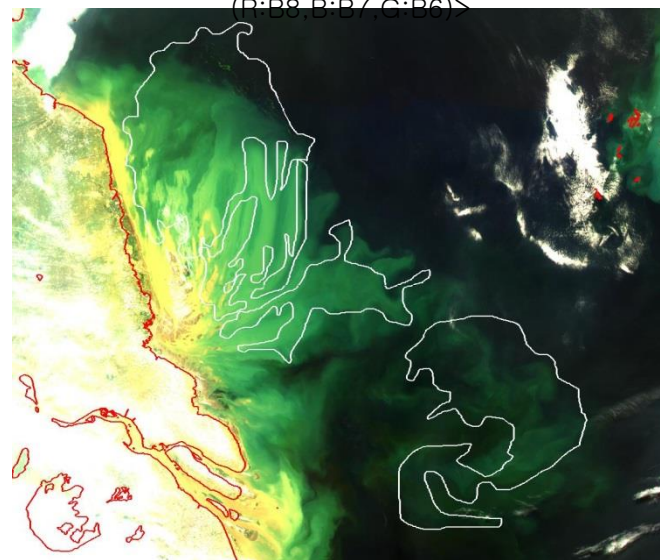
Floating green algae in 2015



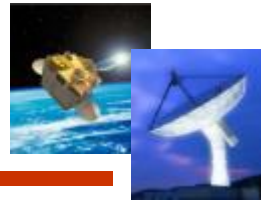
FA Area (2015/05/16~08/23)



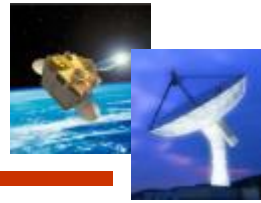
<2015년 5월 25일 12:15 GOCI 레일레이 보정 합성영상 (R:B8, B:B7, G:B6)>



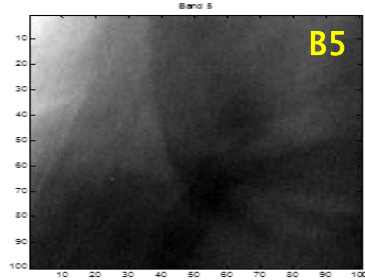
<2015년 5월 25일 12:15 GOCI 레일레이 보정 합성영상 (R:B6, B:B4, G:B2)>



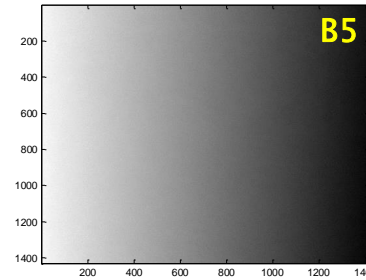
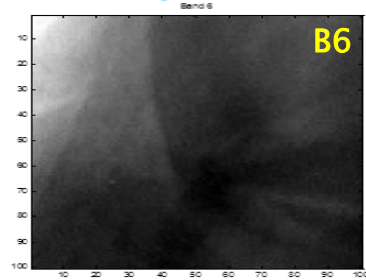
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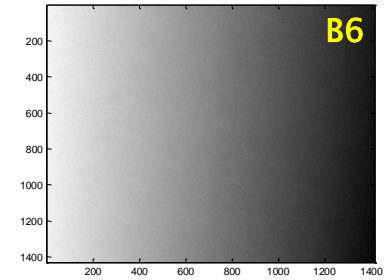
- Assessment Methods for In-Orbit SNR Performance
 - Required Uniform Image for SNR Assessment : $SNR \sim \text{Mean}/STDEV$
 - Method 1: Earth Image Acquisition (Clear Ocean)
 - Method 2: Diffuser Image Acquisition (Solar Diffuser)



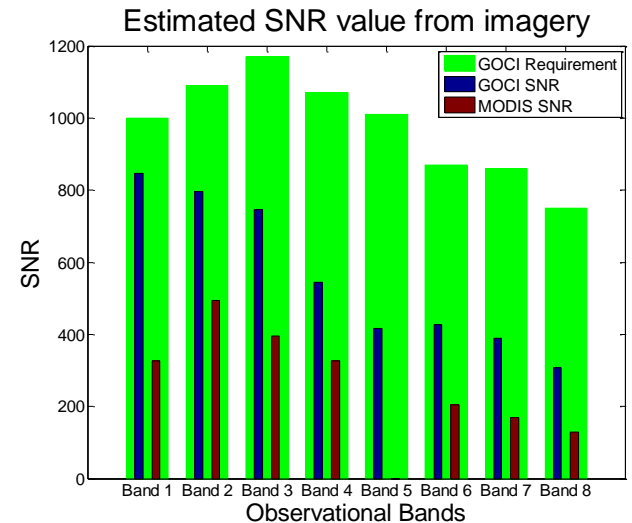
Acquired Earth Image (Clear Ocean)

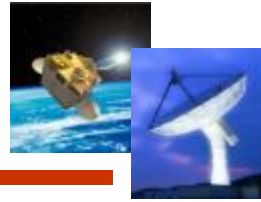


Acquired Diffuser Image (SD)

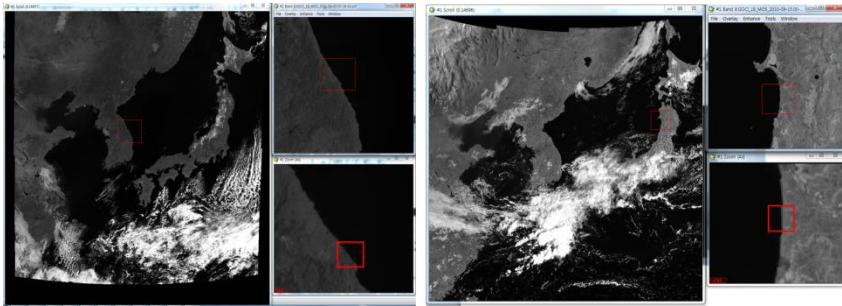


Spectral Band	SNR Requirement	Estimated SNR (Earth Image)	Estimated SNR (Diffuser Image)
Band #1	1077	773.6	N/A
Band #2	1199	1029.2	N/A
Band #3	1316	903.6	N/A
Band #4	1223	809.7	N/A
Band #5	1192	495.2	1214.54
Band #6	1093	457.6	1197.05
Band #7	1107	550.5	983.16
Band #8	1009	444.6	1034.47

