Introduction to eutrophication and Harmful algal blooms (HABs)

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Lecturer

- Degree
  - M.S: Dept. Civil Eng., Purdue University (Geomatics) (2005)
  - Ph.D.: Dept. Civil Eng., Purdue University (Geomatics) (2011)

- Career
  - Post-Doc: Geographical Sciences, Univ. Maryland (2011~2013)
    NESDIS/NOAA, USA (2011~2013)
  - Senior researcher @ Korea Ocean Satellite Center, KIOST (2013~2019)
  - Assistant Professor, Dept. Civil & Environmental Eng. Pusan National Univ. (2019~)

- Service
  - IOCCG, Scientific Committee member : 2017~2022
  - GEO (Group on Earth Observation) Member : 2017~2018
  - Korea-US Joint Field Campaign on Ocean Color, Chief Scientist : 2016

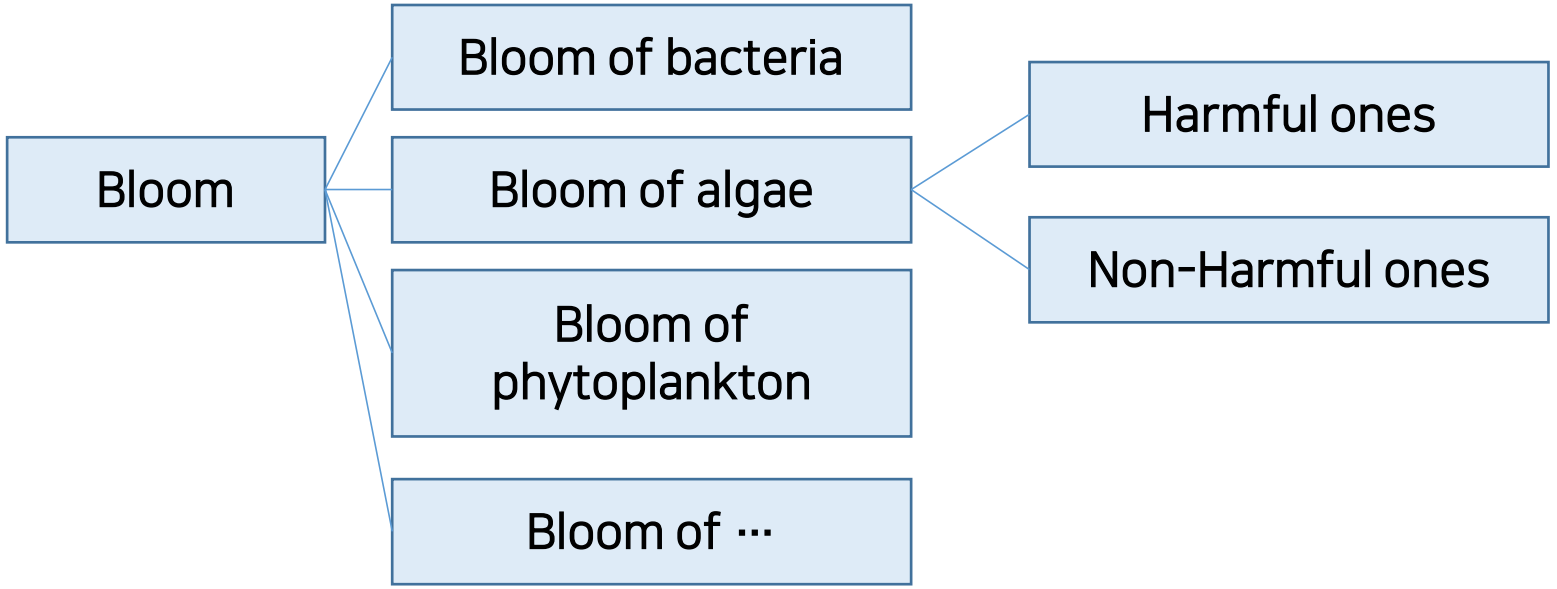
Harmful Algal Bloom

What is Bloom?

- Bloom (Collins dictionary)
  - [Verb] When a plant or tree blooms, it produces flowers. When a flower blooms, it opens.
    - ex) This plant blooms between May and June
  - [Verb] If someone or something blooms, they develop good, attractive, or successful qualities.

- Bloom (Merriam-Webster)
  - [Noun] a rapid and excessive growth of a plankton population (as of algae or dinoflagellates)
  - [Noun] a large aggregation of free-swimming organisms

Classification of Bloom



Harmful to whom?

Definition by WHOI

- Harmful algae
  - are microscopic, single-celled plants that live in the sea
  - Most species of algae or phytoplankton are not harmful

  - Occasionally, the algae grow very fast or "bloom" and accumulate into dense, visible patches near the surface of the water
  - "Red Tide" is a common name for such a phenomenon where certain phytoplankton species contain pigments and "bloom" such that the human eye perceives the water to be discolored
  - Blooms can appear greenish, brown, and even reddish orange depending upon the type of organism, the type of water, and the concentration of the organisms

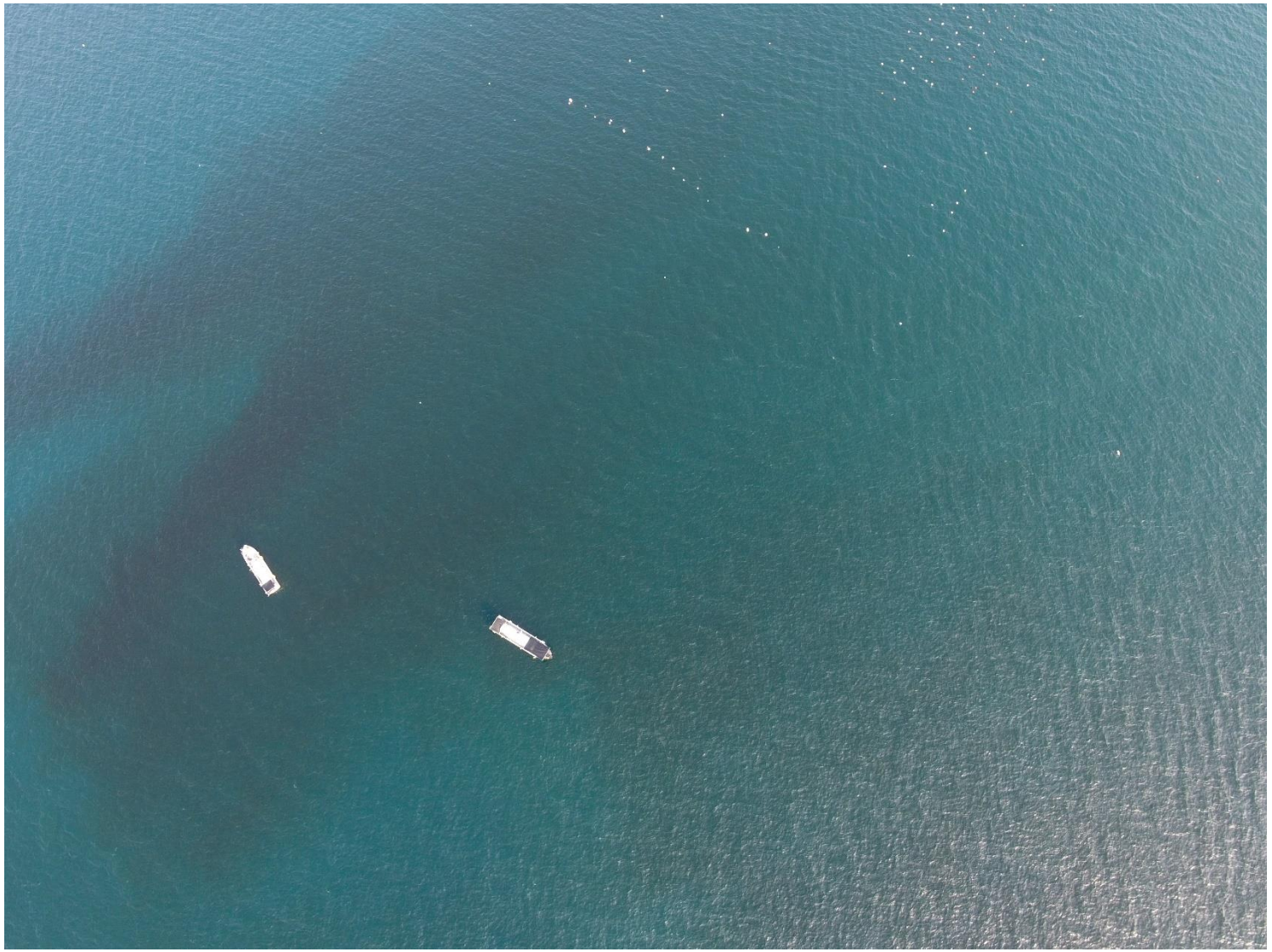
  - The term "red tide" is thus a misnomer because blooms are not always red, they are not associated with tides, they are usually not harmful, and some species can be harmful or dangerous at low cell concentrations that do not discolor the water.

