해양위성센터

Vicarious Calibration Adjustment for GOCI

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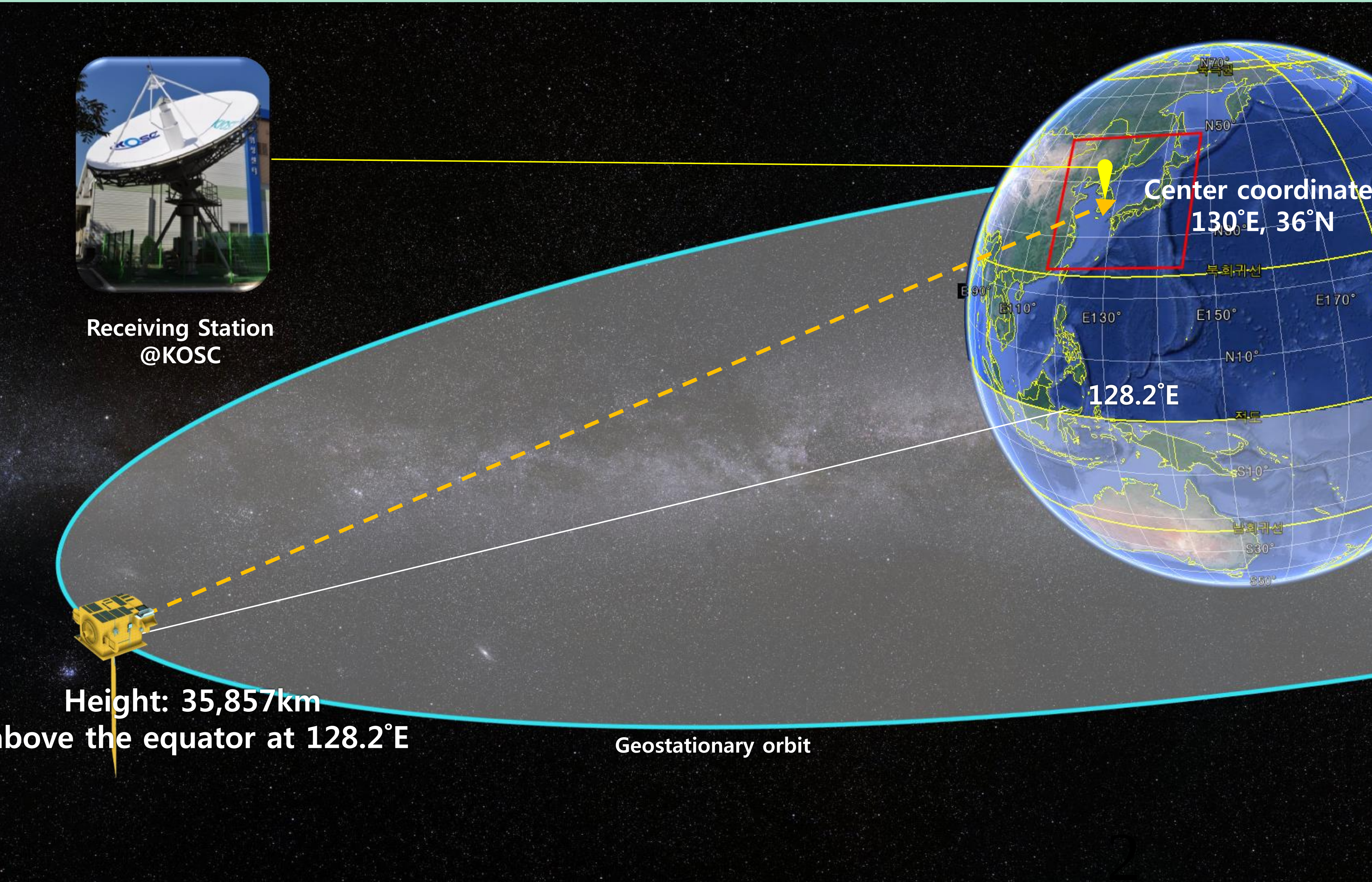
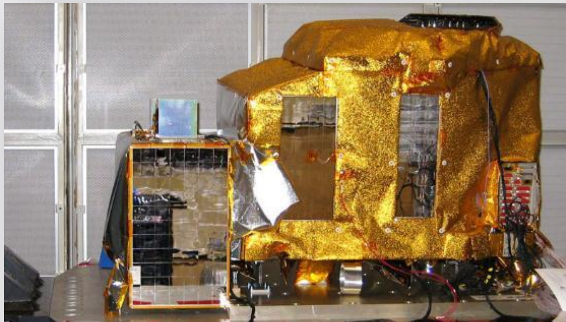
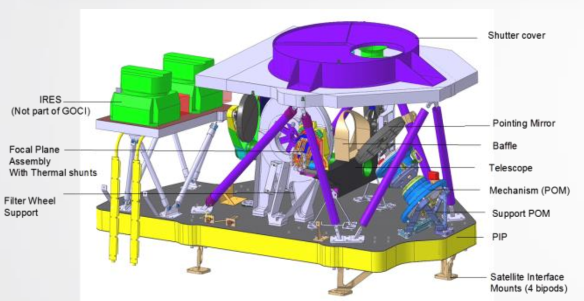
Geostationary orbit for COMS/GOCI



GOCI in brief

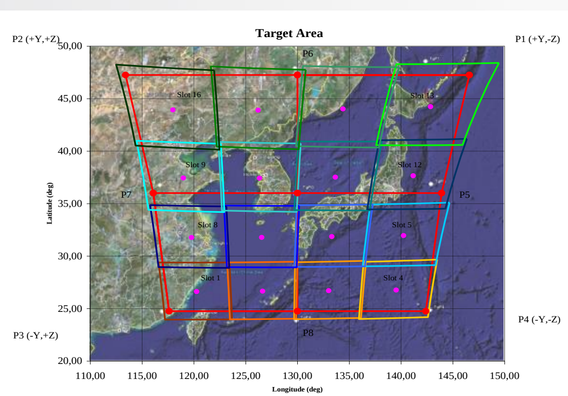


- Geostationary Ocean Color Imager
  - **VIS/NIR Multispectral Imager for Ocean Monitoring**
  - GSD(Ground Sampling Distance) : 500m@130◦E 36◦N (≈ ~390m@nadir)
  - Target Area : 2,500km * 2,500km (Center : 130◦E 36◦N; Pohang-Si, Korea)
  - Temporal Resolution : 1hour (8 times at 1 day)

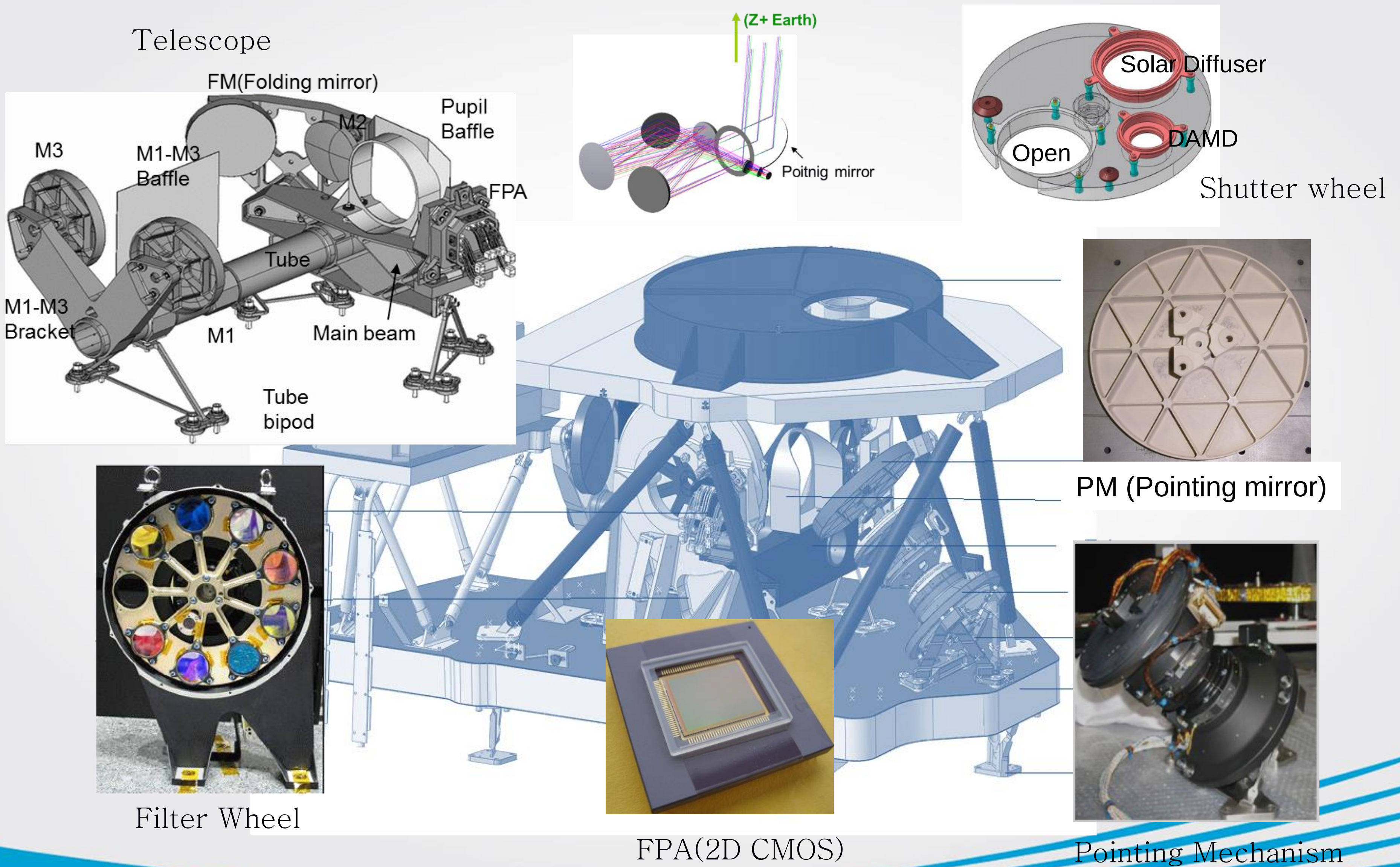


Spectral Bands Characteristics of GOCI

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

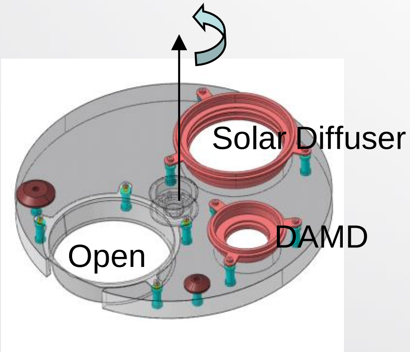


GOCI key elements



GOCI in-orbit solar calibration

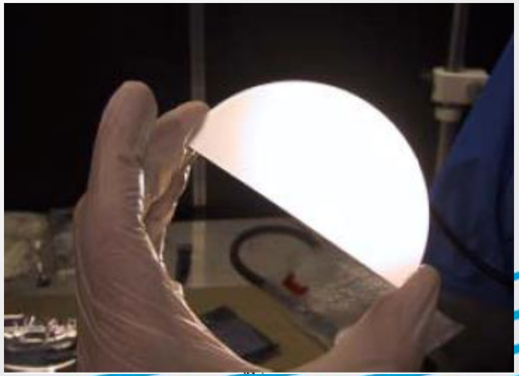
- **Solar Calibration using solar diffuser is the baseline method for Radiometric Calibration of GOCI**
  - Subsystem for Solar Calibration : Solar Diffuser & DAMD
    - DAMD(Diffuser Aging Monitoring Device) is the second diffuser in GOCI
  - Sun is a reference light source for GOCI in-orbit calibration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



