Optical discrimination of *Cochlodinium polykrikoides* blooms from Non-harmful blooms in Korean coastal waters

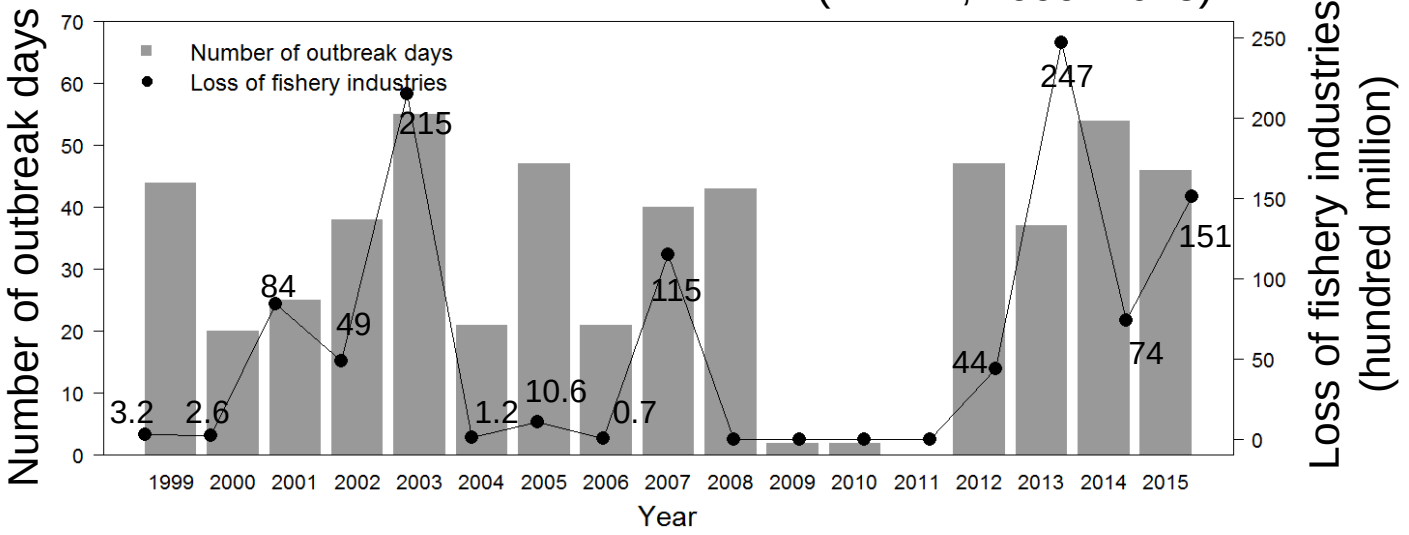
Yeseul Kim[1,2], Sinjae Yoo[1,2,*], Young Baek Son[1]

[1] Jeju International Marine Science Center for Research & Education, KIOST, R Korea
[2] Ocean Science and Technology School, Korea Maritime and Ocean University/Korea Institute of Ocean and Science Technology Joint Program, Busan, R Korea

Background of the research

In Korean coastal waters,
C. polykrikoides blooms
have occurred continuously since the 1990s.

(NFRDI, 1999~2015)

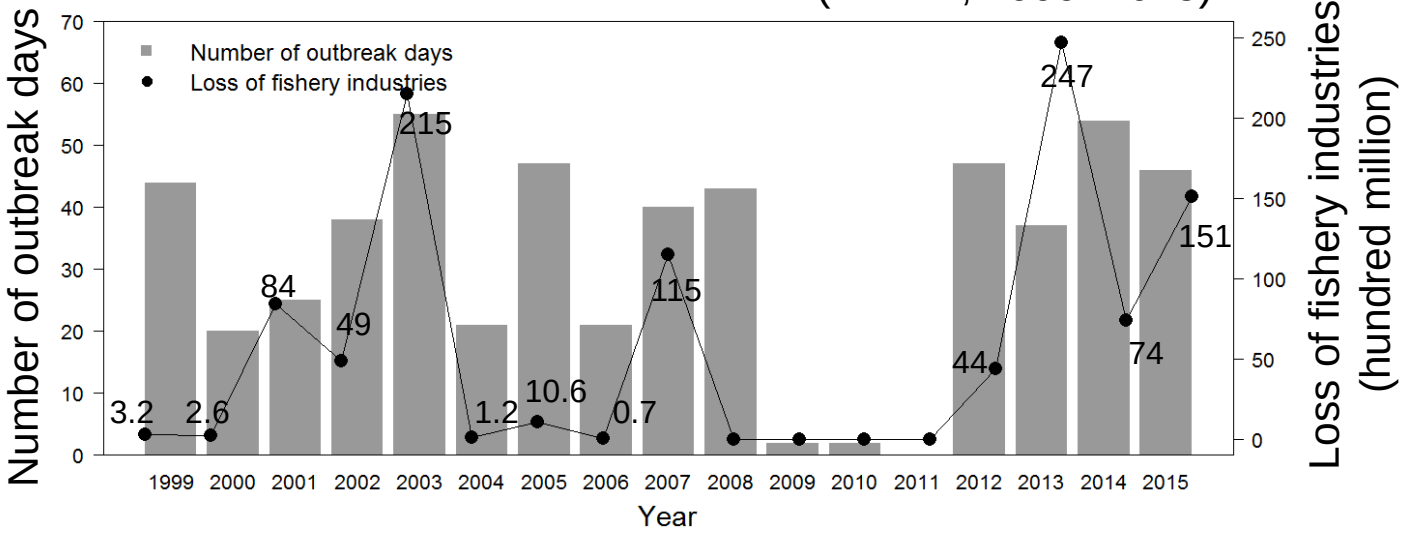


Background of the research

Harmful Algal Blooms caused by *C. polykrikoides* lead to fish kills as resulting in suffocation.