What makes algae bloom?

- Factors that are essential for AB
  - Nutrient
    - Phosphorus and nitrogen
    - **Eutrophication**
  - Temperature
    - The optimal temperature is specie-dependent
  - Light
    - Long periods of high light intensity
  - Stable condition
    - Long retention time
    - Light winds
    - Minimal turbulence
  - Winning the competition with other species

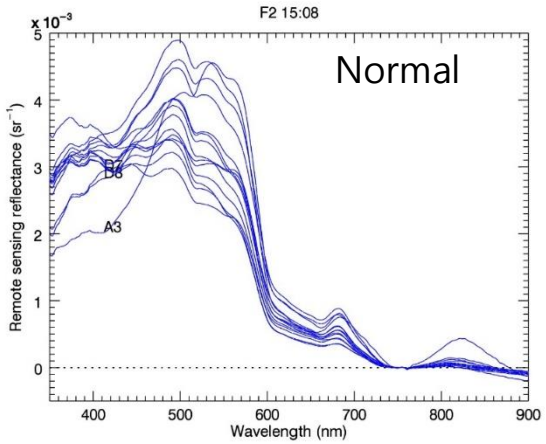
Cochlodinium Polykrikoides Bloom

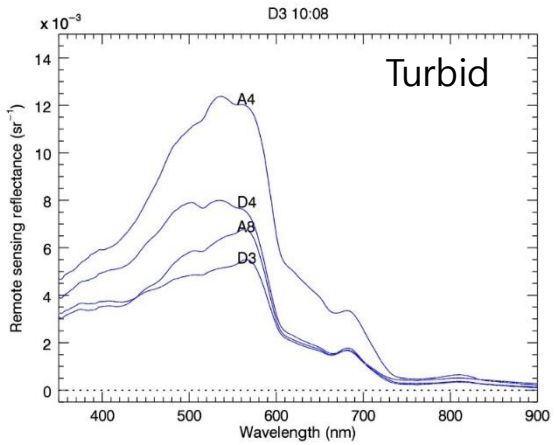
Aug. 2018 @ Tongyeong, Korea

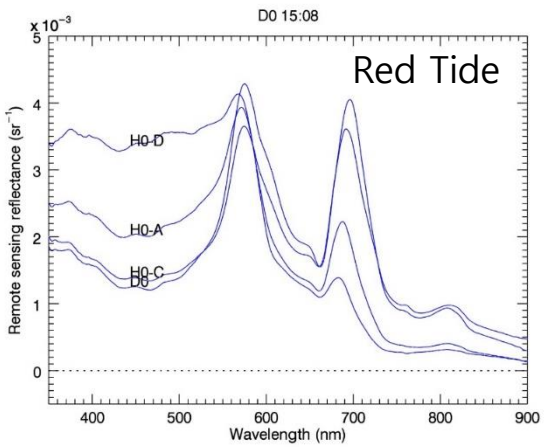


Credit : Dr. Seung-Won Jung, KIOST

Color of Water

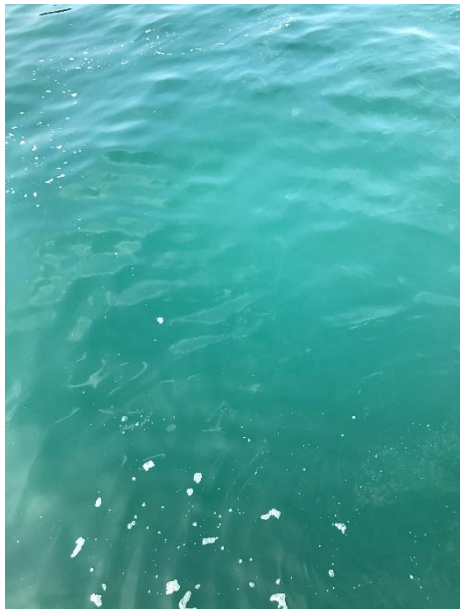






D7 (09:49)

D4 (10:31)



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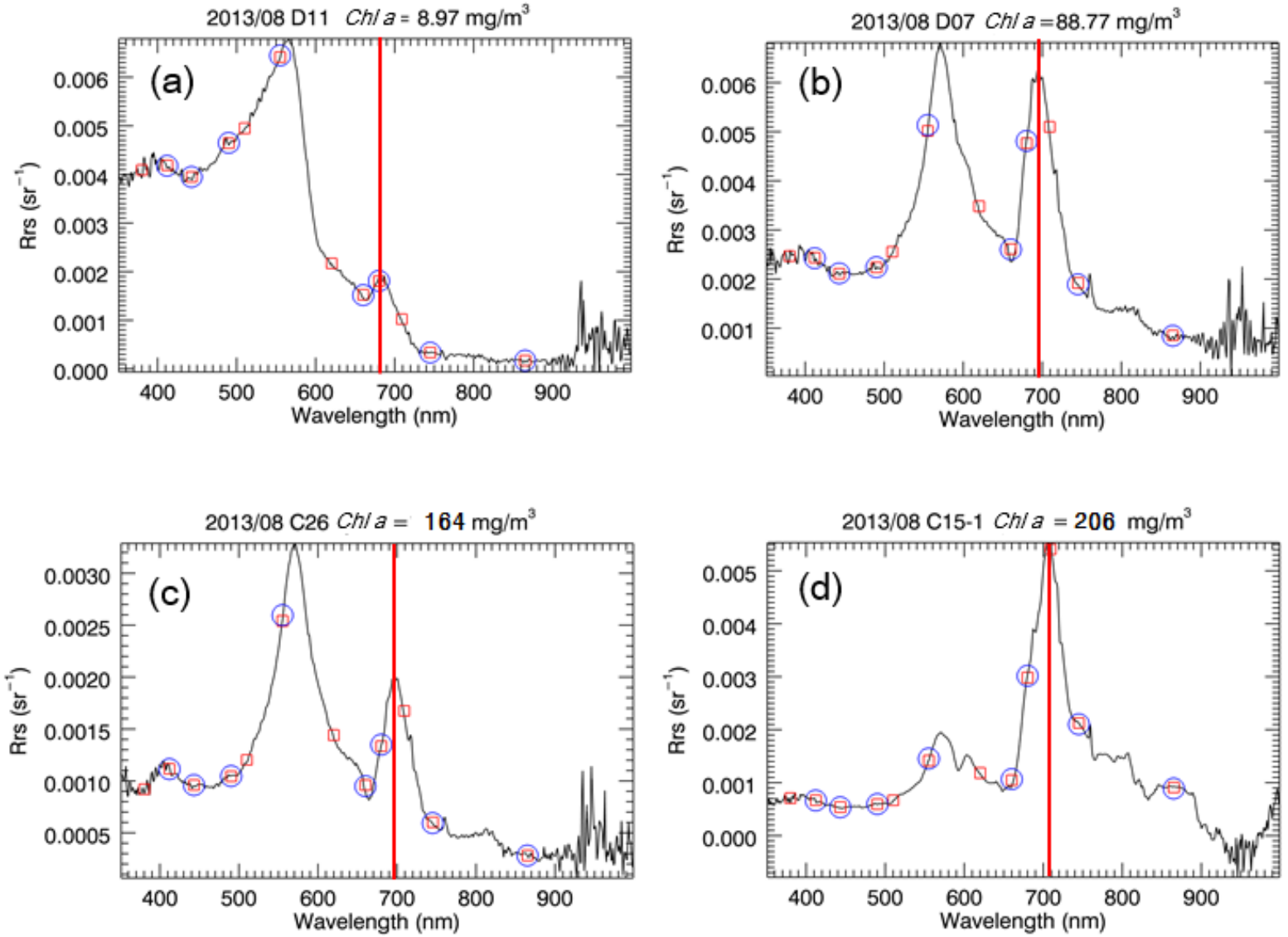