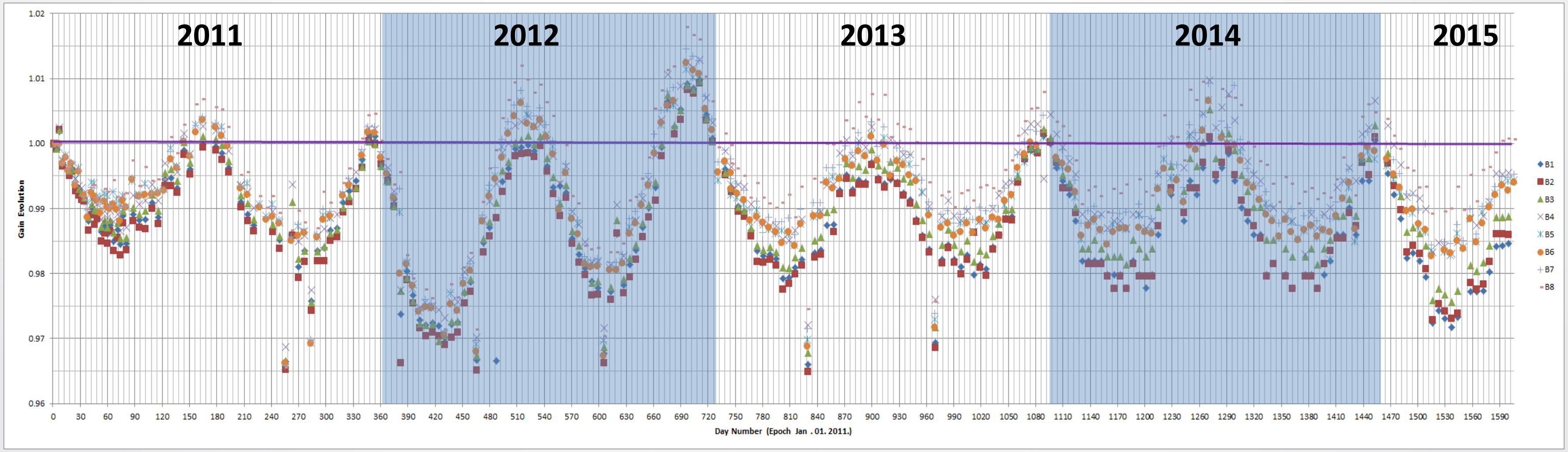
Diffuser for irradiation test
(other half one : reference)

Gain evolution

- GOCI radiometric gain shows sinusoidal variations (see figure below), which is probably from imperfect model of bidirectional transmittance function for the GOCI diffuser

- At same Solar incident(azimuth/elevation) angles, the assessed gain evolution from 2011 to 2014 is ~0.45%. (0.7% for B1, 0.1% for B4)

-> GOCI is in a quite stable & good status five years after launch



Evolution of GOCI Radiometric Gain
Epoch: 2011/01/01 (yyyy/mm/dd)

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GOCI atmospheric correction

GOCI atmospheric correction

- B**ased on the Gordon & Wang (1994)** which is **using two NIR bands** to estimate aerosol optical properties

- A **different aerosol multiple-scattering reflectance estimation scheme** has been implemented [Ahn et al. *Optics Express* (2015)]

- A **different turbid water NIR correction scheme** has been implemented [Ahn et al. *Ocean Science Journal* (2012)]

- Other minor adaption

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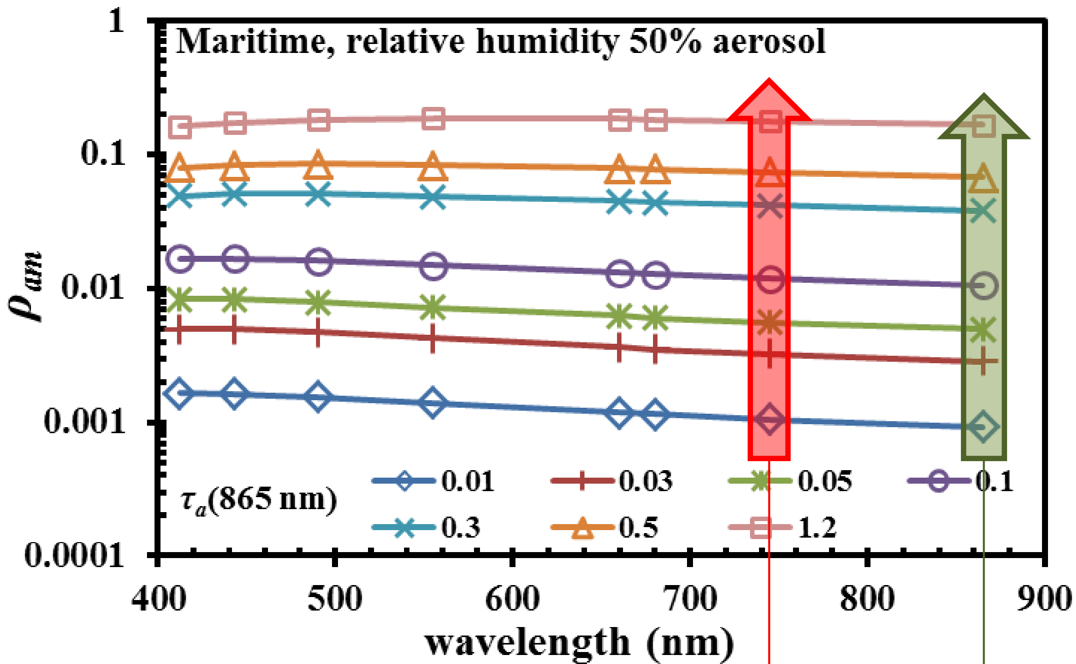
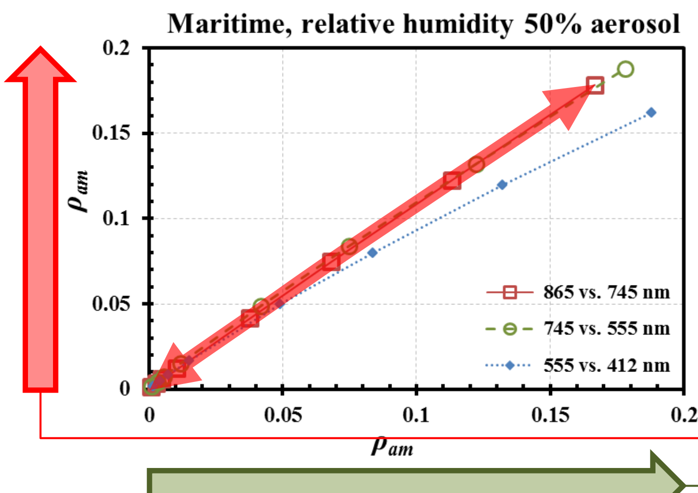
Aerosol correction scheme in the GOCI Atmospheric correction

- **What is unstraightforward in Gordon and Wang (1994)**
  - Conversion of multiple scattering to single scattering
  - Linear weights calculated in the single scattering domain to be used for extrapolation to the visible bands

- **Alternative aerosol correction scheme for GOCI (SRAMS)**
  - It estimates aerosol reflectance fraction of the two models **in the multiple scattering domain directly** without going through the single scattering domain
  - It uses **S**pectral **R**elationships in the **A**erosol **M**ultiple-**S**cattering reflectance between different wavelengths **(SRAMS)**
    - Empirical polynomial relationship established through radiative transfer simulation

Inter-band relationship of multiple scattering aerosol reflectance for specific geometric angle and aerosol model



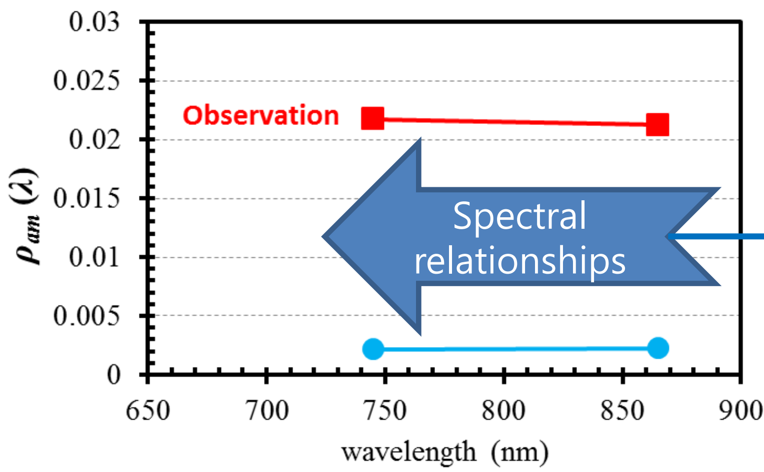


$$\rho_{am}(\lambda_2) = \sum_{n=1}^{D} k_n \rho_{am}(\lambda_1)^n$$

where k_n is the coefficient for specific aerosol model

λ_1 (nm)	865	745	745	745	555	555	555
λ_2 (nm)	745	680	660	555	490	443	412
D	2	3	3	4	4	4	4

Determining two-most- appropriate aerosol models contribution



2 known values **4 unknown values**

$$\rho_{am}^{\mathrm{Obs}}(745\ \mathrm{nm}) = \rho_{am}^{\mathrm{Model1}}(745\ \mathrm{nm}) + \rho_{am}^{\mathrm{Model2}}(745\ \mathrm{nm})$$

$$\rho_{am}^{\mathrm{Obs}}(865\ \mathrm{nm}) = \rho_{am}^{\mathrm{Model1}}(865\ \mathrm{nm}) + \rho_{am}^{\mathrm{Model2}}(865\ \mathrm{nm})$$

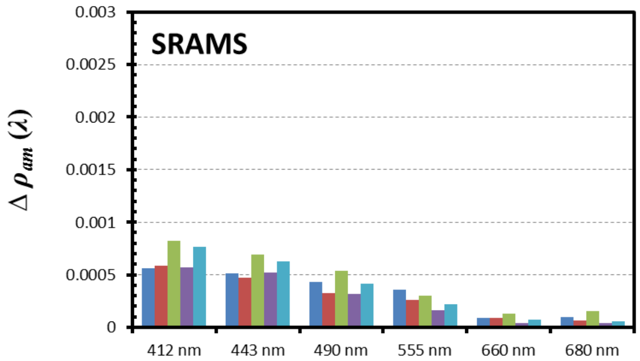
$$\rho_{am}^{\mathrm{Model1}}(745\ \mathrm{nm}) = \mathrm{Func}\left[\rho_{am}^{\mathrm{Model1}}(865\ \mathrm{nm})\right]$$

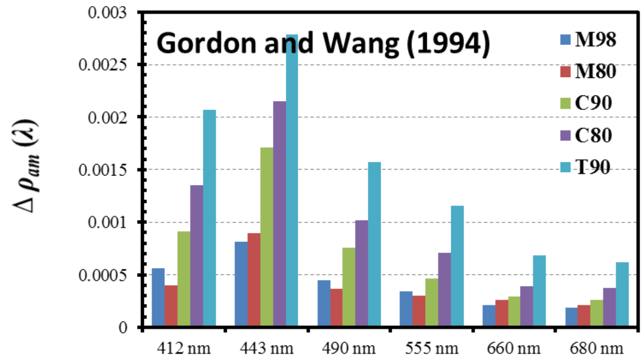
$$\rho_{am}^{\mathrm{Model2}}(745\ \mathrm{nm}) = \mathrm{Func}\left[\rho_{am}^{\mathrm{Model2}}(865\ \mathrm{nm})\right]$$

2 known constraints

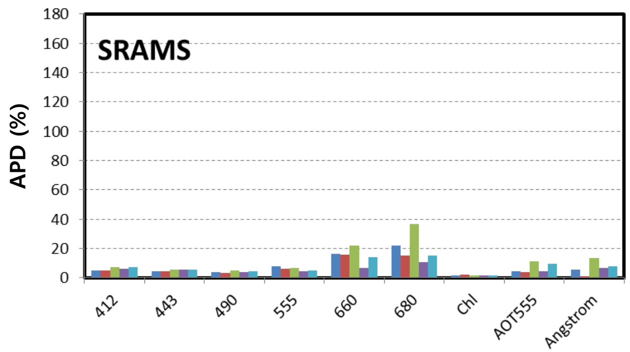
Validation SRAMS with simulation data

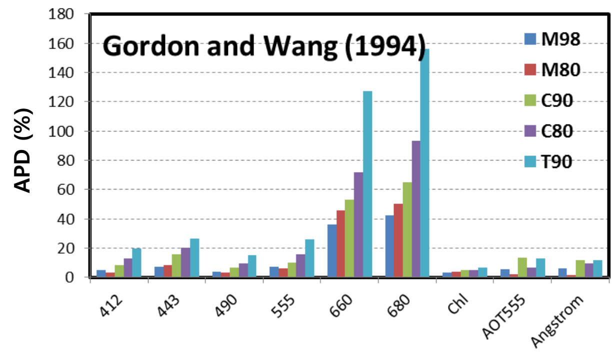
(1) Errors in aerosol reflectance retrieval





(2) Errors in R_{rs} retrieval





$$\text{APD (\%)} = \frac{100}{K}\sum_{n=1}^{K}\left(\frac{\left|Rrs_n^{\text{True}} - Rrs_n^{\text{Estimate}}\right|}{Rrs_n^{\text{True}}}\right)$$

Coarse mod.

