# GOCI Post-launch calibration and GOCI-II Pre-launch calibration plan

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**Breakout Session: Satellite Calibration, IOCS Meeting 2015, 18 June 2015.**

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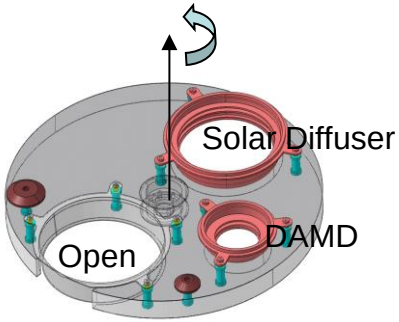
# In-Orbit Solar Calibration of GOCI

**Breakout Session: Satellite Calibration, IOCS Meeting 2015, 18 June 2015.**

# In-Orbit Solar Calibration

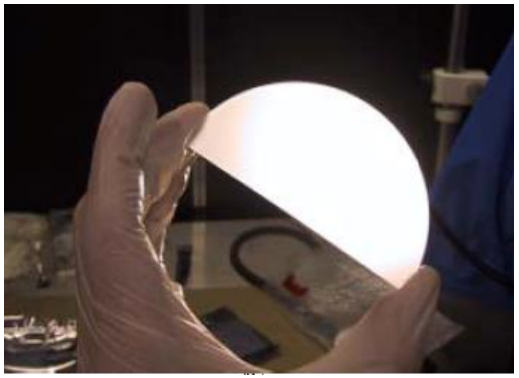
- **Solar Calibration using solar diffuser is the baseline method for Radiometric Calibration of GOCI**
  - Subsystem for Solar Calibration : Solar Diffuser & DAMD
    - DAMD(Diffuser Aging Monitoring Device) is the second diffuser in GOCI
  - Sun is a reference light source for GOCI in-orbit calibration
  - 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

Solar Irradiance

**Functional Description of Instrument, GOCI**

Optical Telescope → Bandpass Filter → Detector → FEE Pre-amplifier → IEU Amplifier / ADC

**Instrument Raw Data Digital Counts(DC)**

**Calibration Radiance Calculation**

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

Reference Radiometric Gains → **Diffuser Aging Factor Model**

Offset Correction (Dark Current) → Calibration Digital Counts(DC)

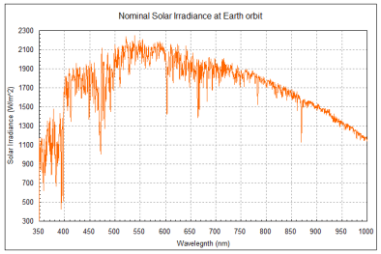
**Radiometric Gain Computation**

Radiometric Gains

**In-Orbit Radiometric Calibration**

# Calibration Radiance Calculation

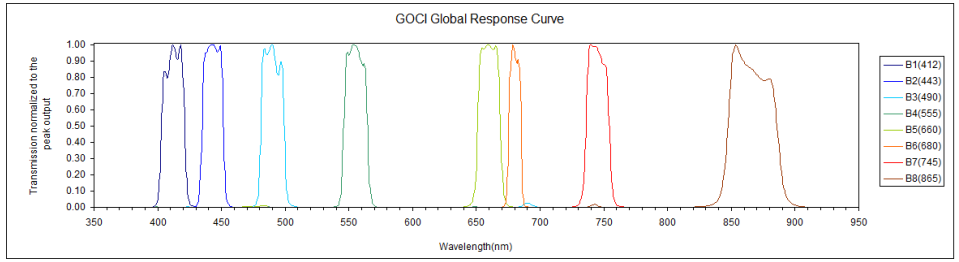
## Solar Irradiance Reference Spectra




(Ref. Thuillier, 2004)