Noh et al. 2018

What determines the reflectance (or color)?

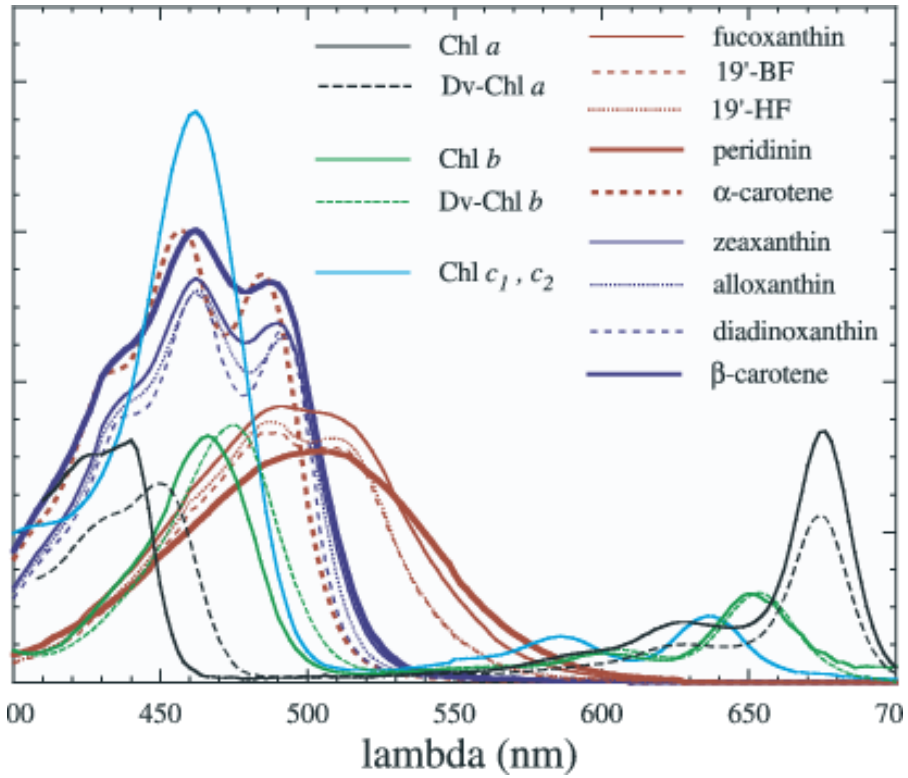
- That is …

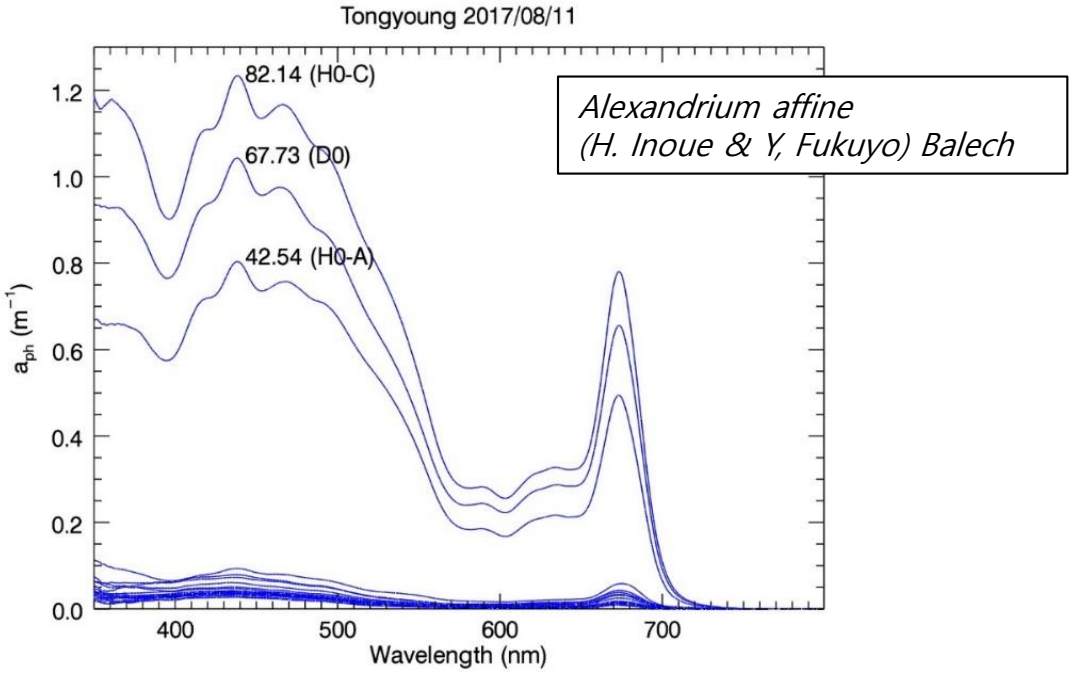
Absorption & Back-Scattering

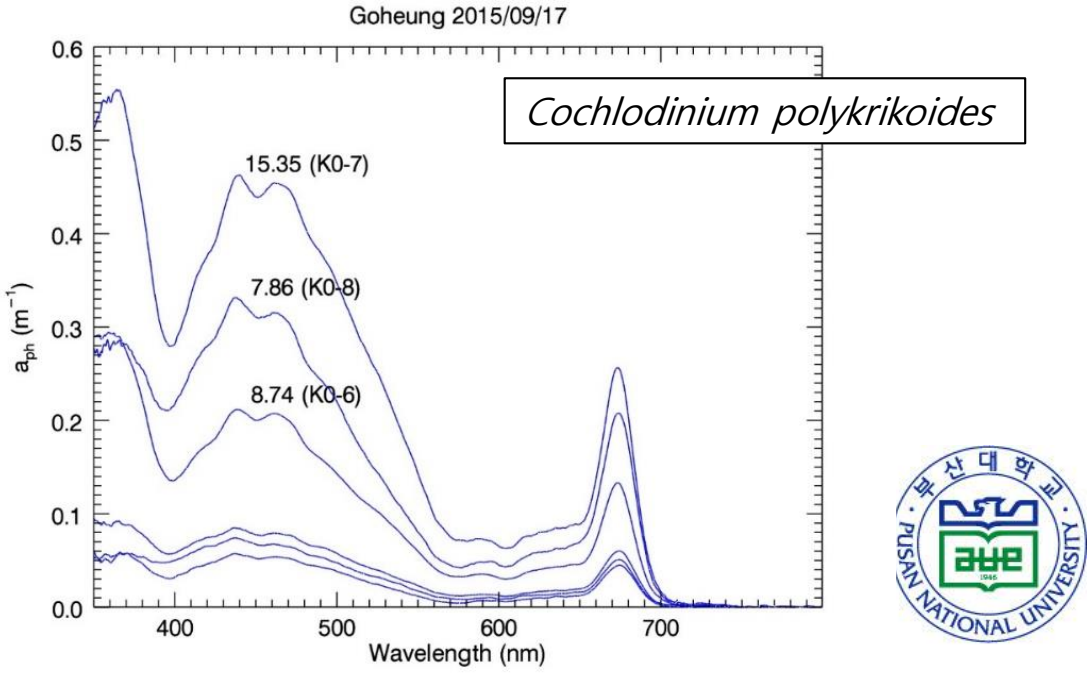
$$R_{rs} = f \frac{b_b}{a + b_b}$$

Absorption spectrum

Bricaud et al., 1996







Algorithms for Red Tide Quantification

- $\mathrm{MRI} = \frac{\mathrm{Rrs}(555) - \mathrm{Rrs}(443)}{\mathrm{Rrs}(490) - \mathrm{Rrs}(443)}$ (Lou and Hu, 2014)

- $\mathrm{RBR} = 1.009 * \left(\frac{\mathrm{R_{rs}}(680)}{\mathrm{R_{rs}}(490)}\right)^{1.314}, \log_{10} Chl_a(RBR) = \frac{\left(-0.19 + 2.51 * RBR^{1.02}\right)}{0.21 + RBR^{1.02}}$

(Noh et al., 2018)

- $\mathrm{SS} = \mathrm{nLw}(490) - \mathrm{nLw}(443) - \left(\mathrm{nLw}(555) - nLw(443)\right) * \left(\frac{490-443}{555-443}\right)$

(Tomlinson et al., 2009)

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HAB Quantification by Satellites

Ocean Color Satellites

Sensor Names	Operation	Countries
SeaWiFS	1997-2010	USA
MERIS	2002-2012	Europe
MODIS	2002-	USA
HY-1B	2007-	China
*GOCI	2010-	Korea