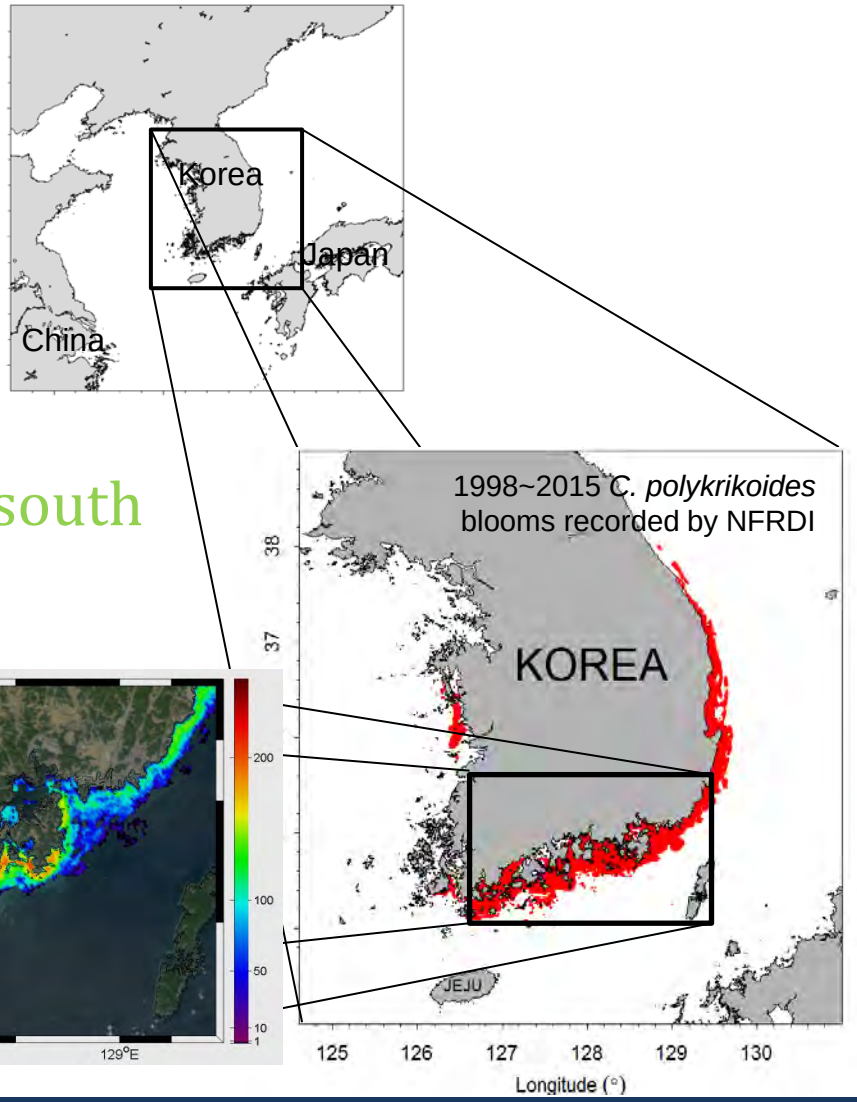
Most fish die in cages

(NFRDI, 1999~2015)



Background of the research

C. polykrikoides blooms are concentrated along the south coast of Korea.



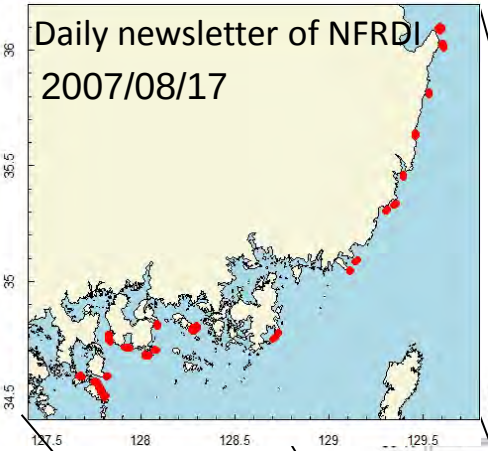
Background of the research

Lee *et al.*, 2013

Table 1
Red tide monitoring program in Korea.

Type of monitoring	Main objectives	Monitoring parameter	Responsible agency	Monitoring frequency
Monthly red tide monitoring	To investigate the status of dominant phytoplankton species and water quality	- Dominant species - Cell density - Water color - Transparency, CTD, Chl a, nutrient	NFRDI (National Fisheries Research and Development Institute)	Monthly (March–November)
Monitoring of potential red tide areas	To check causative species and affected areas	- HAB species - Cell density - Bloom area - Water color - Water temp., salinity	Fisheries extension service station under local government	Irregular (during red tide)
Aerial red tide surveillance	To check the location of affected areas	- Location of blooms - Water color	National Maritime Police Agency	Irregular (during red tide)
Monitoring of *Cochlodinium*	To forecast early warning of *Cochlodinium* blooms	- Phytoplankton species (abundance/succession) - Cell density - Water color - Transparency, CTD, Chl a, nutrient	NFRDI (National Fisheries Research and Development Institute)	June–October (biweekly)
Monitoring of shellfish poisoning	To check abundance of toxic species and poisoning level in the shellfish meat	- Toxic species (PSP, ASP, DSP) - Cell density - Water color - Water temp., salinity - Toxin level	NFRDI (National Fisheries Research Institute)	Monthly/weekly (when poison is detected)