Solar Irradiance

## 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)

**Calibration Radiance Calculation**

Sun-Earth Distance Model

Instrument Spectral Model

In-Band Instrument Solar Irradiance

Solar Incident Angle

**Solar Diffuser BRDF Model**

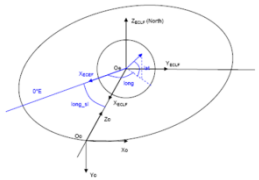
Calibration Radiance

## Solar Incident Angle Calculation

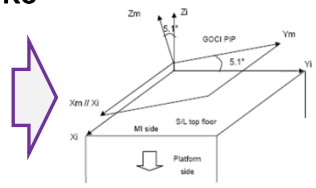
Orbital Position of Sun

Frame Conversion

– 5.1deg rotation in Roll

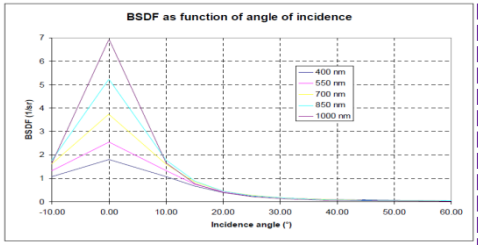


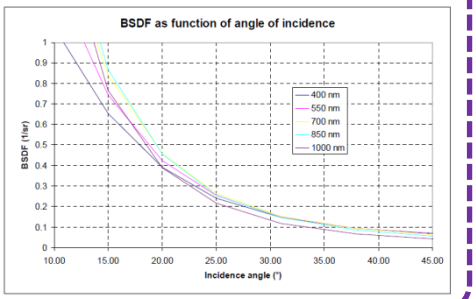
ECEF to ALOF Frame




ALOF to GOCI Reference Pointing Frame

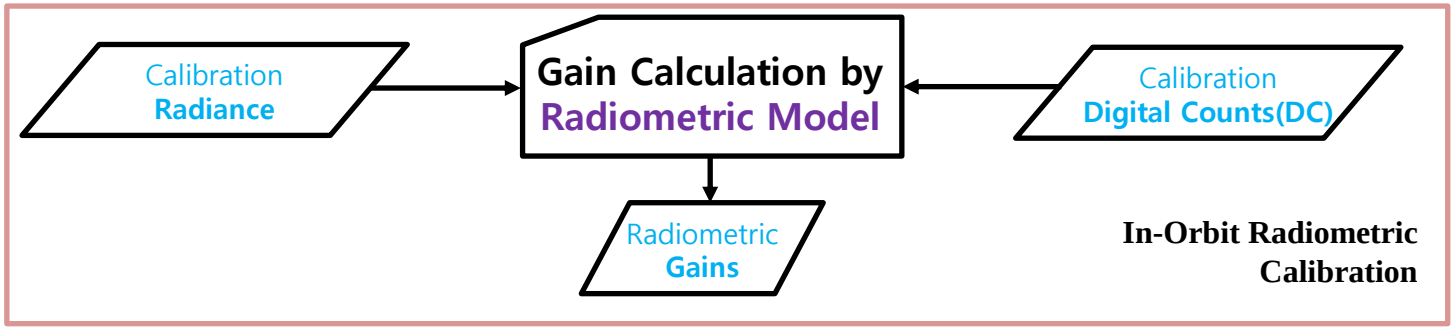
## GOCI Diffuser BRDF Model




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

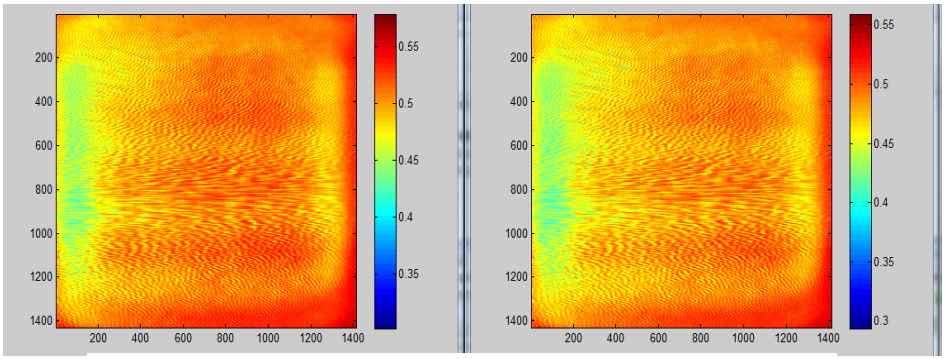
# Radiometric Model



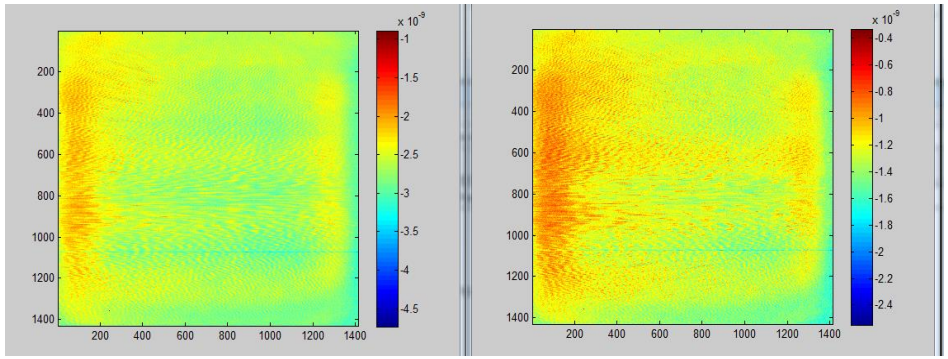

- GOCI Radiometric Model : 3rd-Order Polynomial
  - Mathematical equation to express the relationship between DN(Digital Number), raw data measured from GOCI instrument and radiance