Fine mod.

[M98] Maritime mod. with relative humidity 98%
[M80] Maritime mod. with relative humidity 80%
[C90] Coastal mod. with relative humidity 90%
[C80] Coastal mod. with relative humidity 80%
[T90] Tropospheric mod. with relative humidity 90%

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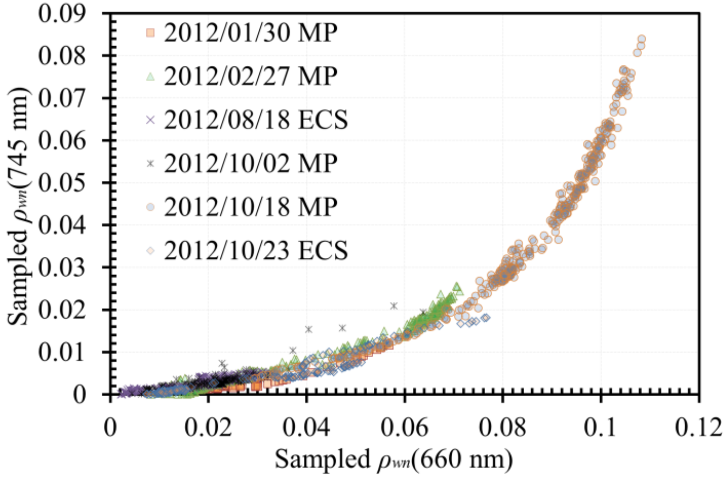
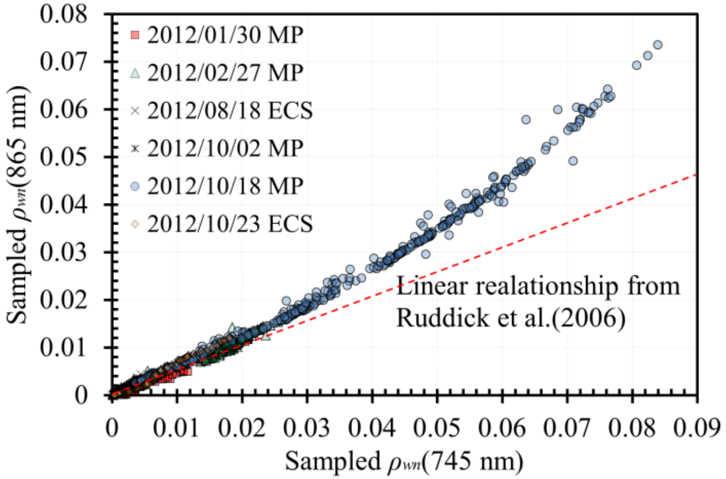
Iterative scheme for turbid water NIR reflectance correction

- Iteratively restores ρ_w(NIR) from a ρ_{wn}(660nm) and ρ_{wn}(NIR) relationship model





$$\rho_{wn}(745nm) = \sum_{i=0}^{5} a_n \rho_{wn}(660nm)^i$$

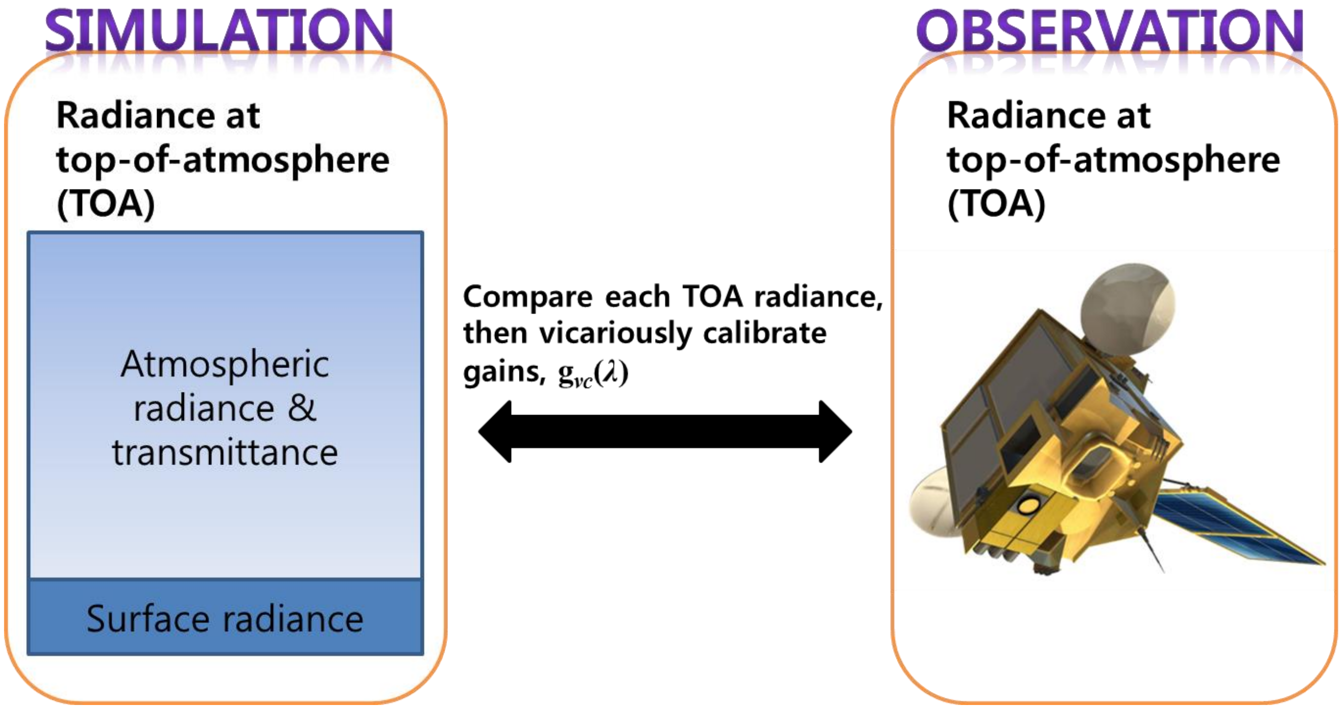
where $a_0, a_1, a_2, a_3, a_4, a_5$: -1.009046E-03, 5.158649E-01, -2.181632E+01, 5.509967E+02, -5.899103E+03, 2.726468E+04

$$\rho_{wn}(865nm) = \sum_{n=1}^{2} k_n \rho_{wn}(745nm)^n$$

where k_1, k_2 : 0.5012, 4.0878

Vicarious adjustment of GOCI calibration gain

Vicarious calibration concept for GOCI



Vicarious calibration for GOCI is based on Franz et al. (2007)

Step 1. 2nd last NIR band (745 nm) calibration

- Assuming that the last NIR band (865 nm) is already calibrated

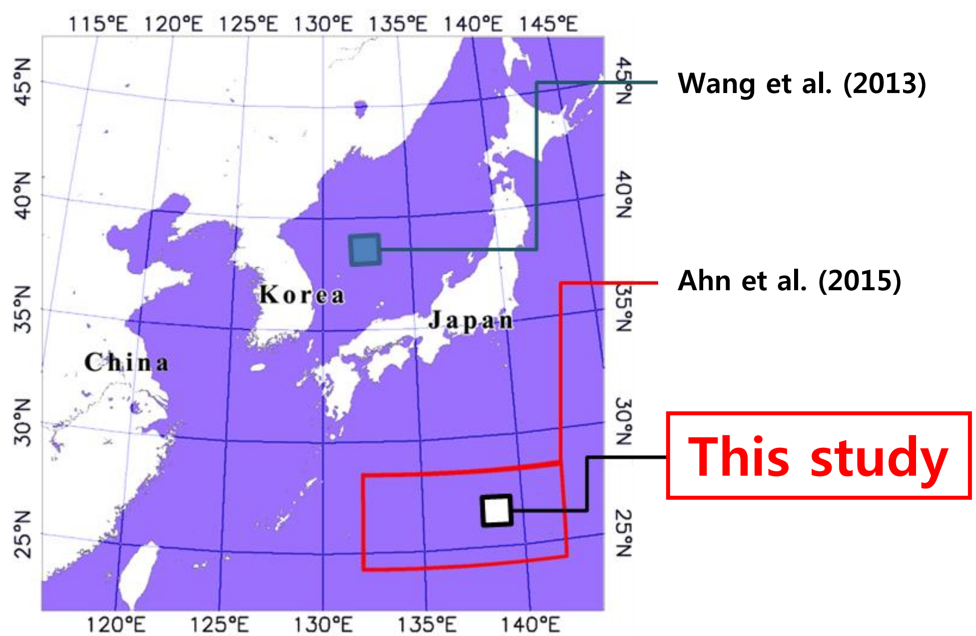
Step 2. VIS bands calibration

- Atmospheric radiance and transmittance can be accurately computed with inter-calibrated two NIR bands

GOCI vicarious calibration

- ## Changes in the GOCI VC scheme

  - Adoption of a different NIR calibration site such that the aerosol model in the site that can be **consistently presumed as Maritime relative humidity (RH) 80%** model
  - **80%** of relative humidity for the presumed maritime model is determined by **meteorological data**



NIR band calibration

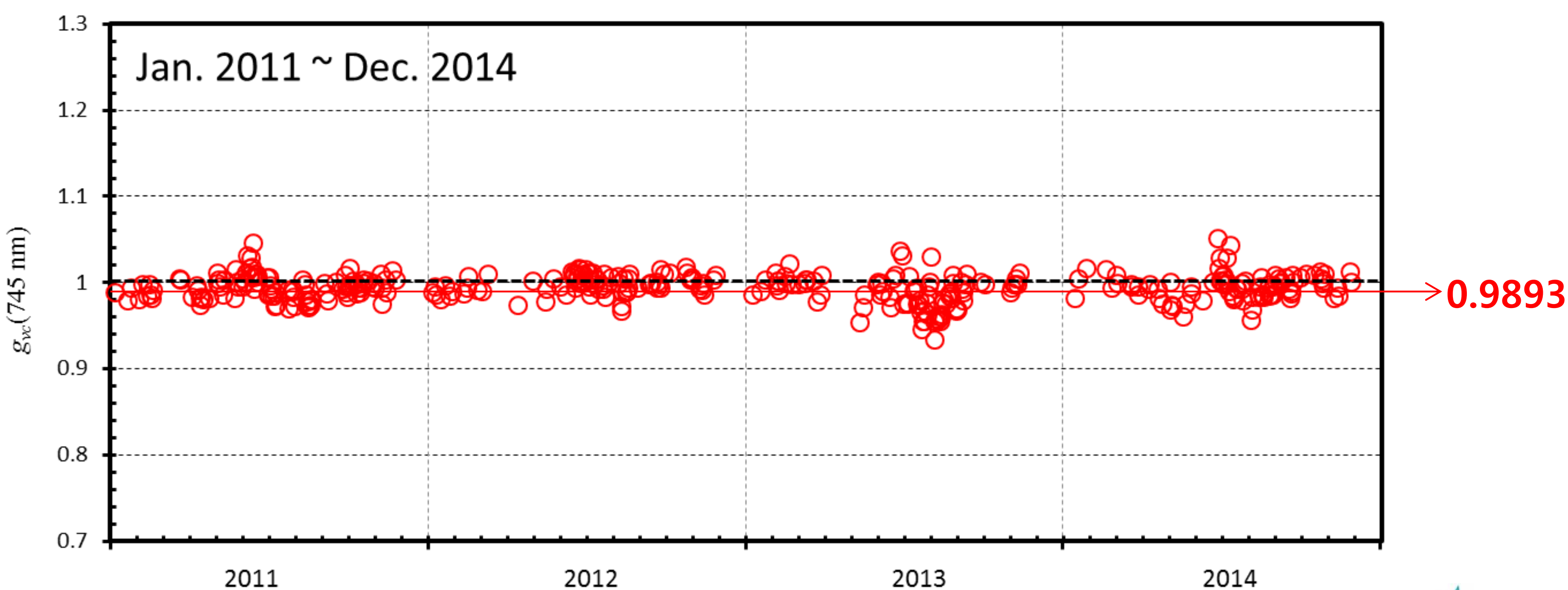
- **2nd last NIR band (745 nm) calibration**
  - Assuming that the last NIR band (865 nm) is already calibrated