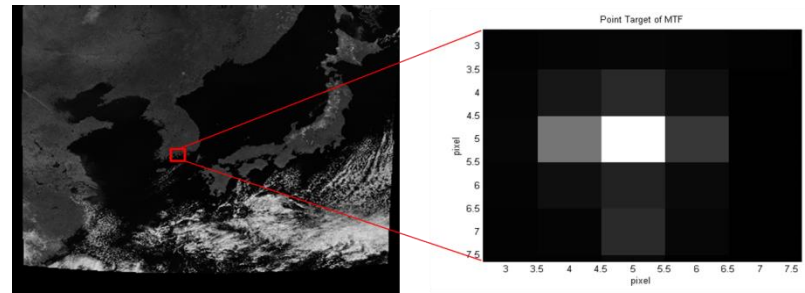




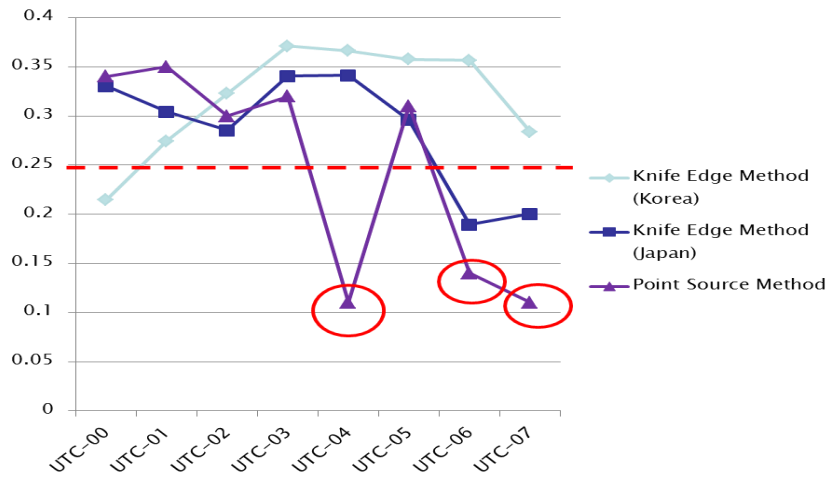
- Assessment Methods for In-Orbit MTF Performance (for Band 8)
 - Method 1: KEM (Knife Edge Method)
 - Method 2: PSF (Point Spread Function)



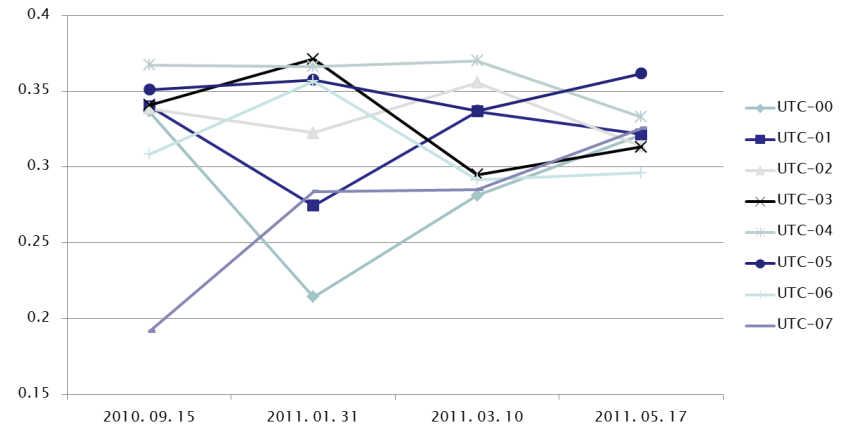
Acquired Image for KEM [Method 1] (L : Korea, R: Japan)



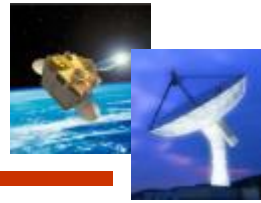
Acquired Image for PSF [Method 2]



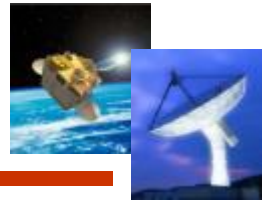
Diurnal MTF Variation at Nyquist Freq.



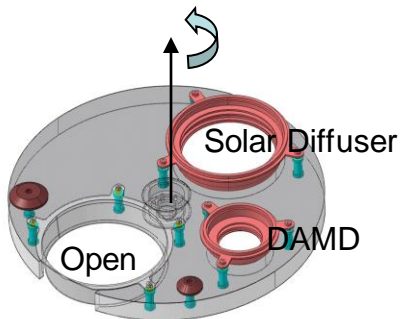
Seasonal MTF Variation at Nyquist Freq.



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- **Solar Calibration using solar diffuser is the baseline method for Radiometric Calibration of GOCI**
 - Subsystem for Solar Calibration : Solar Diffuser & DAMD
 - DAMD(Diffuser Aging Monitoring Device) is the second diffuser in GOCI
 - Sun is a reference light source for GOCI in-orbit calibration
 - Characterization of Diffuser Transmittance with high accuracy is the key to achieve the radiometric accuracy
 - Because GOCI Solar Diffuser shows variation of transmittance with respect to the light incident angle, dedicated characterization model is implemented into calibration S/W developed by this research



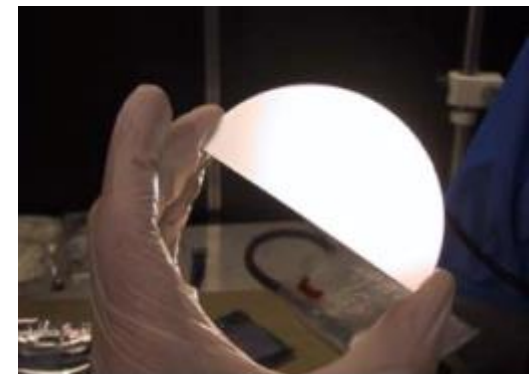
Shutter wheel



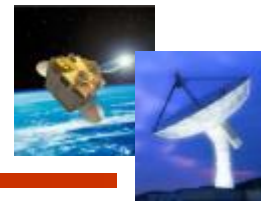
SD(Solar Diffuser)
Dim : 14cm



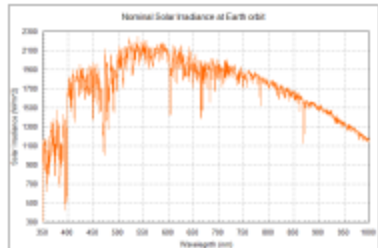
DAMD
Dim : 7cm



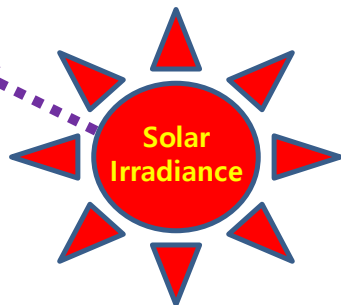
Diffuser for irradiation test
(other half one : reference)



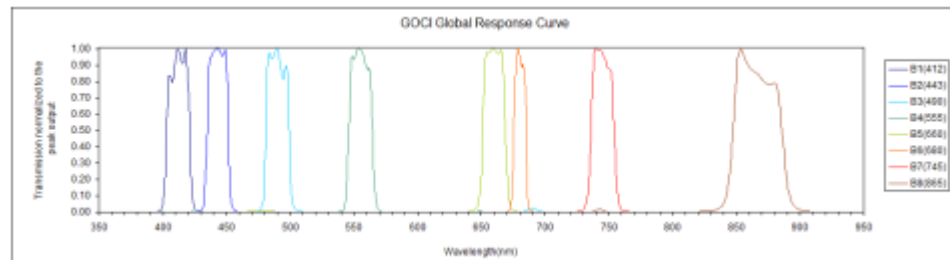
Solar Irradiance Reference Spectra



(Ref. Thuillier, 2004)



GOCI Spectral Response Function



Sun-Earth Distance Model

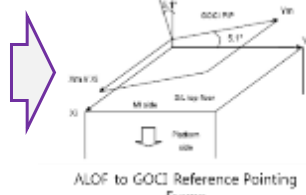
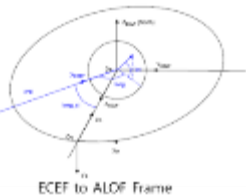
$$D_{es} = 1.00011 + 0.034221 \cos(\Phi_{day}) + 0.00128 \sin(\Phi_{day}) + 0.000719 \cos(2\Phi_{day}) + 0.000077 \sin(2\Phi_{day})$$