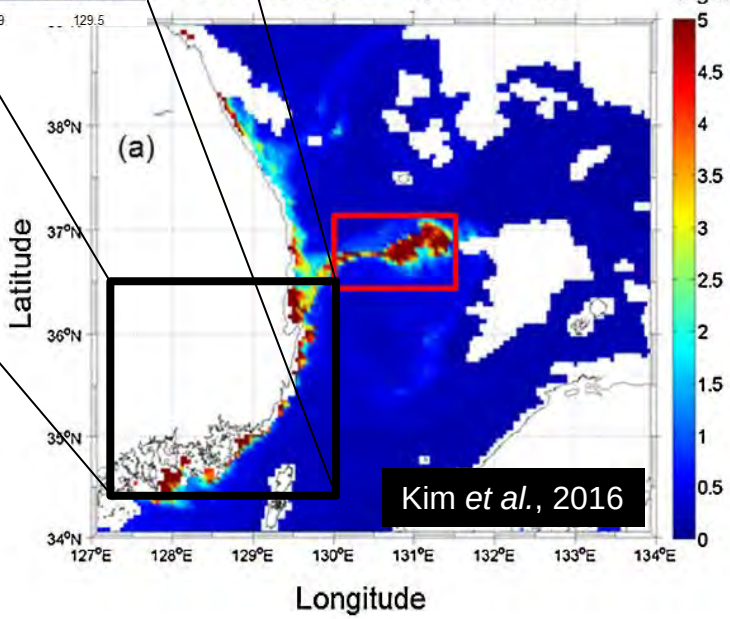
Background of the research



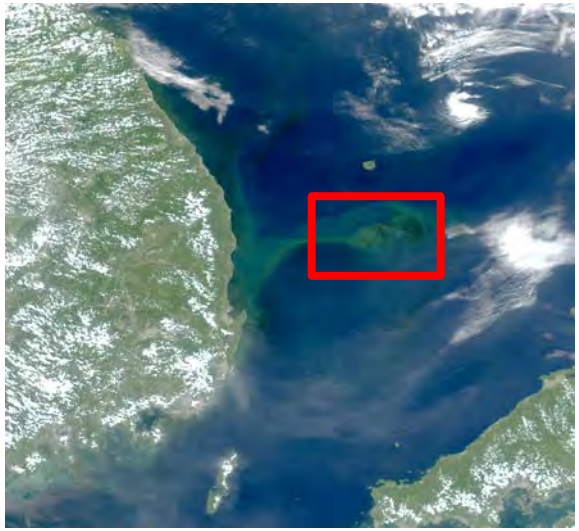
← Daily newsletter is published by NFRDI.

Satellite remote sensing is **powerful tool** for detection of HABs.

MODIS Chl data in August 17, 2007



MODIS true color image in August 17, 2007



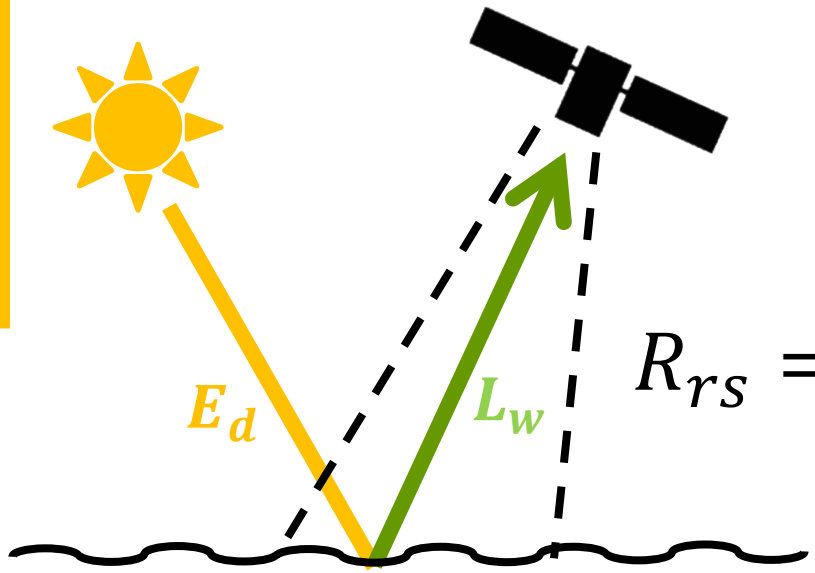
Research objective

(1) To find out the **bio-optical characteristics** of *C. polykrikoides.*

(2) To assess the **possibility of optically discriminating** ***C . polykrikoides*** blooms using **Remote Sensing Reflectance** in various water types.

Target of simulation

What is the **ocean Remote Sensing Reflectance (R_{rs})?**



$$R_{rs} = \frac{L_w}{E_d} = G\,\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}\ [sr^{-1}]$$

Pure water - a_w; b_{bw}
Phytoplankton - a_{ph}; b_{bph}
CDOM - a_g
Detritus/mineral - a_{dm}; b_{bdm}

Seawater constituents

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{dm}(\lambda) + a_g(\lambda)\ [m^{-1}]$$

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bph}(\lambda) + b_{bdm}(\lambda)\ [m^{-1}]$$

Conditions of simulation

*We generated **a large dataset** of simulated R_{rs} spectra (**n=2,275**) **in a wide range of bio-optical***