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

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)

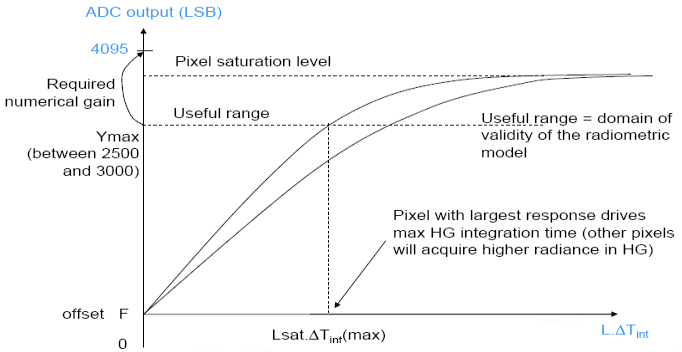


Non-linear Gain (b)

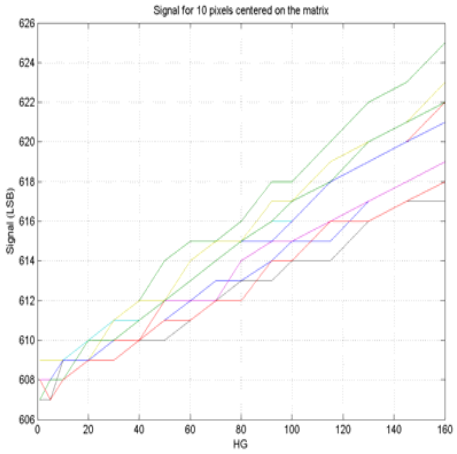
# On-Ground Characterization

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

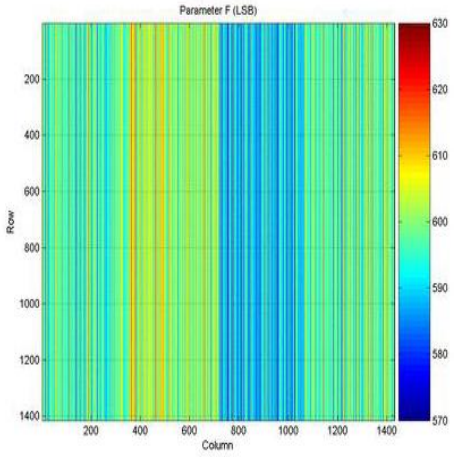
Y : GOCI Output signal after pseudo averaging and offset correction (LSB)
X : Input radiance*Integration Time
G : GOCI Overall Linear Gain
b : GOCI Overall Non-Linear Gain



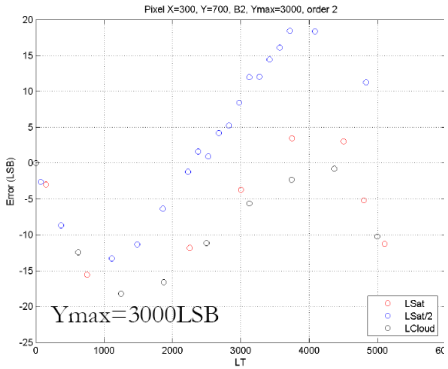

GOCI Radiometric Model Characterization



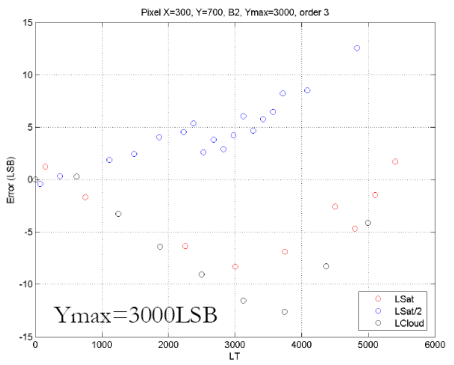

Dark Current(DN) Evaluation




Fixed Offset (F)