(Ref. Spencer, 1971)

Solar Incident Angle Calculation

Orbital Position of Sun
Frame Conversion

- 5.1 deg rotation in Ro^{II}



Sun-Earth Distance Model

Instrument Spectral Model

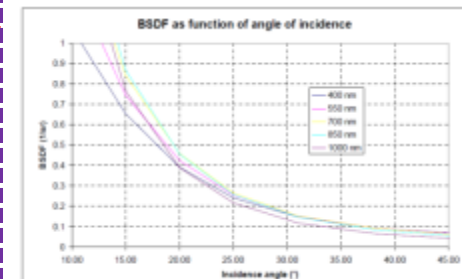
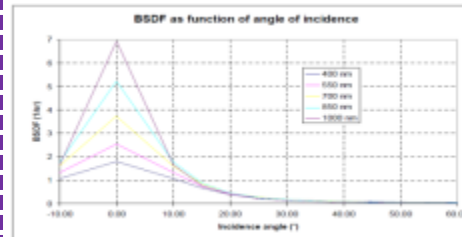
Calibration Radiance Calculation

In-Band Instrument Solar Irradiance

Solar Incident Angle

Solar Diffuser BTF Model

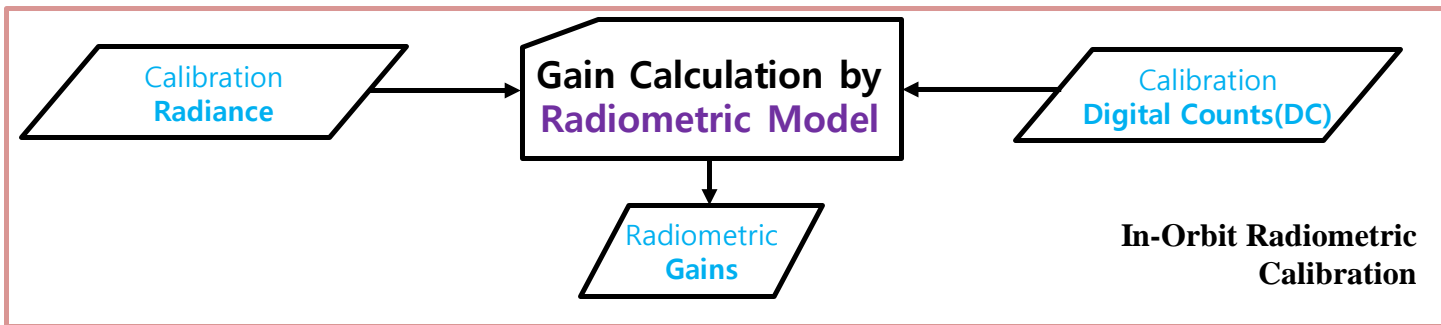
GOCI Diffuser BTF Model



Calibration Radiance

- ECEF: Earth Centered Earth Fixed Frame
- ALOF: AOCS Local Orbital Frame

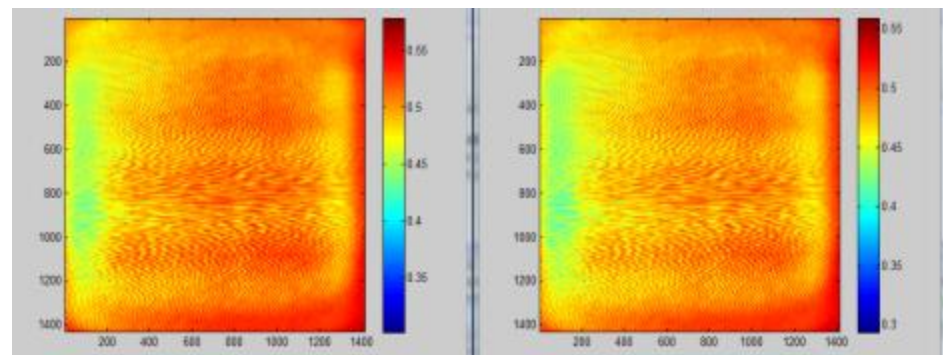
Radiometric Model



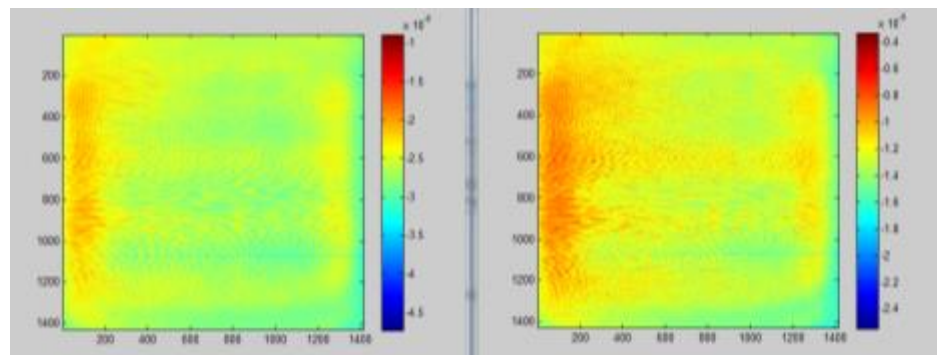
- GOCI Radiometric Model : 3rd-Order Polynomial
 - Mathematical equation to express the relationship between DN(Digital Number), raw data measured from GOCI instrument and radiance

$$S = G \times T_{int} \times L + b \times T_{int}^3 \times L^3 + T_{int} \times O + F$$

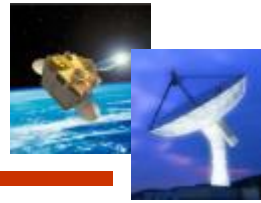
L : Spectral Radiance(W/m²/um/sr)
 G, b : Linear & Non-linear Gain
 T_{int} : Integration Time
 O, F : dark current parameters



Linear Gain (G)

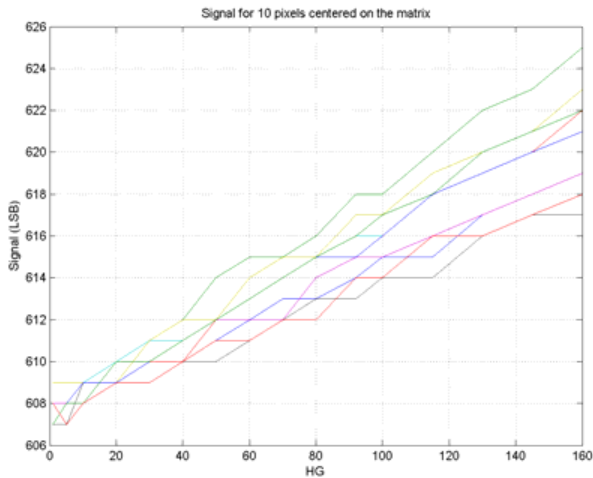


Non-linear Gain (b)