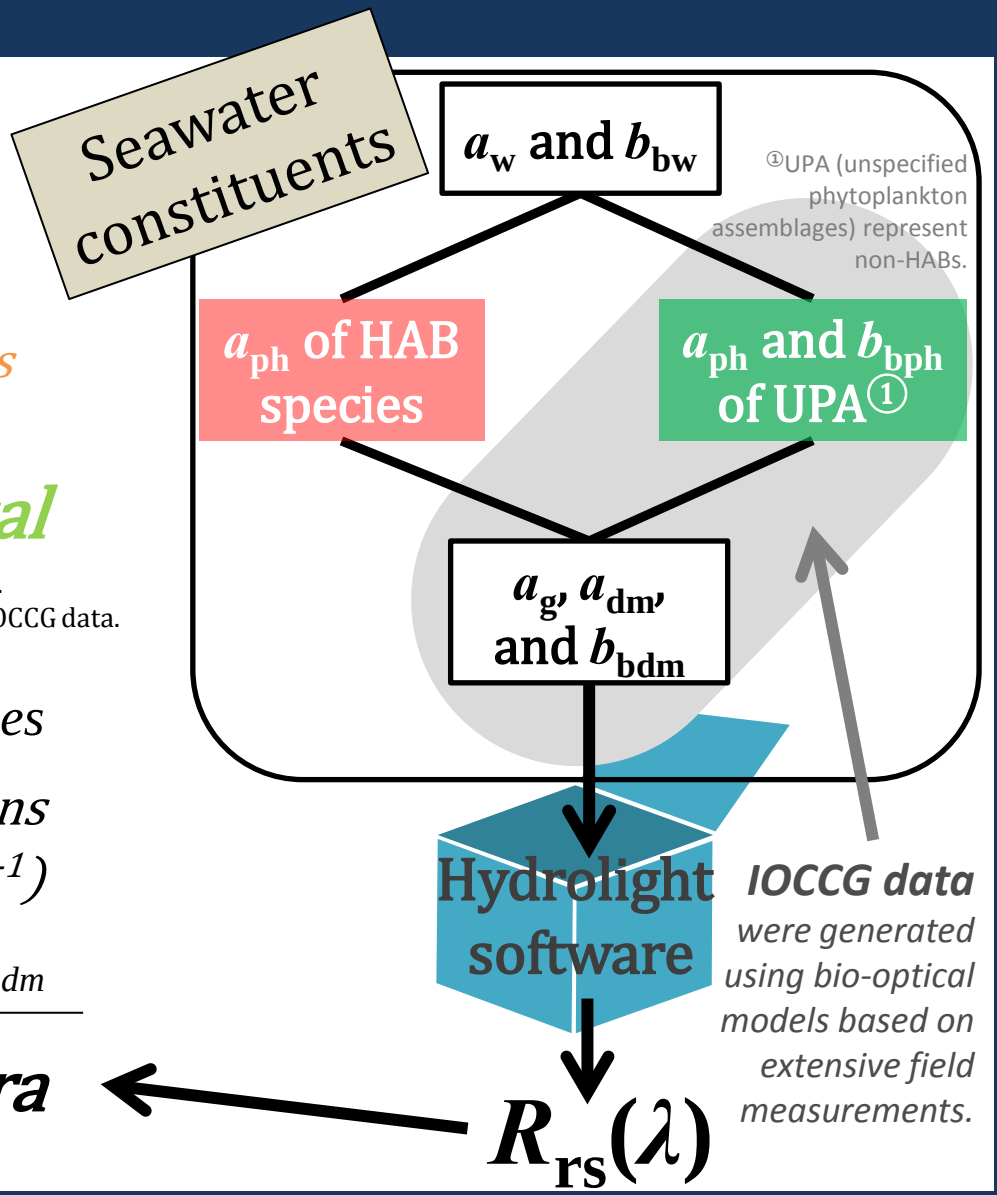
*a_{ph} of four HAB species are measured from culture samples.
**Optical parameters representing UPA are obtained from IOCCG data.

X **5** *kinds of* a_{ph} *for five species*

X **5** *different Chl a concentrations (5, 10, 15, 20, and 30 μg* l^{-1}*)*

X **91** *combinations of* a_g *and* a_{dm}

455 ***2,275 spectra***



Conditions of simulation

Seawater constituents	Optical parameters	Data source
Water	a_w; b_{bw}	Pope and Fry (1997); Smith and Baker (1981)
Phytoplankton	a_{ph}	*C. polykrikoides, Akashiwo, Alexandrium, Scrippsiella** , and UPA**
	b_{bph}	IOCCG data
	Chl *a*	5, 10, 15, 20, and 30 μg l^{-1}
CDOM	a_g	0.015-1.453 m^{-1} (n=13) (IOCCG data)
Detritus/mineral	a_{dm}, b_{bdm}	0.003-0.378 m^{-1} (n=7) (IOCCG data)