VIIRS	2011-	USA
Sentinel-3A	2016-	EU
SGLI	2017-	Japan
Sentinel-3B	2018-	EU
HY-1C	2018-	China
*GOCI-II	2020-	Korea
PACE	2023(est.)	USA

Moderate Resolution Satellites

Sensor Names	GSD	Countries
Landsat Series	30 m, Multispectral	USA
Sentinel-2	10~20 m, Multispectral	Europe
PRISMA	30 m, Hyperspectral	Italy

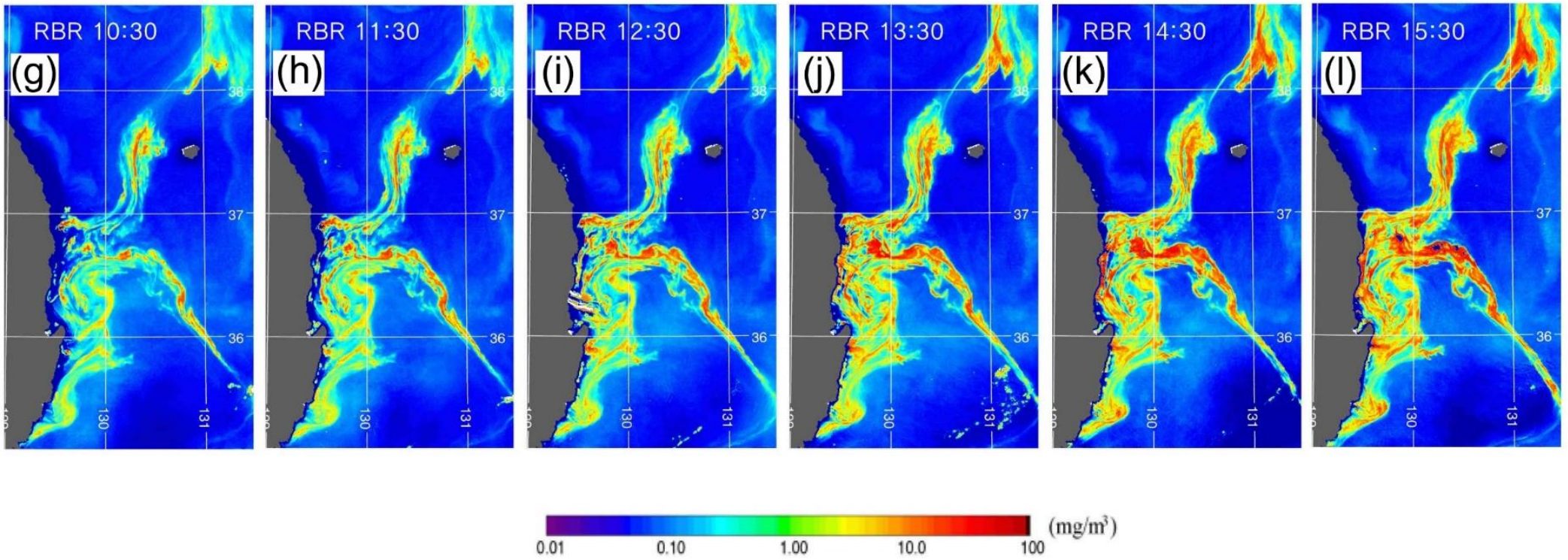
- However, polar orbiting satellites are not ideal for red tide monitoring
- because the overpass time is usually in the morning local time
- while the HAB blooms typically migrates to the surface layer in the afternoon (2~5PM)

Why Not High-Resolution Satellites?

Sensor Names	GSD	# of Bands
RapidEye Series	5 m, Multispectral	5
WorldView Series	1~2 m, Multispectral	8
Planet Scope	3 m, Multispectral	4

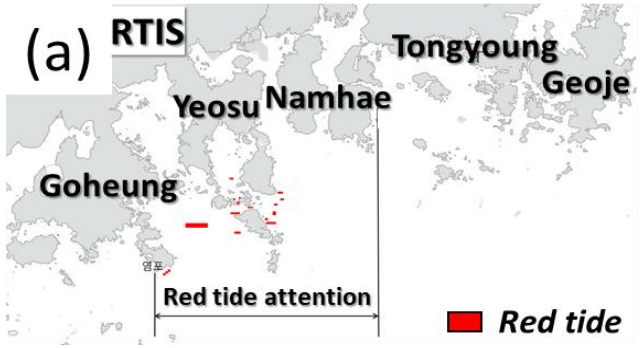
- Unlike Landsat-8 and Sentinel-2, atmospheric correction (AC) for water surface has not been implemented so far

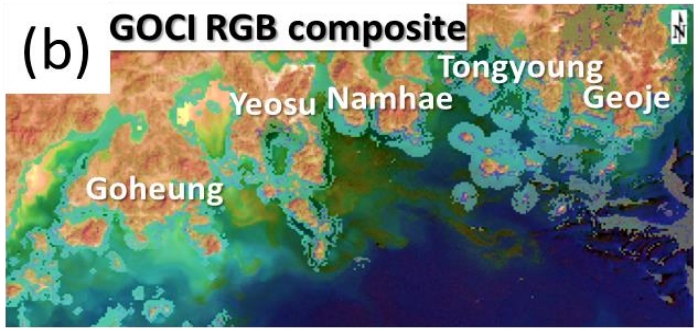
- AC is more challenging for this type of HRS' that have lower radiometric quality than Landsat and Sentinel, not to mention the OC satellites