$$L_{TOA}^{VC}(745\,\mathrm{nm}) = \boxed{L_r(745\,\mathrm{nm})} + \boxed{L_a(745\,\mathrm{nm}) + L_{ra}(745\,\mathrm{nm})} + \boxed{t_d^v L_w(745\,\mathrm{nm})}$$

negligible

Estimated by radiative transfer simulation

directly derived from L_a(865 nm) + L_{ra}(865 nm) by using SRAMS



NIR band calibration

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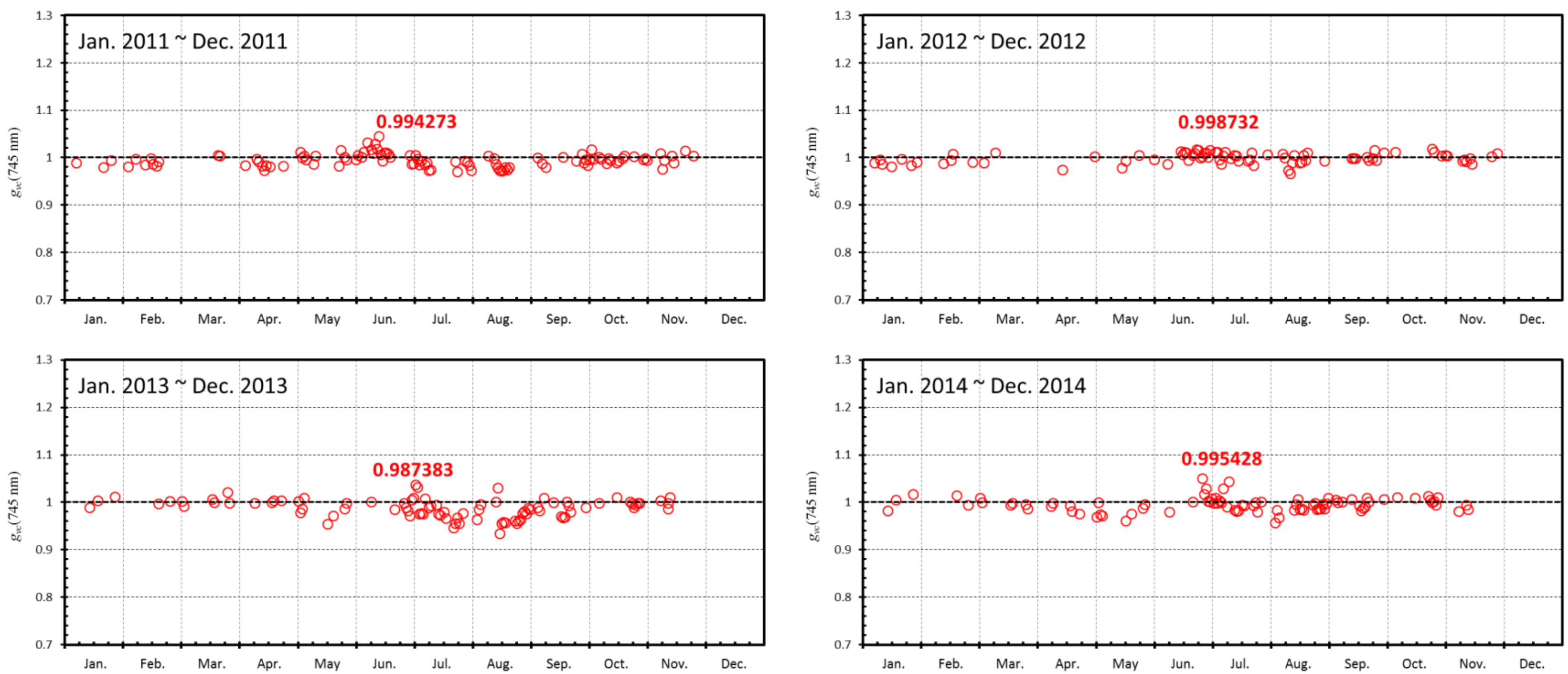
Estimated by radiative transfer simulation

directly derived from L_a(865 nm) + L_{ra}(865 nm) by using SRAMS



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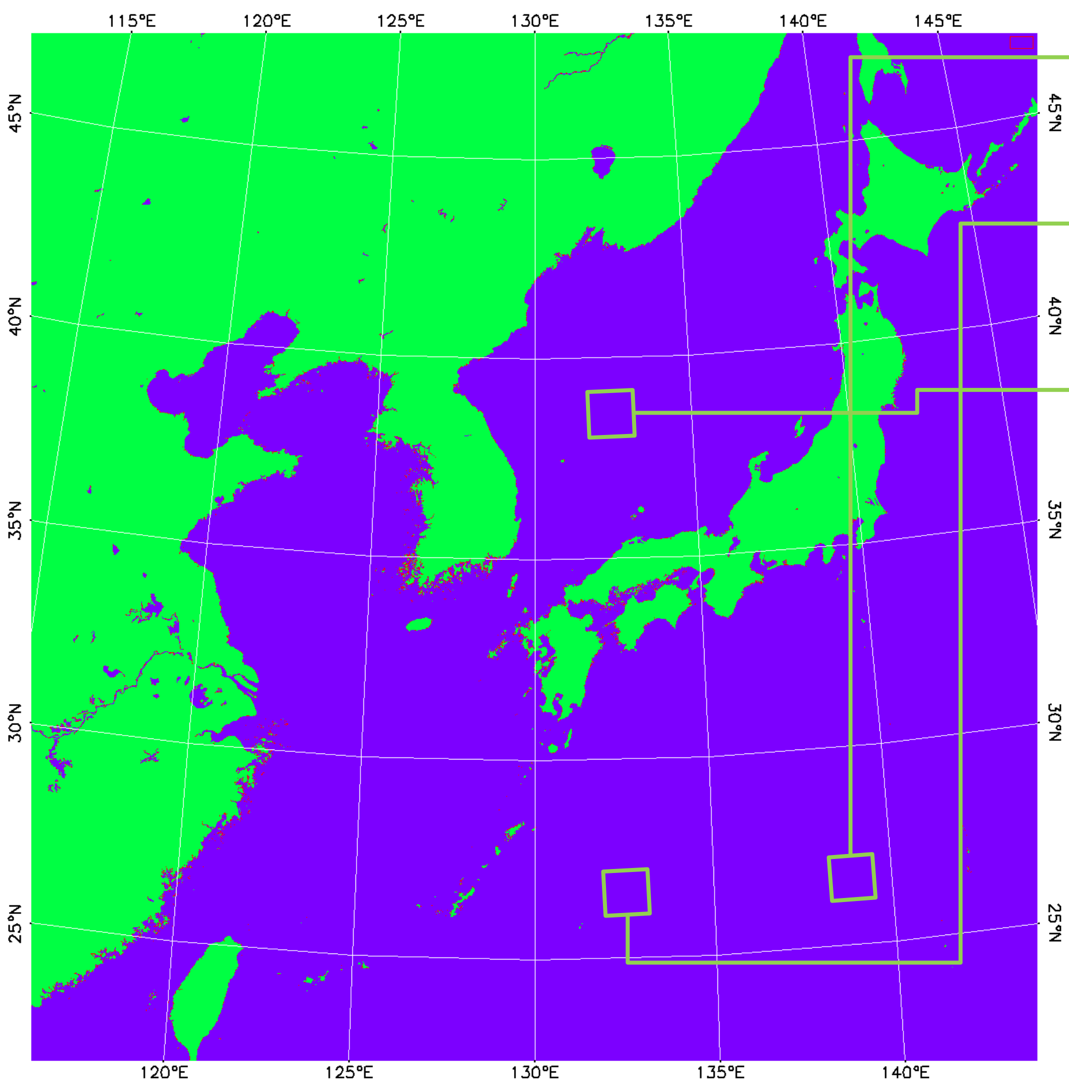
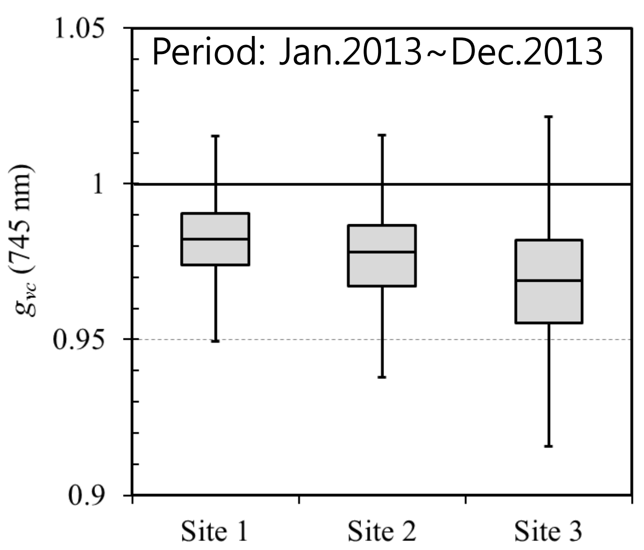
Effect of NIR calibration site to the NIR gain



NIR calibration **site 1**
(Recently Applied to GOCI)

NIR calibration **site 2**
(test site)

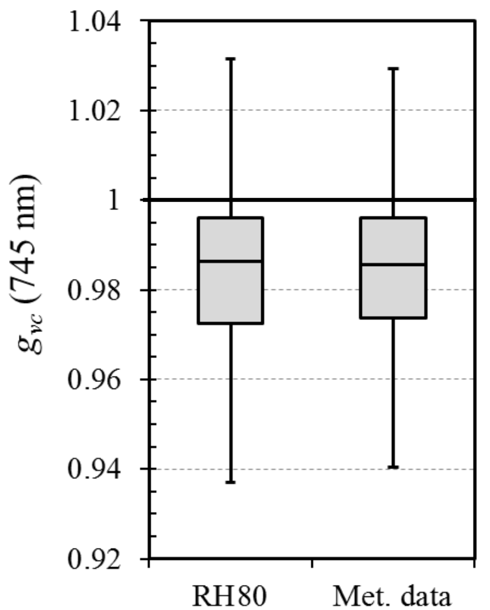
NIR calibration **site 3**
(Wang et al., 2013)



Using meteorological humidity on the assumed aerosol model

NIR gains calibrated with assumed relative humidity (RH) vs. meteorological RH data

