Introduction of GOCI and GOCI-II Mission with Lunar Calibration

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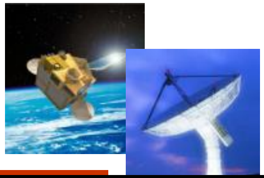
OVERVIEW

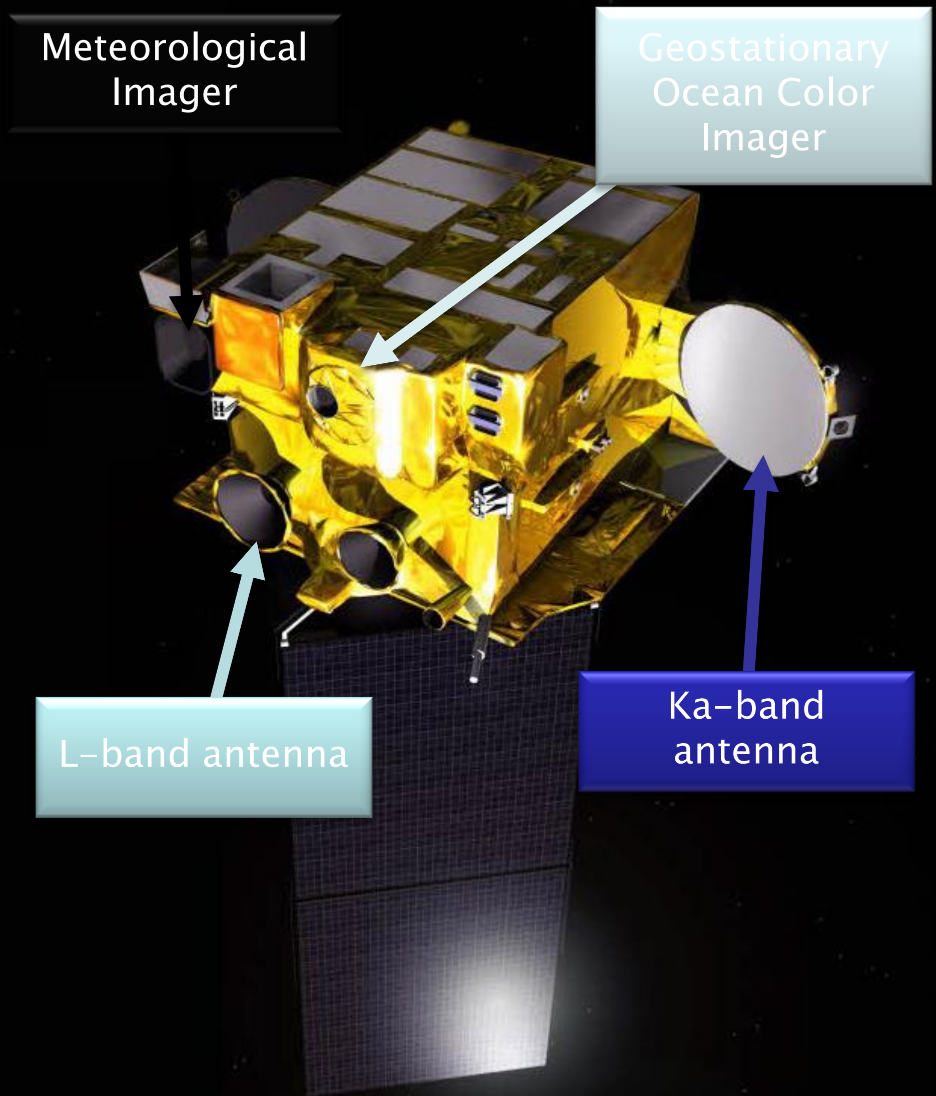
- **Introduction : GOCI/COMS**
  - Development and Application of GOCI
- **Introduction : GOCI-II Mission**

- **In-Orbit Solar Calibration of GOCI**
- **GOCI-II Lunar Calibration**
- **Issues and Concerns**

Introduction: GOCI/COMS

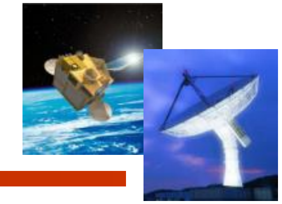
COMS (Chollian)

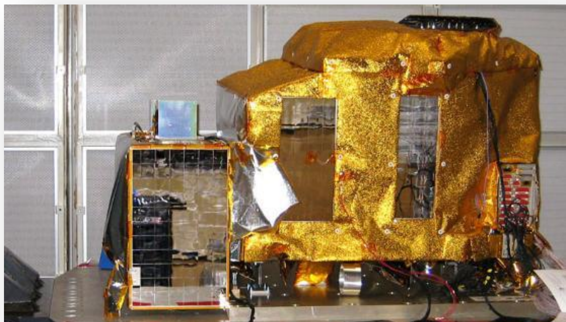




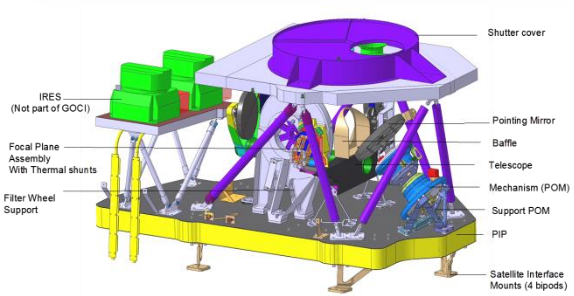
- COMS : Communication, Ocean & Meteorological Satellite
  - Developments of COMS(H/W) and GDPS(S/W) : 2003
  - Establishment of KOSC (Ground System) : 2005
  - The first Korean Geostationary multipurpose Satellite
  - Launch date : June 27 2010
  - Lifetime : 7 years
  - Payloads (3 Missions)
    -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

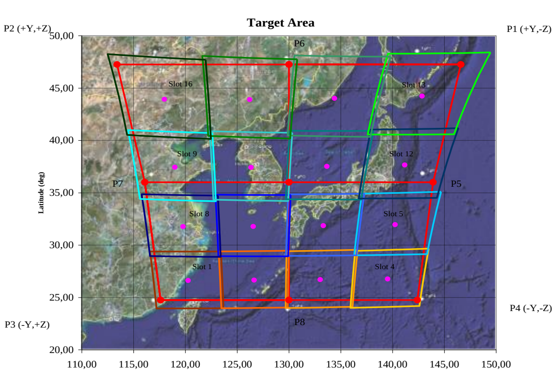
GOCI : Overview





- Geostationary Ocean Color Imager
  - **VIS/NIR Multispectral Imager for Ocean Monitoring**
  - GSD: 500m@130 ˚ E 36 ˚ N, ~390m@nadir
  - Target Area : 2,500km * 2,500km
    (Center : 130 ˚ E 36 ˚ N; Pohang-Si, Korea)
  - Temporal Resolution : 1hour (8 times at 1 day)



