System vicarious calibration for the Geostationary Ocean Color Imager (GOCI)

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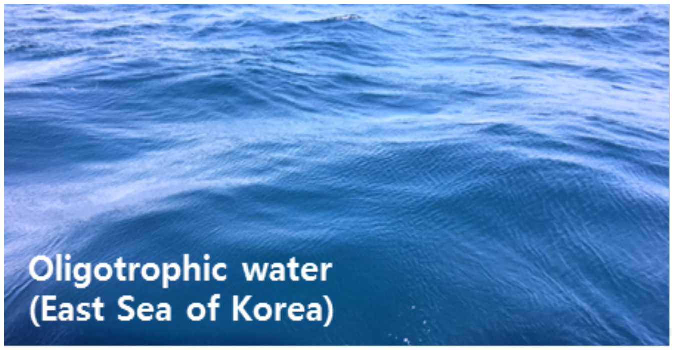
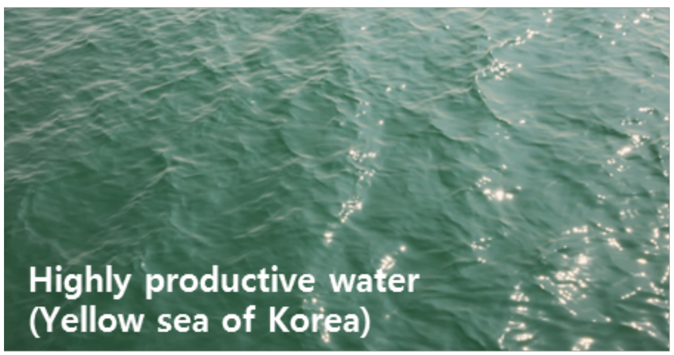
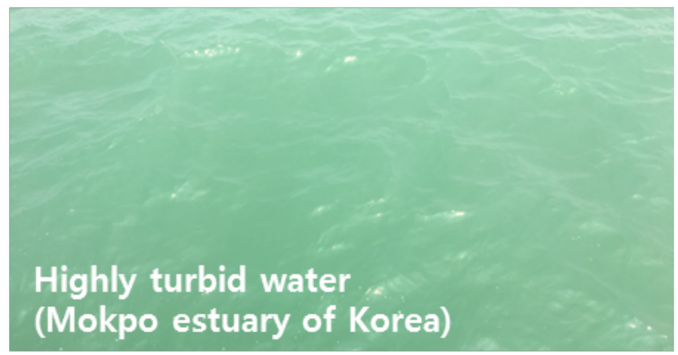
Ocean color remote sensing

- The reflectance spectra of ocean is determined sun light interacted by substances or particles in the sea water

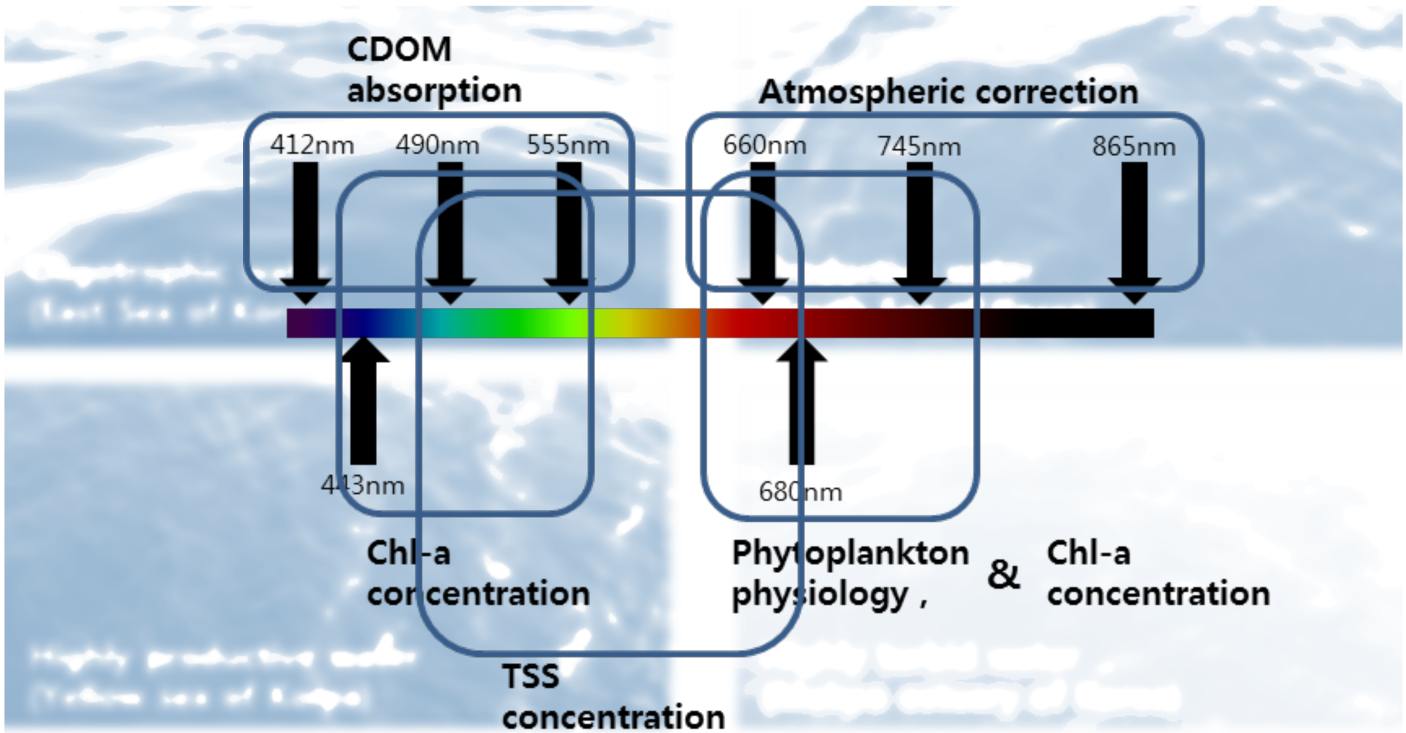




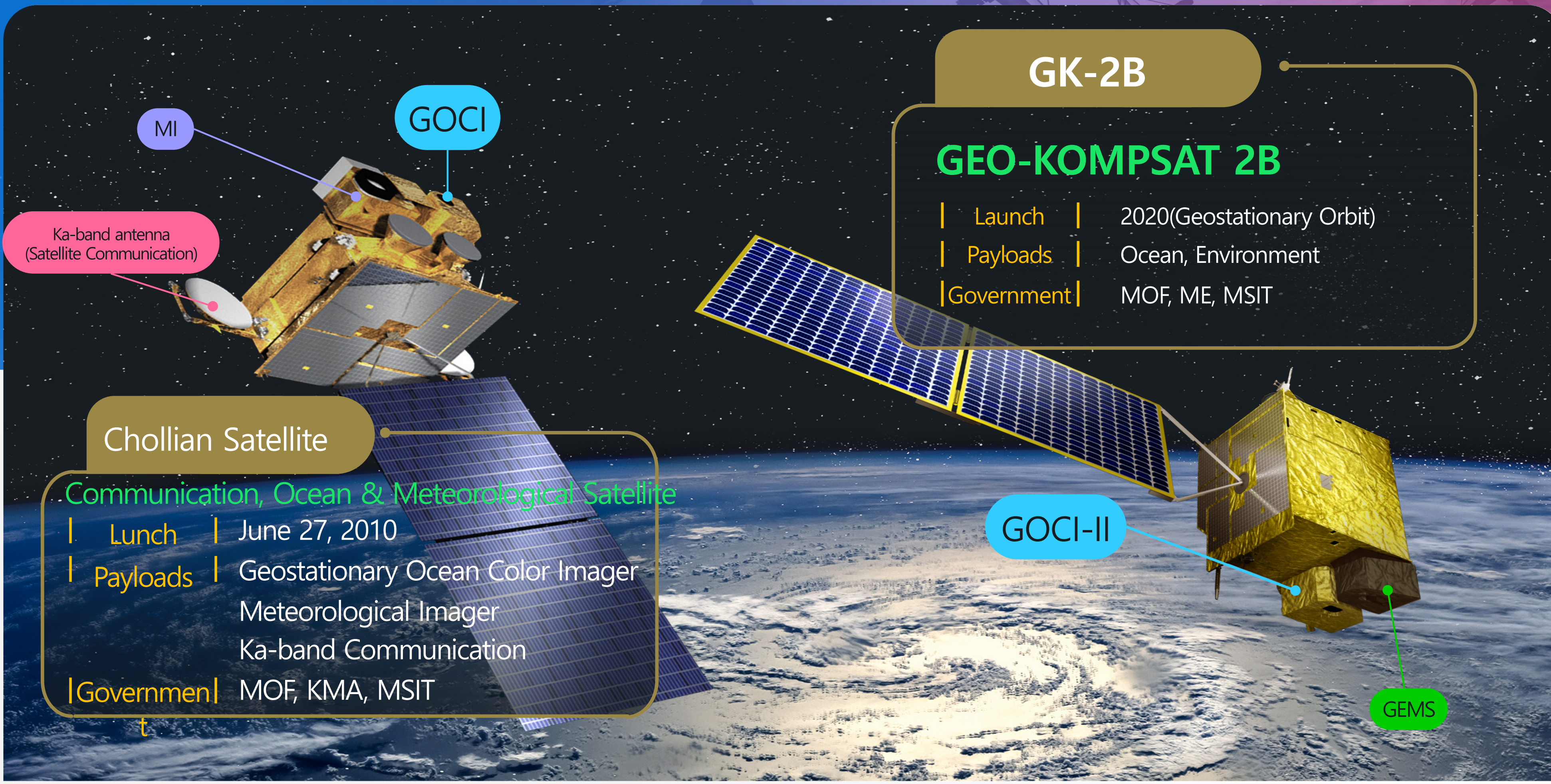


Ocean color remote sensing

- The reflectance spectra of ocean is determined sun light interacted by substances or particles in the sea water