Period: Jan.2011~Dec.2012

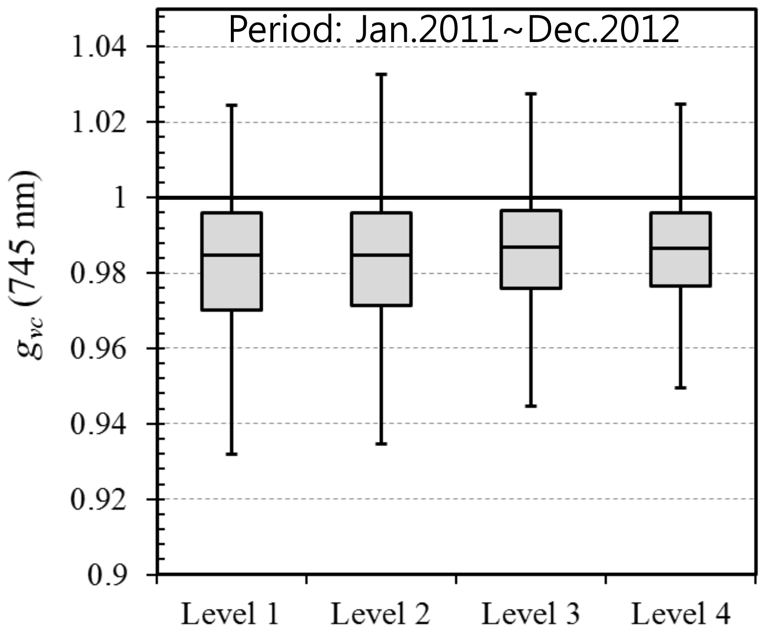


- Maritime aerosol with RH 80%
- Maritime aerosol with meteorological RH data

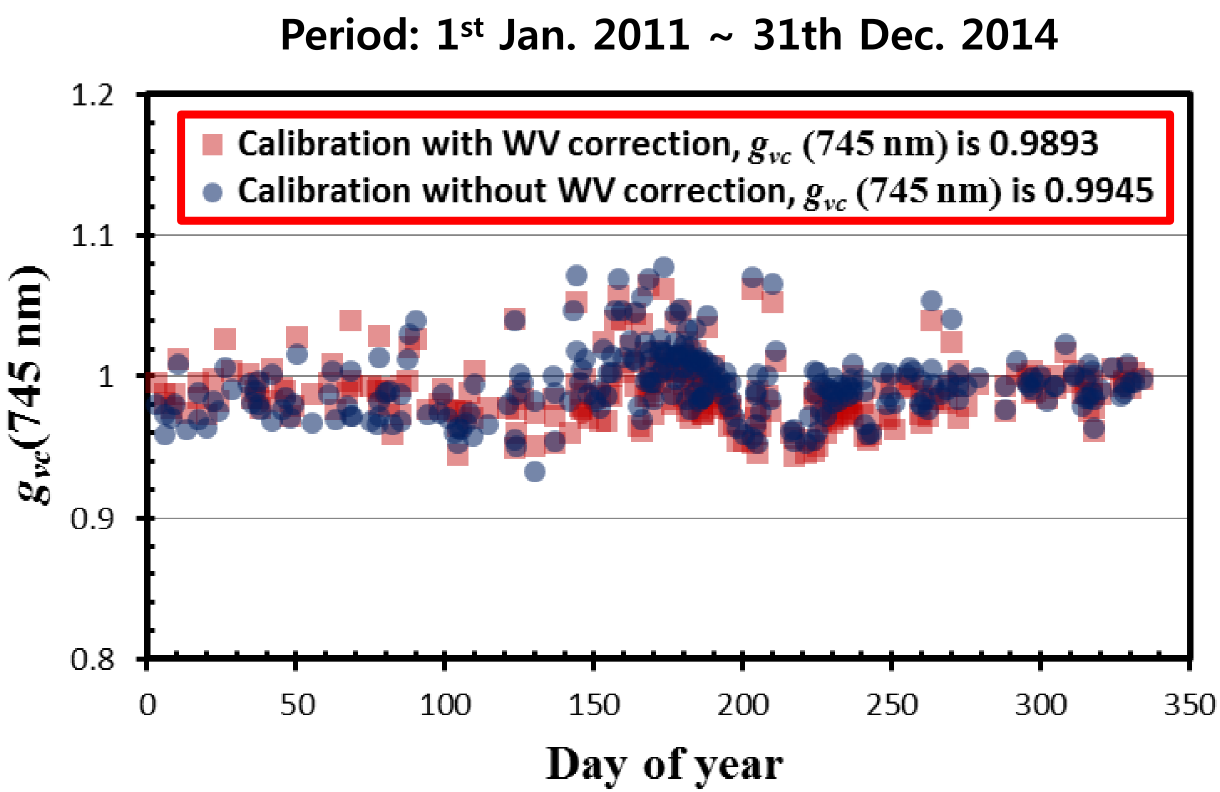
Effect of masking criteria to the NIR calibration gain

Thresholds for data exclusion
(calibration period: 2011~2015)

- Masking level 1 (Num. of available data : 246)
  - Max. wind speed (m/s) : 16.5
  - ρ_{am}(865 nm) for cloud masking: 0.028
- Masking level 2 (Num. of available data : 239)
  - Max. wind speed (m/s) : 10.0
  - ρ_{am}(865 nm) for cloud masking: 0.025
- Masking level 3 (Num. of available data : 189)
  - Max. wind speed (m/s) : 6.0
  - ρ_{am}(865 nm) for cloud masking: 0.020
- Masking level 4 (Num. of available data : 146)
  - Max. wind speed (m/s) : 4.9
  - ρ_{am}(865 nm) for cloud masking: 0.015



Effect of water vapor (WV) correction to the NIR gain



g_{vc} (λ): vicarious gain at λ

VIS bands calibration

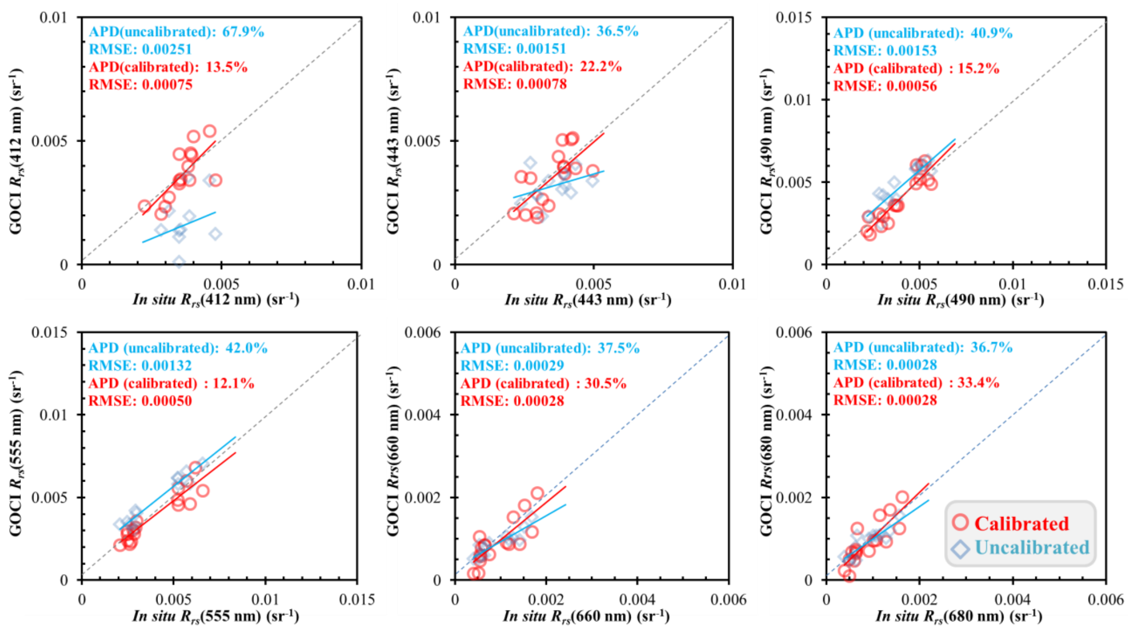
- **VIS bands calibration**
  - Assuming that atmospheric radiance and transmittance can be accurately derived from inter-calibrated two NIR bands

$$L_{TOA}^{VC}(\mathrm{VIS}) = \boxed{L_r(\mathrm{VIS})} + \boxed{L_a(\mathrm{VIS}) + L_{ra}(\mathrm{VIS}) + t_d^v}\boxed{L_w(\mathrm{VIS})}$$

Applying bidirectional effect model to *in situ* nL_w

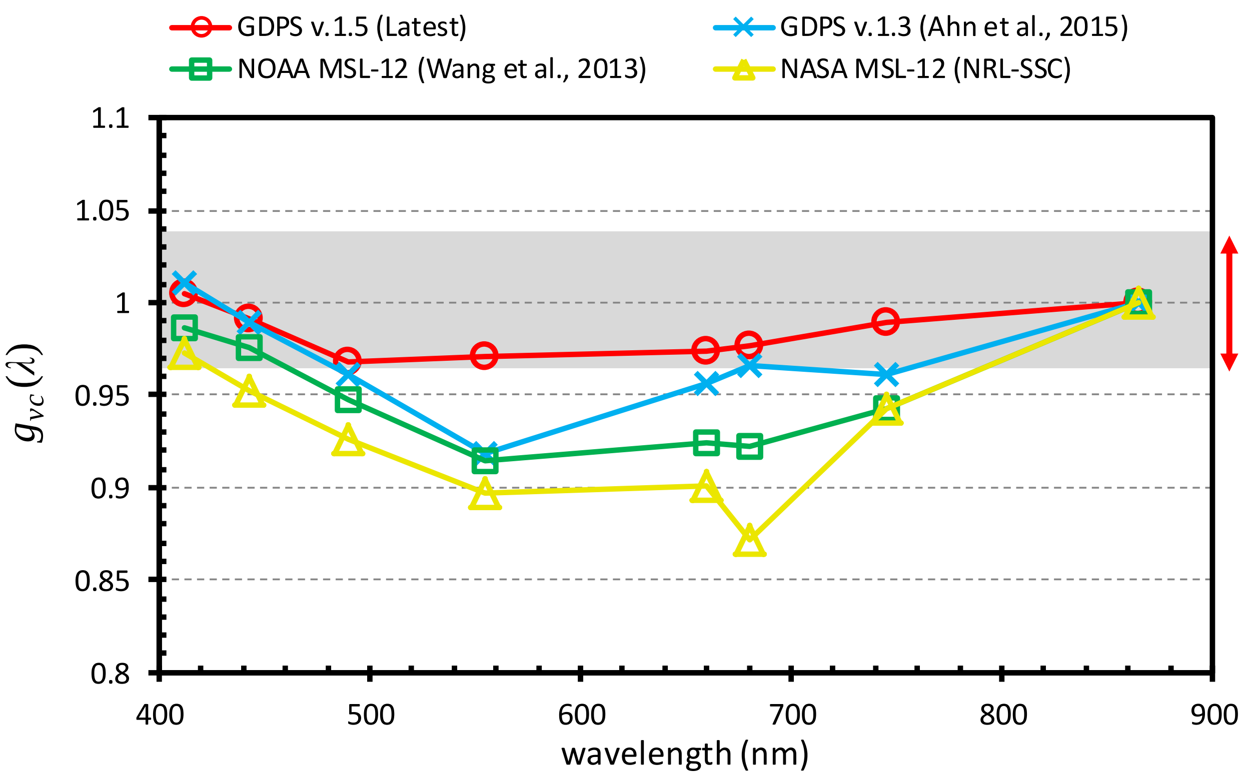
Estimated by radiative transfer simulation

derived by inter-calibrated L_a(NIR) + L_{ra}(NIR)



Verification of the vicarious calibration gain factors. Red circles and blue squares represent the GOCI and *in situ* R_{rs} match-up pairs derived with- and without vicarious calibration, respectively.

Derived vicarious gains

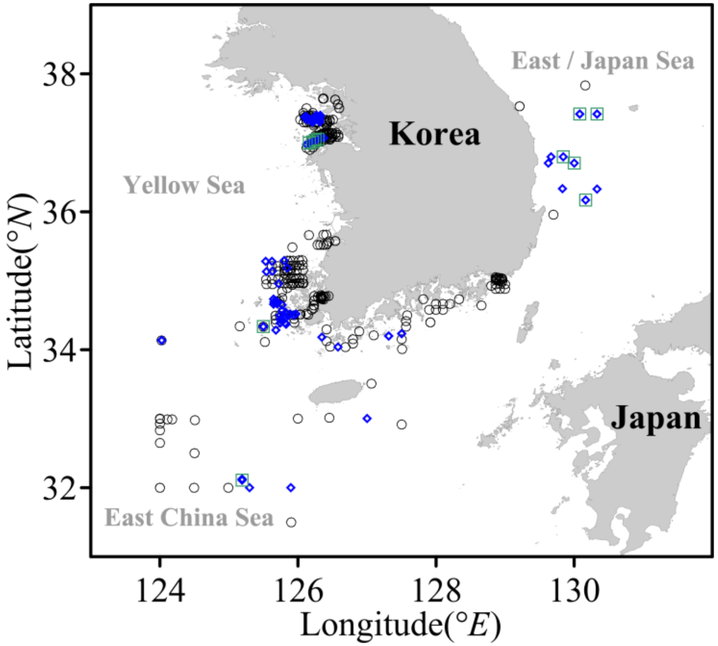


Instrument calibration uncertainty : ±3.8%

	412	443	490	555	660	680	745	865
This study	**1.00531**	**0.99113**	**0.96805**	**0.97044**	**0.97391**	**0.97698**	**0.9893**	**1**
GOCI A.C. v.1.3 (Ahn et al., 2015)	1.0105	0.9891	0.9611	0.9186	0.9567	0.9659	0.9613	1.0
NOAA MSL-12 (Wang et al., 2013)	0.9862	0.9753	0.9473	0.9149	0.9245	0.9223	0.943	1.0
NASA MSL-12 (NRL-SSC)	0.9726	0.9520	0.9258	0.8974	0.9007	0.8719	0.943	1.0