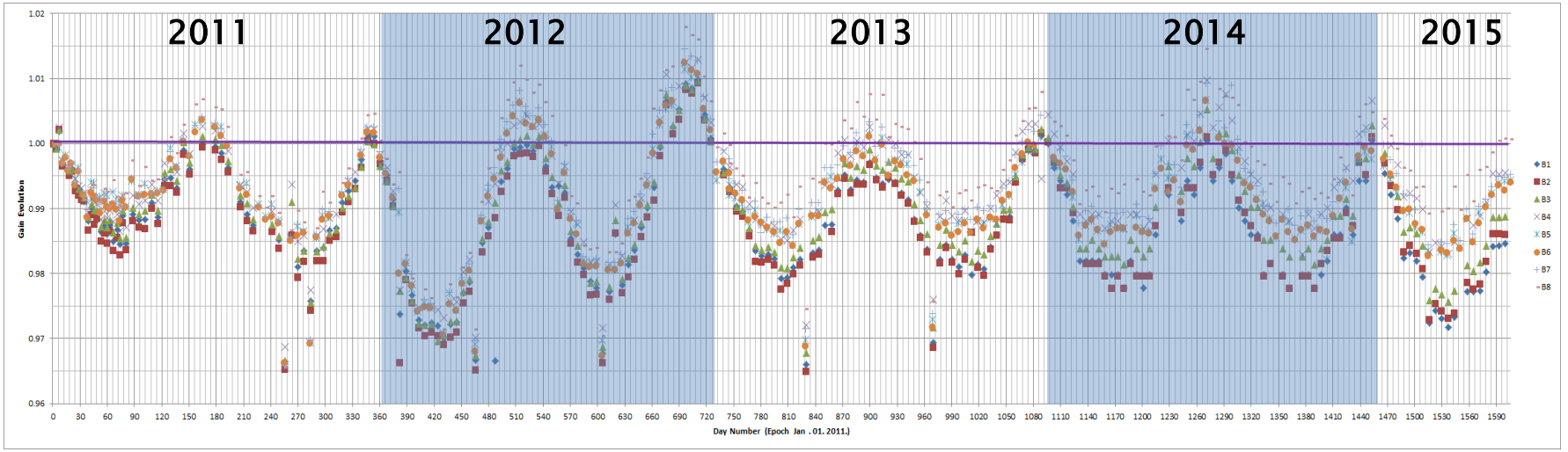

Fitting error (Order 2)




Fitting error (Order 3)

# Discussion for Gain Evolution (3/3)

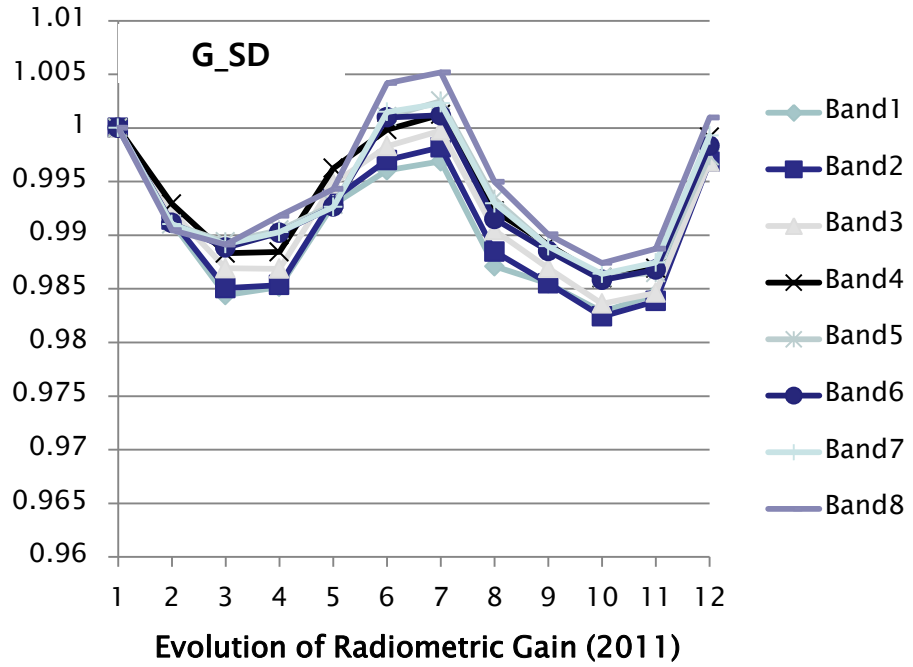
- **Evolution of Radiometric Gain (Jan. 2011~May 2015)**
  - In 2012, unexpected gain evolution was found.
  - No challenging issue for gain evolution (except for the poor diffuser BSDF model with respect to the solar incident angle(az))
  - At same Solar incident(az/el) angle, assessed annual gain evolution is ~0.12% for mean value from 2M pixels. (Worst Case : ~0.25% for B1)