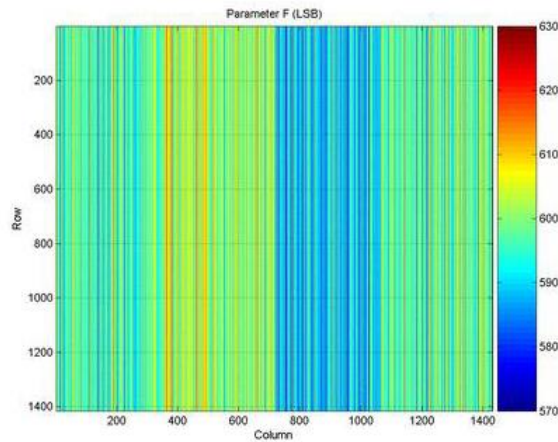


• Radiometric Test : Offset Correction

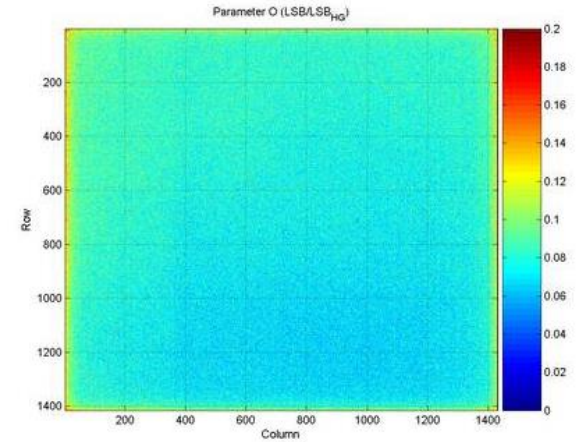
- Sensor background noise shall be corrected before calibration.
- DN at dark position = $O \times T + F$ (Linear Model)
 - O : Dark Signal - proportional to integration time & temperature
(GOCI dark signal increasing rate = 2 times/8°C)
 - T : Integration time
 - F : Fixed Offset - Baseline background noise



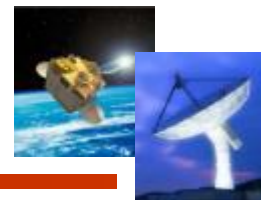
Dark Image(DN) Evaluation for 10 pixels



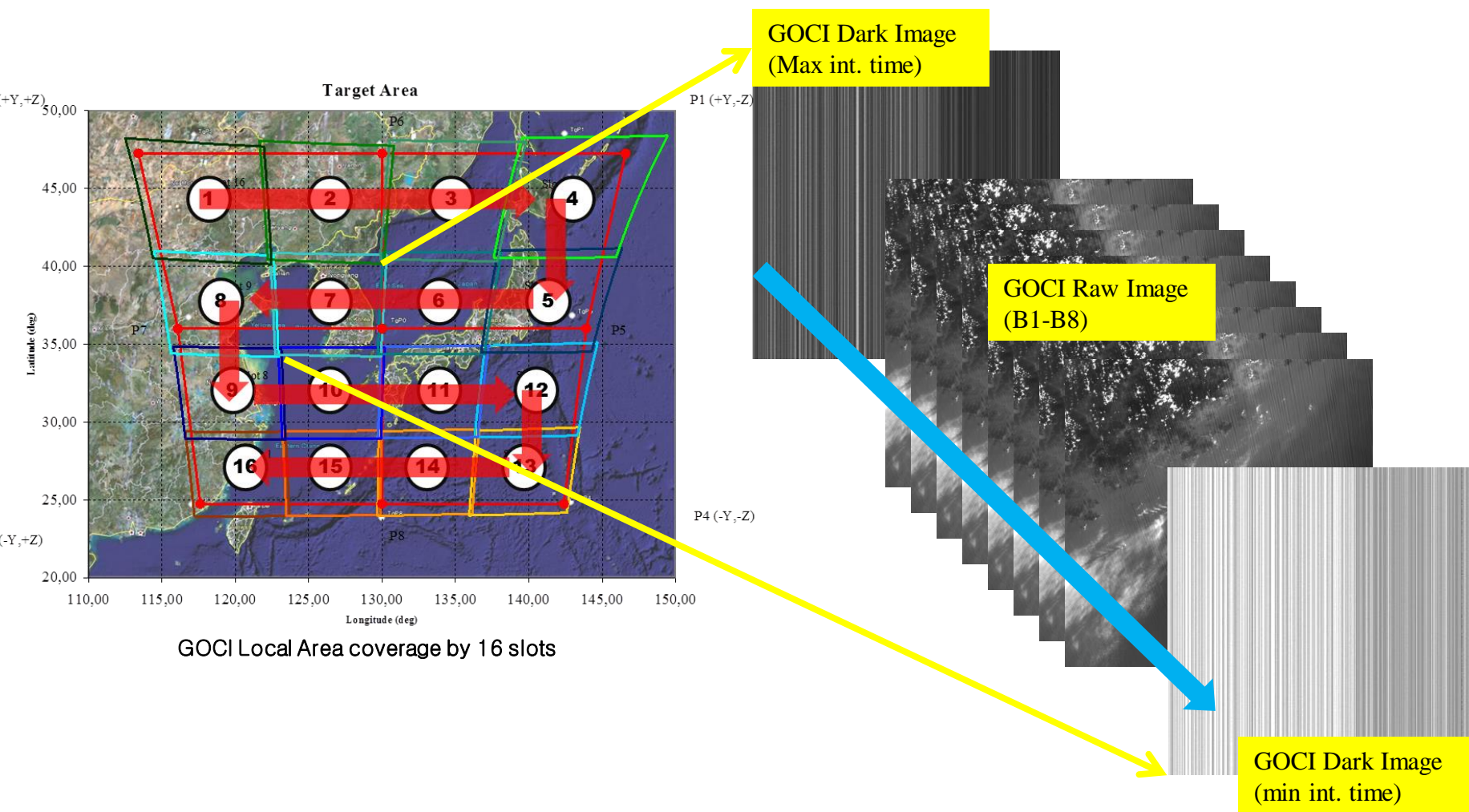
Fixed Offset (F)

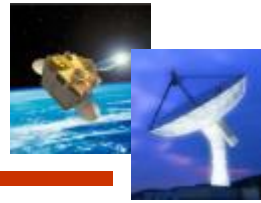


Parameter O



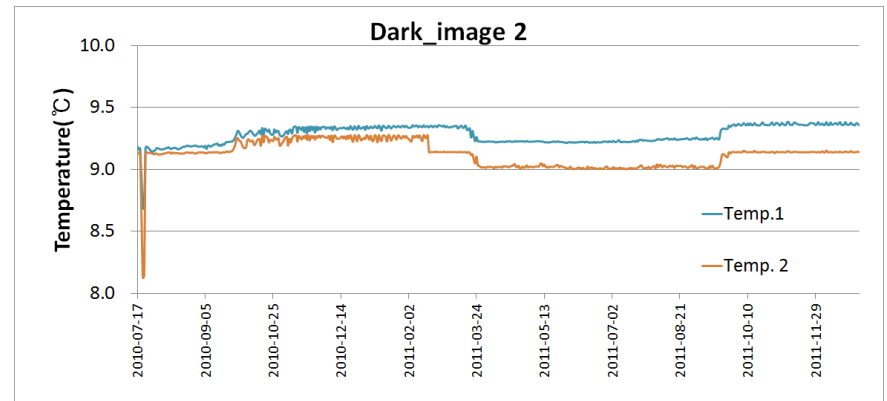
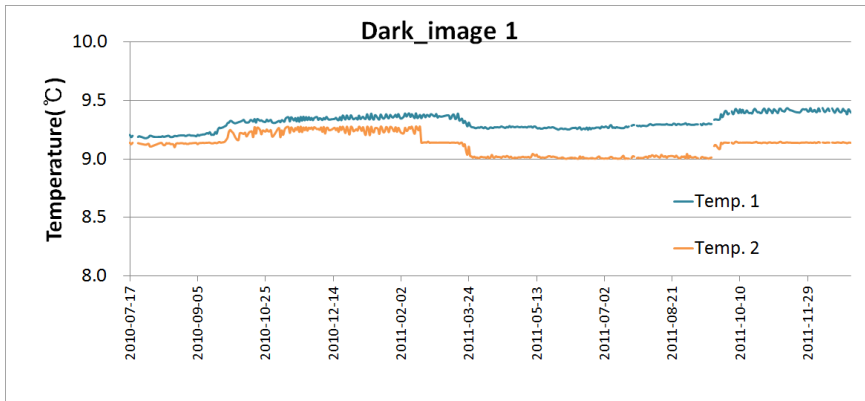
• GOCI Image Acquisition Sequence