Validations

Validation with *in situ* data

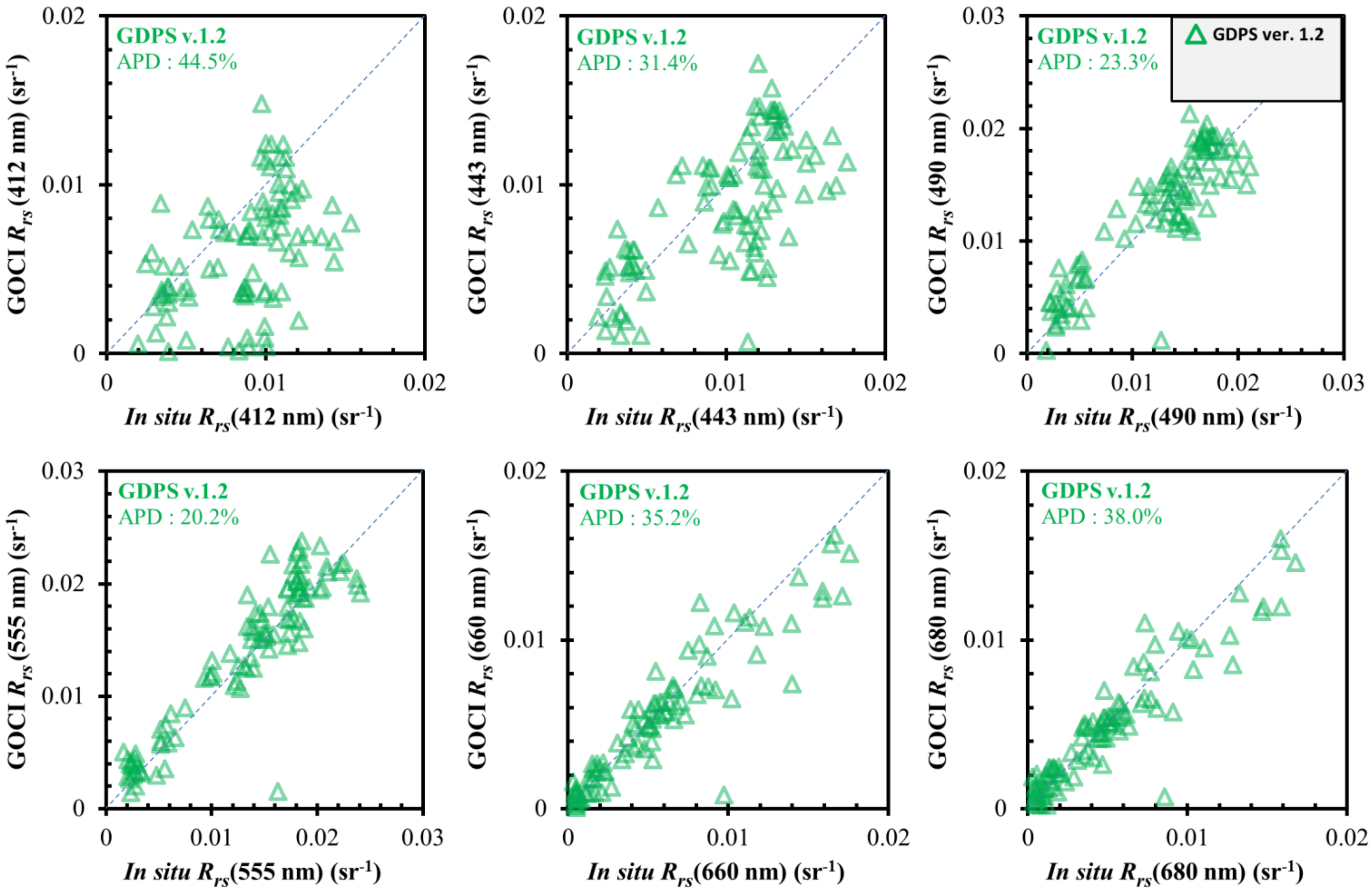


65 sets of *in situ* R_{rs} collected from the Korea Ocean Satellite Center (KOSC) cruise campaigns since 2010

67 sets of *in situ* R_{rs} collected from the AERONET-OC observation installed at the Ieodo and the Gageocho Station since 2011 Oct.

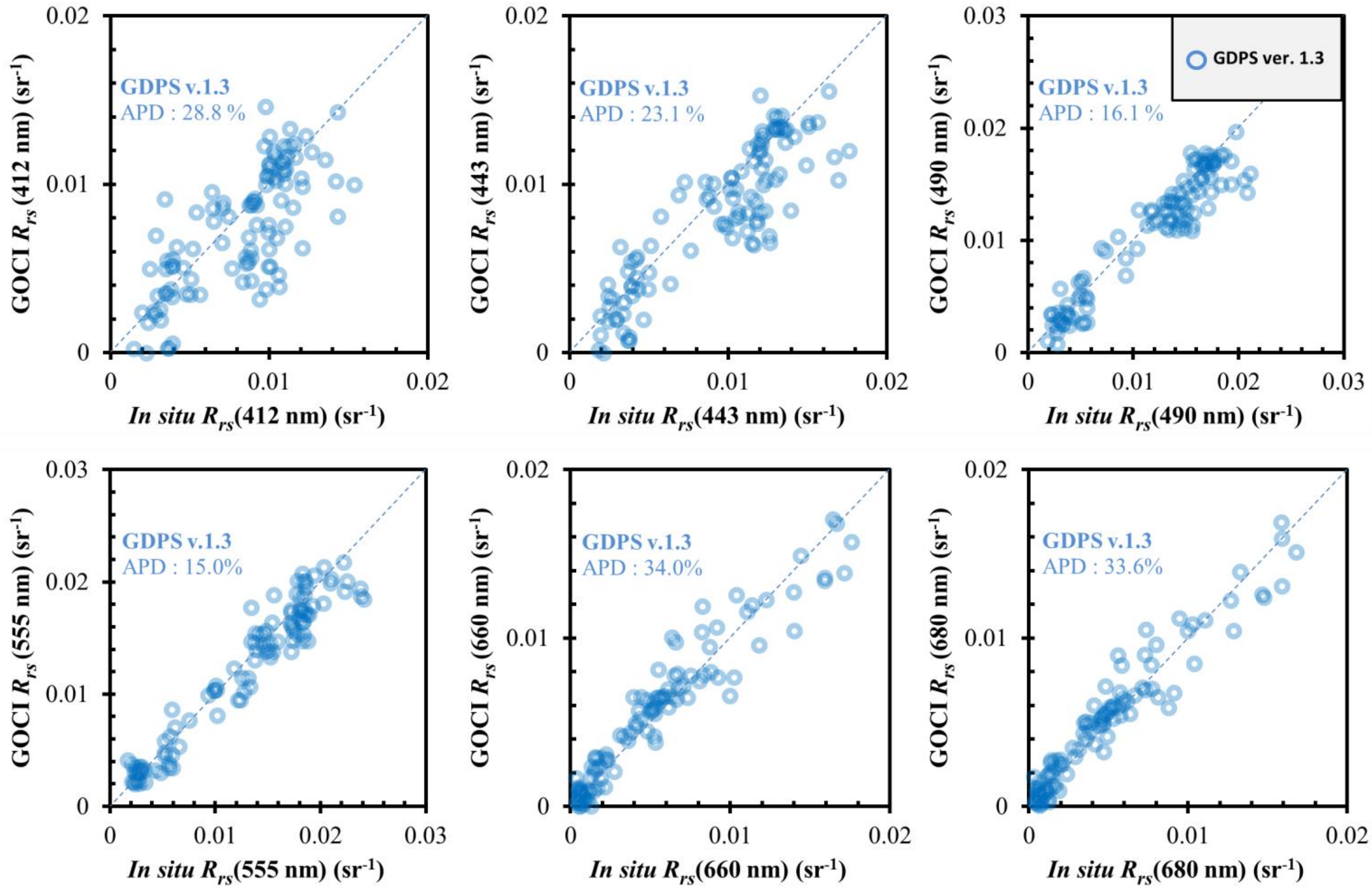
Validation with *in situ* data

In situ Match-up result of the atmospheric correction ver. 1.1 & 1.2 (Ahn et al., 2012)



Validation with *in situ* data

In situ Match-up result of the atmospheric correction ver. 1.3
→ Vicarious calibration & BRDF corr. are applied (Ahn et al., 2015)

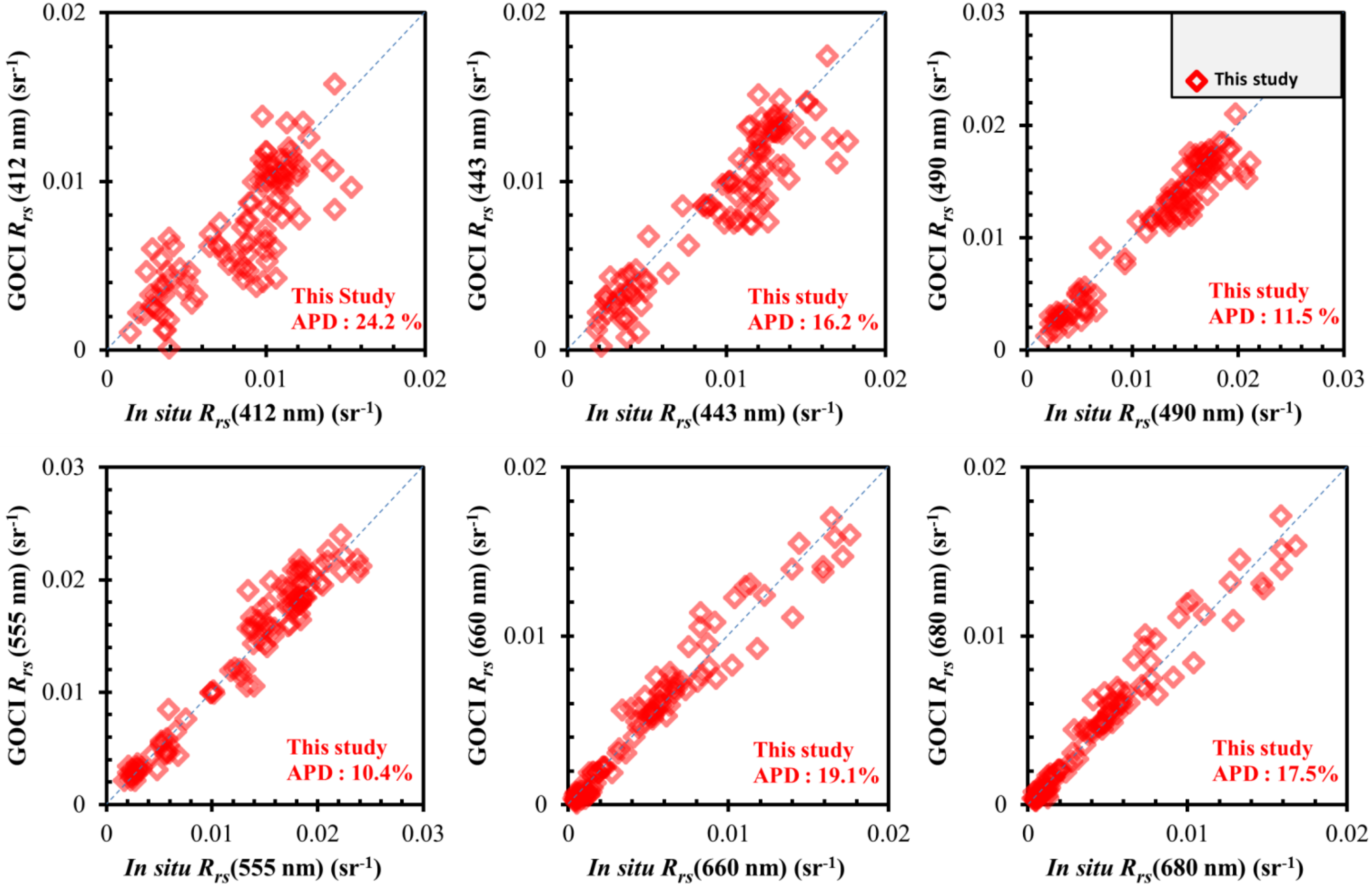


Validation with *in situ* data

In situ Match-up result of the atmospheric correction ver. 1.5

→ SRAMS scheme with extended num. of aerosol models (Ahn et al., 2016)