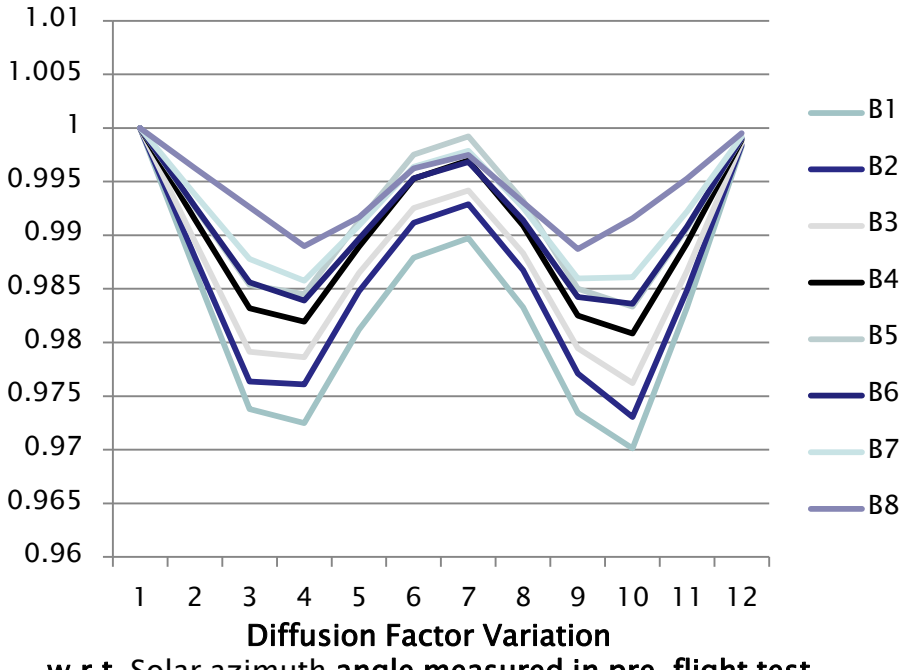

**Epoch: 2011/01/01 (yyyy/mm/dd)**

# Discussion for Gain Evolution

- **Evolution of GOCI Radiometric Gain (2011.~2012.)**
  - Sinusoidal Variation of Radiometric Gain : ~ 2% (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)



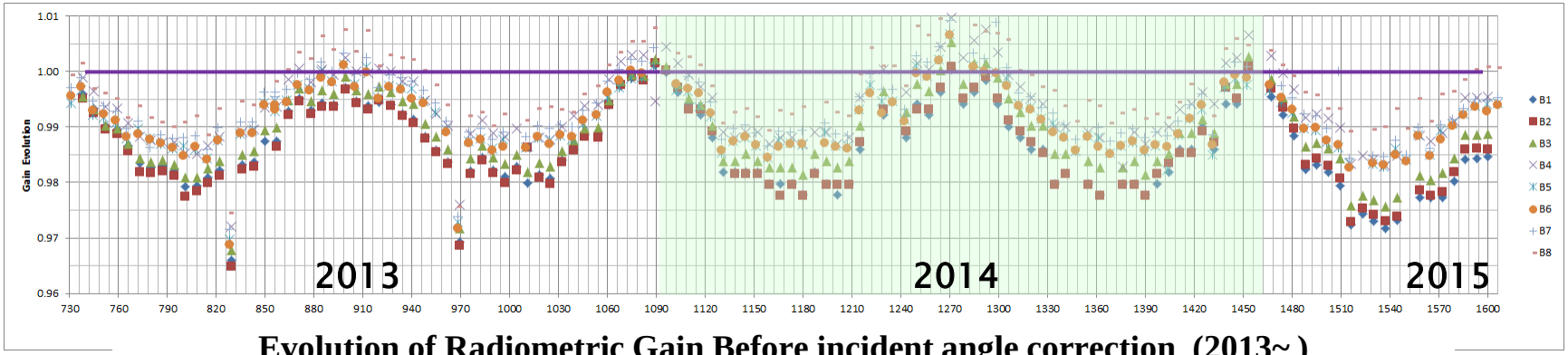

Evolution of Radiometric Gain (2011)