Geostationary Ocean Color Imager Series (GOCI, GOCI-II)



세계가 주목하는 천리안 해양관측위성

해양수산부의 세계최초 정지궤도 해색위성

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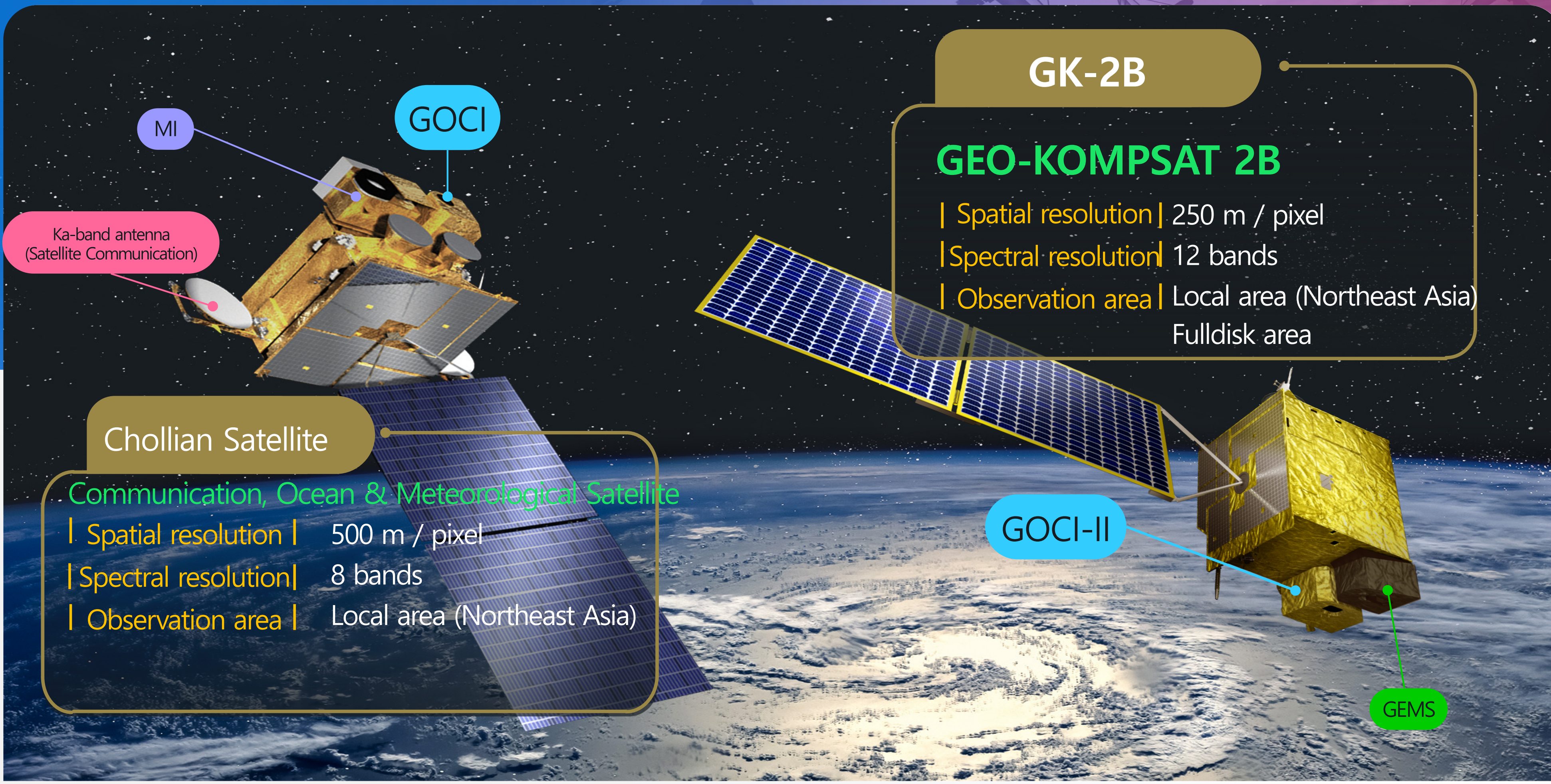
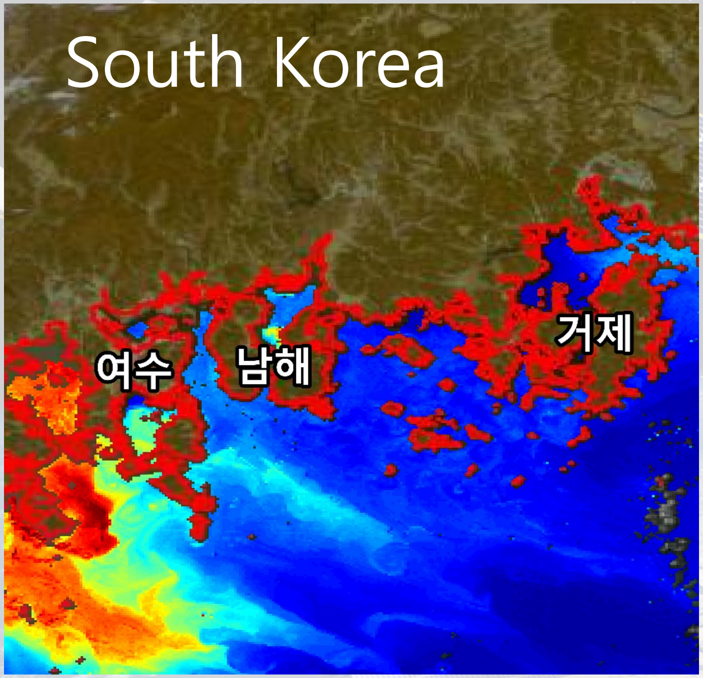
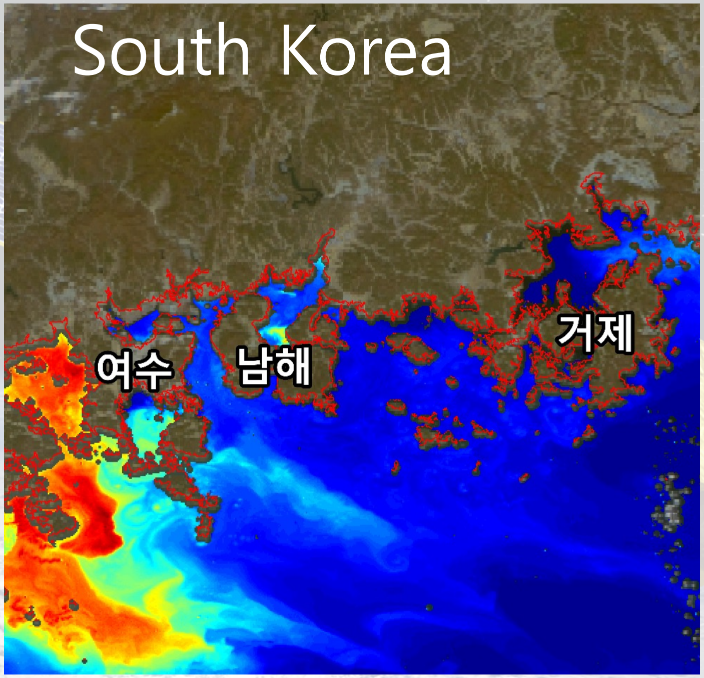


Geostationary Ocean Color Imager Series (GOCI, GOCI-II)

Spatial resolution comparison between GOCI and GOCI-II (2021/02/16 12:25)



GOCI (500 m / pixel)



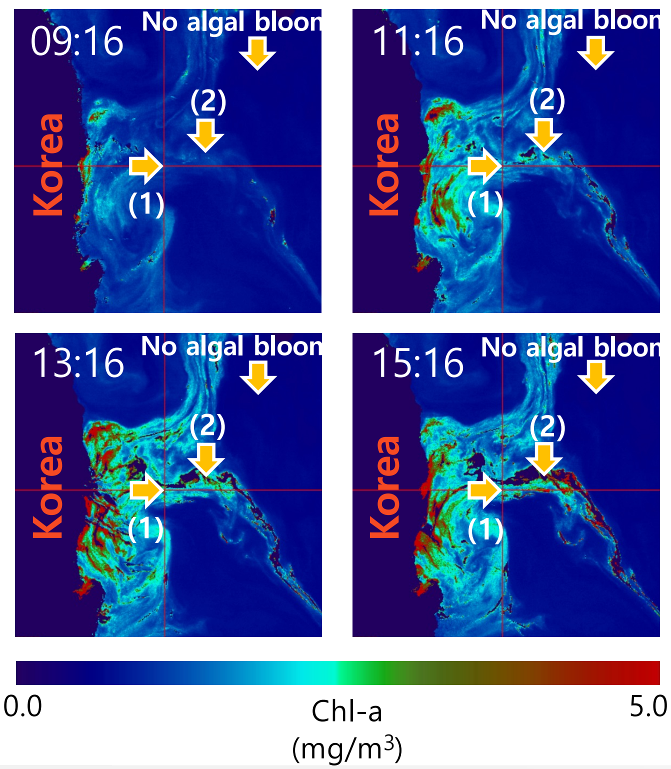
GOCI-II (250 m / pixel)