→ correction of water vapor absorption for 660, 745, and 865 nm bands



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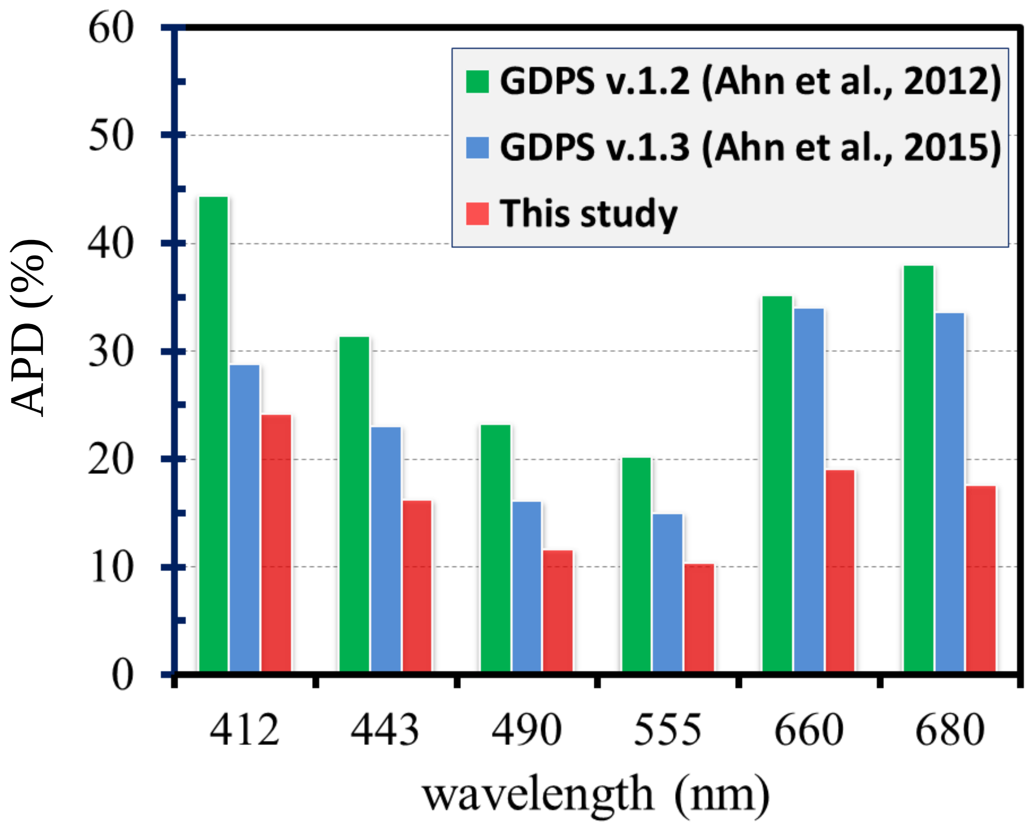
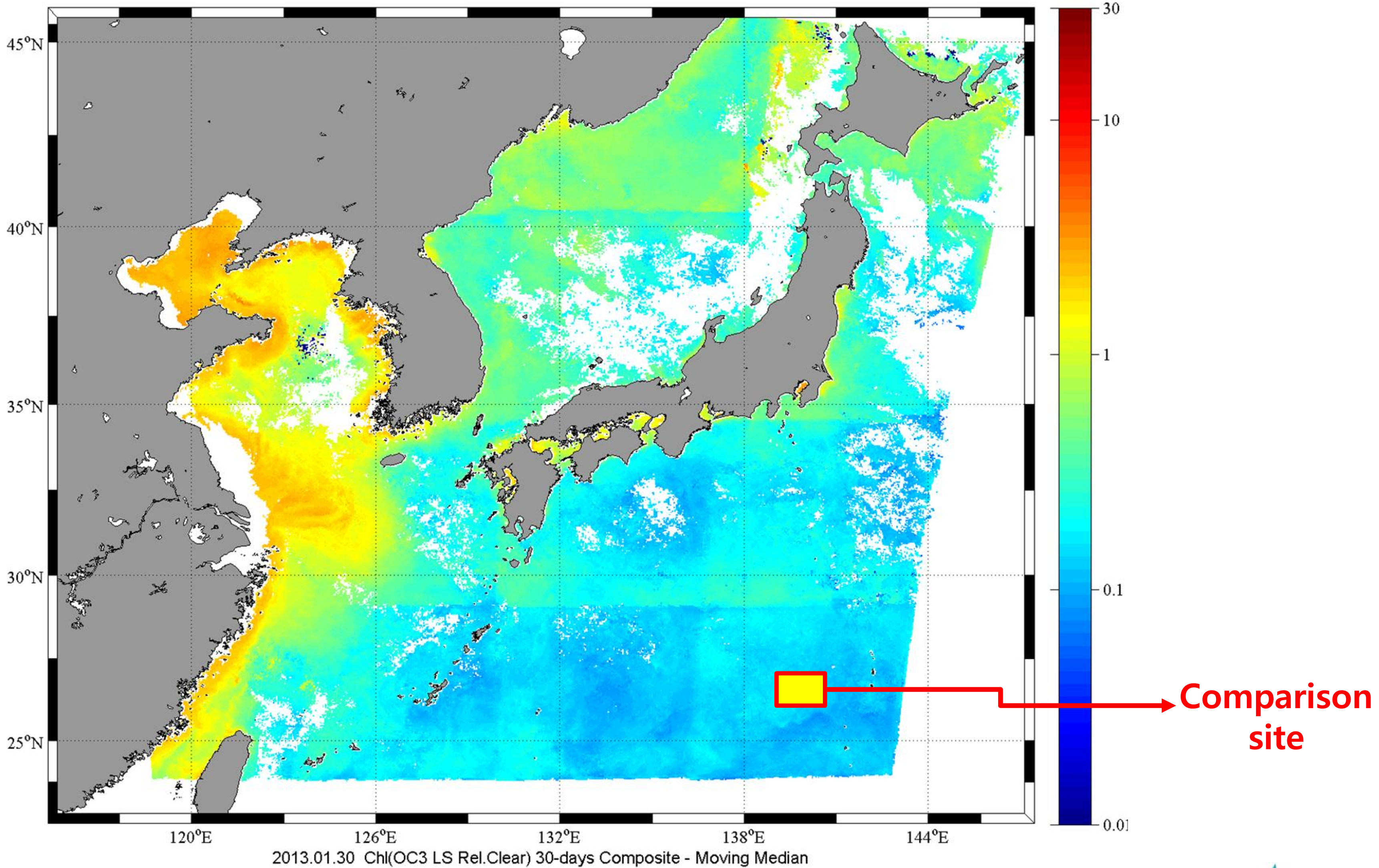
Validation with *in situ* data

Summary of AC improvements through the GDPS updates

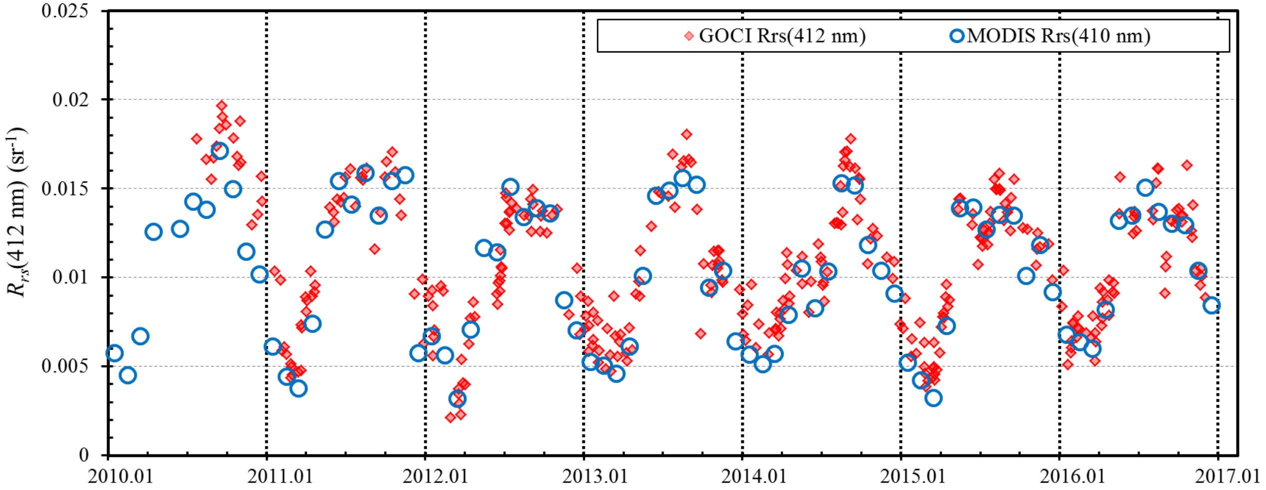


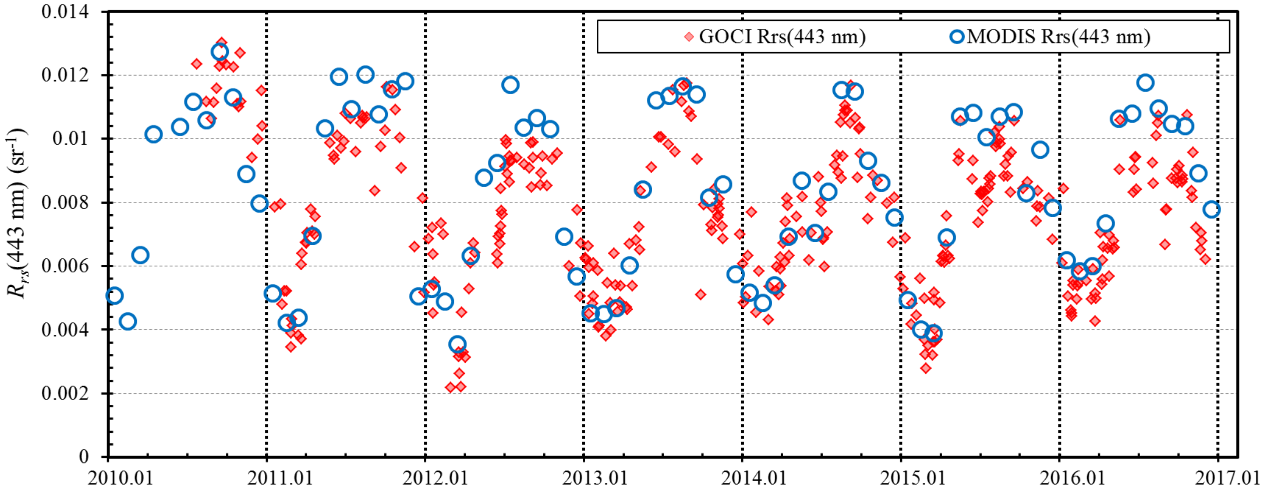
R_{rs} time series comparison (GOCI vs. MODIS-Aqua vs. VIIRS)