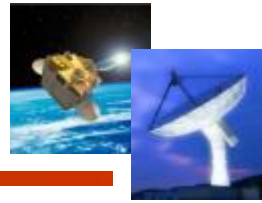


- Trend Monitoring of FPA Temperature**

The GOCI detector(2D CMOS) includes internal temperature acquisition which are part of the image data and correspond to the first(0) and last columns(1431) of the detector.

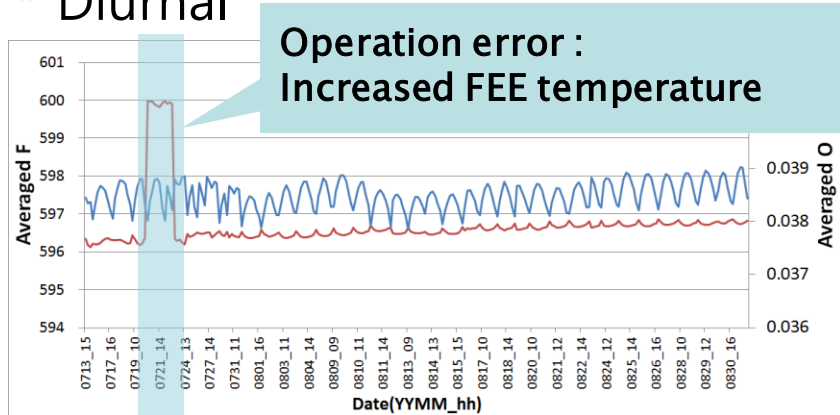


Temperature of GOCI FPA is stable.



• Trend Monitoring of Dark Current

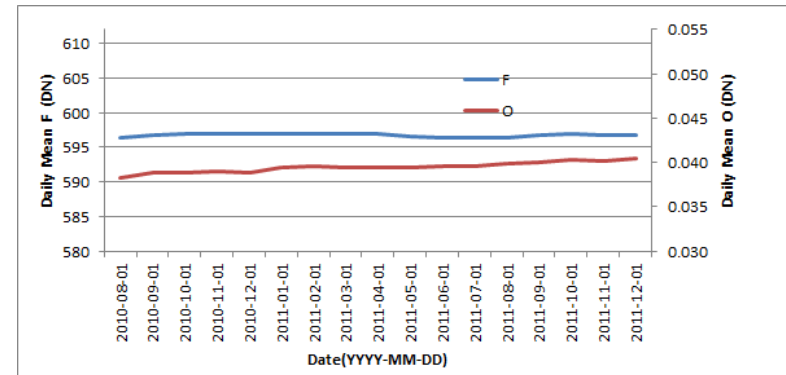
* Diurnal



Diurnal Trend of Dark Current Parameters(O, F)

The averaged O is sensitive to temperature variation of sensor by increasing the integration time. Though integration time is not changed, the diurnal variation is found in fig. 2. (Cf. $O \propto 1/F$)
(max : 03 or 04 UTC, min : 00 and 07 UTC)
The pattern of 'O' seems to be related with diurnal solar energy variation. The uptrend shown in fig. 1 is also found in fig. 2.

* Daily

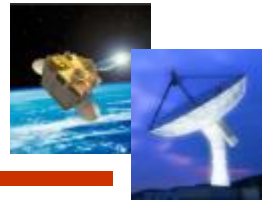


Daily Trend of Dark Current Parameters(O, F) from Aug. 2010 to Dec. 2011.

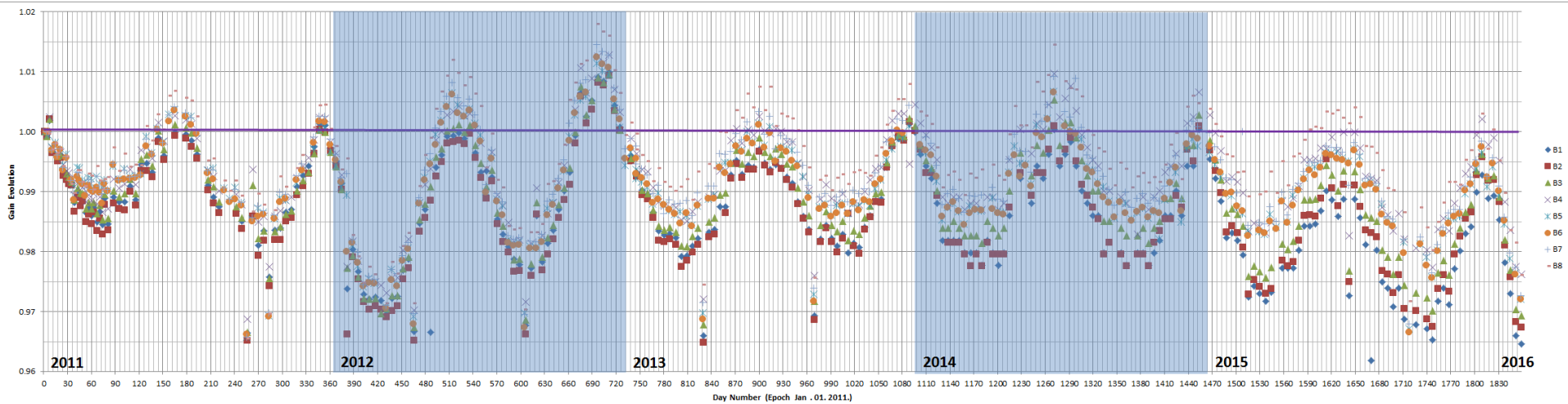
Daily mean F and O are about 596 ± 16 and 0.04 ± 0.013

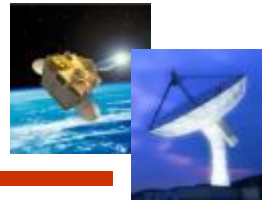
Only, the daily mean O is increasing slightly. But the variation is very small.