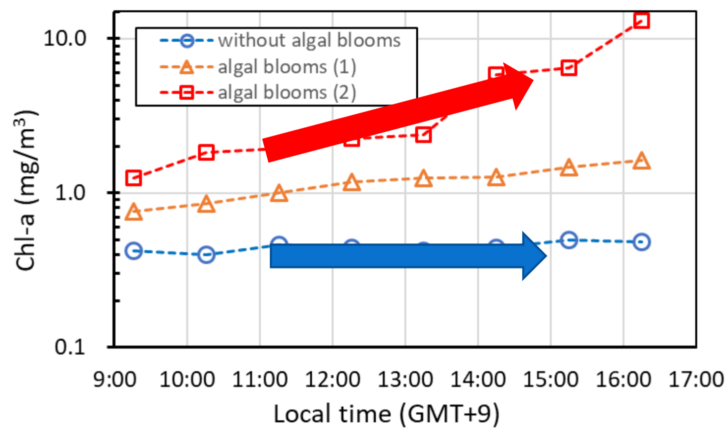
Geostationary Ocean Color Imager Series (GOCI, GOCI-II)

GOCI	GOCI-II	
	380	atmospheric correction for absorbing aerosols absorption of dissolved organic matter
412	412	
443	443	
490	490	
	510	chlorophyll absorption
555	555	
	620	suspended sediment for turbid waters
660	660	
680	680	
	709	atmospheric correction for turbid waters
745	745	
865	865	

Diurnal migration of harmful algal blooms (red tide)

13th/August/2013, GOCI diurnal Chl-a images

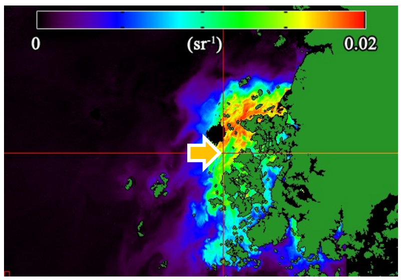




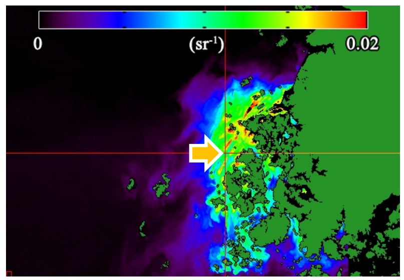
Ocean Color Remote Sensing from Geostationary Orbit

Diurnal variability turbidity (suspended sediment monitoring)

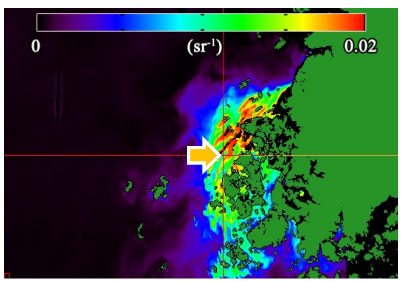
30th/May/2016, GOCI diurnal R_{rs}(660 nm) images



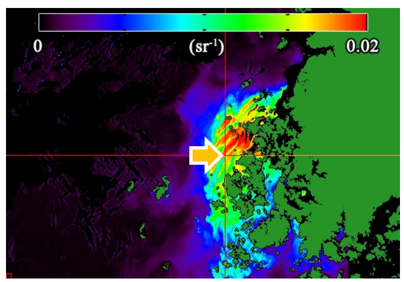
09:16 (local), R_{rs}(660 nm)



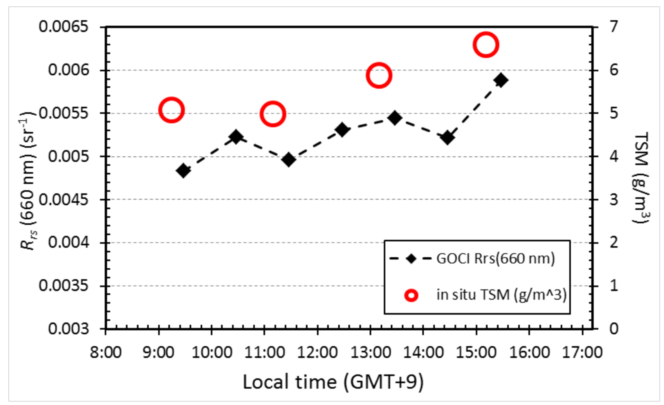
11:16 (local), R_{rs}(660 nm)



13:16 (local), R_{rs}(660 nm)



15:16 (local), R_{rs}(660 nm)



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해양수산부의 세계최초 정지궤도 해색위성

Atmospheric Correction for Ocean Color Remote Sensing

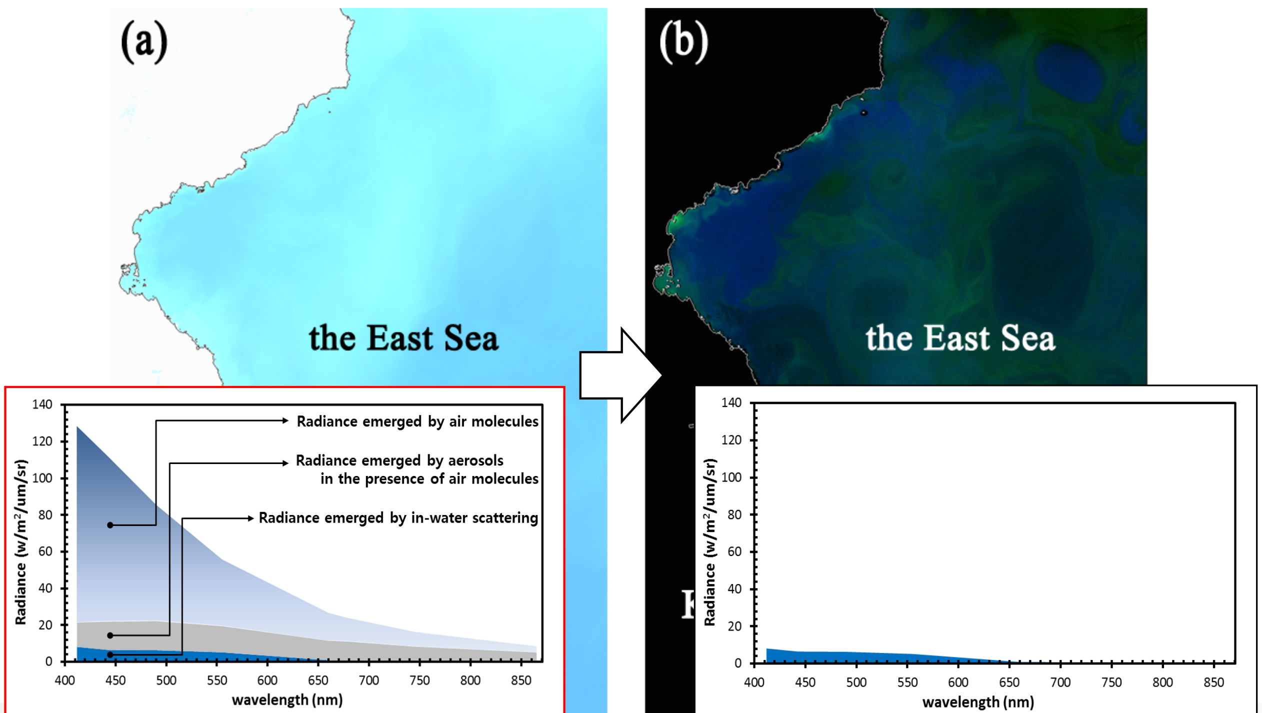
$$L_{\mathrm{TOA}}(\lambda) = L_r(\lambda) + L_{am}(\lambda) + t_d^v(\lambda)\, t_d^s(\lambda)\, L_{wn}(\lambda)$$

Radiance at the water surface (desired value)