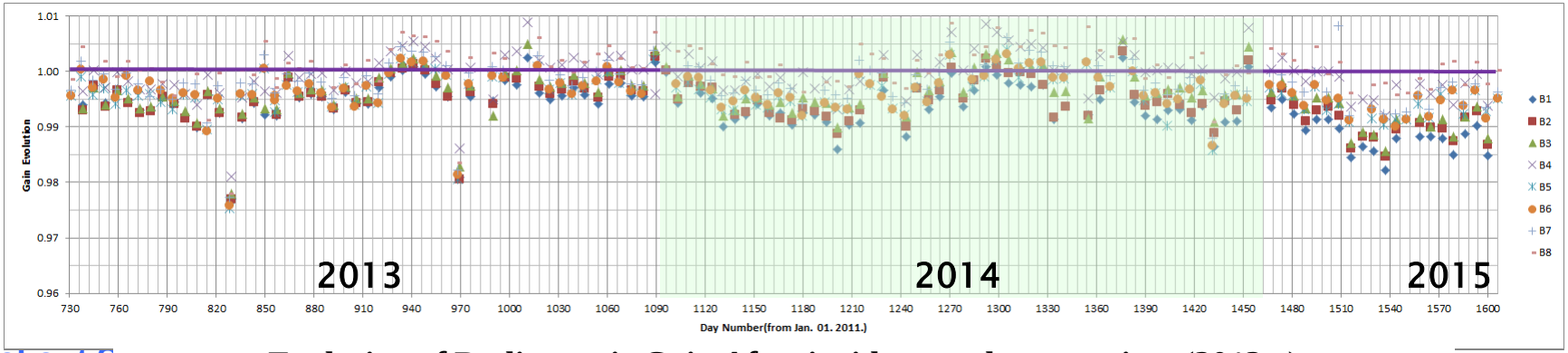

Diffusion Factor Variation
w.r.t. Solar azimuth angle measured in pre-flight test