GOCI detector has been operated
in stable

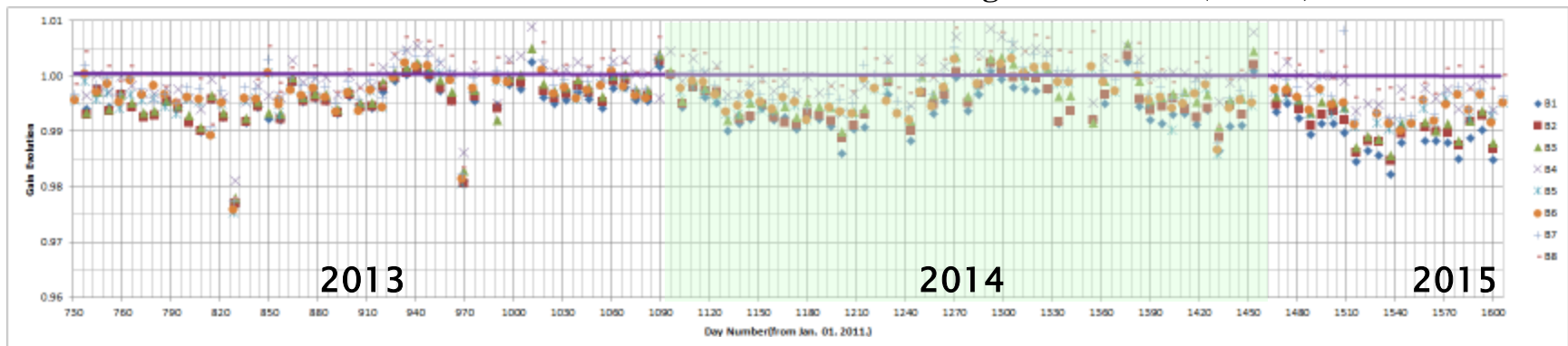
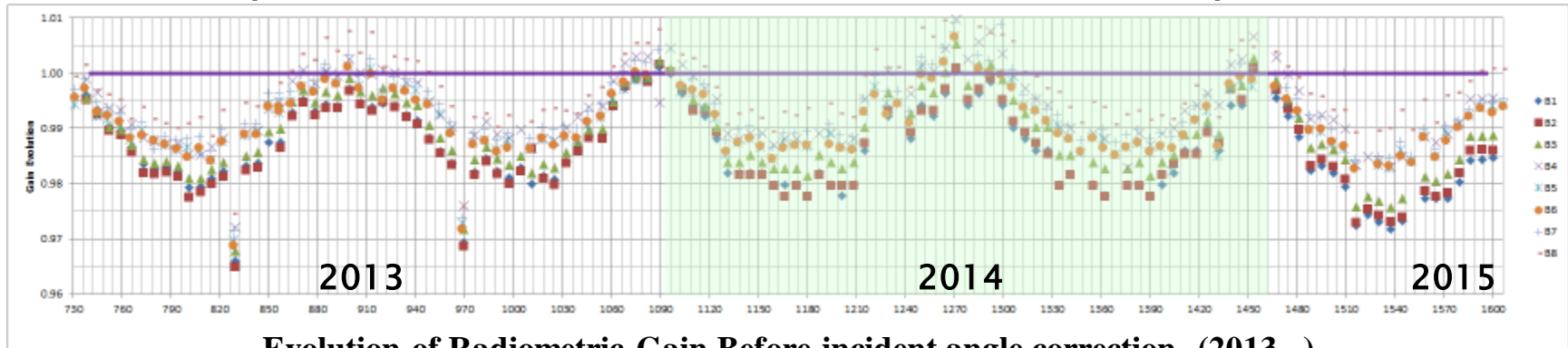


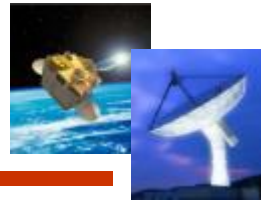
- Evolution of Radiometric Gain (Jan. 2011~May 2015)
 - In 2012, unexpected gain evolution was found.
 - No challenging issue for gain evolution (except for the poor diffuser BSRDF characterization with respect to the solar incident angle(az))
 - After diffuser aging corection using DAMD, assessed annual gain evolution is $\sim 0.2\%$ (2011~2014) and $\sim 0.6\%$ (2015~) for mean gain value of 2M pixels.





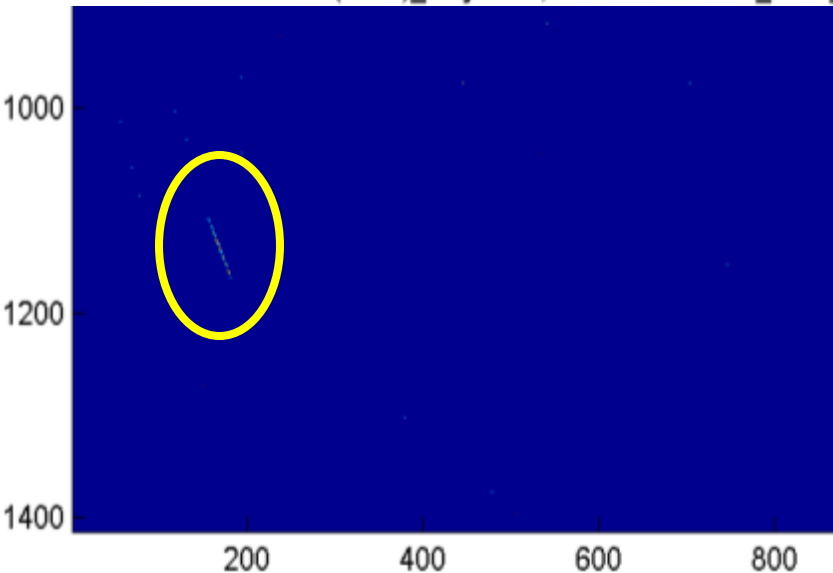
- **Solar incident angle effect(AZ) correction**
 - Due to the insufficient characterization of solar diffuser (variation of diffuser transmittance w.r.t. solar incident angle) in pre-launch test,
 - Empirical correction method is in the development.



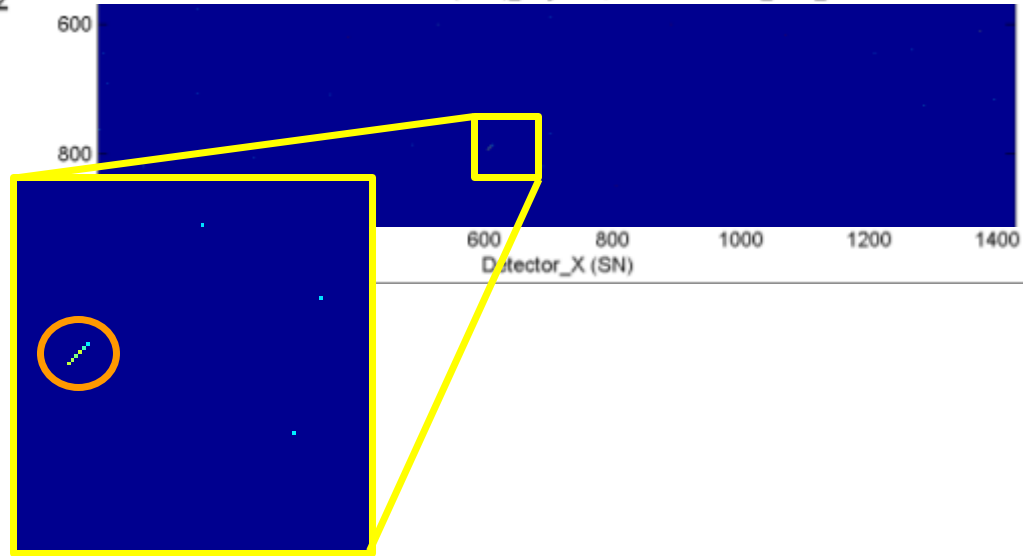


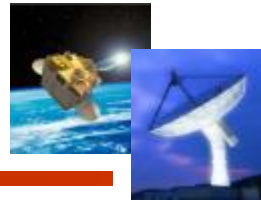
- **Defective pixels determined from Dark Images**
 - Dedicated DARK position in Filter Wheel helps to acquire dark images in every slot imaging(32 times/acquisition).
 - From 2011 to 2014, there is very small variation of dark current. (-0.04% after correction of seasonal variation)
 - Defective pixels determined from dark images (same approach in pre-launch test) is increased about 24%.