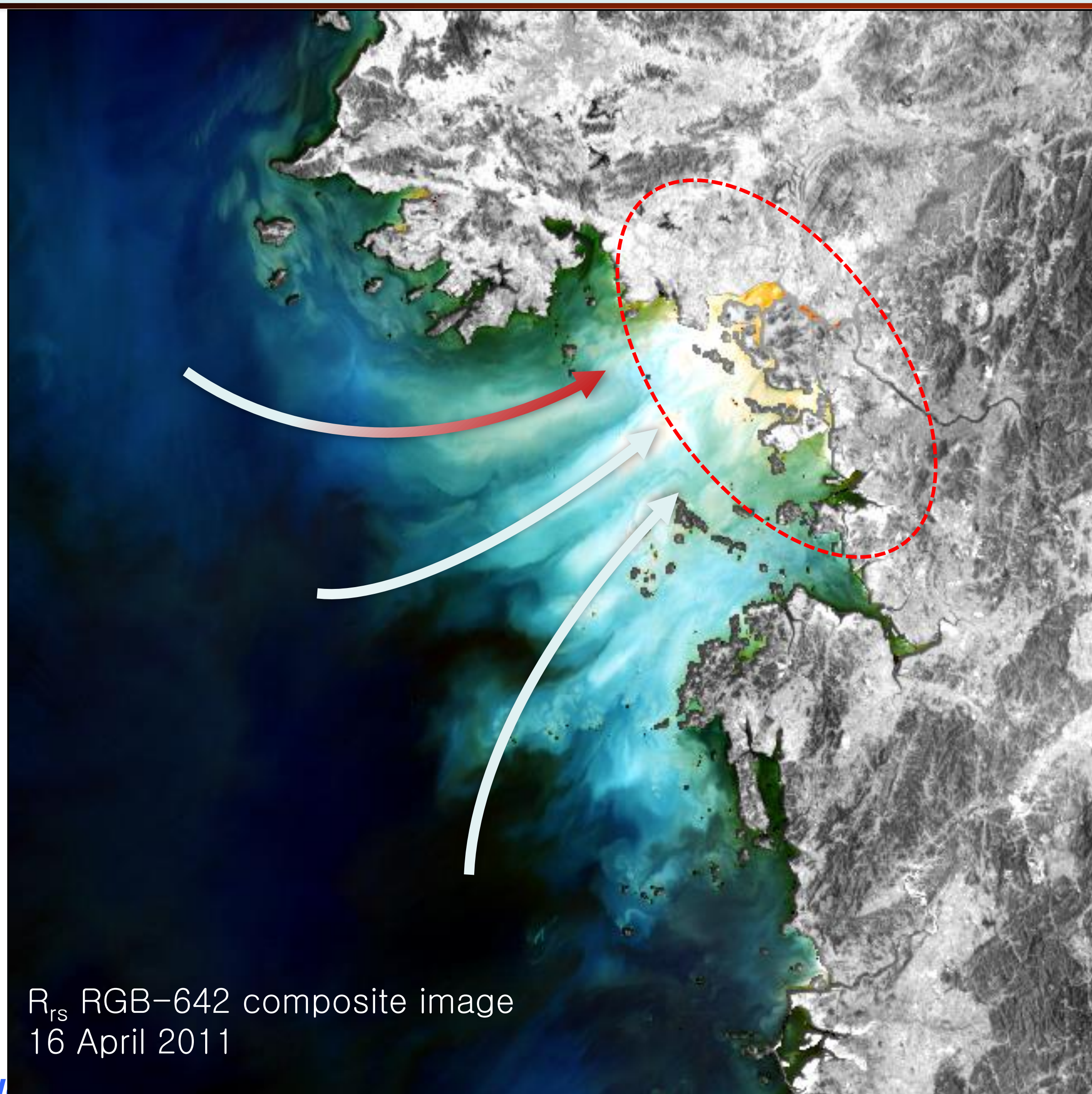


- **Spectral Bands Characteristics of GOCI**

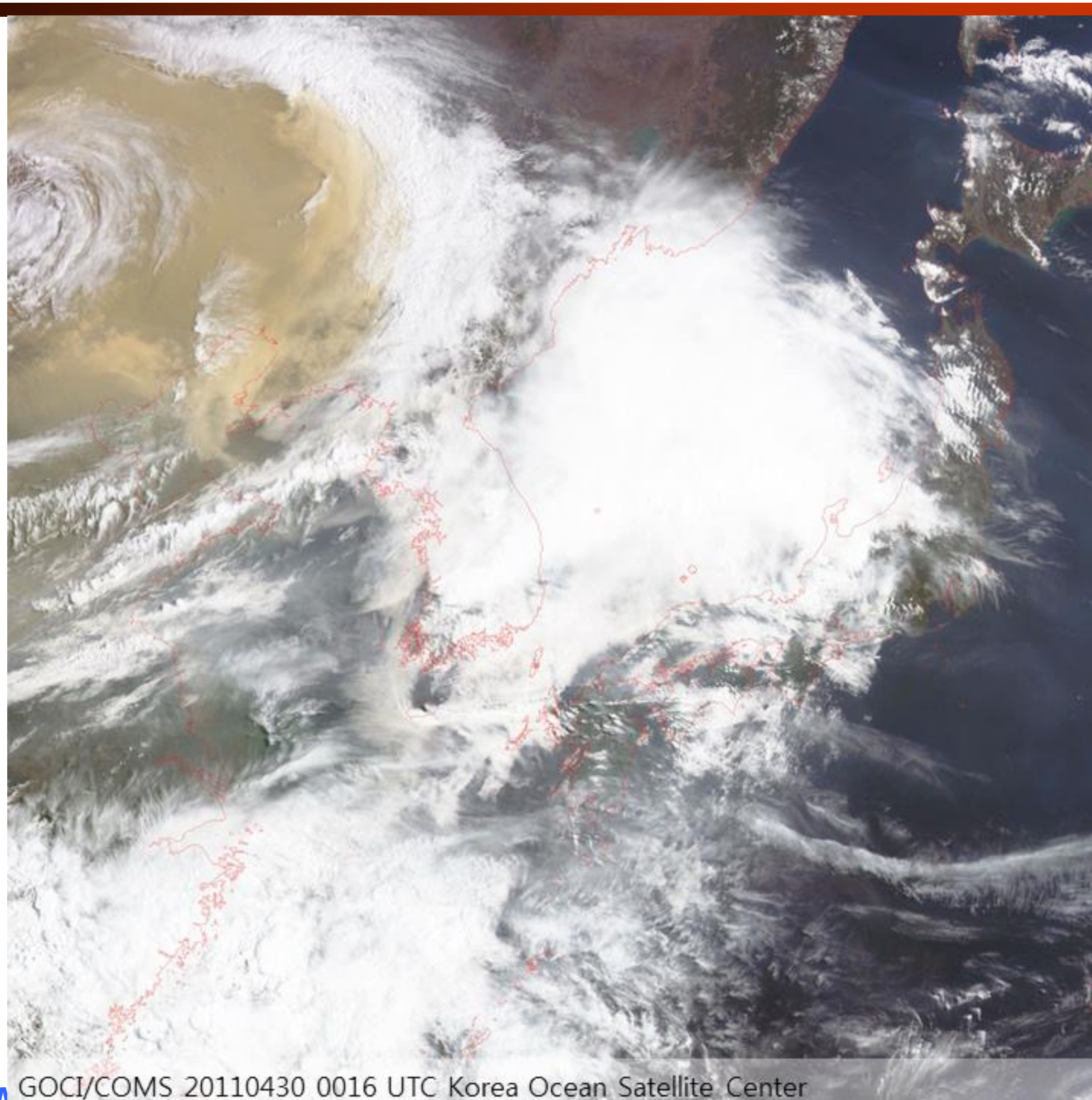
Band	*Band Center*	*Band Width*	*SNR*	*Type*	*Primary Application*
B1	412 nm	20 nm	1,000	Visible	Yellow substance and turbidity
B2	443 nm	20 nm	1,090	Visible	Chlorophyll absorption maximum
B3	490 nm	20 nm	1,170	Visible	Chlorophyll and other pigments
B4	555 nm	20 nm	1,070	Visible	Turbidity, suspended 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

Application of GOCI

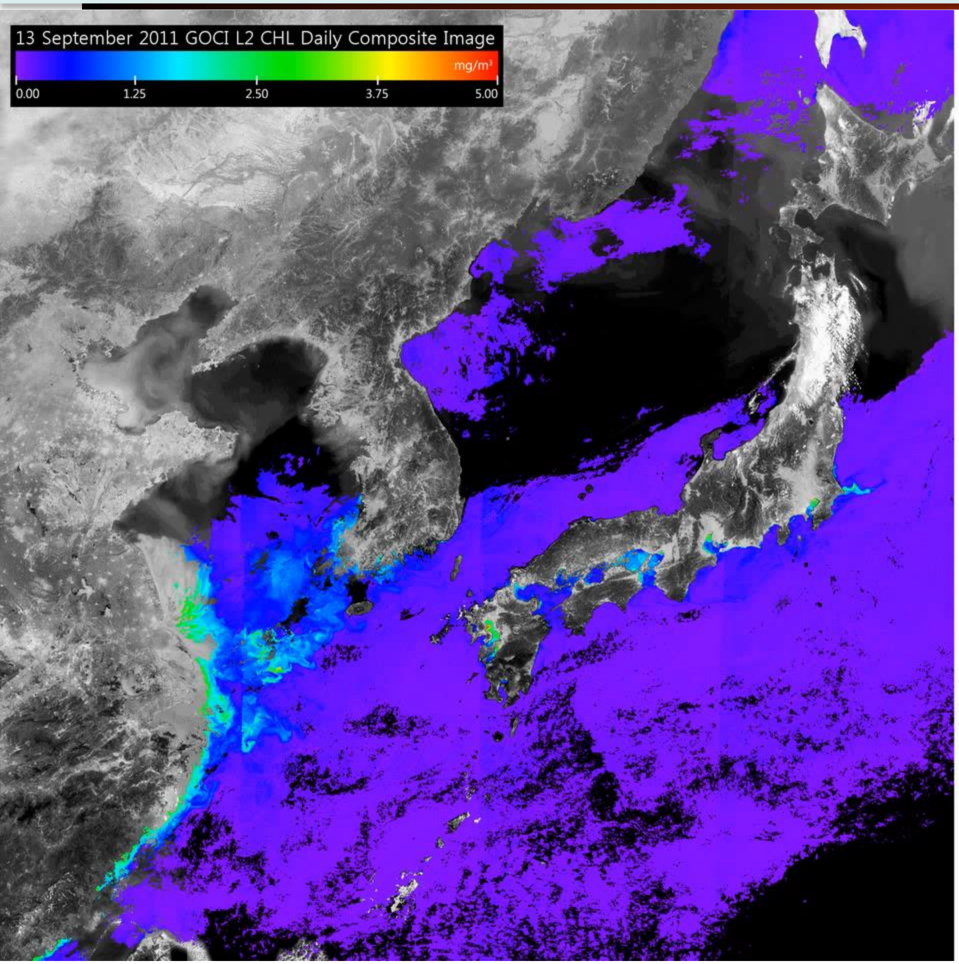
GOCI: Tidal Movement

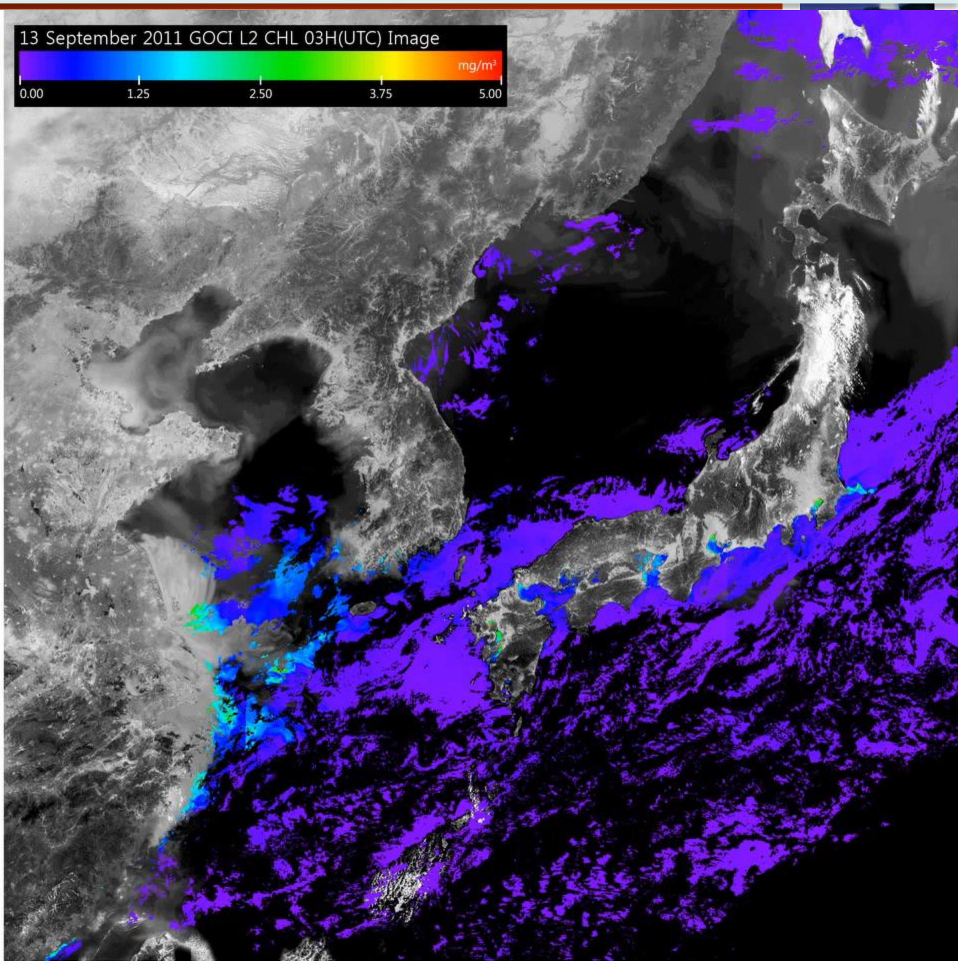


GOCI: Asian Dust



Effective Data Acquisition Ratio





DAILY COMPOSITE
8 SCENES / DAY

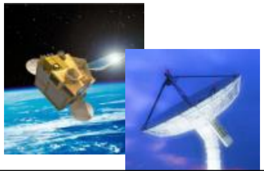
28%

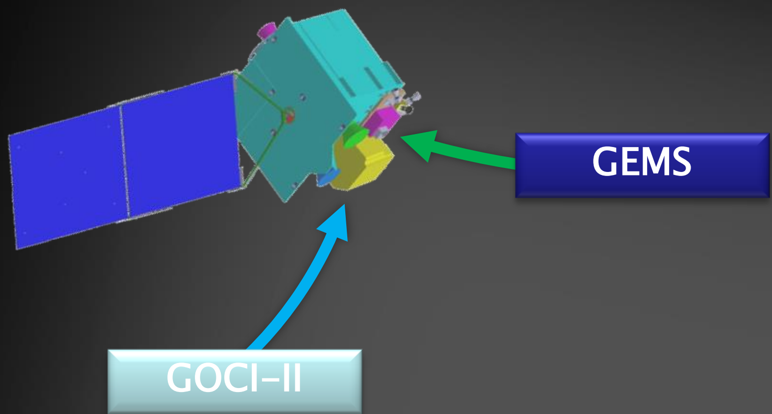
1 SCENE / DAY

10%

GOCI-II Mission

GOCI-II / GK-2B

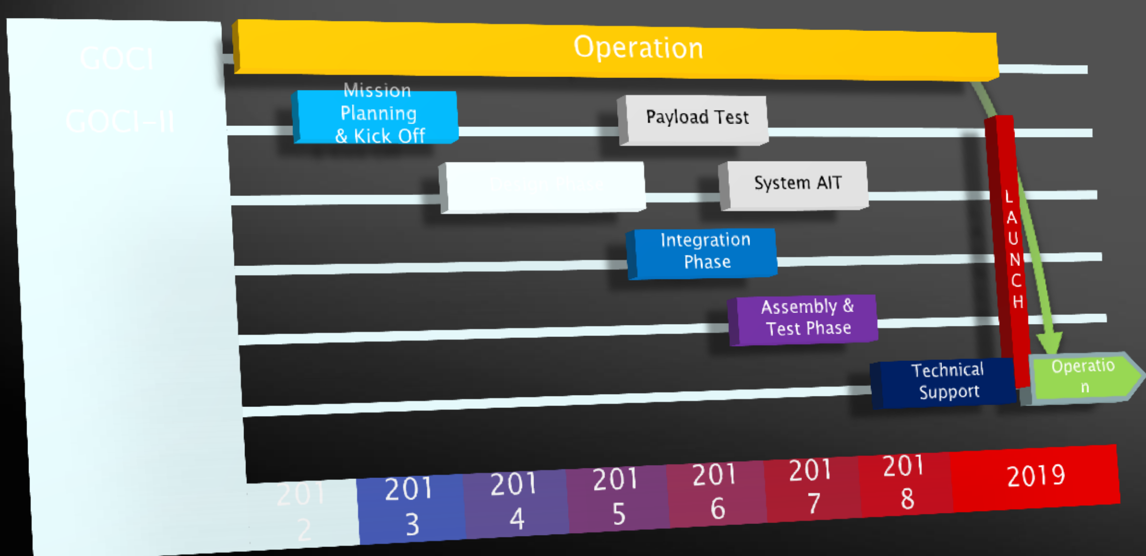




GeoKompsat-2A : AMI (ABI)