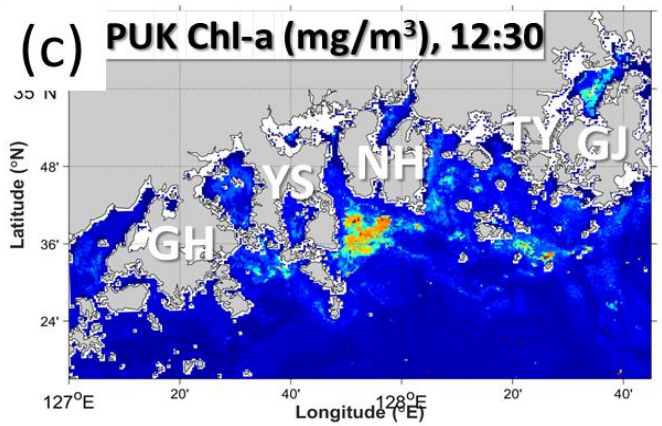


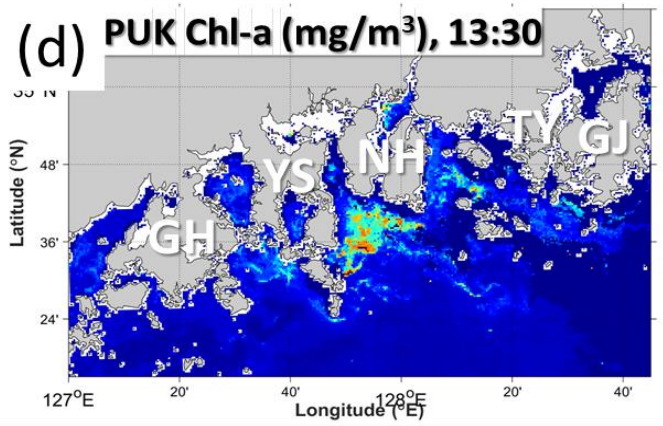
Hourly Chla estimates for HAB

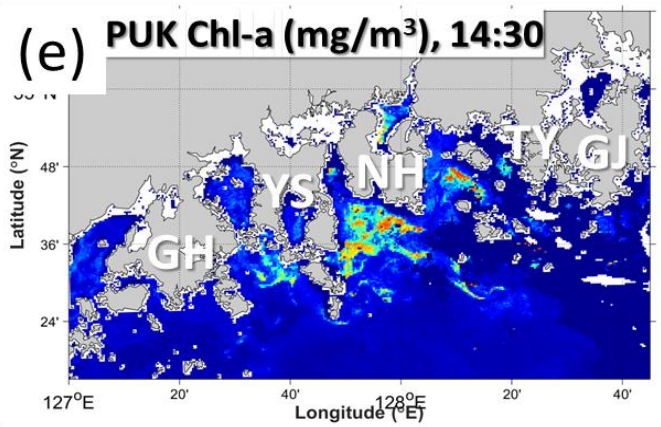
- Time: 2013/8/13
- Location : Eastern coast of Korea
- Satellite data : GOCI
- HAB algorithm : RBR (Noh et al., 2018)

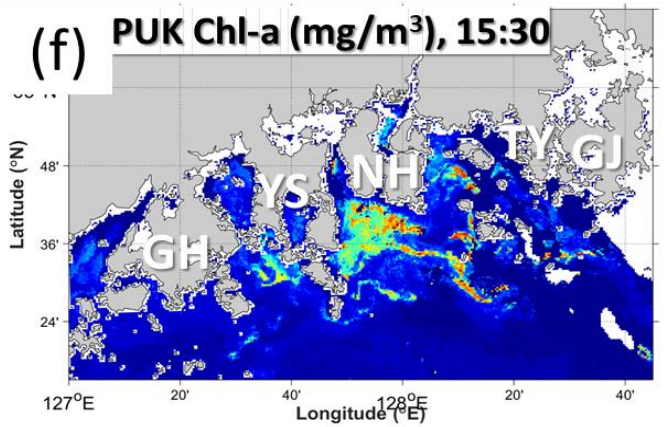












Hourly Chla estimates for HAB

- Time: 2018/7/26
- Location : Southern coast of Korea
- Satellite data : GOCI
- HAB algorithm : PUK (Kim et al., 2022)

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HAB Quantification by UAV

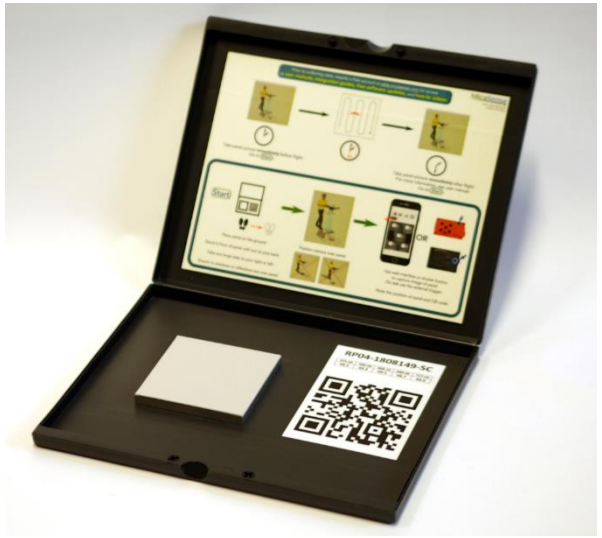
Instruments (Rededge-M)

- Micasense Rededge-M

GPS/IMU

DLS
(Downward
Irradiance Sensor)

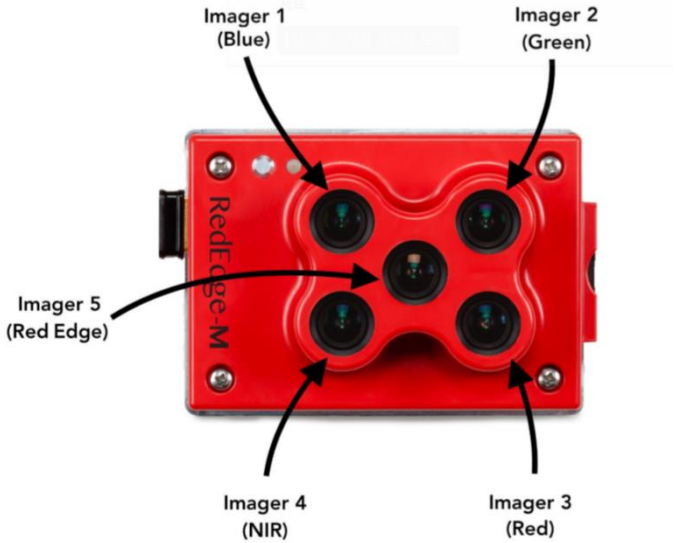
Specifications	
Weight:	150 g (5.3 oz)
Dimensions:	12.1 cm x 6.6 cm x 4.6 cm (4.8 in x 2.6 in x 1.8 in)
External Power:	5.0 V DC, 4 W nominal
Spectral Bands:	Blue, green, red, red edge, near IR (narrowband)
Ground Sample Distance:	8 cm per pixel (per band) at 120 m (~400 ft) AGL
Capture Rate:	1 capture per second (all bands), 12-bit RAW
Interface:	Serial, Ethernet, GPS
Field of View:	47.2 ° HFOV