2011-04-25.13-19-20(UTC)_Day- 115, Defective Pixels_Dark_02



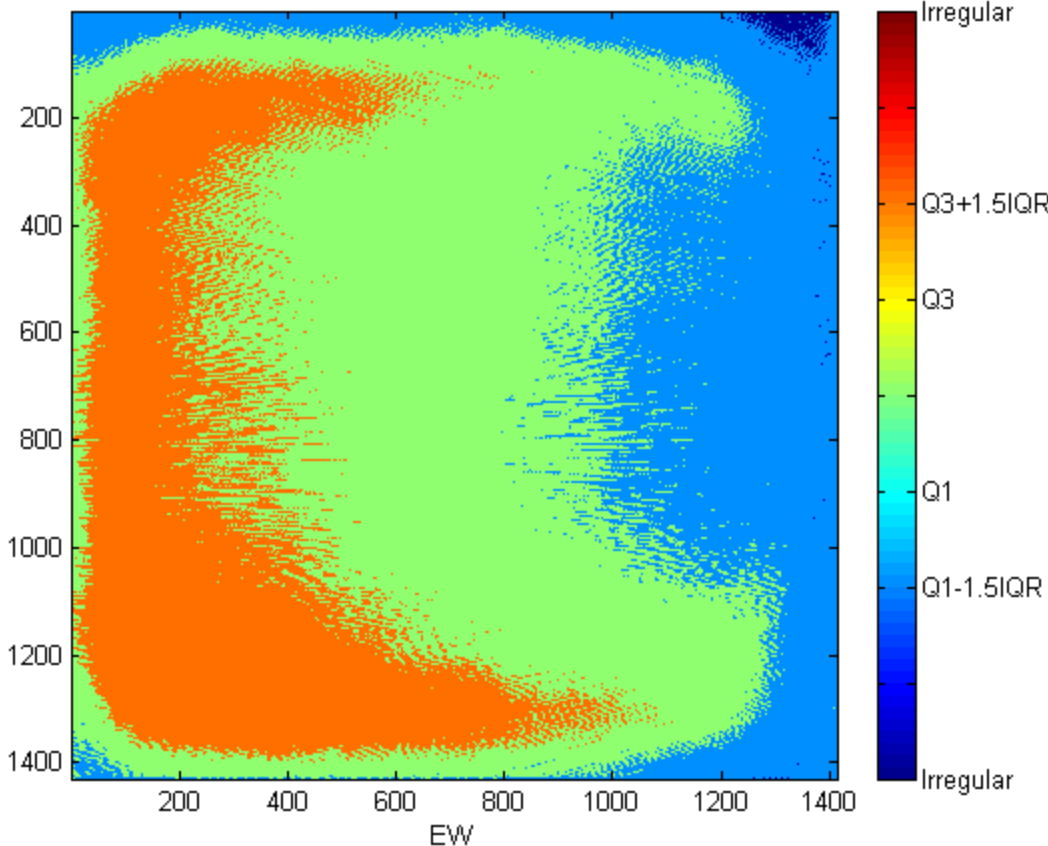
2013-08-05.13-31-13(UTC)_Day- 948, Defective Pixels_Dark_02





- **Evolution of Radiometric Gain for Each Pixel**
 - About 0.4% pixels on 2M(1413 x 1430) CMOS detector have irregular radiometric gain.

2014-10-14.13-17-19(UTC)_Day- 1383, G_GAIN_SD_B4



Q1 : 1st quartile
Q3 : 3rd quartile
IQR : Interquartile range

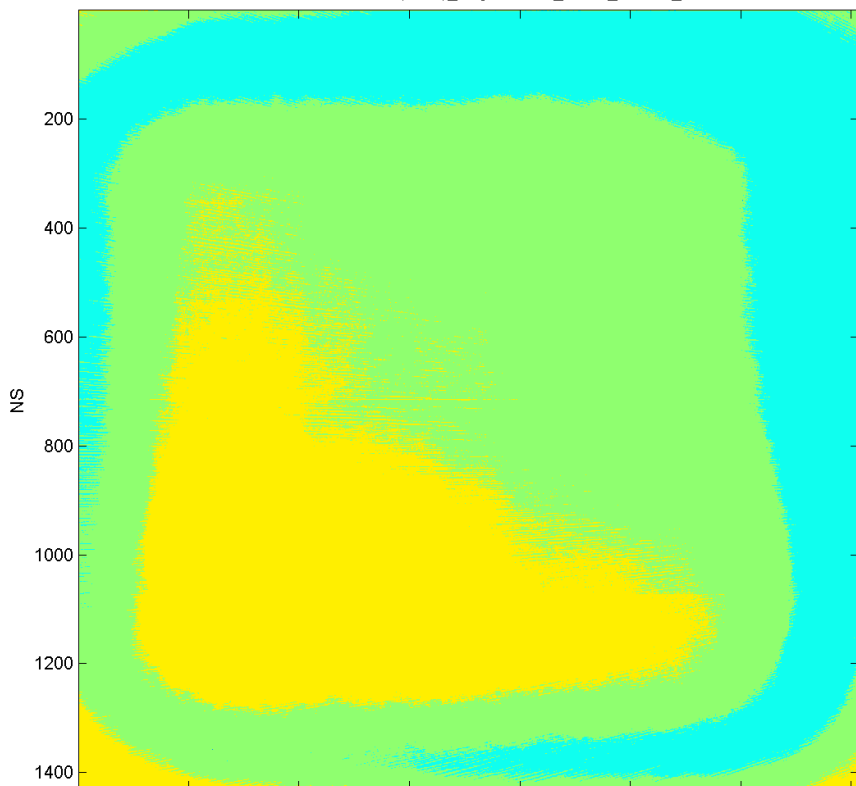
Definition of Irregular gain pixels
: pixel values are below Q1 -1.5IQR
: or above Q3 + 1.5IQR
(similar to Box-plot scheme in statistics)

Radiometric Gain for BAND 4
of Irregular gain pxls : 8,023 [2014.10.]