GeoKompsat-2B : GOCI-II & GEMS

- Ground Station & Data processing system Development (Ministry of Land, Transport and Maritime Affairs)
  - Performing precedent study (2012)
  - Project Period **(2013 ~ 2018)**
- Pre-processing system (Ministry of Education, Science and Technology)
  - Algorithm : KIOST and KARI
  - S/W Development : KIOST



- GOCI-II Development :
  - Sensor: Joint Development of KIOST-KARI-Airbus DS
  - GS(H/W & S/W): KIOST
  - Bus system – KARI
- Supervisor : KIOST

GOCI-II Major User Requirements

- Comparison to GOCI

	GOCI	GOCI-II
Bands	8(VIS/NIR)	13(VIS/NIR)
Ground Sampling Distance	500m (Local Area Mode)	250m (Local Area Mode) 1km (Full Disk Mode)
Coverage	North-East Asian Sea around Korea	NE Asian Sea + Event Area Full Disk
S/N	~1000	~ 1000
Observation interval	An hour (8 times/day)	An hour (10 times/day)

- Rational for the User Requirements

Items	Specs	Rational
Increased Number of Bands	13 bands	- PFT, HAB detection - Atmospheric correction improvement
Improved spatial resolution	250m	- Monitoring of river estuaries and coastal environments
More frequent daily observations	10 times/day	- Study of short-term ocean processes
Pointable & Full Disk coverage	Local Area + Full Disk	- Monitoring of events in the coverage - Study of large-scale phenomena (e.g. ENSO)

Spectral Bands and Performance

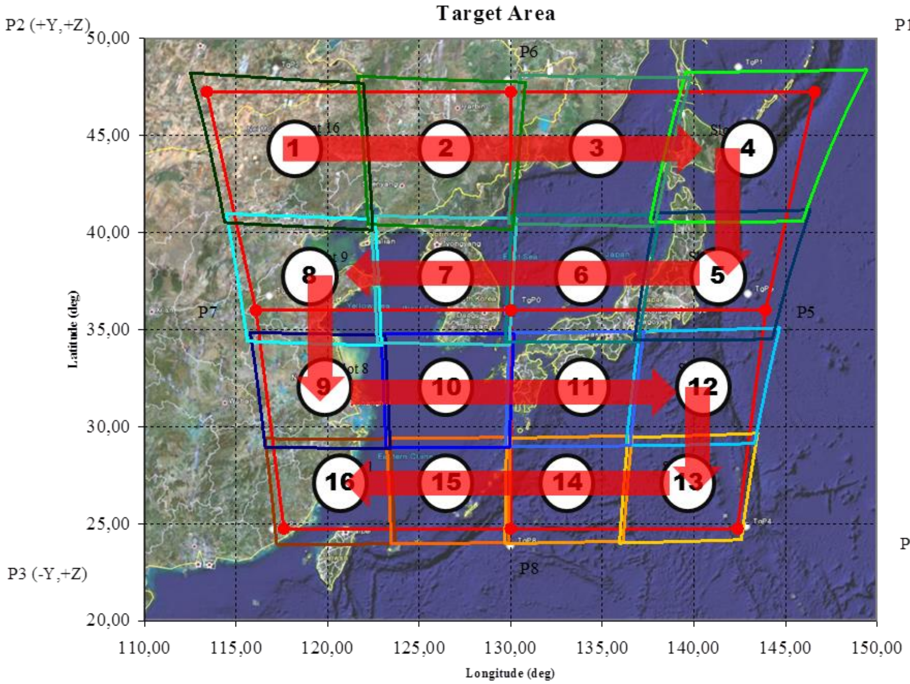
- Spectral Bands Requirements
  - 13 Bands (GOCI : 8 Bands)
  - ROLO model coefficients for 13 bands are required for lunar cal.

Radiance : $W/m^2/um/sr$

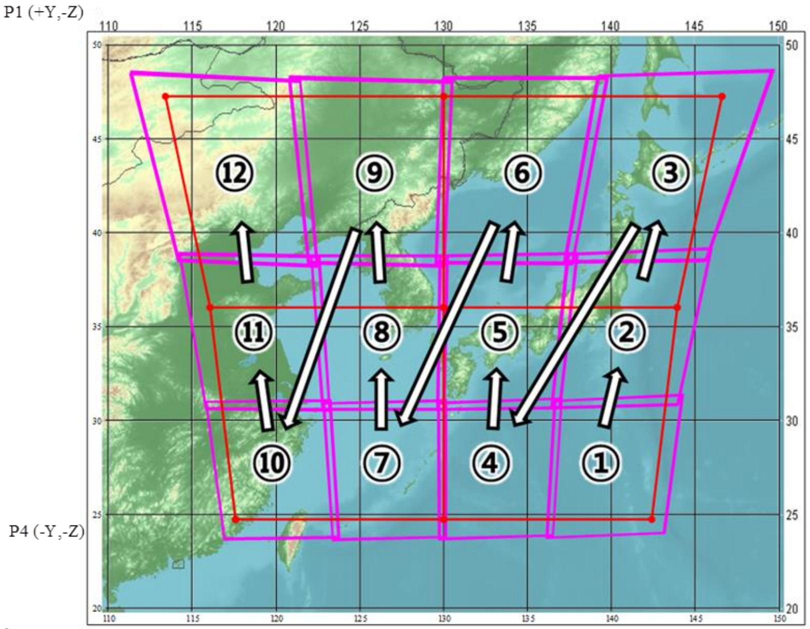
GOCI Band	GOCI-II Band	Bandcenter	Bandwidth	Nominal Radiance	Maximum Ocean radiance	Threshold Radiance	Maximum Cloud Radiance	NEdL	SNR @ Nominal radiance
-	1	380 nm	20 nm	93	139.5	143.1	634.4	0.093	998
1	2	412 nm	20 nm	100	150	152	601.6	0.095	1050
2	3	443 nm	20 nm	92.5	145.8	148	679.1	0.081	1145
3	4	490 nm	20 nm	72.2	115.5	116	682.1	0.059	1128
-	5	510 nm	20 nm	64.9	108.5	122	665.3	0.055	1180
4	6	555 nm	20 nm	55.3	85.2	87	649.7	0.049	1124
-	7	620 nm	20 nm	53.3	64.1	65.5	629.5	0.048	1102
5	8	660 nm	20 nm	32	58.3	61	589	0.03	1060
6	9	680 nm	10 nm	27.1	46.2	47	549.3	0.03	914
-	10	709 nm	10 nm	27.7	50.6	51.5	450	0.03	914
7	11	745 nm	20 nm	17.7	33	33	429.8	0.02	903
8	12	865 nm	40 nm	12	23.4	24	343.8	0.015	788
-	13	643.5 nm	483 nm	-	-	-	-	-	-

GOCI-II Imaging Sequence_LA

- Reference Local Area (RLA)
  - Baseline for slot imaging acquisition
    - Column-by-column Raster scan
    - South to North within a column, East to West between column
    - For the reduction of ISRD (Inter Slot Radiance Discrepancy) in operation level



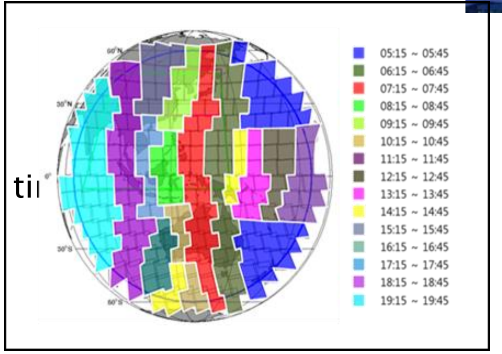
GOCI Local Area coverage by 16 slots

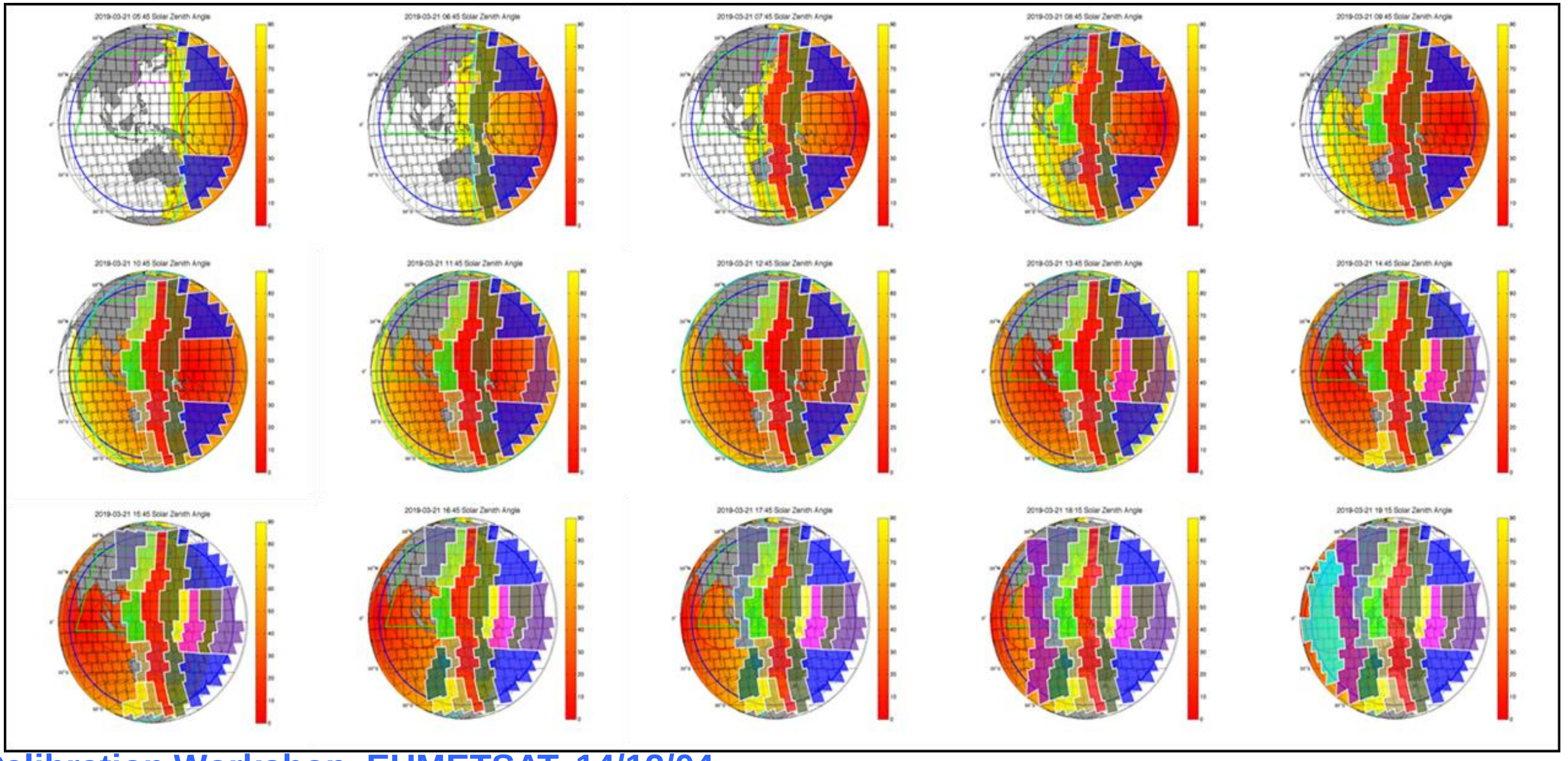


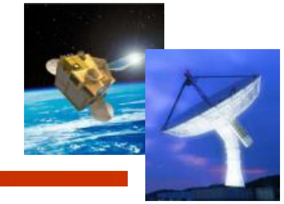
GOCI-II Reference Local Area coverage by 12 slots