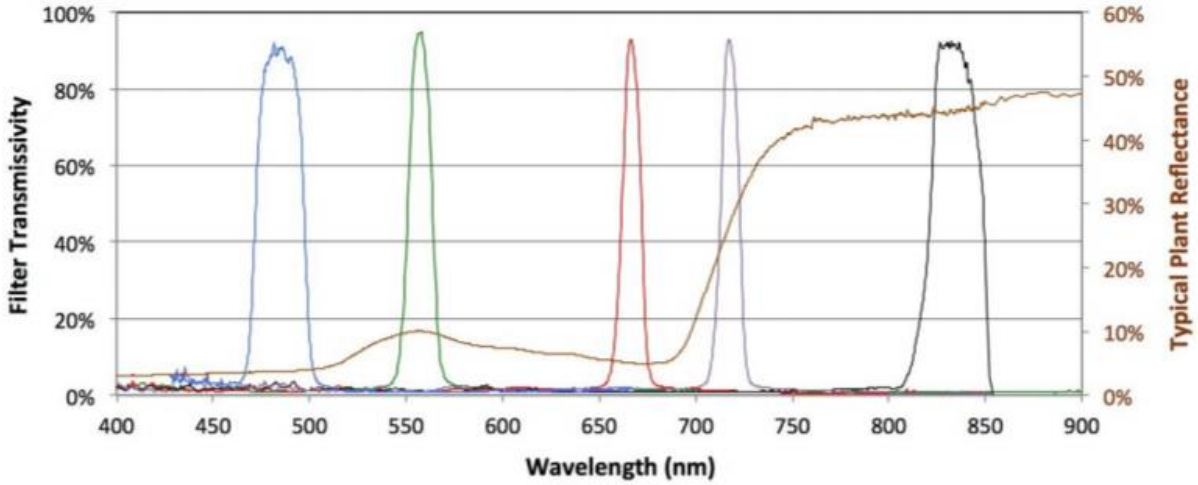


Reference Panel

Instruments (Rededge-M)

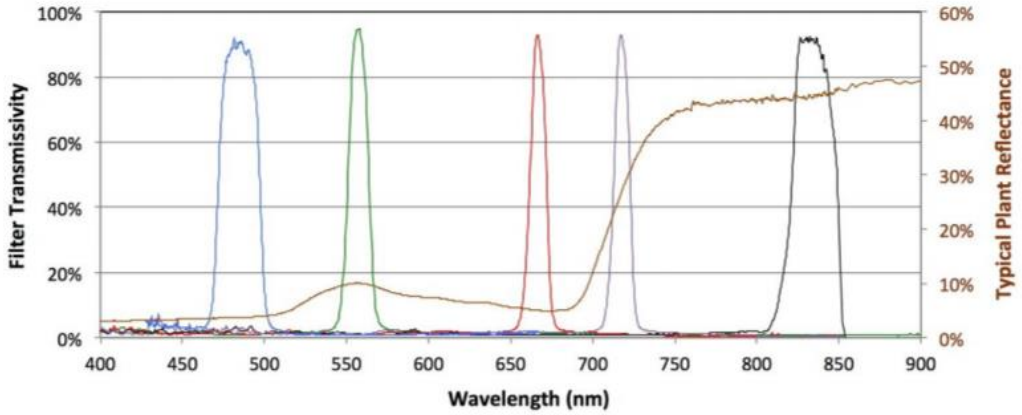
- Band composition
  - 1 Blue, 1 Green, 1 Red, and 2 NIRs
  - Shortest Blue is 475 nm
    (No 412 nm or 443 nm, which is useful in ocean color sensors)





Band Number	Band Name	Center Wavelength (nm)	Bandwidth FWHM (nm)
1	Blue	475	20
2	Green	560	20
3	Red	668	10
4	Near IR	840	40
5	Red Edge	717	10

RedEdge



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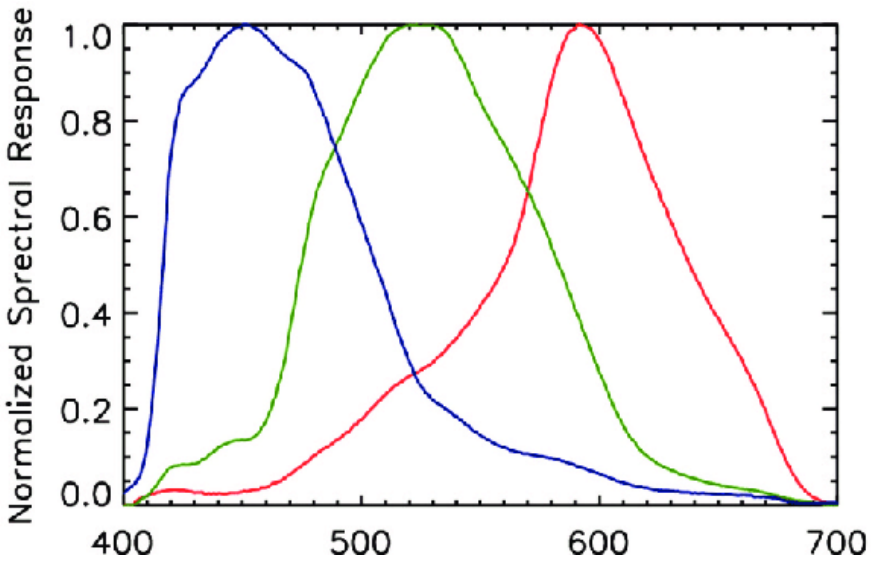
Canon EOS 50D