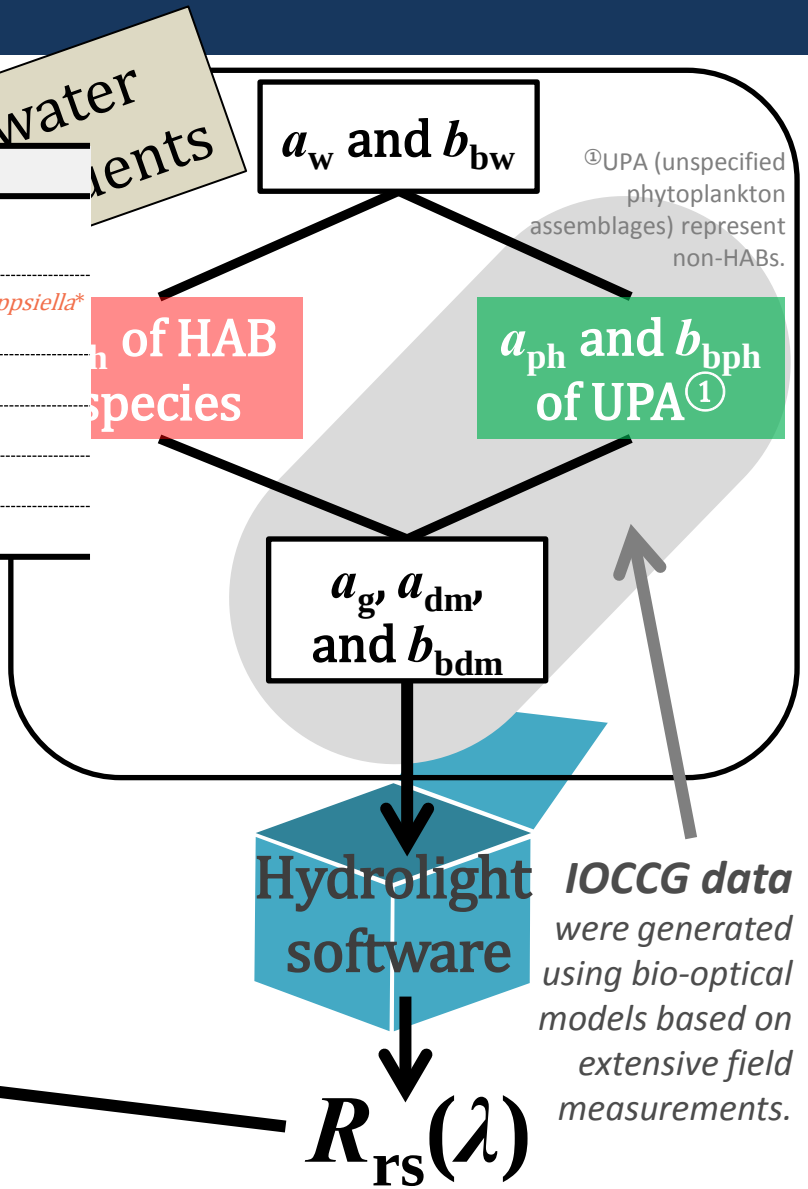
*a_{ph} of four HAB species are measured from culture samples.
**Optical parameters representing UPA are obtained from IOCCG data.

X **5** *kinds of* a_{ph} *for five species*

X **5** *different Chl a concentrations (5, 10, 15, 20, and 30 μg* l^{-1}*)*

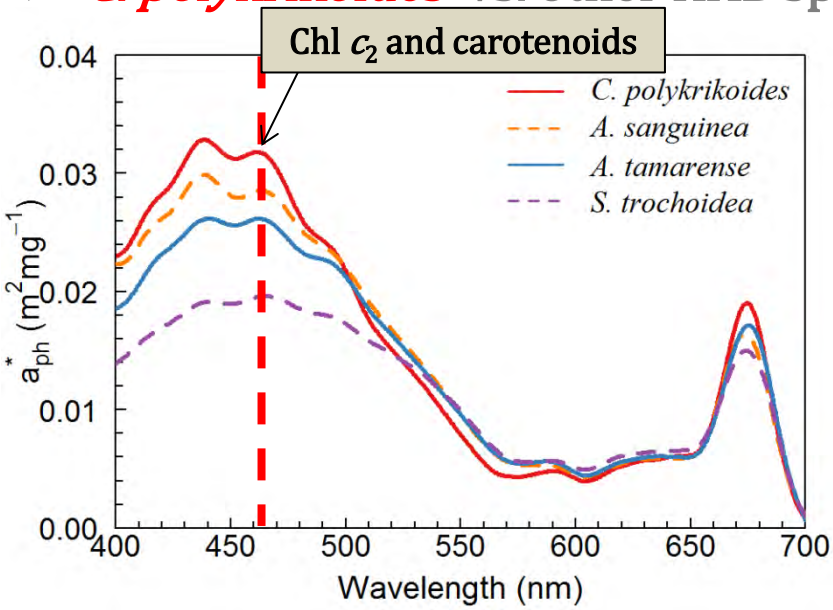
X **91** *combinations of* a_g *and* a_{dm}