GOCI-II Imaging Sequence_FD

- Full Disk (FD) (TBD)
  - The Imaging time for FD < 240 minutes
  - FD image acquisition : 1 image per day (5:15 – 19:45 Korean local ti
  - FD imaging criteria
    - Solar Zenith Angle < 80 degrees
    - Sunglint Reflectance < 0.01 sr-1
  - Preliminary assessment in GOCI-II instrument level based on PDR Design



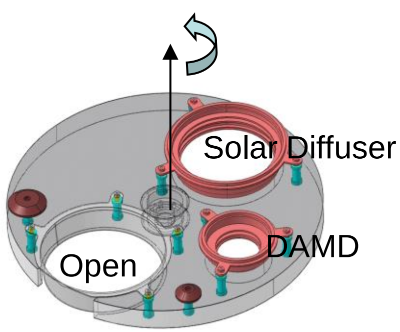




In-Orbit Solar Calibration of GOCI

In-Orbit Solar Calibration

- **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



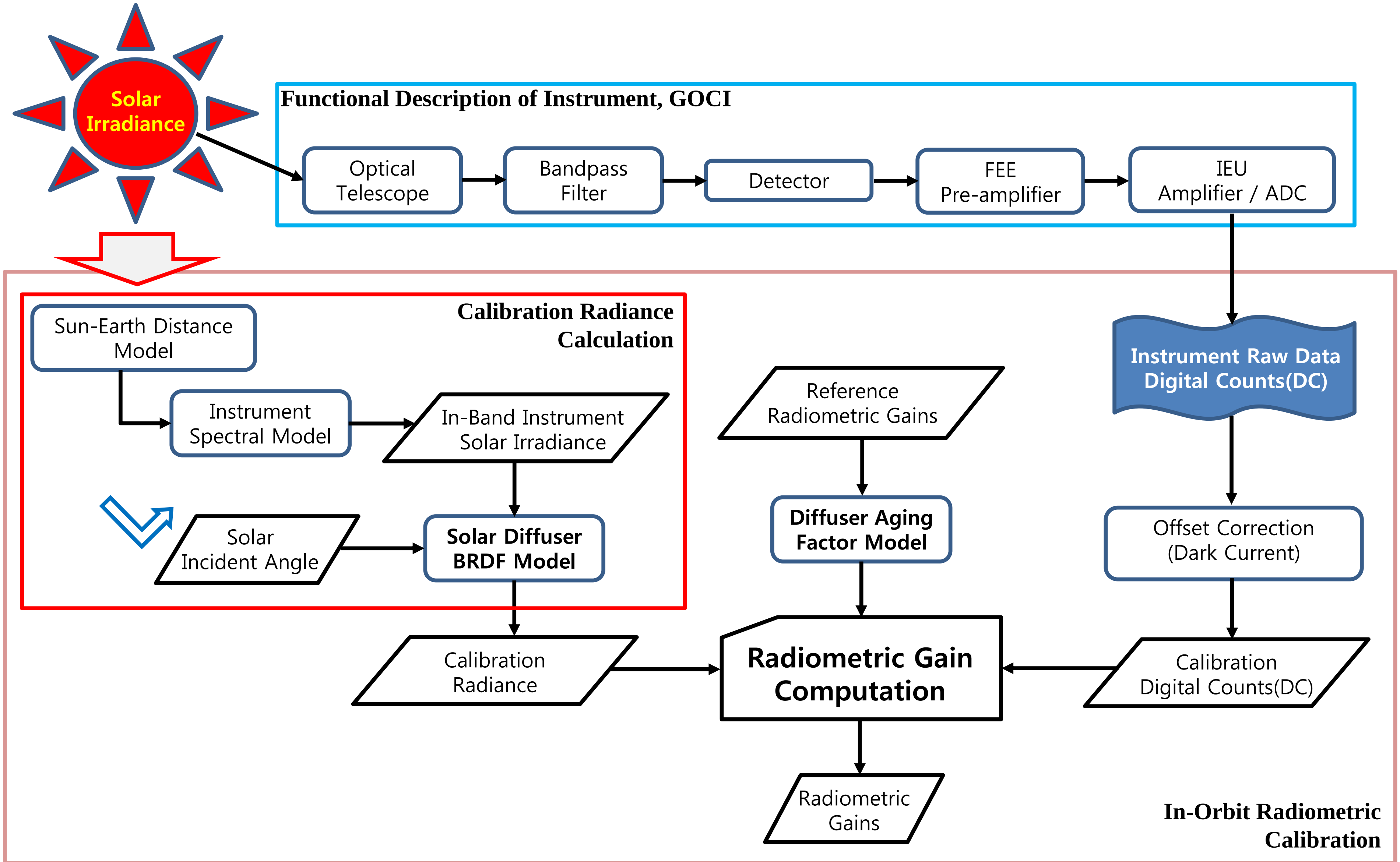
Shutter wheel

SD(Solar Diffuser)
Dim : 14cm

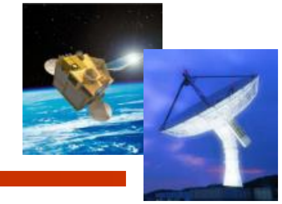
DAMD
Dim : 7cm

Diffuser for irradiation test
(other half one : reference)

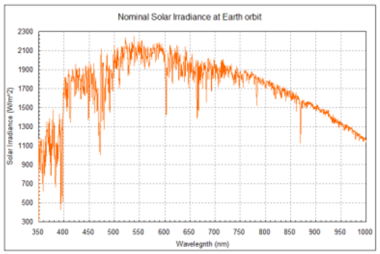
Solar Calibration Processing



Calibration Radiance Calculation



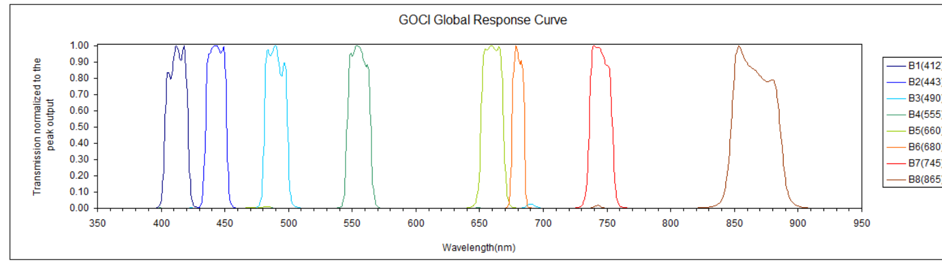
Solar Irradiance Reference Spectra



(Ref. Thuillier, 2004)

Solar Irradiance

GOCI Instrument Spectral Model



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)

Calibration Radiance Calculation

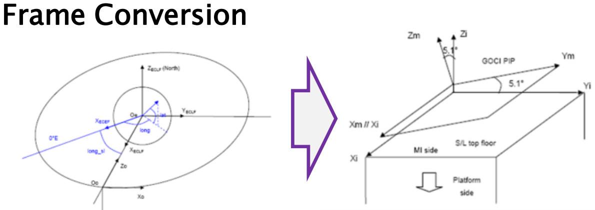
- Sun-Earth Distance Model
- Instrument Spectral Model
- In-Band Instrument Solar Irradiance
- Solar Incident Angle
- **Solar Diffuser BRDF Model**
- Calibration Radiance

Solar Incident Angle Calculation

Orbital Position of Sun

– VSOP82 Model **(Ref. P. Bretagnon, 1982)**

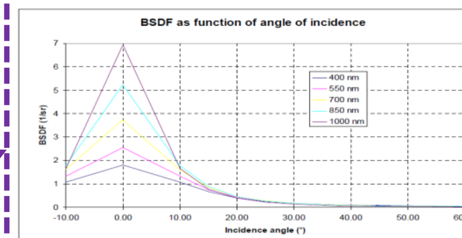
Frame Conversion

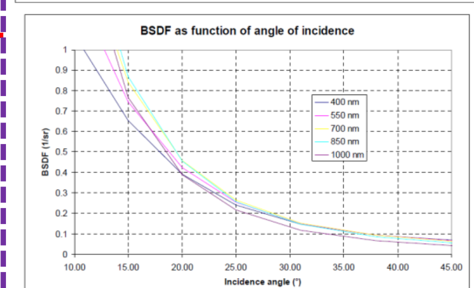


ECEF to ALOF Frame

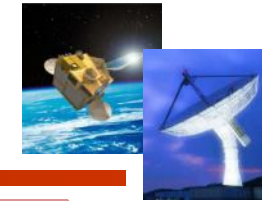
ALOF to GOCI Reference Pointing Frame

GOCI Diffuser BRDF Model

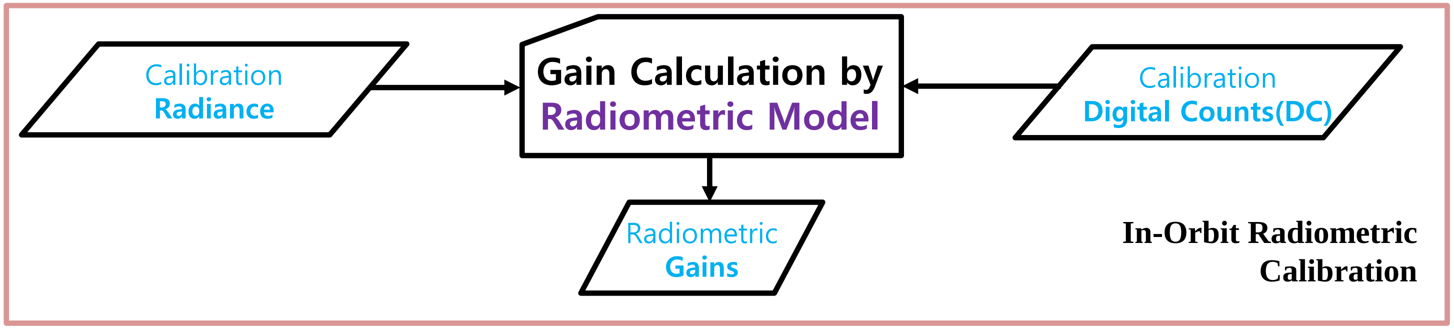




- **VSOP: Variations Séculaires des Orbites Planétaires**
- **ECEF: Earth Centered Earth Fixed Frame**
- **ALOF: AOCS Local Orbital Frame**



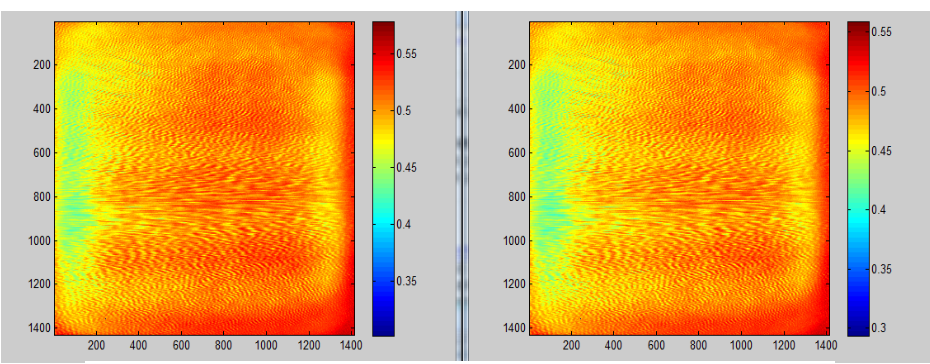
Radiometric Model



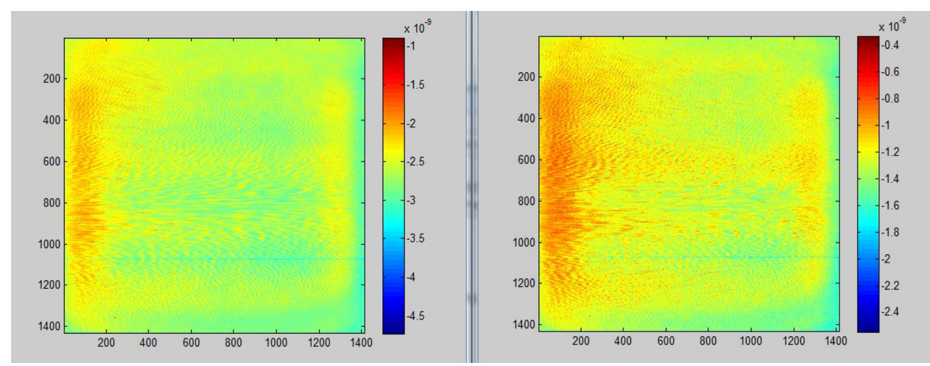
- GOCI Radiometric Model : 3rd-Order Polynomial
  - Mathematical equation to express the relationship between DN(Digital Number), raw data measured from GOCI instrument and radiance