Rayleigh scattering reflectance

Aerosol reflectance

diffuse transmittance



Gaseous absorption & whitecap correction

↓

Correction of Rayleigh reflectance

↓

Correction of aerosol reflectance

↓

Correction of bidirectional effect

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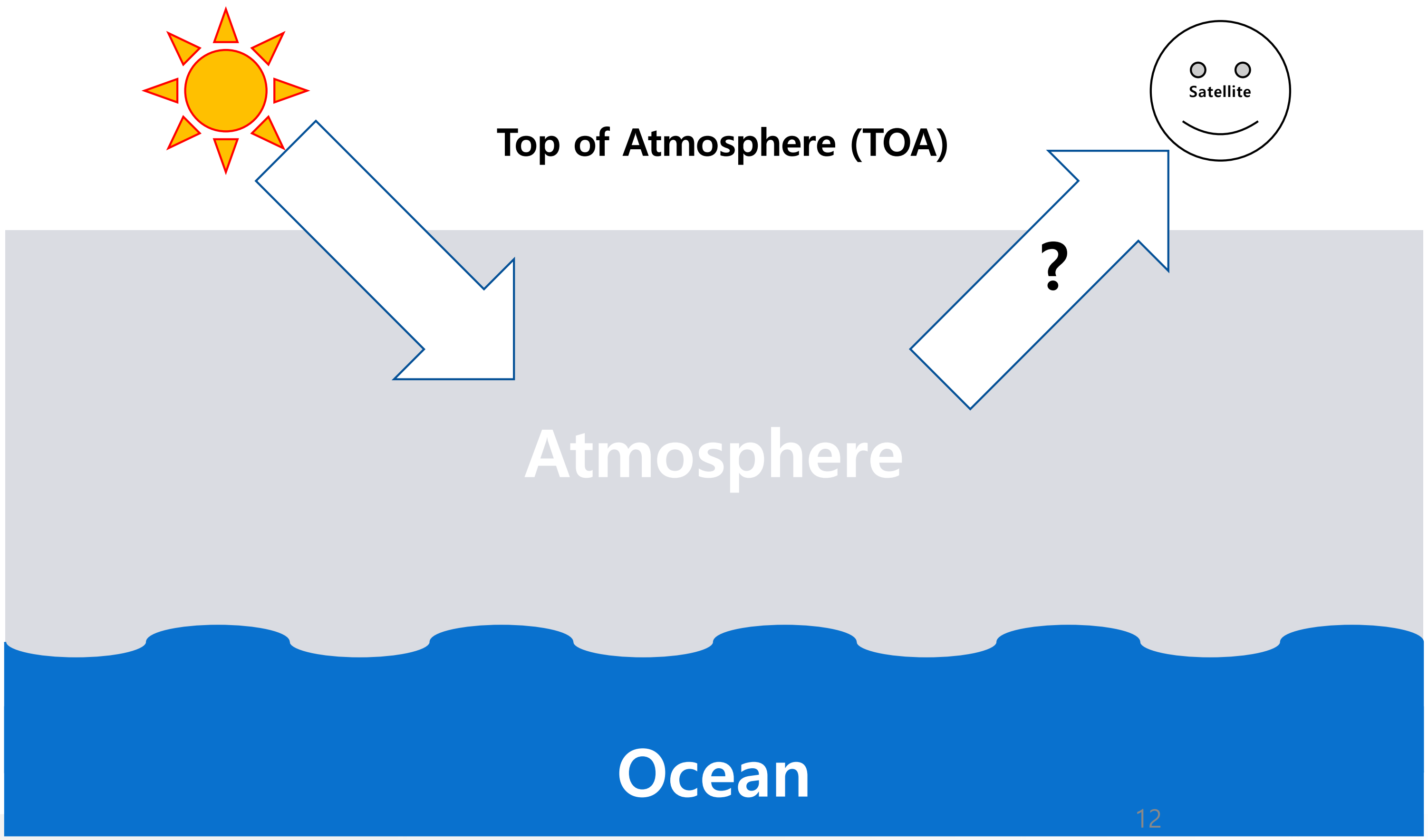
Composition of TOA radiance

$$L_{TOA}(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T_d^v(\lambda) \times L_w(\lambda)$$



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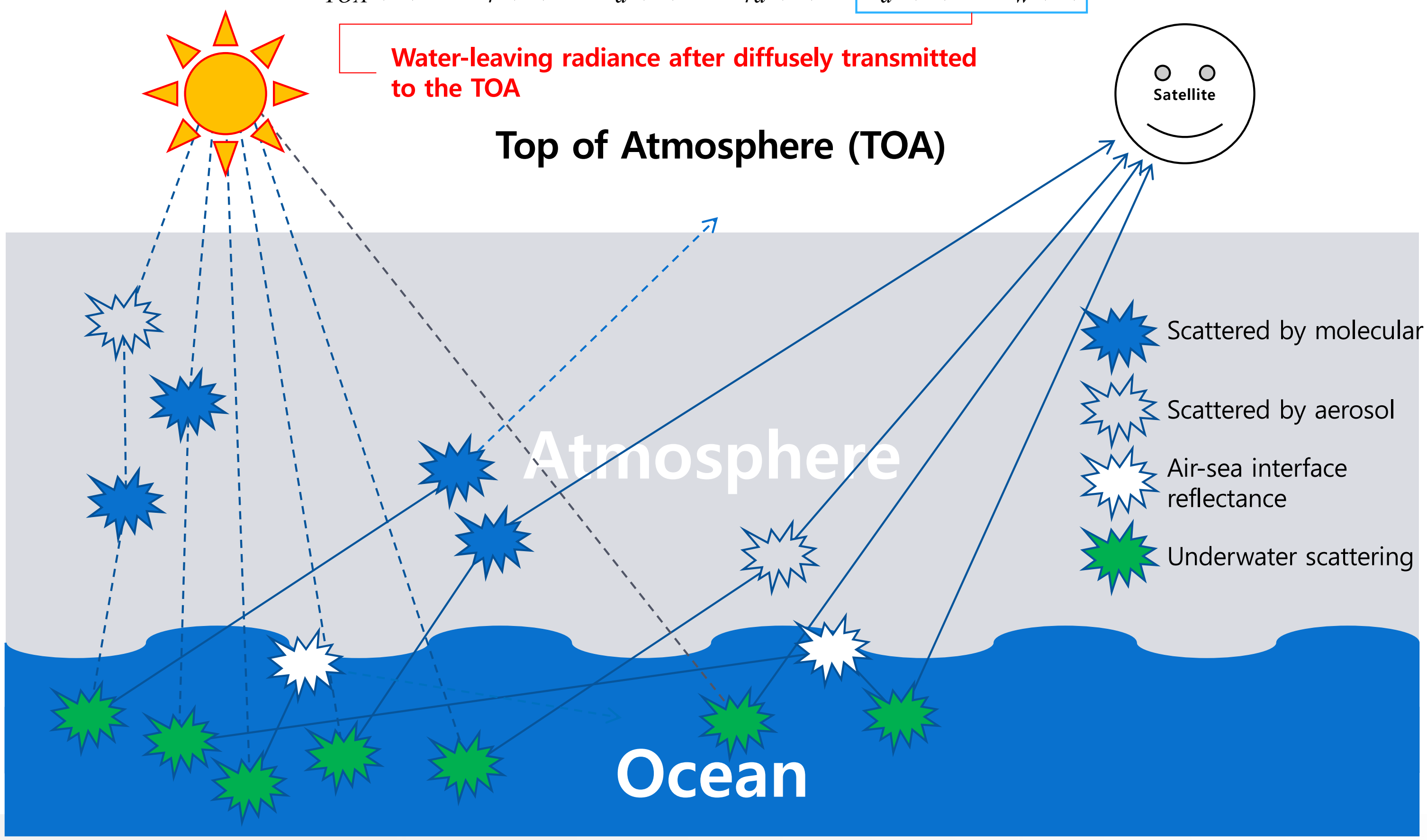