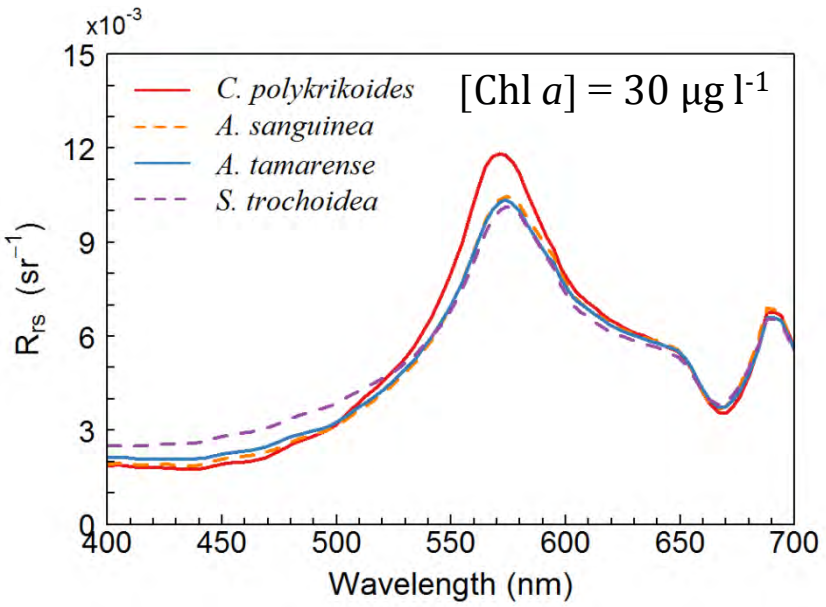
455 ***2,275 spectra***



Optical properties of HAB species

► *C. polykrikoides* vs. other HAB species



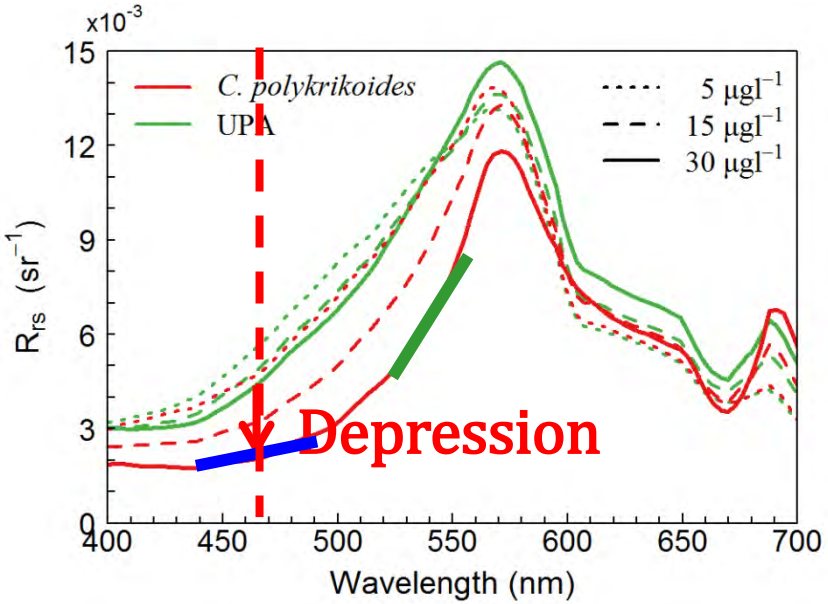


(1) The **peak at 465 nm** is the combined absorption maximum of **chlorophyll c_2 and carotenoids** which are synchronously detected as typical pigments of dinoflagellate species.

(2) **We could not find the unique and significant differences** in spectral shapes of R_{rs} among **HAB species**.

Comparison of R_{rs} spectra

- *C. polykrikoides* vs. UPA (Unspecified Phytoplankton Assemblages)



(1) **The most conspicuous differences** can be observed in the slope of the blue-green range (440-600 nm).

(2) This distinct feature of R_{rs} **becomes more pronounced** with increasing Chl *a* concentration.

Depression?

- This feature is **an outcome of a_{ph} characteristics at 465 nm**.
- The slope of R_{rs} for ***C. polykrikoides*** **is flatter in the blue region but steeper** than that of UPA in the green region.

Discrimination based on R_{rs} ratios

Multispectral analysis - Spectral band algorithm

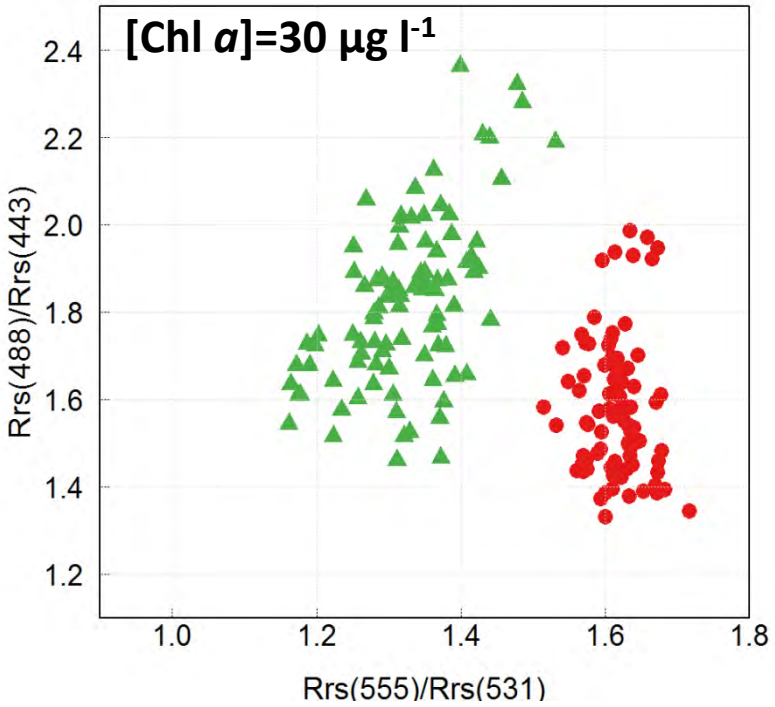
(1) The optimal bands were selected **to capture the depression of R_{rs}**.

(2) MODIS bands were adopted **to examine the applicability of satellite data**.