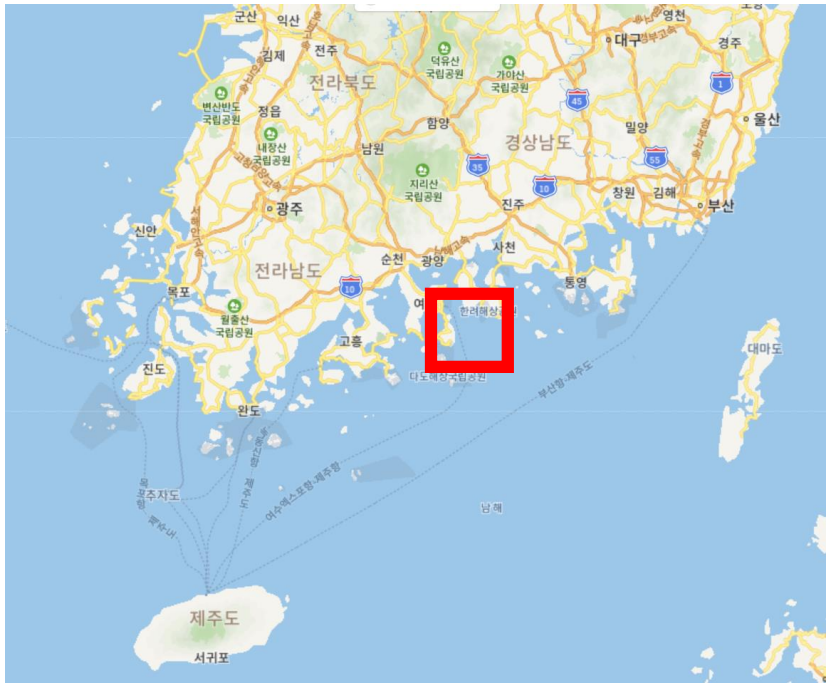
UAV with Rededge-M

- DJI Inspire
  - Zenmuth X7
  - Gopro Camera
  - Rededge-M

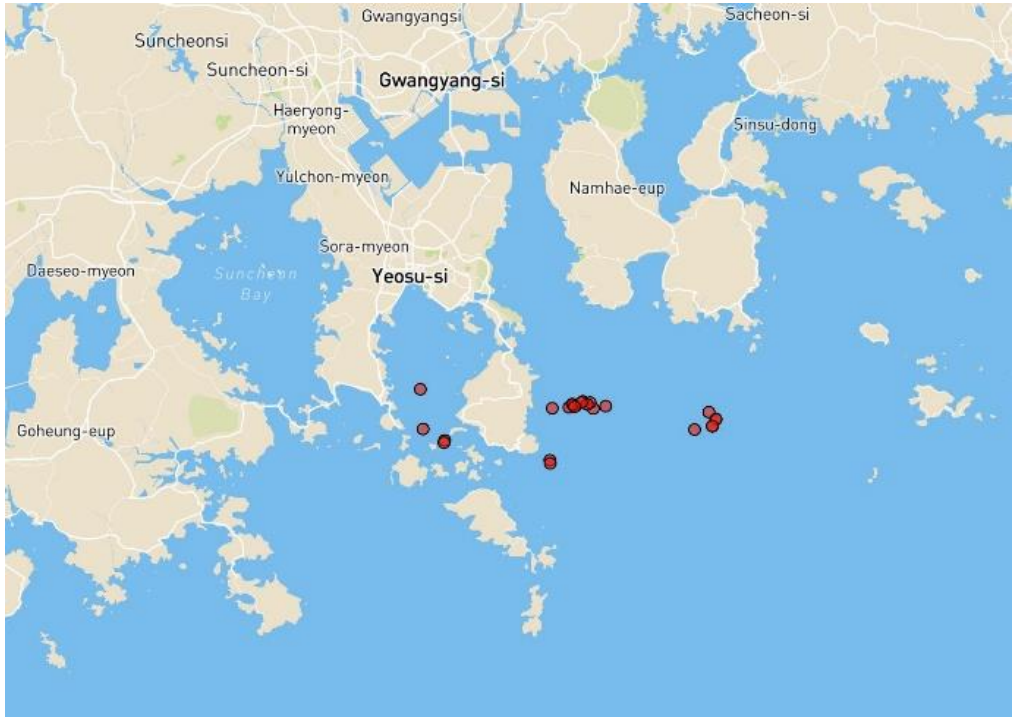
DJI RTK 300 + RedEdge MX

Field Campaign

- Time : 08/30/2019
- Location : Yeosu, Southern coast of Korea
- Image frame rate : 2 second
- R/V : Cheonnam National University
- Field campaign participation supported by KIOST




PRIMORSKY KRAI
ПРИМОРСКИЙ
КРАЙ
GOLIA
治区
LIAONING
PROVINCE
辽宁省
CE
South Korea
Japan
JIANGSU
PROVINCE
江苏省
ZHEJIANG
浙江省


Gwangyangsi
Sacheon-si
Suncheonsi
Suncheon-si
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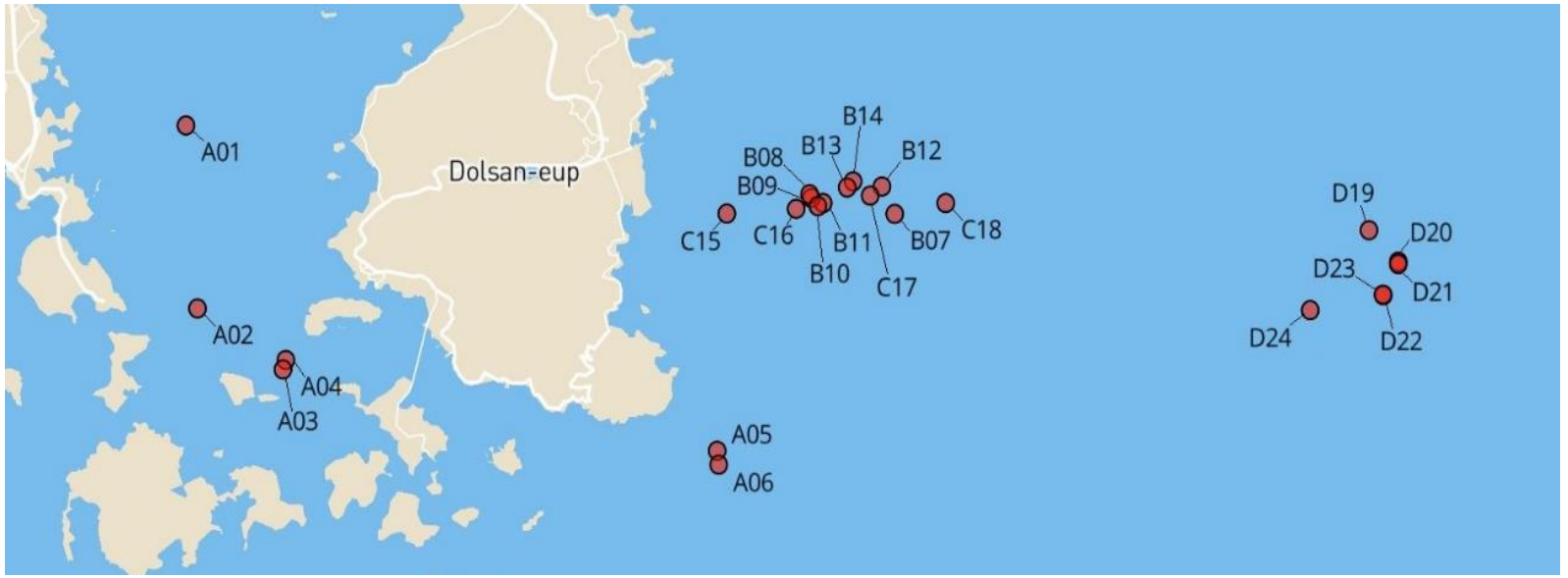
Sora-myeon
Daeseo-myeon
Yeosu-si
Suncheon
Bay
Goheung-eup


A01
Dolsan-eup
B14
B13
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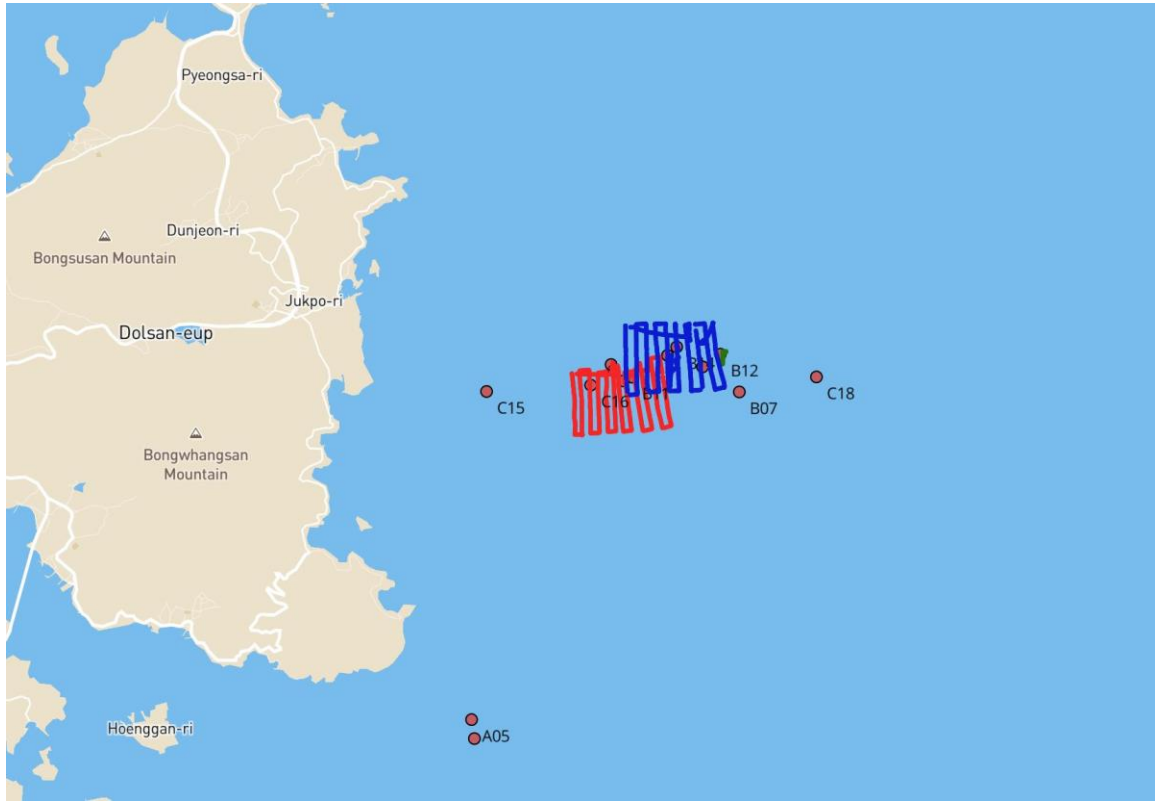
Pyeongsa-ri
Dunjeon-ri
Bongsusan Mountain
Jukpo-ri
Dolsan-eup
Bongwhangsan Mountain
Hoenggan-ri
C15
C16
B12
B07
C18
A05