R_{rs} time series comparison at 412, 443nm

Time series: GOCI (red) vs **MODIS-Aqua (blue)**





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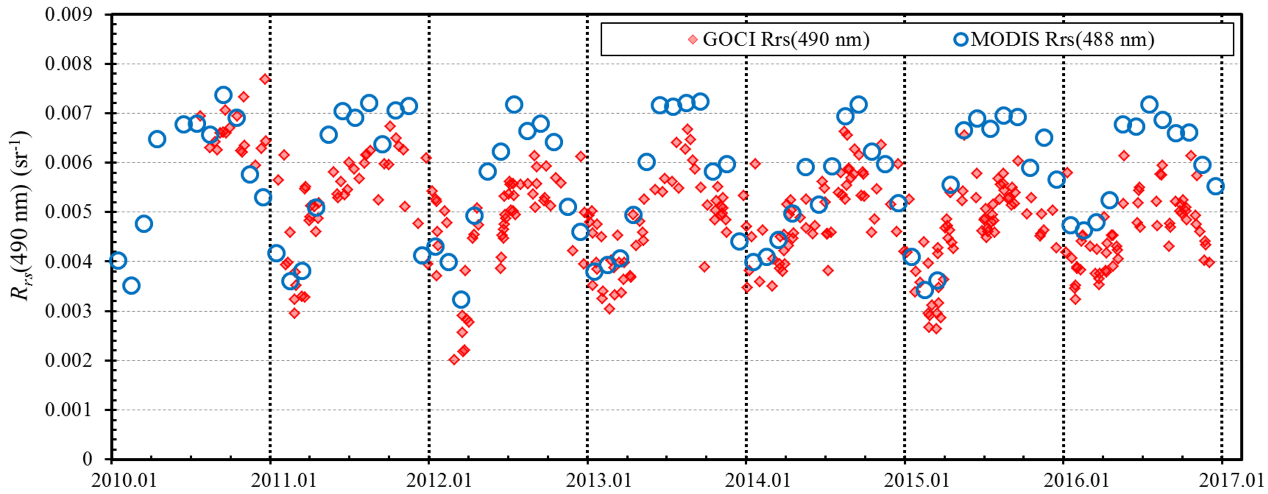
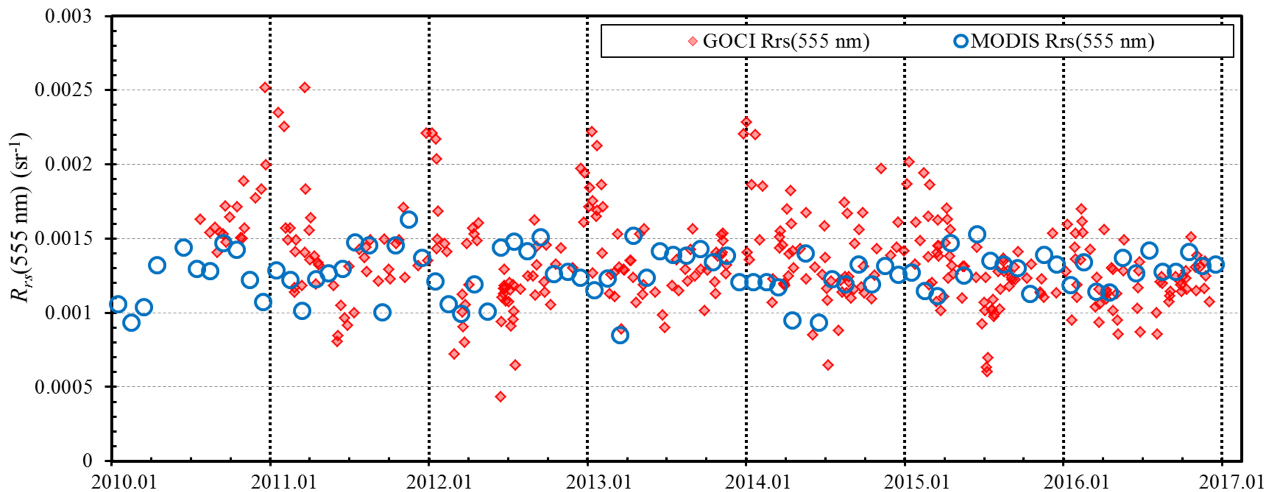
R_{rs} time series comparison at 490, 555nm

Time series: GOCI (red) vs MODIS-Aqua (blue)





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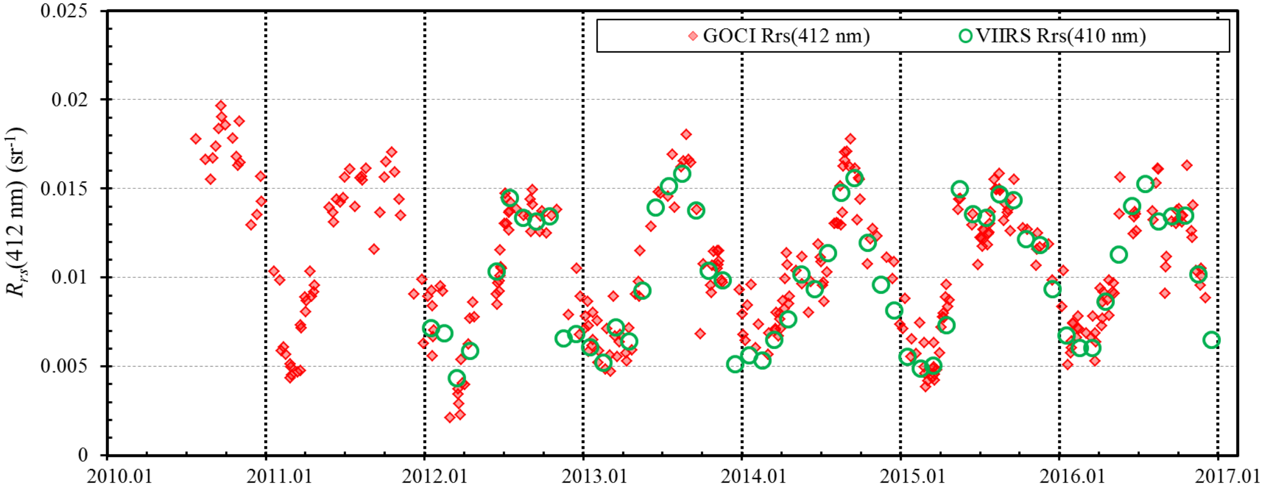
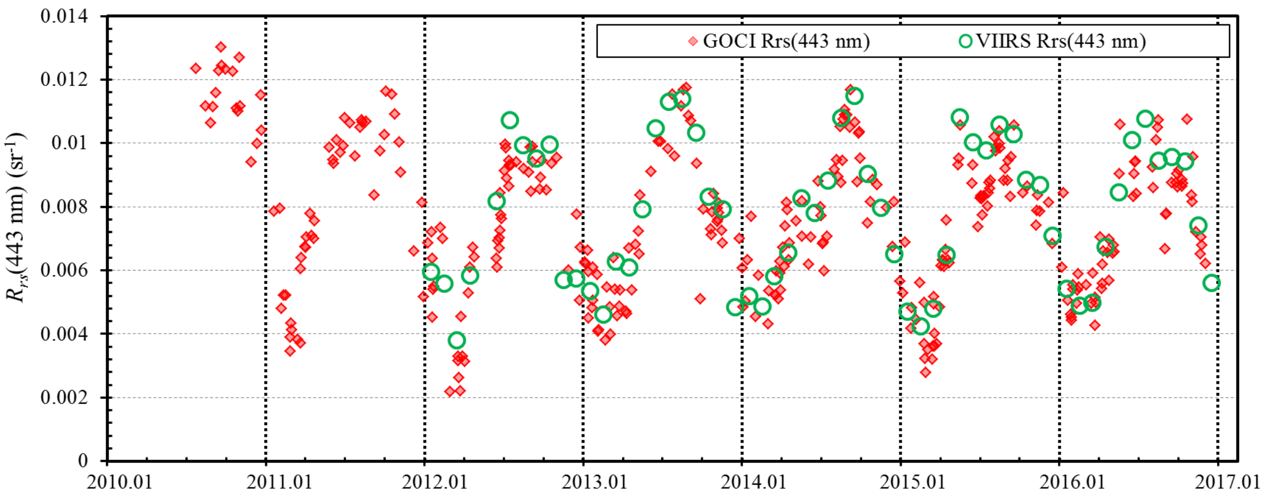
R_{rs} time series comparison at 412 and 443nm

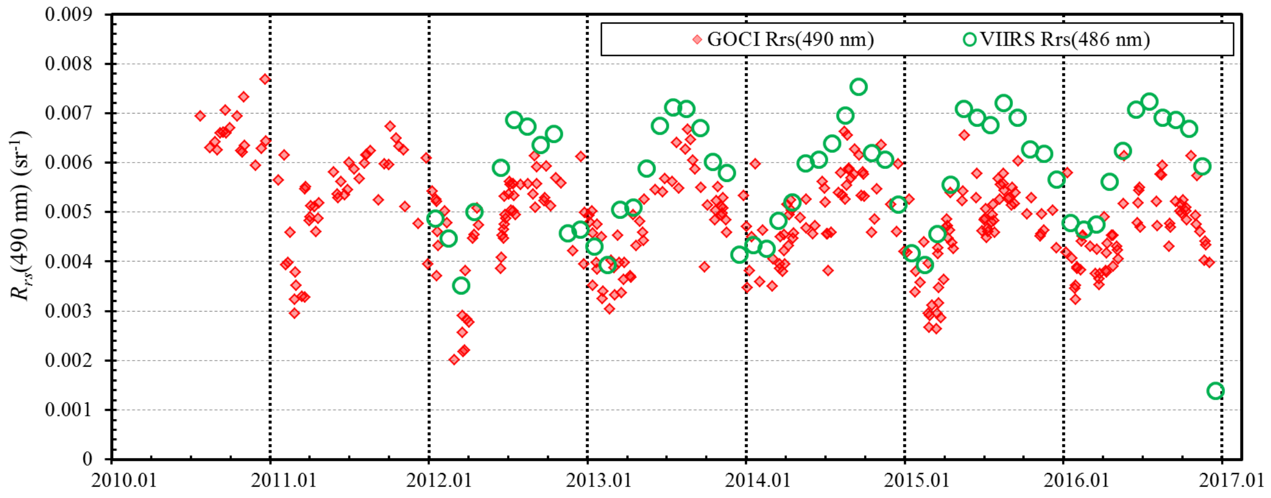
Time series: GOCI (red) vs VIIRS (green)

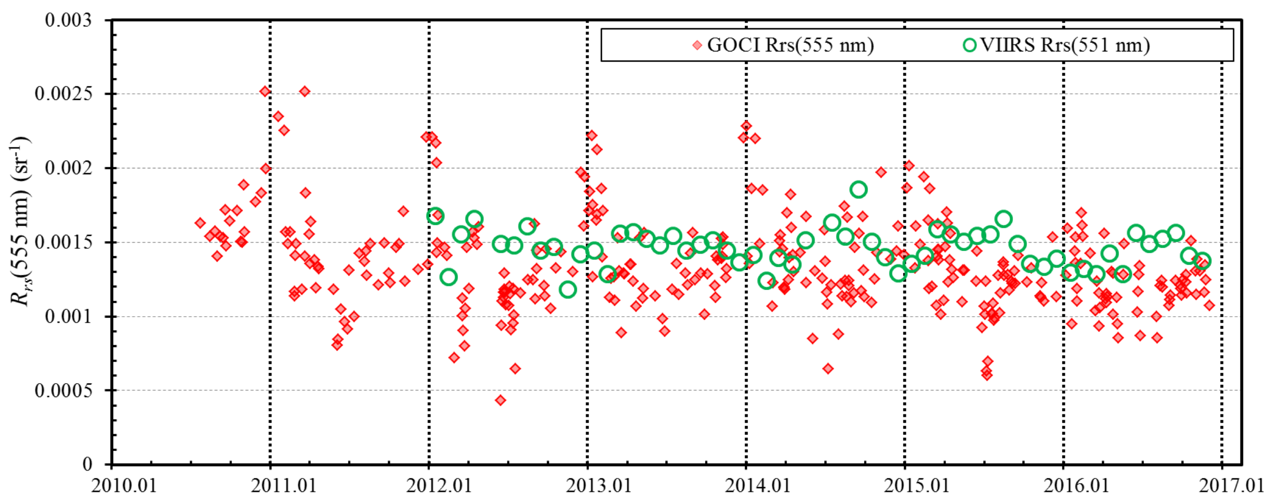




R_{rs} time series comparison at 490 and 555nm

Time series: GOCI (red) vs VIIRS (green)





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Summary and plans

Summary

- GOCI atmospheric correction
  - Theoretically based on the SeaWiFS method which is using two NIR bands to estimate aerosol optical properties (Gordon and Wang, 1994)
    - A different aerosol multiple-scattering reflectance estimation scheme has been implemented
      - Using **s**pectral **r**elationship of **a**erosol **m**ultiple-**s**cattering reflectance between different wavelengths (SRAMS) (Ahn et al., 2016)
    - A different turbid water NIR correction scheme has been implemented
      - Using spectral relationship of water reflectance between red and two NIR bands (Ahn et al., 2015)

- GOCI vicarious calibration
  - Theoretically based on the Franz et al. (2007)
    - Assumptions
      - The last NIR band is already calibrated
      - Aerosol characteristics in the NIR calibration site can be presumed
      - Atmospheric radiance and transmittance can be accurately computed after the NIR band calibration
    - NIR calibration
      - Presumed aerosol model: Maritime RH 80% aerosol model
    - VIS calibration
      - *In situ* radiometric data in relatively clear waters

Long term calibration plan with *in situ* data

- **Vicarious calibration with *in situ* data**
  - Cruises in the relative clear waters
  - AERONET-OC
    - Gageocho station (33.94°N, 124.59°E): Oct. 2011 ~ May 2012
    - Ieodo station (32.12°N, 125.18°E): Nov. 2013 ~ present
    - Socheongcho station (37.42°N , 124.74°E): Oct. 2015 ~ present
  - East Sea Ocean Optical Buoy (ESOOB)
    - Site 1 (37.53°N, 129.22°E) : Apr. 2012 ~ Aug. 2012
    - Site 2 (37.85°N, 129.04°E) : May 2014 ~ Sep. 2016

- **Comparison of VC gains derived by**
  - *In situ* data
  - Cross-calibration with MODIS and VIIRS
  - Cross-calibration with OLCI

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Thank for your attention

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