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

L : Spectral Radiance(W/m^2/um/sr)
G, b : Linear & Non-linear Gain
T_{int} : Integration Time
O, F : dark current parameters



Linear Gain (G)

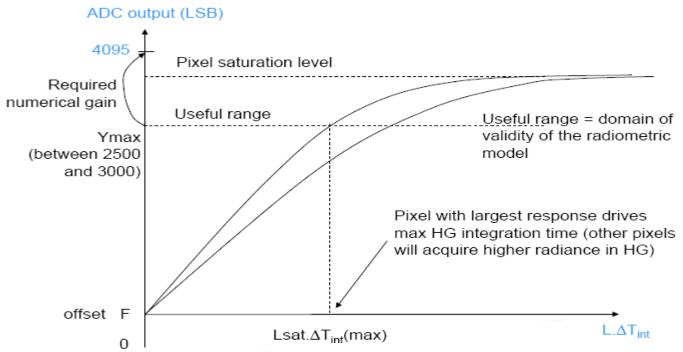


Non-linear Gain (b)

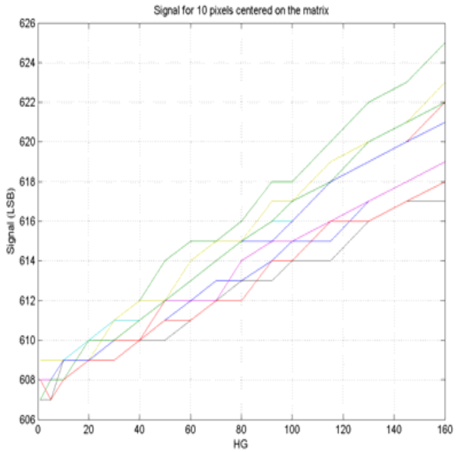
On-Ground Characterization

- **Radiometric Model Determination**
  - Two GOCI Radiometric Model Candidates
    - 2^{nd} order model ($Y=bX^2+GX$)
    - 3^{rd} order model ($Y=bX^3+GX$)

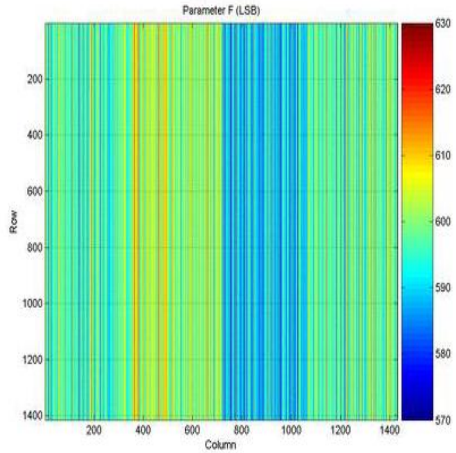
Y : GOCI Output signal after pseudo averaging and offset correction (LSB)
X : Input radiance*Integration Time
G : GOCI Overall Linear Gain
b : GOCI Overall Non-Linear Gain



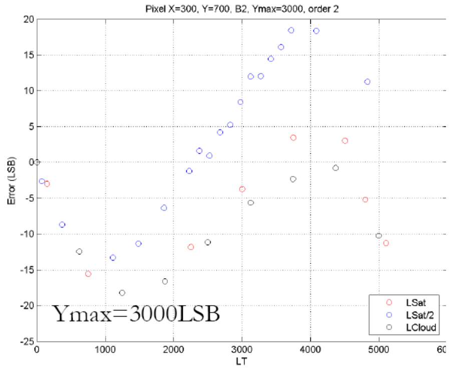
GOCI Radiometric Model Characterization



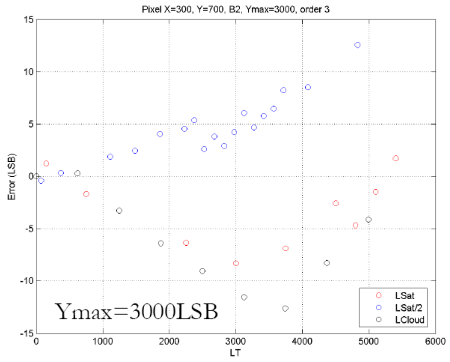
Dark Current(DN) Evaluation



Fixed Offset (F)



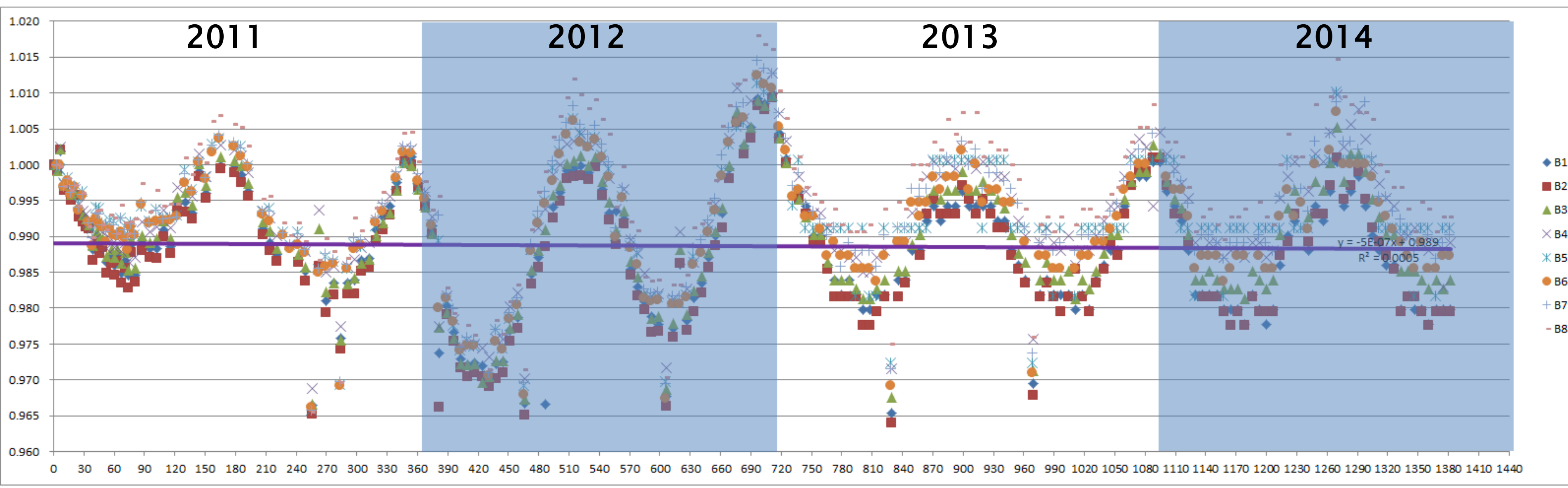
Fitting error (Order 2)



Fitting error (Order 3)

Discussion for Gain Evolution (3/3)

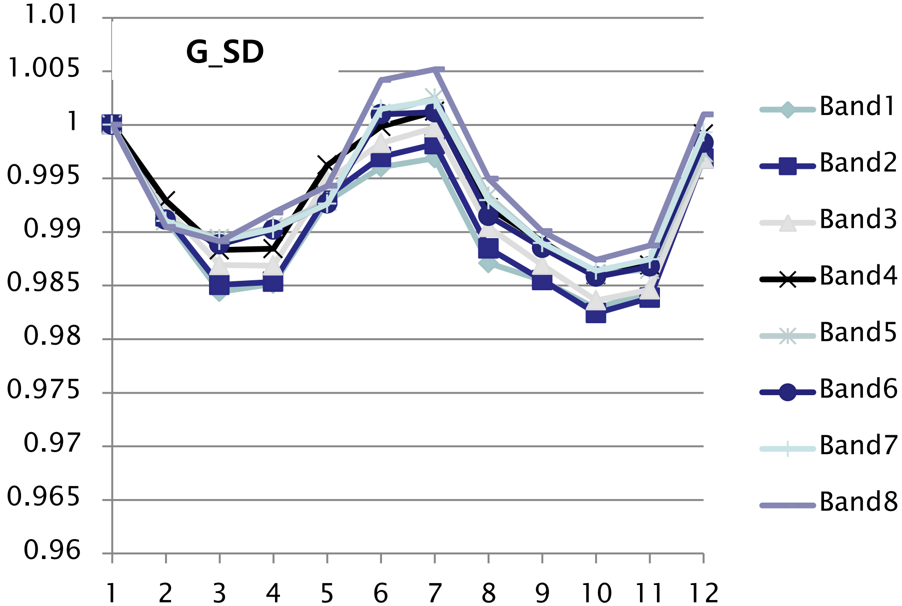
- **Evolution of Radiometric Gain (2011~2014)**
  - Gain Variation is re-stabilized from 2013
  - At same Solar incident(az/el) angle, assessed Gain evolution from 2011 to 2014 is ~0.45%. (0.7% for B1, 0.1% for B4)
  - Annual gain variation is ~0.12% for mean value from 2M pixels.



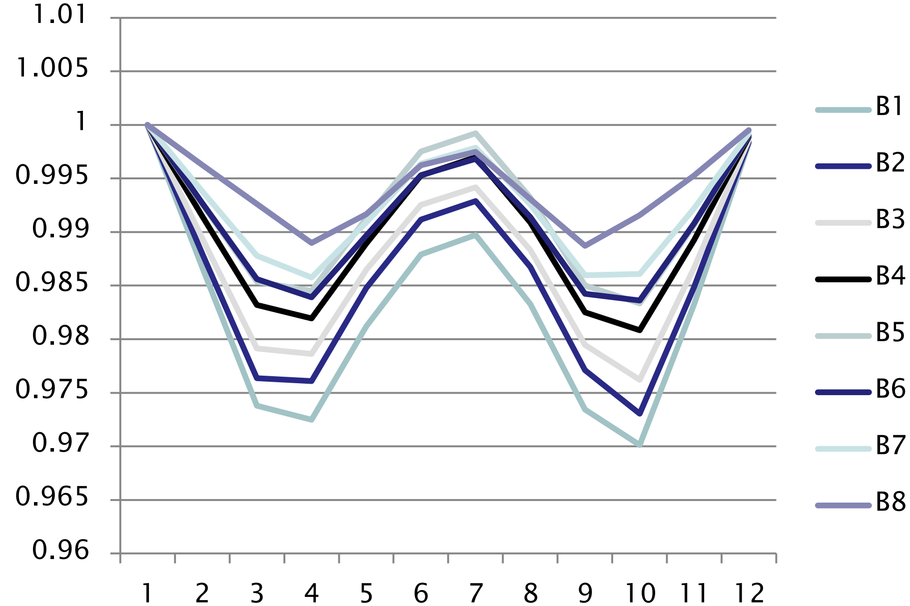
Epoch: 2011/01/01 (yyyy/mm/dd)

Discussion for Gain Evolution (1/3)

- **Evolution of GOCI Radiometric Gain (2011.~2012.)**
  - Sinusoidal Variation of Radiometric Gain : ~ 2.5% (2011.)
  - Gain Evolution with same solar Azimuth/Elevation angle
    - ~0.51% (G_SD, Weekly Obs.) , ~0.14% (G_DAMD, Monthly Obs.)
    - Annual Solar angle variation : 108.4°/10.5° (AZ/EL)
  - Gain Variation(Uniformity) over FPA : ~5% (CV; STDEV/Mean)