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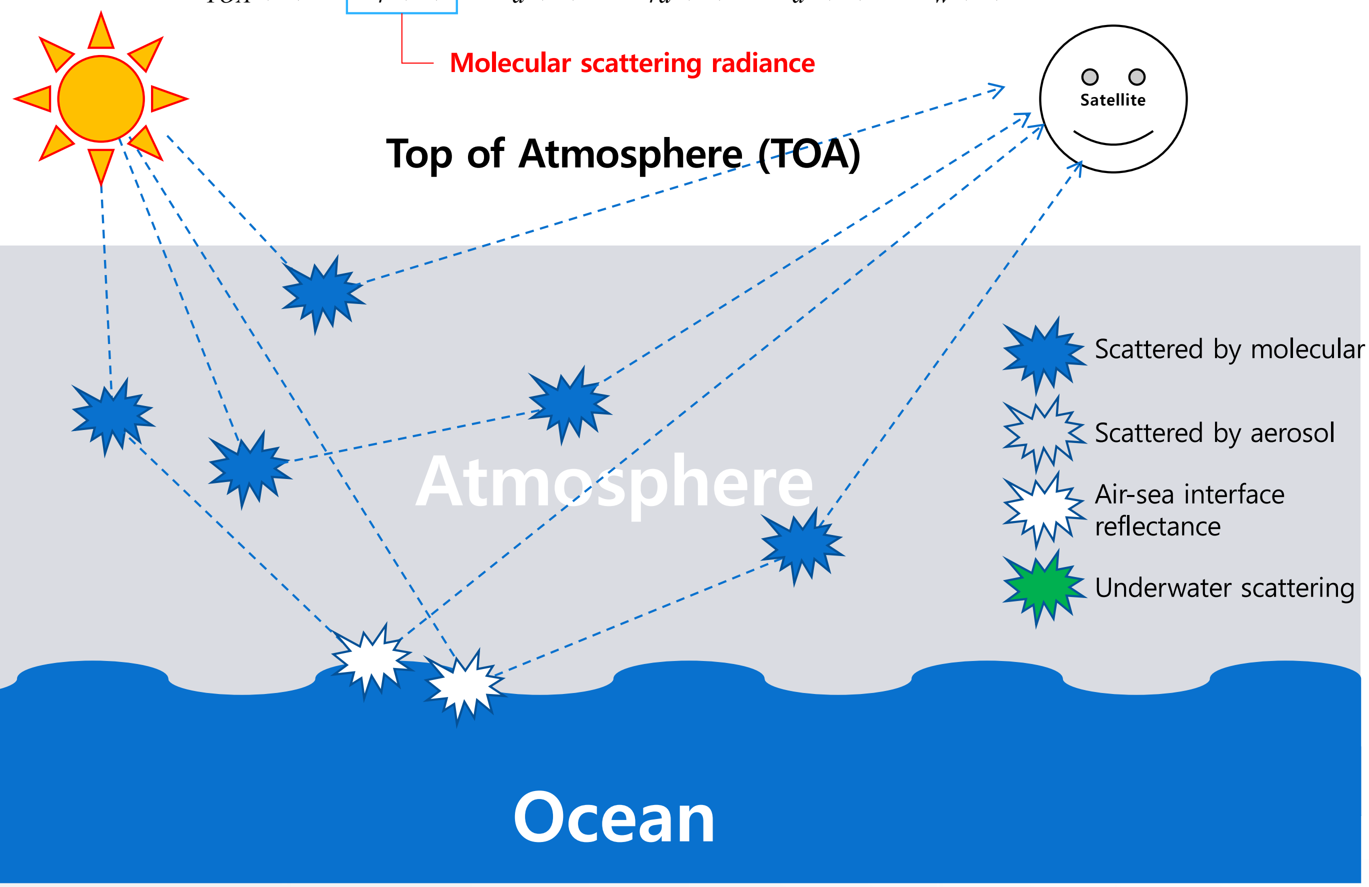
Composition of TOA radiance

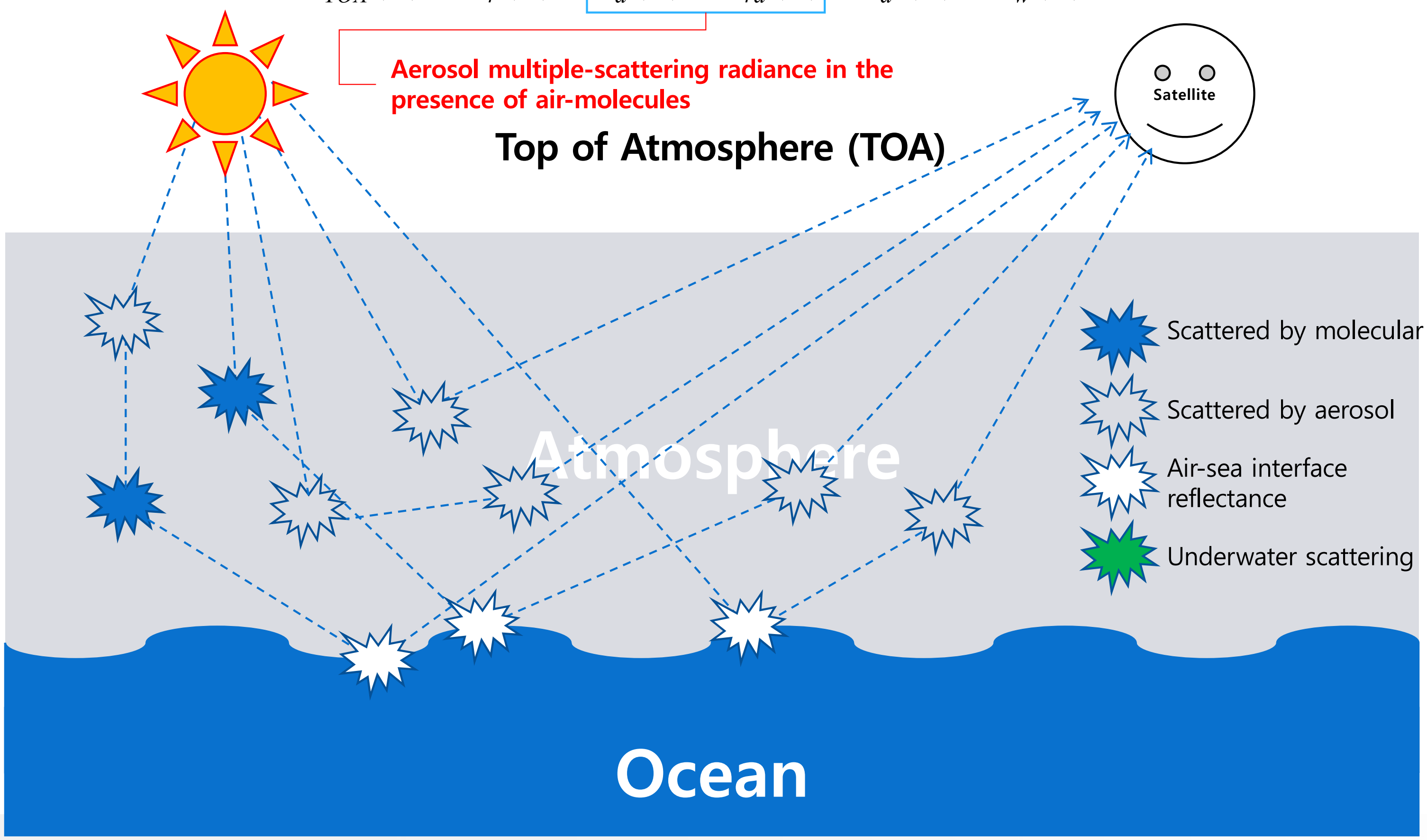
$$L_{TOA}(\lambda) = \boxed{L_r(\lambda)} + L_a(\lambda) + L_{ra}(\lambda) + T_d^v(\lambda) \times L_w(\lambda)$$

Molecular scattering radiance



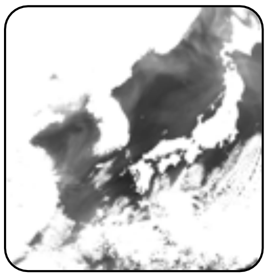
Composition of TOA radiance

$$L_{TOA}(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T_d^v(\lambda) \times L_w(\lambda)$$

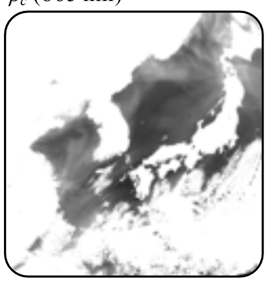


Composition of TOA radiance

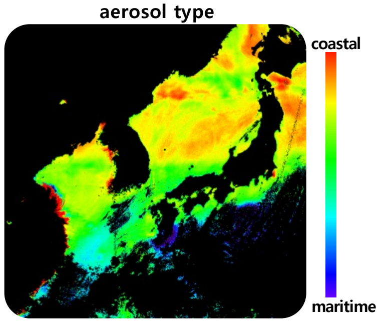
Rayleigh corrected reflectance at 745 nm, ρ_c (745 nm)



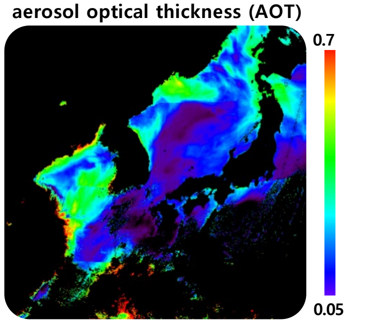
Rayleigh corrected reflectance at 865 nm, ρ_c (865 nm)



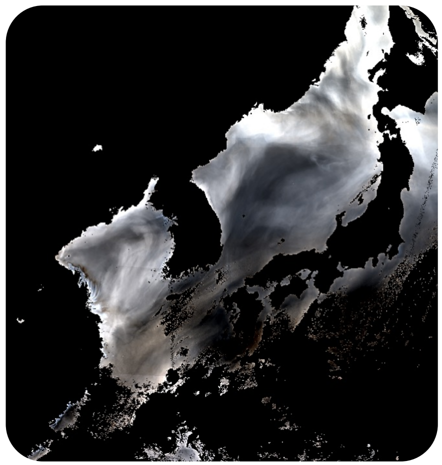
aerosol type

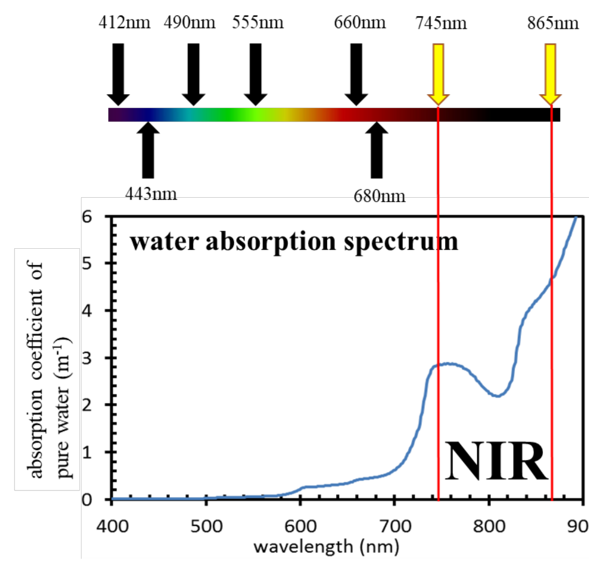


aerosol optical thickness (AOT)