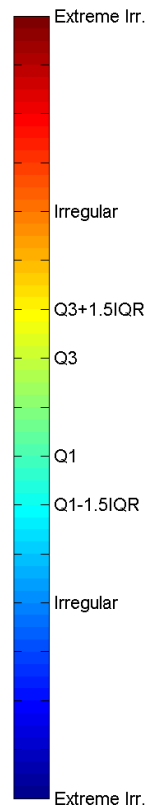
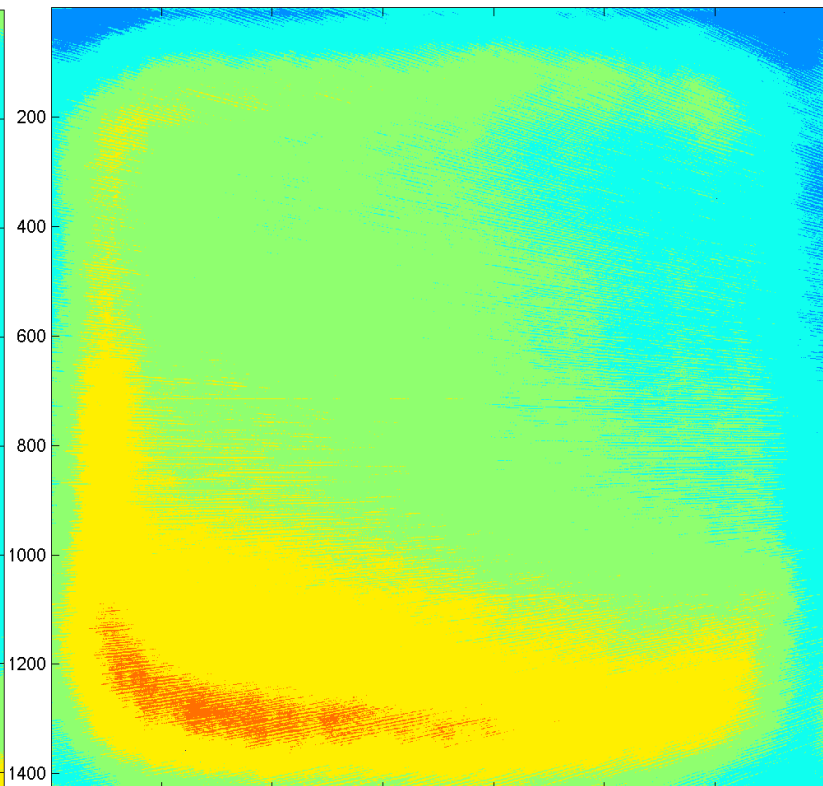


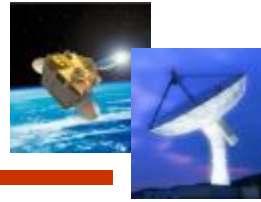
- **Evolution of Radiometric Gain for Each Pixel**
 - Annual variation due to solar incident angle(az) derives annual gain variability (# of irregular gain pixels : 7,000~89,000)

2013-01-14.14-38-43(UTC)_Day- 745, G_GAIN_DAMD_B5

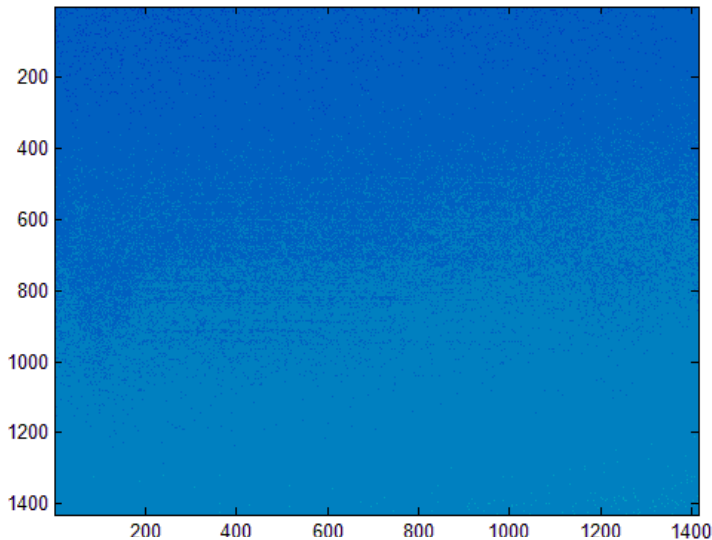


2013-01-15.14-38-49(UTC)_Day- 746, G_GAIN_DAMD_B4

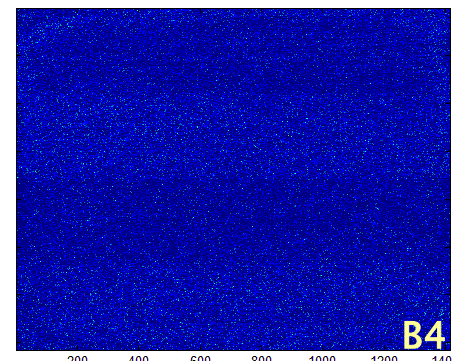
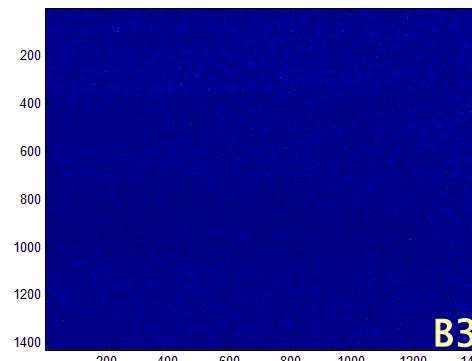
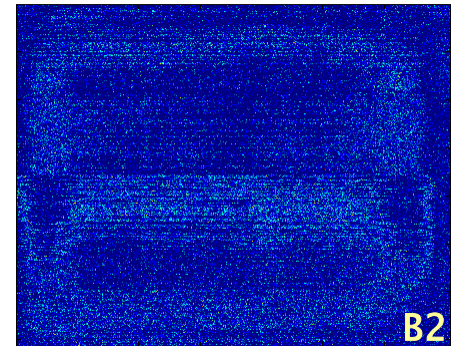
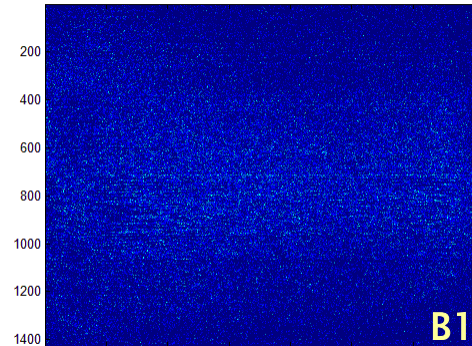


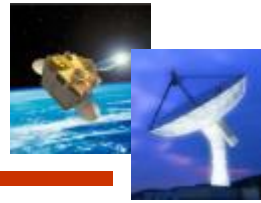


- **Assessment of Residual PRNU**
 - On-orbit Quasi-uniform image acquired by daytime diffuser operation for Earth observation
 - Assessed residual PRNU of L1A image
 - **B1: 0.28%, B2: 0.36%**, B3: 0.12%, B4: 0.23%

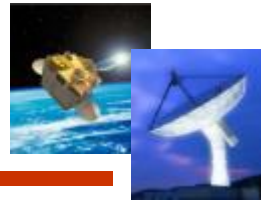


On-orbit Quasi-uniform image
 (GOCI Lv1A, B2)





- **Introduction**
 - Ocean Color Radiometry
 - GOCI Overview
- **Operation Status**
 - GOCI Imagery and Applications
 - In-orbit performance (SNR & MTF)
- **In-Orbit Solar Calibration**
 - Radiometric & Calibration Model
 - In-Orbit Calibration Results
- **Concluding Remarks**



- **In-Orbit Calibration of GOCI**
 - No blocking point of Mission operation & No critical issue
 - Annual variability of gain & residual radiometric error processing results are planned to be presented in GOCI PI Workshop 2016.
- **Lessons for GOCI-II**
 - Lunar Calibration for 2nd solar diffuser aging monitoring
 - Dedicated PRNU correction
 - Diffuser material with Lambertian characteristics
 - Dedicated test campaign for diffuser characterization



Tsukuba

감사합니다.

GOCI L1A True Color RGB