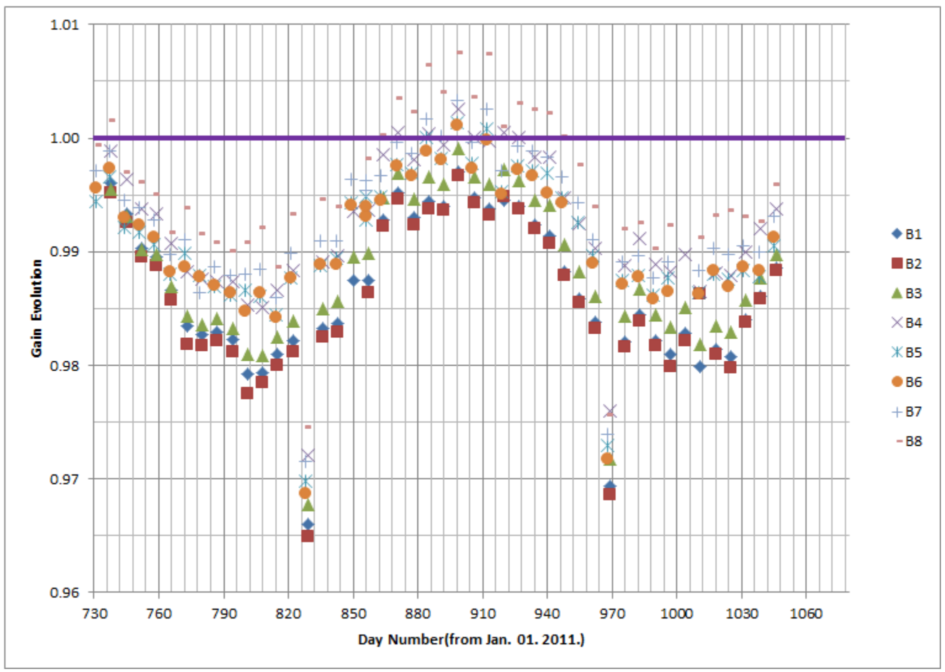
Evolution of Radiometric Gain (2011)



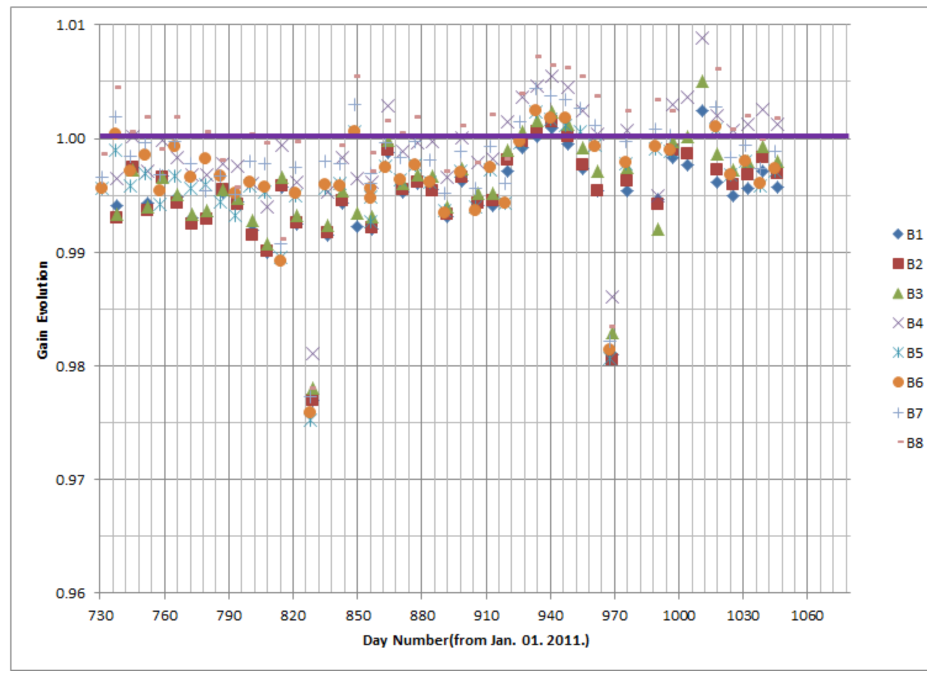
Diffusion Factor Variation
w.r.t. Solar azimuth **angle measured in pre-flight test**

Systematic Behavior Correction

- **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.



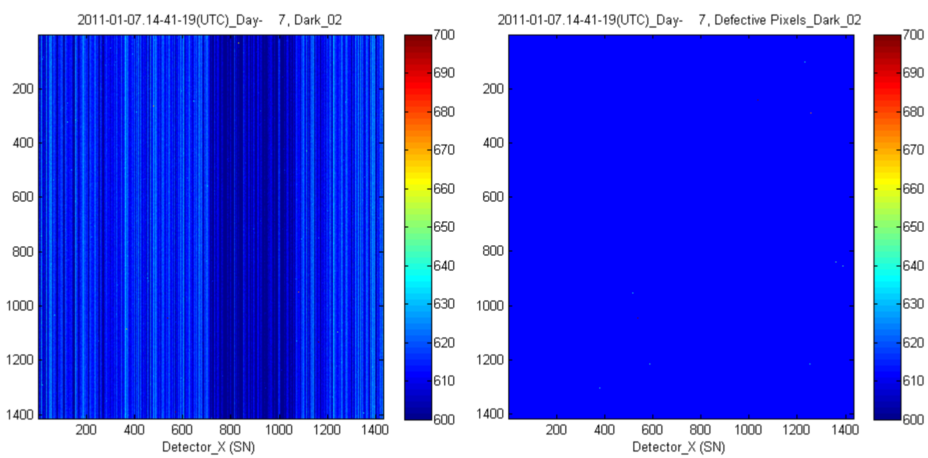
Evolution of Radiometric Gain
Before incident angle correction (2013)



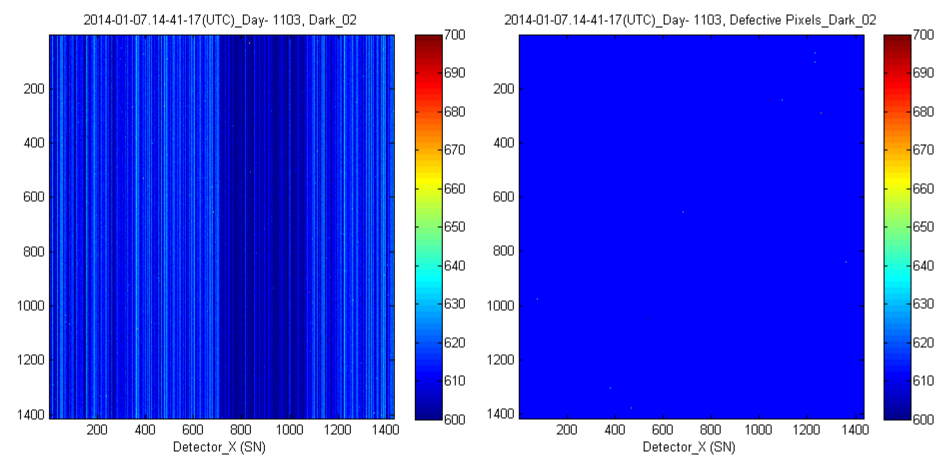
Evolution of Radiometric Gain
After incident angle correction (2013)

Evolution of Defective Pixel

- **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%.
    - # of Detective pixels : **215 pxl** (2011), **266 pxl** (2014)



Dark Image(L) & Defective Pixel Map (R) [2011]

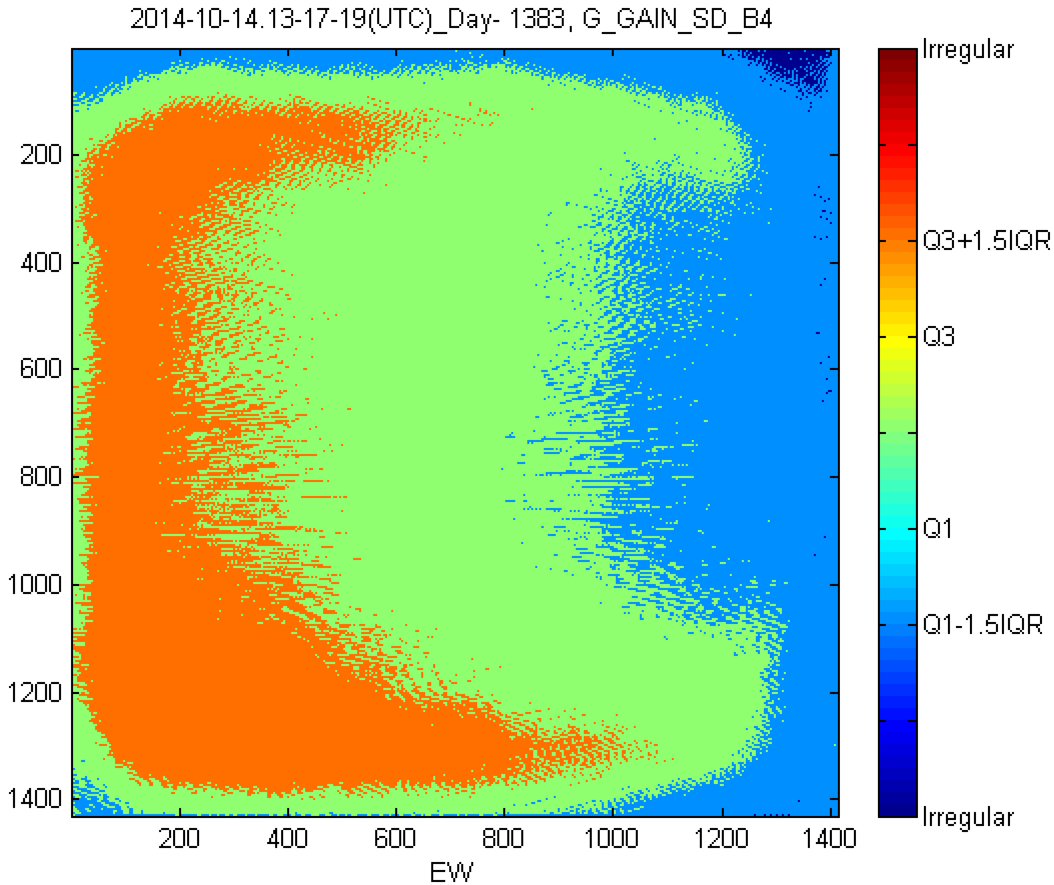


Dark Image(L) & Defective Pixel Map (R) [2014]

L

Pixel-level assessment of GAIN

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



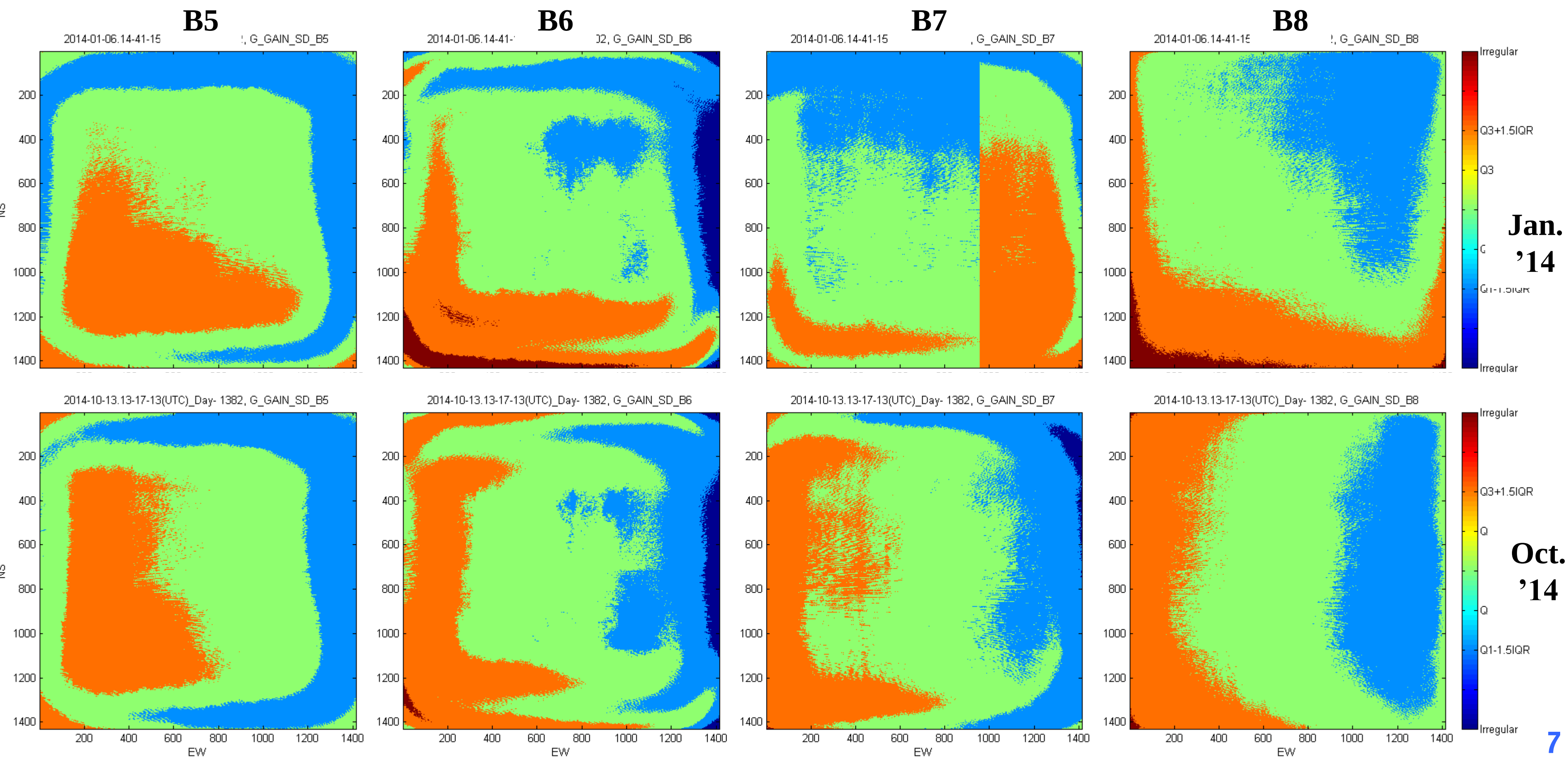
Q1 : 1st quartile
Q3 : 3rd quartile
IQR : Interquartile range