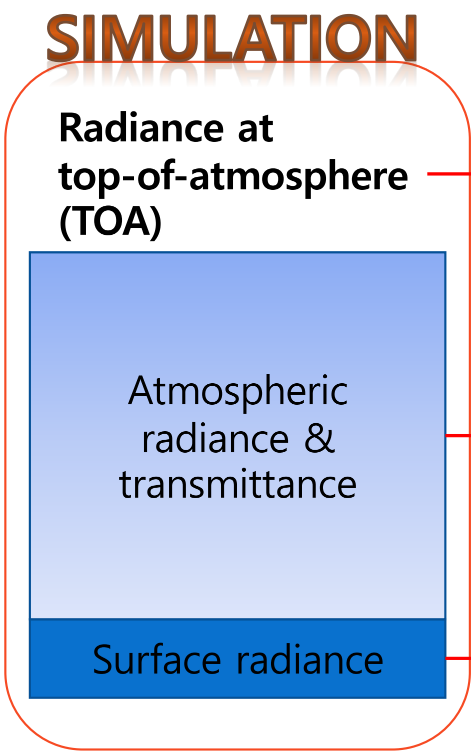


aerosol radiance for all visible band





Vicarious Calibration



$$L_{\mathrm{TOA}}^{VC}(\lambda) = \left[L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + td_r^v(\lambda) \times td_a^v(\lambda) \times L_w^{VC}(\lambda) \right]$$

Computed by simulation using 2 NIR bands imput

Vicarious Calibration

SIMULATION

Radiance at top-of-atmosphere (TOA)

Atmospheric radiance & transmittance

Surface radiance

OBSERVATION

Radiance at top-of-atmosphere (TOA)

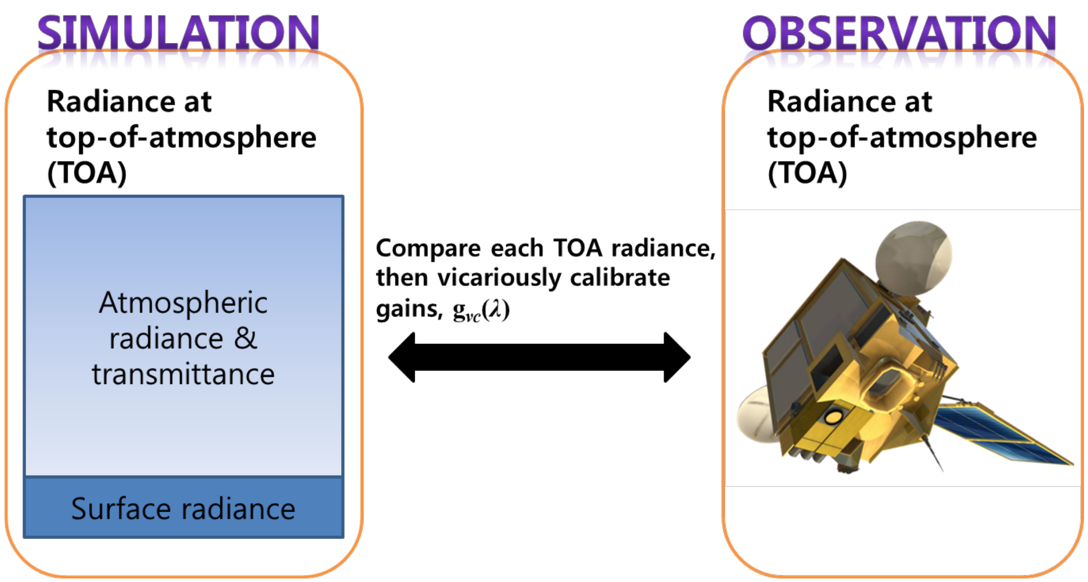
Atmospheric radiance & transmittance

Surface radiance

Compare each TOA radiance, then vicariously calibrate gains, $g_{vc}(\lambda)$

$$g_{vc}(\lambda) = \left[\sum_{n=1}^{N} \left\{ L_{\mathrm{TOA}}^{VC}(\lambda) / L_{\mathrm{TOA}}(\lambda) \right\} \right] / N$$

Vicarious Calibration



Calibration approach is almost identical to Franz et al. (2007)

Step 1. 2^{nd} 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 745 nm calibration example

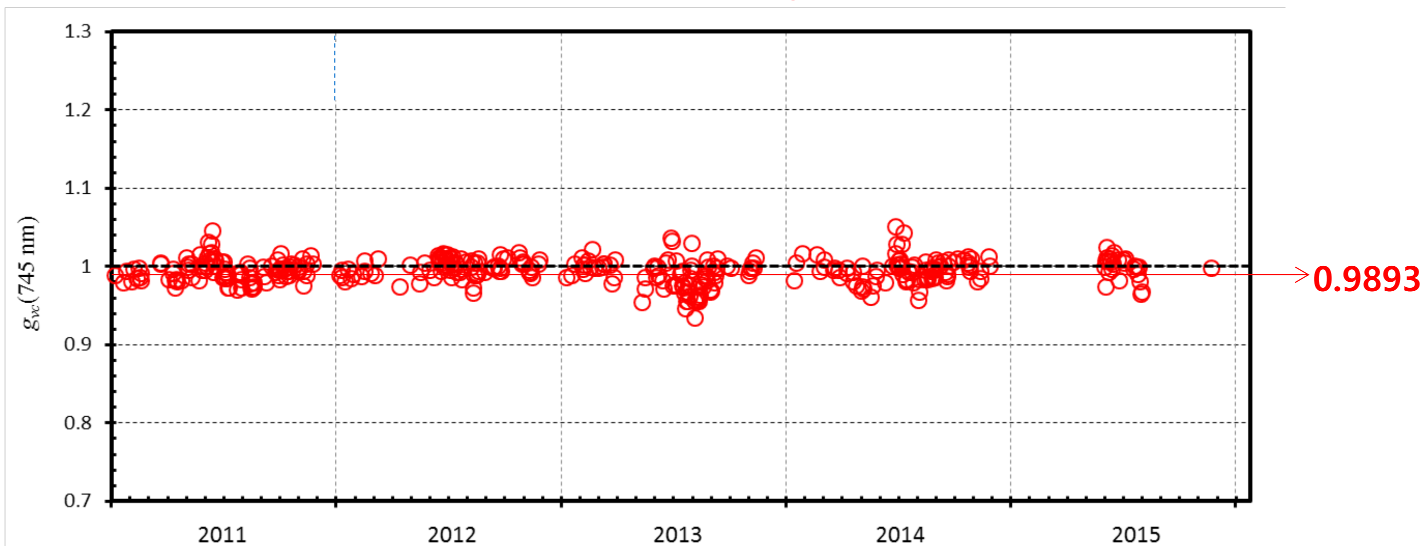
- **2nd last NIR band (745 nm) calibration**
  - Assuming that the last NIR band (865 nm) is already calibrated

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

→ **negligible**

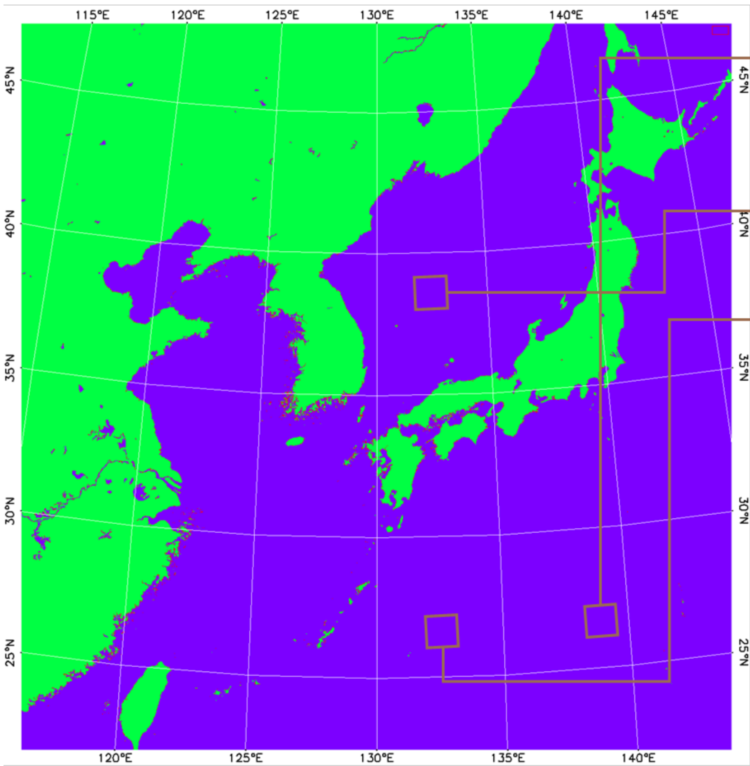
Estimated by radiative transfer simulation (for $L_r(745\,\mathrm{nm})$)

directly derived from $L_a(865\,\mathrm{nm}) + L_{ra}(865\,\mathrm{nm})$ by using spectral relationship of aerosol reflectance for given aerosol model (for $L_a(745\,\mathrm{nm}) + L_{ra}(745\,\mathrm{nm})$)