# 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.



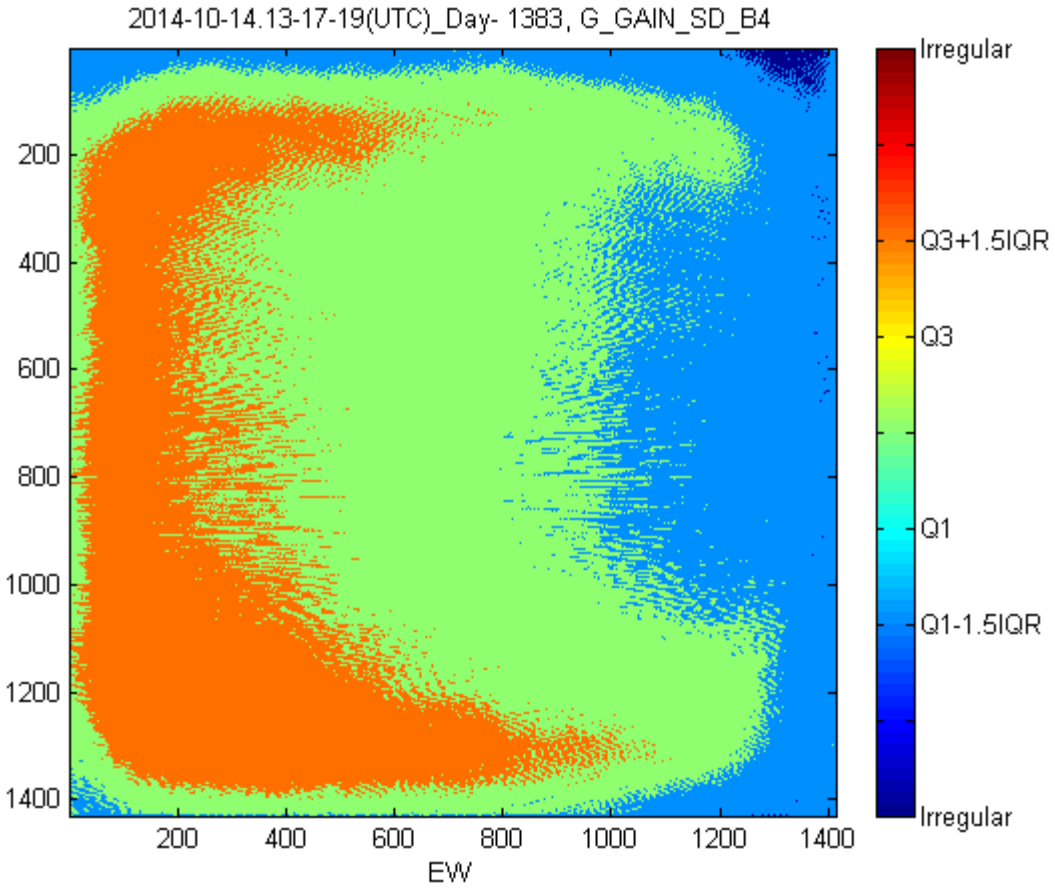

**Evolution of Radiometric Gain Before incident angle correction (2013~ )**




**Evolution of Radiometric Gain After incident angle correction (2013~ )**

# 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.



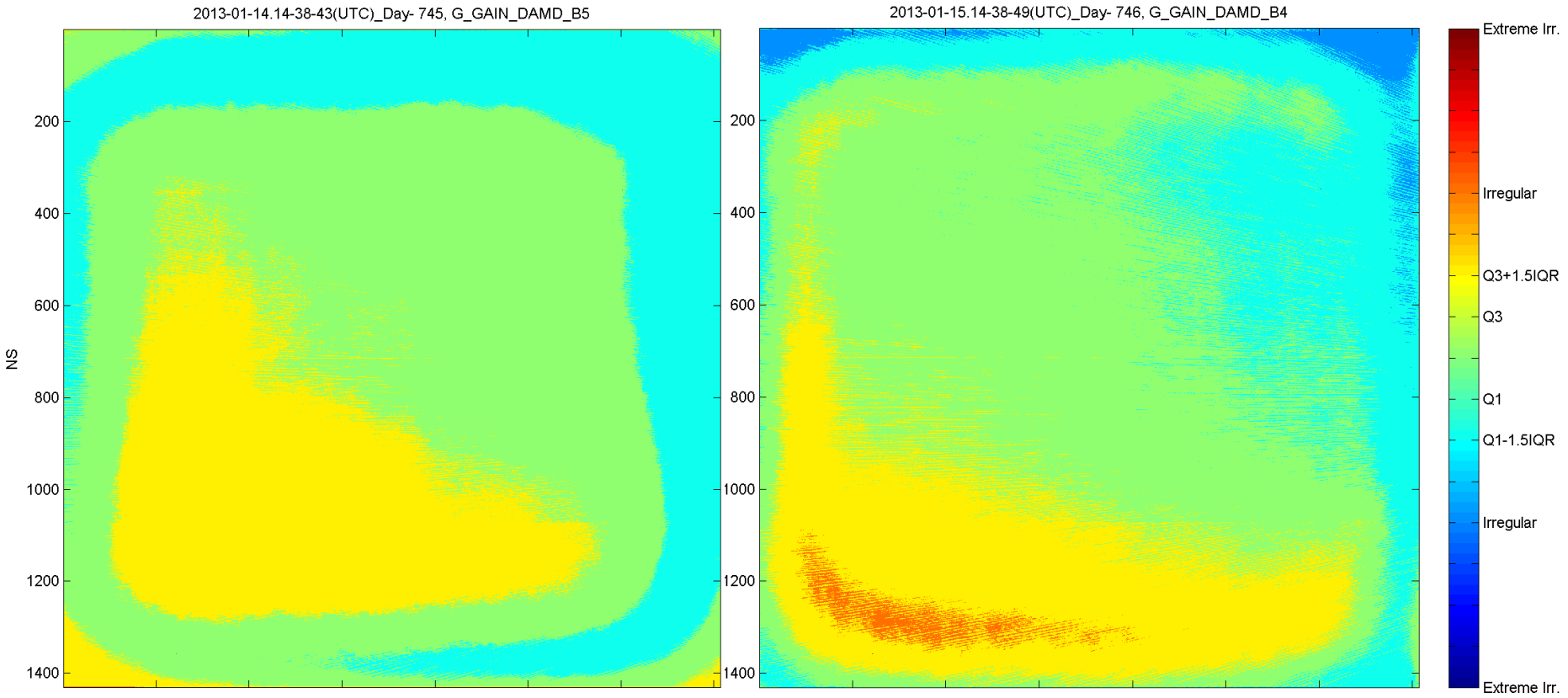

**Q1 : 1st quartile**
**Q3 : 3rd quartile**
**IQR : Interquartile range**

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



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# GOCI-II Calibration Plan

# 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 Processing


**Functional Description of Instrument, GOCI-II**

Optical Telescope → Bandpass Filter → Detector → FEE Pre-amplifier → IEU Amplifier / ADC

**Instrument Raw Data in Digital Number(DC)**

Offset Correction (Dark Current) → Radiance Restitution Processing → Lunar Radiance measured by GOCI-II → Oversampling Correction Model (if required) → **GOCI-II Lunar Irradiance ($I_{GC2}$)**

**Reference Lunar Irradiance Calculation**

**ROLO based Lunar Reflectance model**
- Phase Angle Correction
- Libration Correction
- Opposition Effect Correction

**ROLO based Integrated Lunar Irradiance Model**
- Sun-Moon & Moon-Satellite Distance Correction
- GOCI-II Spectral Response
- Reference Solar Irradiance