- R_1: $R_{rs}(555)/R_{rs}(531)$;
  R_2: $R_{rs}(488)/R_{rs}(443)$
  which show maximum change in slope

In case of *C. polykrikoides*,

R1↑and R2↓



Discrimination based on R_{rs} ratios

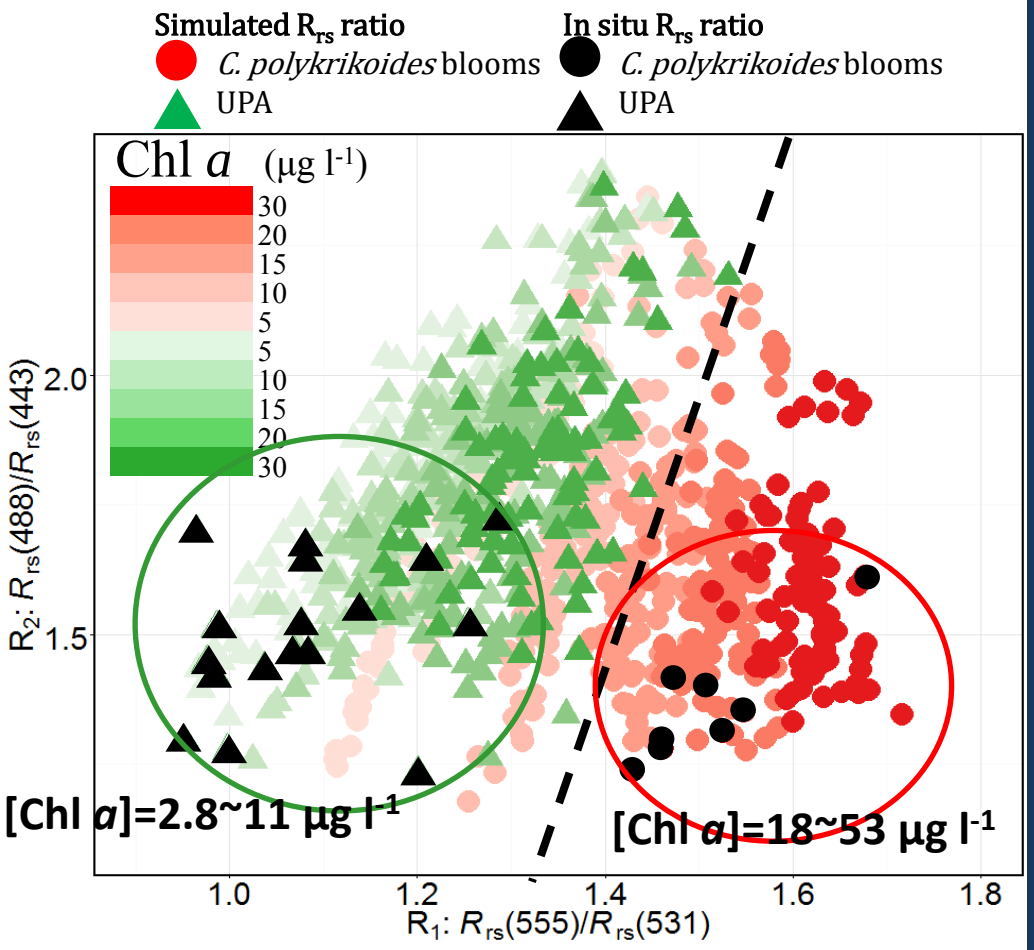
Availability of R_{rs} ratios in Korean coastal waters

- *In situ* R_{rs} data were obtained from the 2014 and 2015 summer hydrographic cruise in the south coast of Korea.

(1) ***C. polykrikoides* blooms were clearly separated** from UPA **in simulation** and ***in situ* data**.

(2) Band ratios of ***in situ* data closely tied with those of the simulation** dataset.

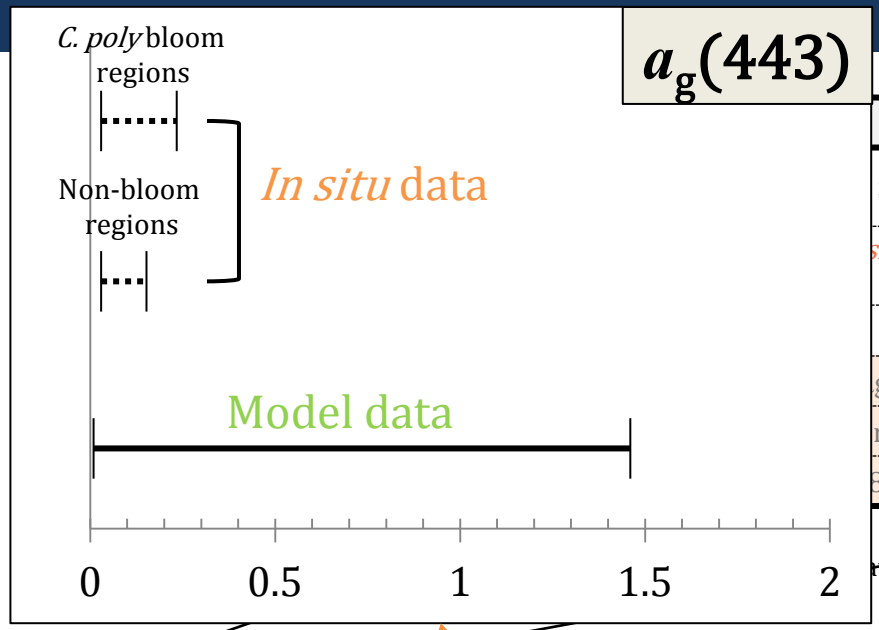
(3) Band ratios of ***in situ*** *C. polykrikoides* blooms and UPA **occupy lower R_2 regions**.