Vicarious Calibration

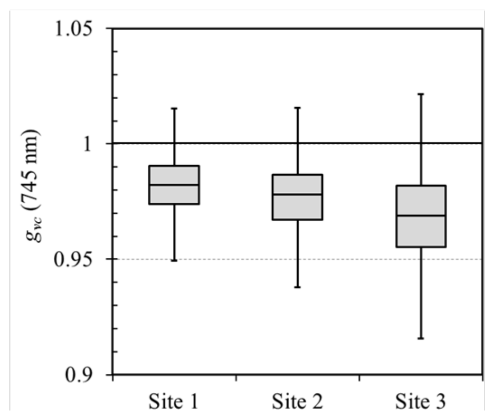
Impact of NIR calibration site



NIR calibration site 1
(Selected for GOCI & GOCI-II)

NIR calibration site 2
(Wang et al., 2013)

NIR calibration site 3 (test)



GOCI VIS bands calibration example

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

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

$L_w(\text{VIS})$ → ***in situ* measurements**

$L_r(\text{VIS})$ → **Estimated by radiative transfer simulation**

$L_a(\text{VIS}) + L_{ra}(\text{VIS})$ → **derived by inter-calibrated $L_a(\text{NIR}) + L_{ra}(\text{NIR})$**

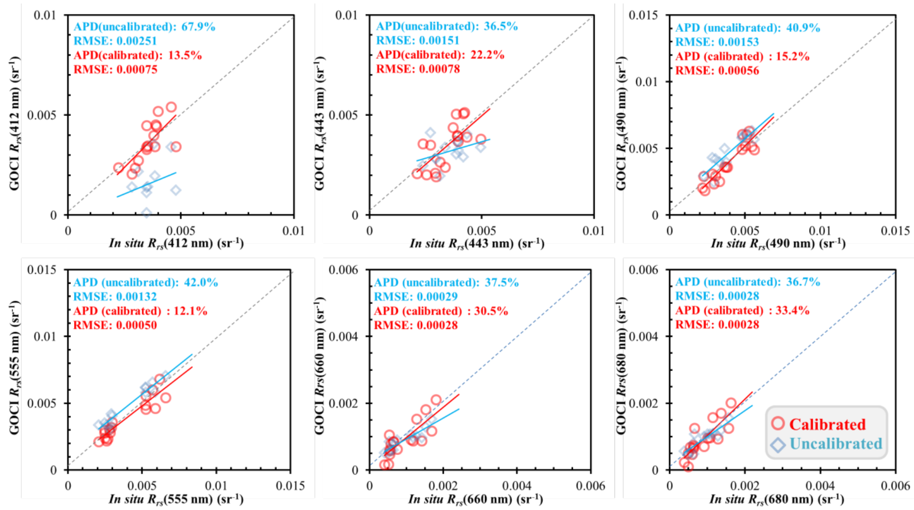
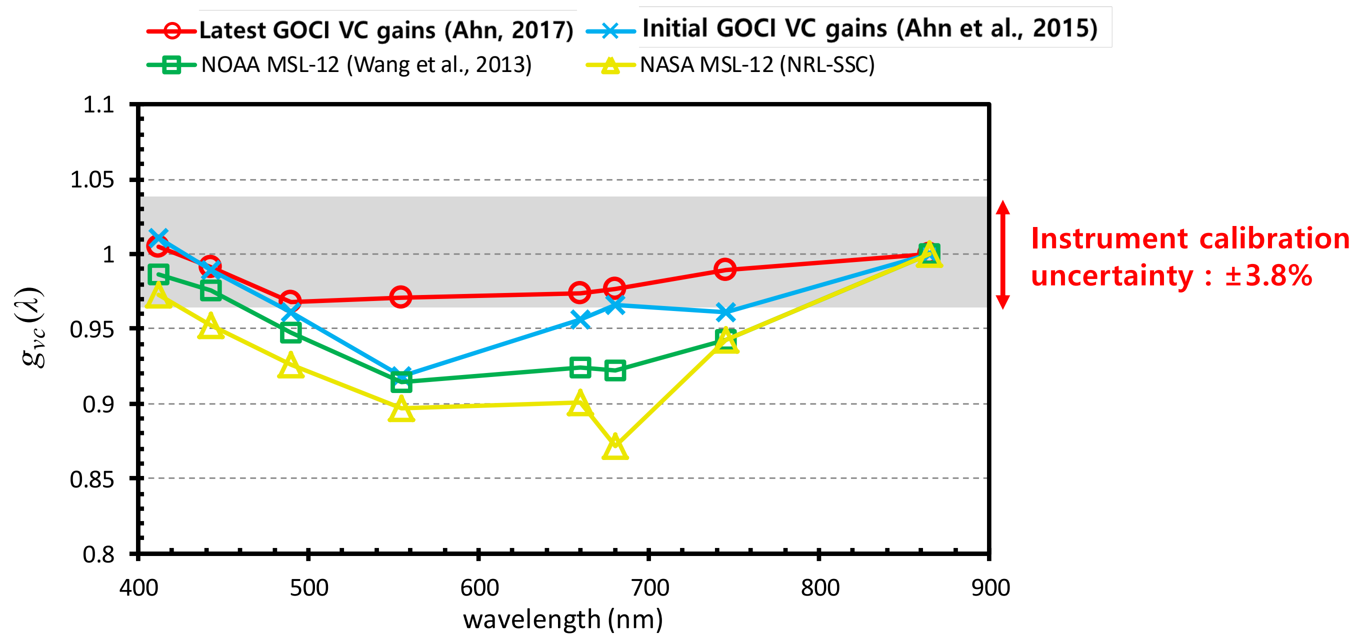


Fig. Verification of the vicarious calibration gain factors. Red circles and blue squares represent the GOCI and *in situ* R_{rs} match-up pairs derived with- and without vicarious calibration, respectively.

세계가 주목하는 천리안 해양관측위성 해양수산부의 세계최초 정지궤도 해색위성

Vicarious Calibration

VC result can be different by different approach



	412	443	490	555	660	680	745	865
Latest GOCI VC gains	**1.00531**	**0.99113**	**0.96805**	**0.97044**	**0.97391**	**0.97698**	**0.9893**	**1**
Initial GOCI VC Gains	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

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Validation of GOCI Data After Applying the Vicarious Calibration

In situ radiometric data for the validation

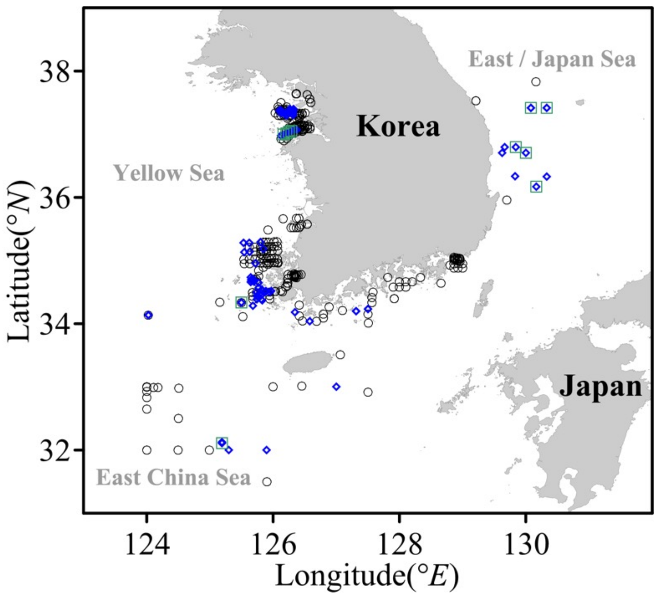
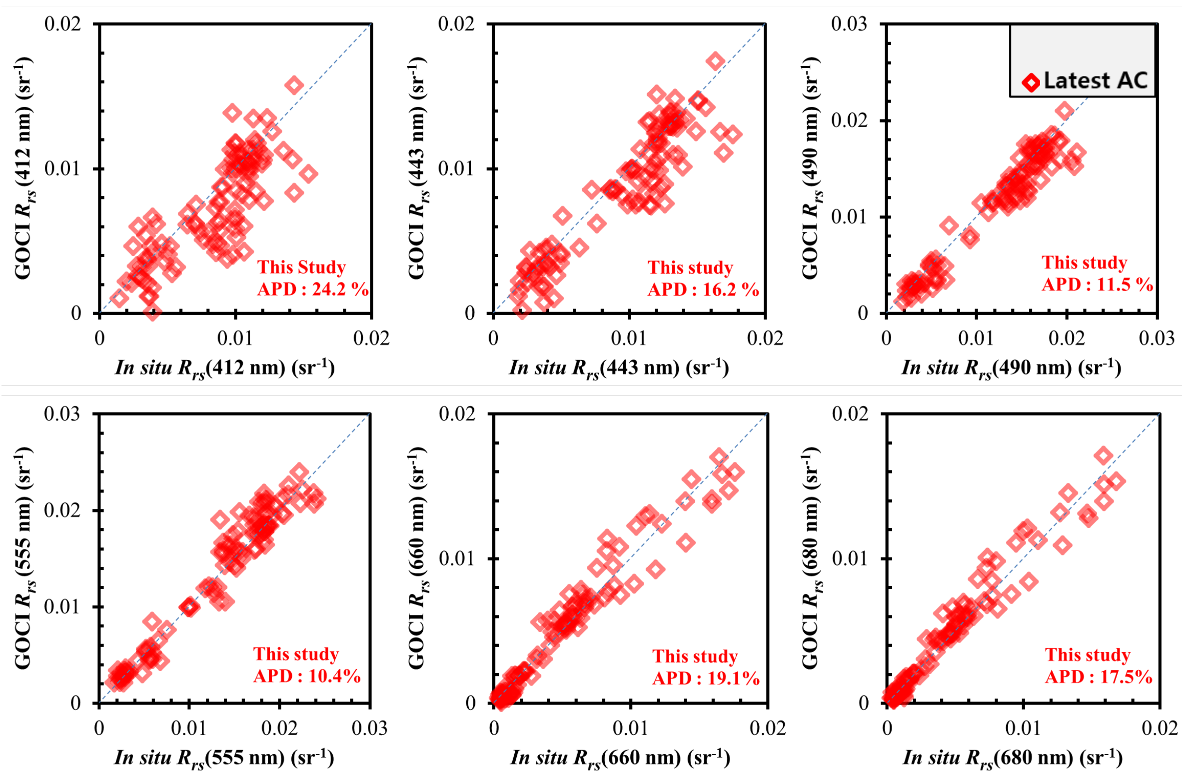