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

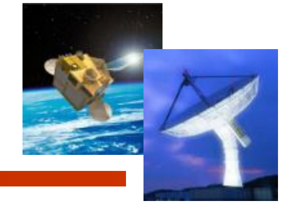
Radiometric Gain for BAND 4
# of Irregular gain pxls : 8,023 [2014.10.]

Pixel-level assessment of GAIN

- **Evolution of Radiometric Gain for Each Pixel**
  - Black & Red area corresponds to irregular gain pixels which has lower & higher gain value, respectively.

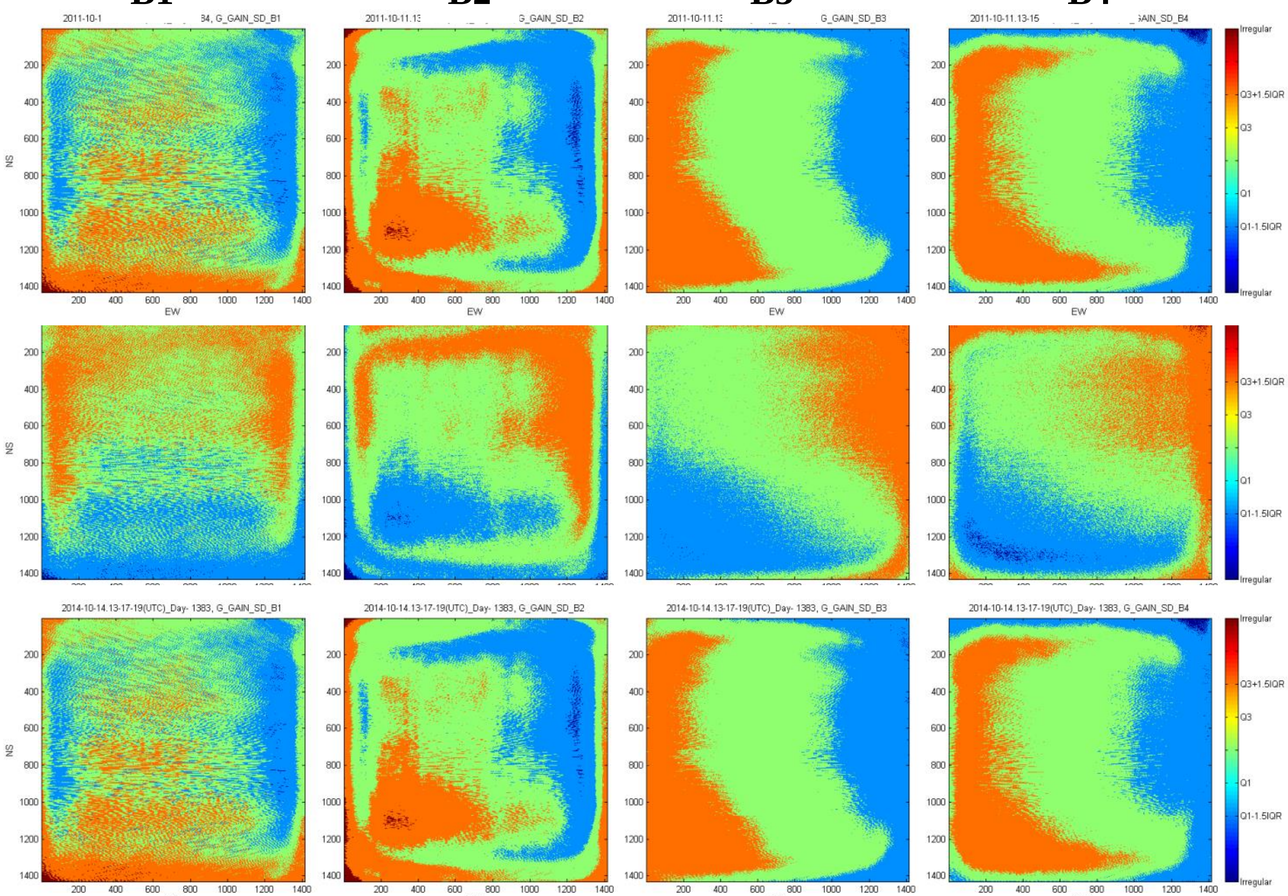


Pixel-level assessment of GAIN



- **Evolution of Radiometric Gain for Each Pixel**
  - Annual variation due to solar incident angle derives annual gain variation

B1 **B2** **B3** **B4**



Radiometric Gain for BAND 4
# of Irregular gain pxls : 7,003
[Oct. 2011]

Radiometric Gain for BAND 4
# of Irregular gain pxls : 88,742
[Jan. 2014]

Radiometric Gain for BAND 4
# of Irregular gain pxls : 8,023
[Oct. 2014]

GOCI-II Lunar Calibration

In-Orbit Calibration Plan

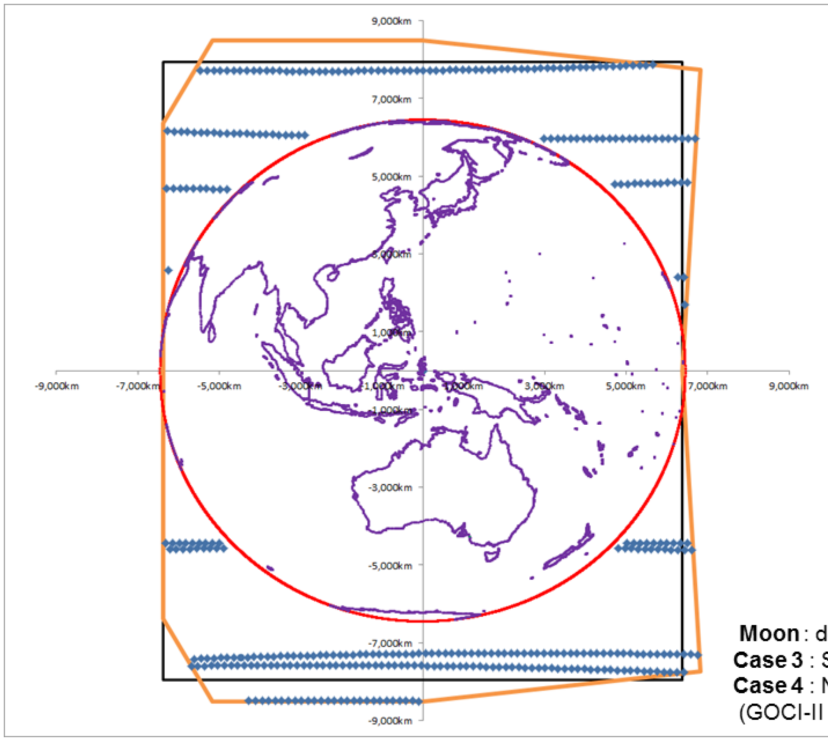
- **Enhancement of Radiometric Performance**
  - Better uniformity of detector response (PRNU) is expected
    - On-going verification of in-house detector prototype performance test
- **Enhancement of Solar Calibration**
  - Full Characterization of diffuser w.r.t. incident angle variation is planned
    - This was not fully performed for GOCI even though highly requested by User
  - Lambertian transmission is one of key criteria for the selection of diffusers
    - Nearly perfect Lambertian diffuser is introduced for GOCI-II
    - Internal gas bubbles enable ideal light scattering for Lambertian property
    - Lambertian characteristics is recently verified by in-house sample test
  - Same as GOCI, second diffuser for monitoring the aging of main diffuser is implemented for GOCI-II
- **Lunar Calibration : New implementation of calibration**
  - ROLO model : Reference Lunar Spectra Model for GOCI-II
  - Required Research for Mission Operation Plan of Lunar Calibration
    - Observable Time Period for Lunar Calibration
  - Operational Issues for GOCI-II Lunar Calibration
    - Moon(even in 100% phase) may not cover the whole GOCI-II IFOV
    - Limitation of Moon Image Acquisition due to the payloads operation policy

Lunar Calibration Plan

Lunar intrusion assessment within GOCI-II FoR (1/2)

- 4 cases of GOCI-II FoR (including actual GOCI-II FoR)

-**Case 1**: ±8.7 degs in EW, ±8.7 degs in SN
-**Case 2**: ±8.7 degs in EW, ±9.8 degs in SN
-**Case 3**: ±8.7 degs in EW, ±11.0 degs in SN
-**Case 4**: assigned GOCI-II FOR
(Ref. GC2.TCN.00062.ASTR)
* Earth disk size corresponds to ±8.7 deg



Moon : dot in blue
Case 3 : Square in black
Case 4 : Nonagon in Orange
(GOCI-II FoR)

Monthly lunar intrusion in GOCI-II FOR (Jan. 2019)

	Case 4 GOCI-II FOR (# of Sequences)	Case 4 GOCI-II FOR (minutes)	Case 3 ±11.0 deg in S/N (minutes)	Case 2 ±9.8 deg in S/N (minutes)	Case 1 ±8.7 deg in S/N (minutes)
Jan.	15	362	334	107	107
Feb.	15	342	259	207	68
Mar.	15	244	184	184	109
Apr.	16	404	258	180	102
May	19	338	286	275	132
Jun.	14	362	299	134	65
Jul.	15	253	189	189	121
Aug.	16	392	308	131	131
Sep.	18	355	299	205	144
Oct.	14	303	228	150	87
Nov.	13	260	200	123	123
Dec.	14	391	352	221	81

Duration of lunar intrusion w.r.t. GOCI-II FOR (4 cases) in 2019

Result:

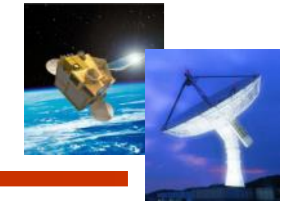
Assessed monthly lunar intrusion within GOCI-II FOR : about 334 mins/month (~5.5 hours/month)