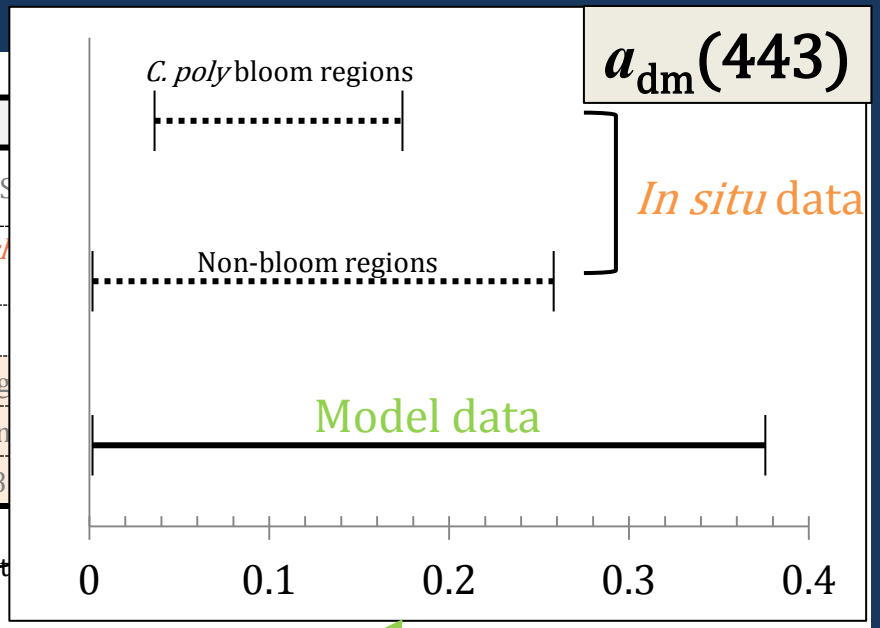


Summary

1. We generated **a large dataset of simulated R_{rs}** to explore the possibility of optical discrimination of *C. polykrikoides* from non-HABs and/or other HABs.
2. *C. polykrikoides* and other HAB species show the **similar spectral shapes in R_{rs} because of similar a_{ph} characteristics**.
3. The distinct feature of **a_{ph} for *C. polykrikoides* are translated into a depressed R_{rs}** in the blue-green regions, while **no depression was observed for UPA**.
4. Band ratios that effectively depict this depression of R_{rs} were selected to discriminate *C. polykrikoides* from UPA.
   - **R_1: R_{rs} (555)/R_{rs}(531); R_2: R_{rs} (488)/R_{rs}(431)**

General applicability of this analysis





Parameters	Model data	Field data	
	IOCCG synthetic data	Non-bloom regions	*C. polykrikoides* bloom regions
Chl *a*	5-30 μg l^{-1}	0.459-11 μg l^{-1}	18-53 μg l^{-1}
$a_g(443)$	0.015-1.453 m^{-1}	0.027-0.148 m^{-1}	0.027-0.228 m^{-1}
$a_{dm}(443)$	0.003-0.378 m^{-1}	0.003-0.261 m^{-1}	0.035-0.171 m^{-1}

The *in situ* data mostly fell within the ranges of the model data.

Conclusion

1. *C. polykrikoides* blooms were **clearly separated from UPA** in optical conditions.
2. The **discrimination of *C. polykrikoides*** blooms from UPA seems **possible when Chl *a* concentration is sufficiently high**.
3. Our results can be applied to other geographical regions, because **our approach covers a much wider range of optical conditions**.
4. In order to apply **this approach in satellite remote sensing**, the standing issues, which cause the errors in retrieving R_{rs}, must be resolved.

Research Article | Vol. 24, No. 22 | 31 Oct 2016 | OPTICS EXPRESS A1471

Optics EXPRESS

Optical discrimination of harmful *Cochlodinium polykrikoides* blooms in Korean coastal waters

YESEUL KIM,[1,2] SINJAE YOO,[1,2,*] AND YOUNG BAEK SON[1]

[1]*Jeju International Marine Science Center for Research and Education, Korea Institute of Ocean Science and Technology, Jeju 63349, South Korea*
[2]*Ocean Science and Technology School, Korea Maritime and Ocean University/Korea Institute of Ocean Science and Technology Joint Program, Busan 49112, South Korea*
[*]*sjyoo@kiost.ac.kr*

Abstract: We investigated the possibility of optically discriminating harmful algal blooms (HABs), focusing on *Cochlodinium polykrikoides*, the major HAB causative dinoflagellate species in Korean waters. We produced a large data set of simulated remote sensing reflectance (R_{rs}) spectra in a wide range of bio-optical conditions using Hydrolight software and bio-optical data provided by the International Ocean-Color Coordinating Group. The two R_{rs} band ratios ($R_{rs}(555)/R_{rs}(531)$ and $R_{rs}(488)/R_{rs}(443)$) were determined to be effective in discriminating high-density *C. polykrikoides* blooms. The results were consistent with *in situ* observations and seem applicable to diverse coastal environments. Our findings provide theoretical and quantitative criteria upon which in-water HAB detecting algorithms can be developed.

OCIS codes: (010.4450) Oceanic optics; (010.1030) Absorption; (010.0280) Remote sensing and sensors.

References and links

1. C. J. Gobler, A. Burson, F. Koch, Y. Tang, and M. R. Mulholland, "The role of nitrogenous nutrients in the occurrence of harmful algal blooms caused by *Cochlodinium polykrikoides* in New York estuaries (USA)," Harmful Algae **17**, 64–74 (2012).
2. Y. B. Son, J. Ishizaka, J. C. Jeong, H. C. Kim, and T. Lee, "*Cochlodinium polykrikoides* red tide detection in the South Sea of Korea using spectral classification of MODIS data," Ocean Sci. J. **46**(4), 239–263 (2011).
3. Y. H. Ahn and P. Shanmugam, "Detecting the red tide algal blooms from satellite ocean color observations in optically complex Northeast-Asia Coastal waters," Remote Sens. Environ. **103**(4), 419–437 (2006).

THANK YOU
FOR
YOUR
ATTENTION!

yees0408@kiost.ac.kr