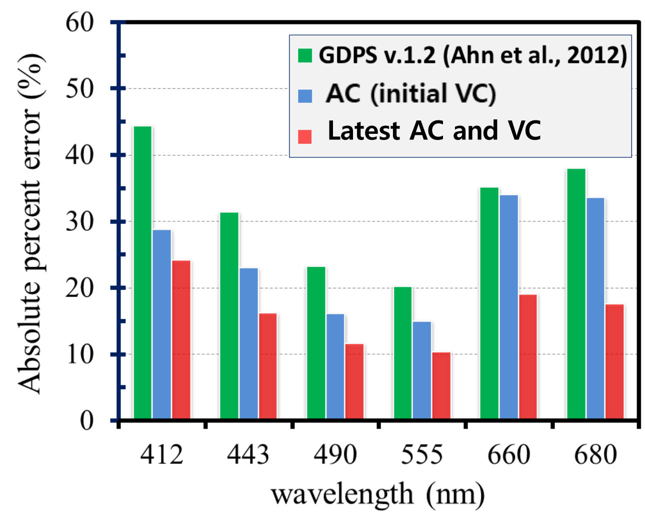
Fig. Locations of *in situ* radiometric measurements in coastal and open-ocean waters around Korea. A total of 421 samples were collected, and subsequently reduced to 65 (blue diamonds) through strict quality control of both the *in situ* measurements and GOCI observations. Of these data, only 12 spectra were used in the vicarious calibration process (green squares).

AERONET-OC data from Ieodo & Socheongcho station

Validation of GOCI Data After Applying the Vicarious Calibration

Validation results with *in situ* data





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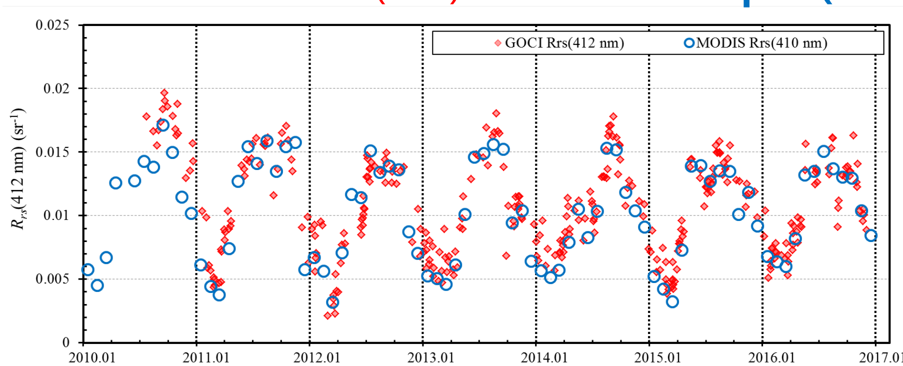
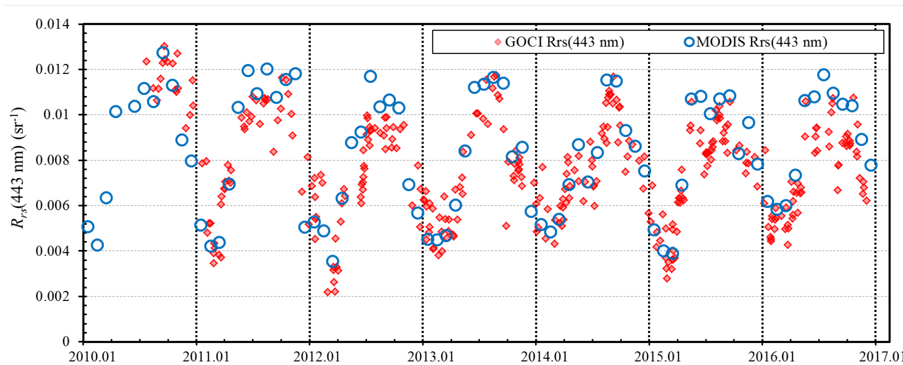
Validation of GOCI Data After Applying the Vicarious Calibration

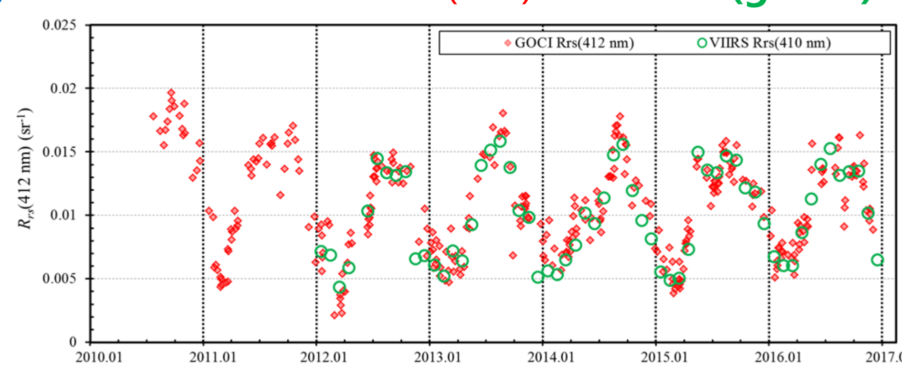
Validation results with other satellite data

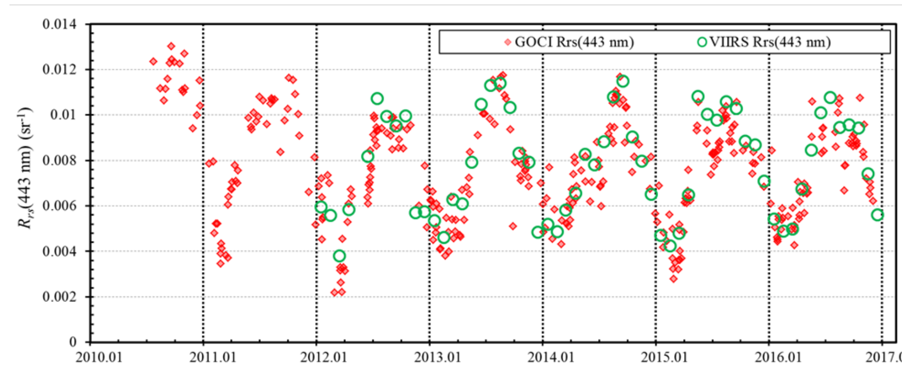
Time series: GOCI (red) vs **MODIS-Aqua (blue)**





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





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Summary

- Vicarious calibration is necessary to enhance agreement between atmospheric correction & sensor system and actual observation
- GOCI Atmospheric correction and vicarious calibration have been developed theoretically based on the NASA ocean color mission's approach
- GOCI had been successfully calibrated through a long-term vicarious calibration efforts

Vicarious calibration for GOCI-II

- **GOCI-II requires further reference remote-sensing reflectance (R_{rs}) dataset at the ocean surface for the VC**
  - **The GOCI-II initial VC uses R_{rs} dataset from MODIS-aqua and VIIRS processed by NASA OBPG**
  - **Due to the early termination of the GOCI mission, we could not collect sufficient GOCI R_{rs} dataset**
  - **Further *in situ* R_{rs} dataset is necessary for the GOCI-II VC**

How can GOCI data contribute to the calibration of other sensors?

- After the vicarious calibration, we can provide water-leaving radiance for other sensors' calibration within 10% error over oligotrophic ocean
- Hyper spectral water-leaving radiance in 350~900 nm can be modeled from MODIS, VIIRS, GOCI, and GOCI-IIs' atmospheric correction result

Thank you!

Further questions, brtnt@kiost.ac.kr