→ **Reference Lunar Irradiance ($I_{ROLO}$)**

**Calibration between Lunar Irradiances**

→ **Lunar Calibration Factor ($R_{Moon}$)**

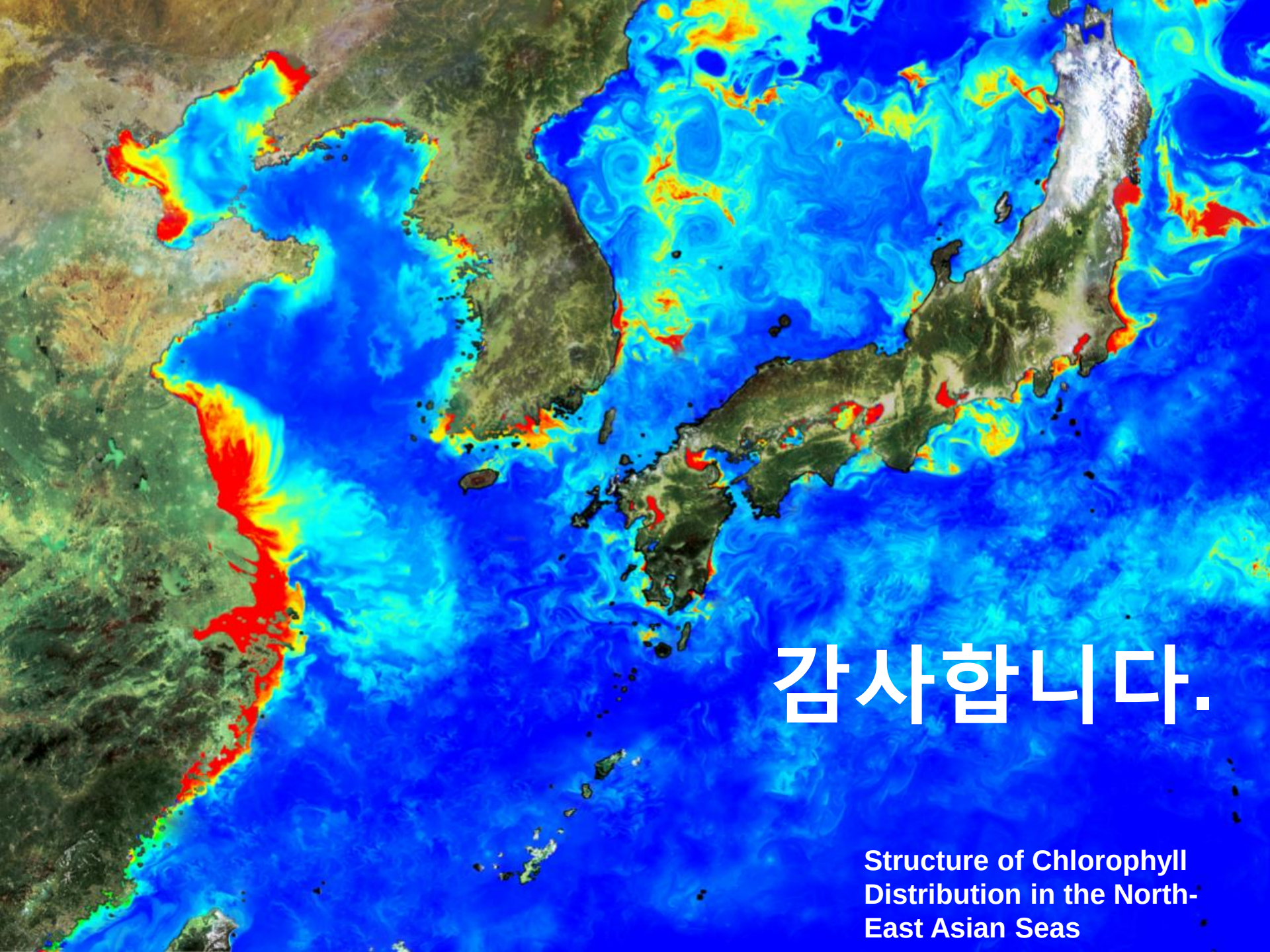
**In-Orbit Lunar Calibration**

# Concluding Remarks

- **In-Orbit Calibration of GOCI**
  - No blocking point of Mission operation & No critical issue
  - Annual variability of gain & residual radiometric error processing result are planned to be presented in SPIE Optics & Photonics 2015.

- **Solar Calibration for GOCI-II**
  - Solar Diffuser & 2nd diffuser for diffuser aging monitoring
  - Diffuser material design planned to be modified

- **Lunar Calibration for GOCI-II**
  - FoR of GOCI-II is the trade-off between Moon observability & H/W constraints(mass, volume, etc.).
  - ROLO based Lunar Calibration is planned for GOCI-II.
    - Complementary Calibration Method
    - Inter-Satellite Calibration with Moon




Structure of Chlorophyll Distribution in the North-East Asian Seas