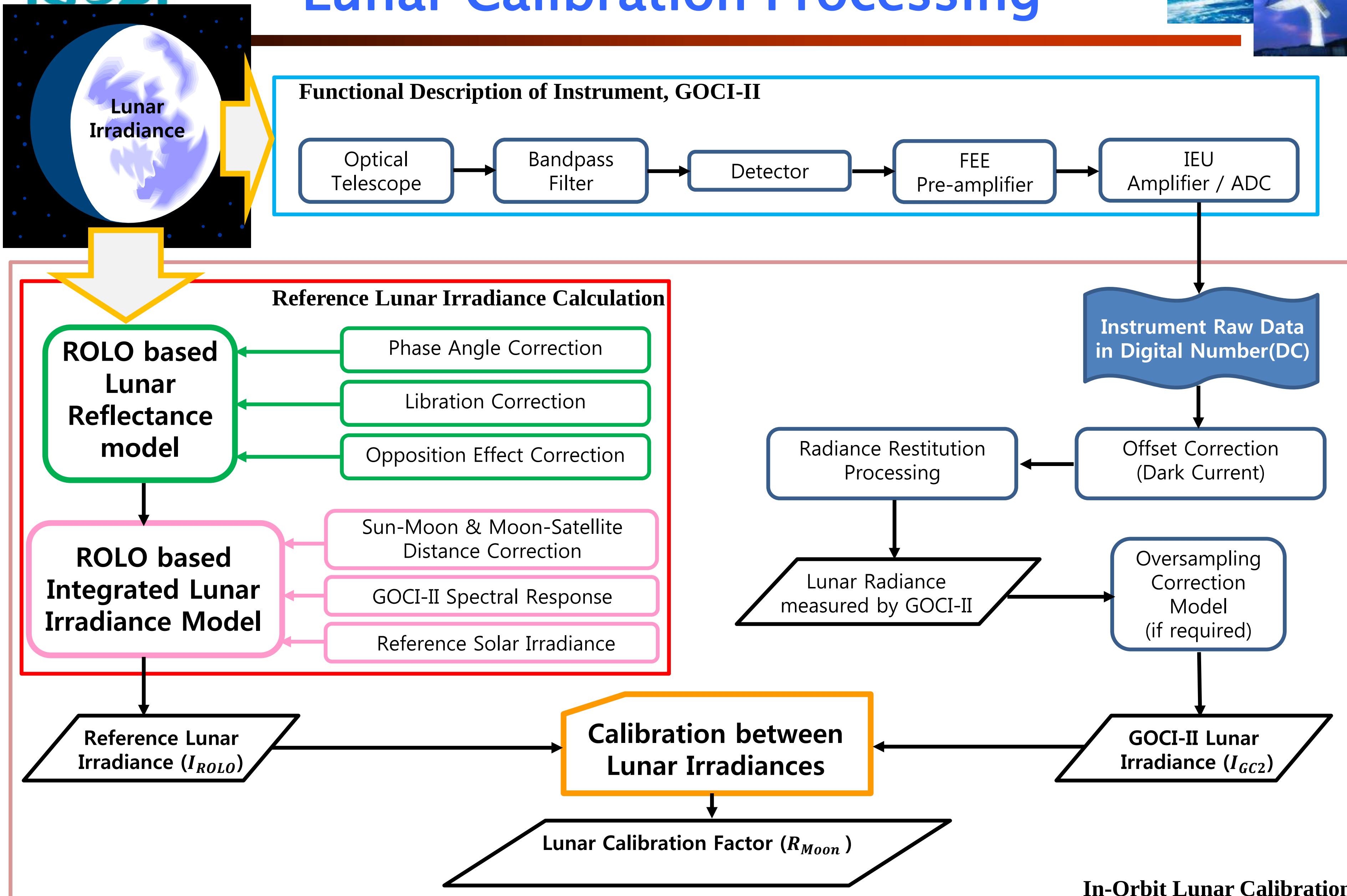
Satellite level moon observability of GOCI-II : about 53 mins/month

(Regarding operation timeline of the other payload, Moon phase larger than half moon)

No issue for the minimum revisit time requirement of Moon imaging (1 time/month in instrument level)

Lunar Calibration Processing





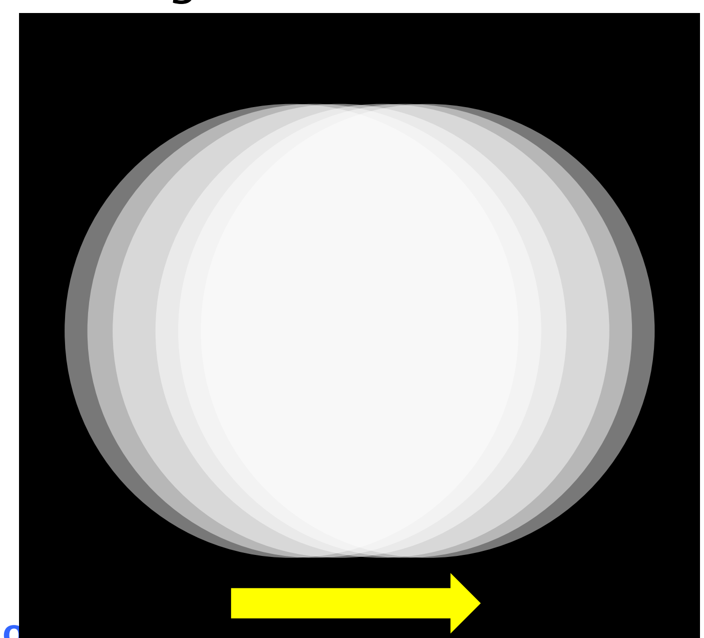
Issues & Concerns

Dark Signal Determination

- **Dark Signal correction for GOCI & GOCI-II**
  - For Lunar Calibration, dedicated dark image acquisition at dark position in filter wheel is planned.
    - 2 dark images acquisition before(and after) Moon acquisition
    - Every dark image is generated after on-board averaging of multi frames.
  - Dark signal is corrected by linear interpolation with 2 dark images w.r.t. actual integration time of each band.
    - Each spectral band of GOCI-II has different integration time w.r.t. its spectral response and required SNR performance.
  - Q) For the Lunar Calibration, dedicated dark image acquisition is sufficient or dark signal determination over the dark area in the Moon image is additionally required?

Moon Image Acquisition (1/2)

- **Moon Image Acquisition for GOCI-II (HG or LG)**
  - HG(High Gain) & LG(Low Gain) image acquisition of GOCI-II
    - Fully separated & consecutive HG and LG image acquisitions are required to cover the wide dynamic range with high SNR.
  - Because GOCI-II has non-adjustable single electronic gain, HG and LG acquisition is defined by the integration time and # of accumulated image (1 for LG).
    - Integration time of HG is about 4.5sec per band.



Relative motion of the Moon during HG image acquisition(~4.5sec integration time) on GOCI-II IFOV

KIOST 한국해양과학기술원

Moon Image Acquisition (2/2)

- **Moon Image Acquisition for GOCI-II (HG or LG)**
  - Moon acquisition with HG gives
    - Relative motion of the Moon (~40 pixels) with different actual pixel integration time (issue of PRNU)
    - High SNR (~1,000)
  - Moon acquisition with LG gives
    - No or small relative motion of the Moon
    - Low SNR (~200)

Q) For the effective Lunar Calibration, which acquisition mode(HG or LG) is more suitable for GOCI-II?

Spectral Response Function

- **SRF for GOCI-II**
  - SRF variation(incl. band shift) over detector region
  - Planned SRF w.r.t. sub-area of detector or each pixel
  - Q) For the Lunar Calibration (GIRO), 1nm band shift within IFOV at 20nm bandwidth shall be taken into account?

- **Absolute SRF for Sensitivity analysis**
  - Generally, lower spectral response of the sensor gives lower radiometric performance (ex. SNR due to dark current).
  - For the effective sensitivity analysis, absolute SRF may be useful to assess actual radiometric performance of each band and each sensor.
    - Normalized SRF can be easily calculated from absolute SRF.

Straylight/Ghost

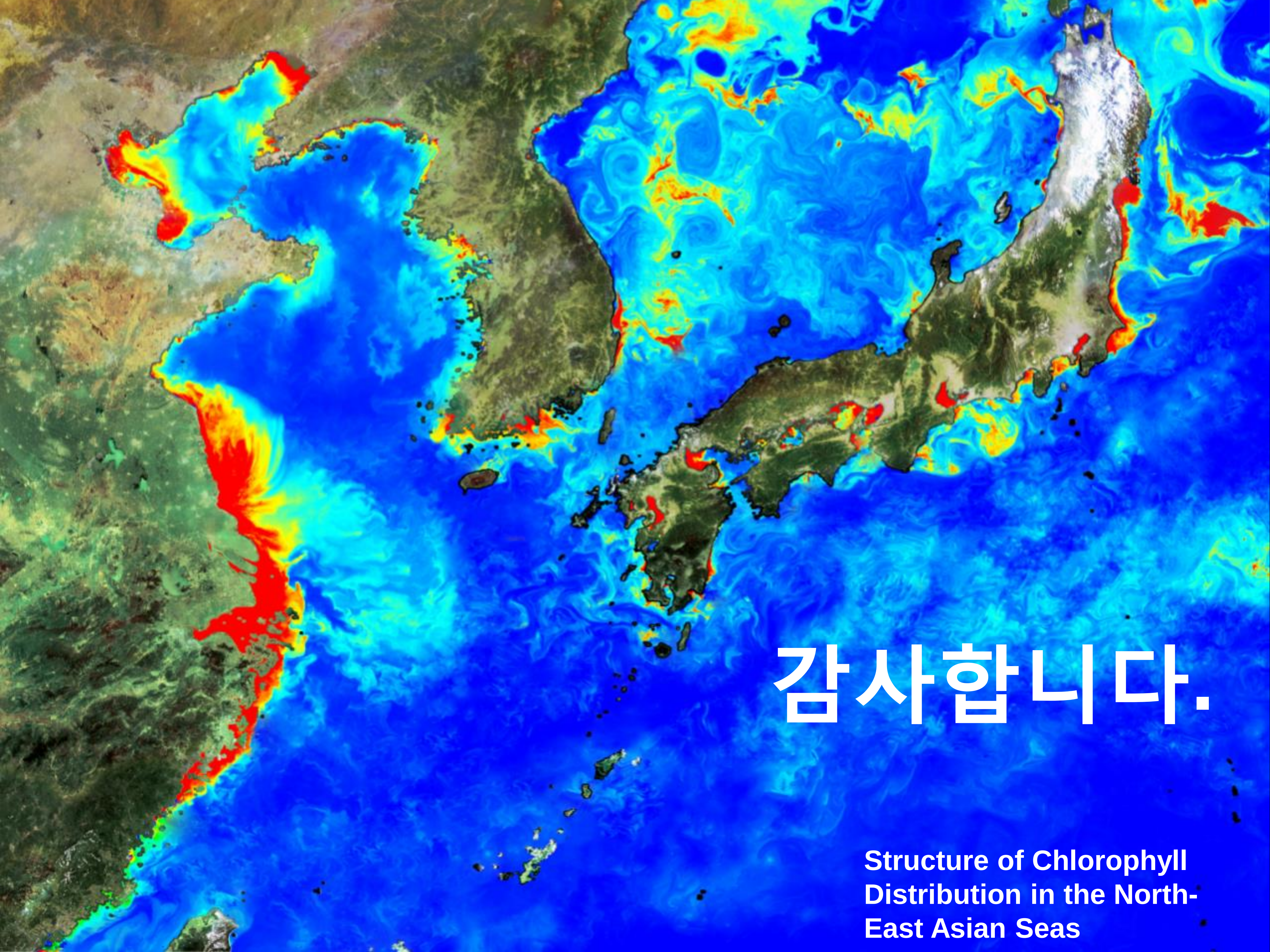
- **Optical Design and Test Plan of GOCI-II**
  - Field Stop in the intermediate focal point is added to minimize straylight & optical ghost.
  - Inclined between filter and detector to minimize diffusion straylight
  - PSF over the Focal Plane will be characterized, and if necessary, straylight correction method will be applied for lunar calibration.

Concluding Remarks

- **Development of GOCI-II**
  - With on-going operation of GOCI derives GOCI-II principal user requirements such as lunar calibration.
  - Heritage of lunar calibration results are very helpful to develop the sensor.

- **Lunar Calibration for GOCI-II**
  - According to the calibration heritage of GOCI, Lunar Calibration is essential for GOCI-II.
  - GIRO application and related activities are very helpful for GOCI-II lunar calibration.
  - Advices or comments for GOCI-II lunar calibration are highly appreciated.

감사합니다.



Structure of Chlorophyll Distribution in the North-East Asian Seas