B14
B13
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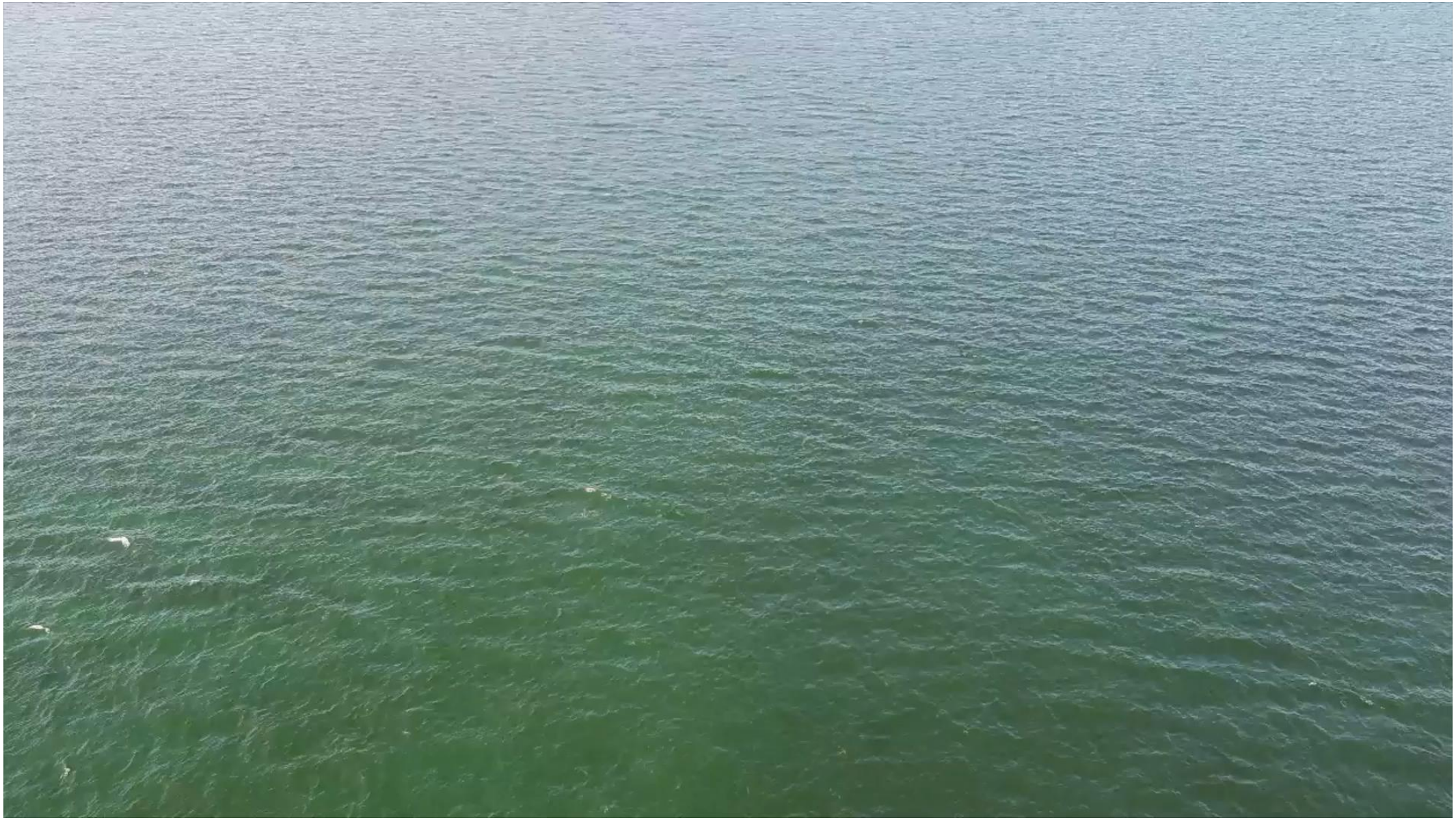
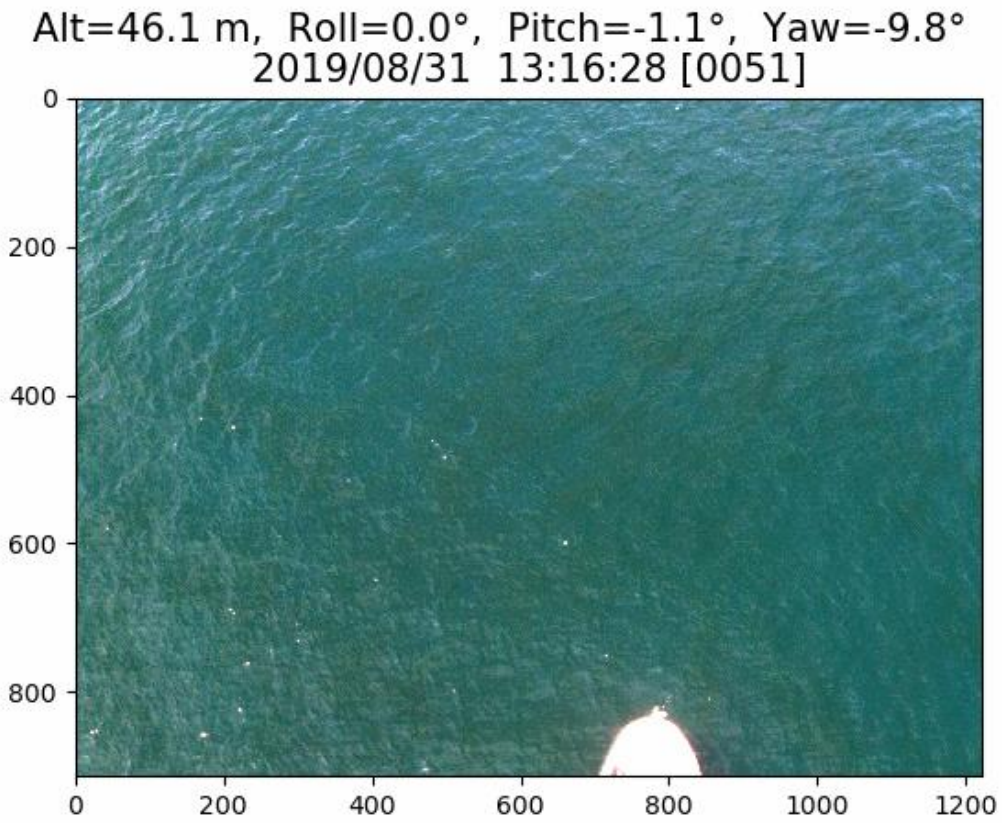
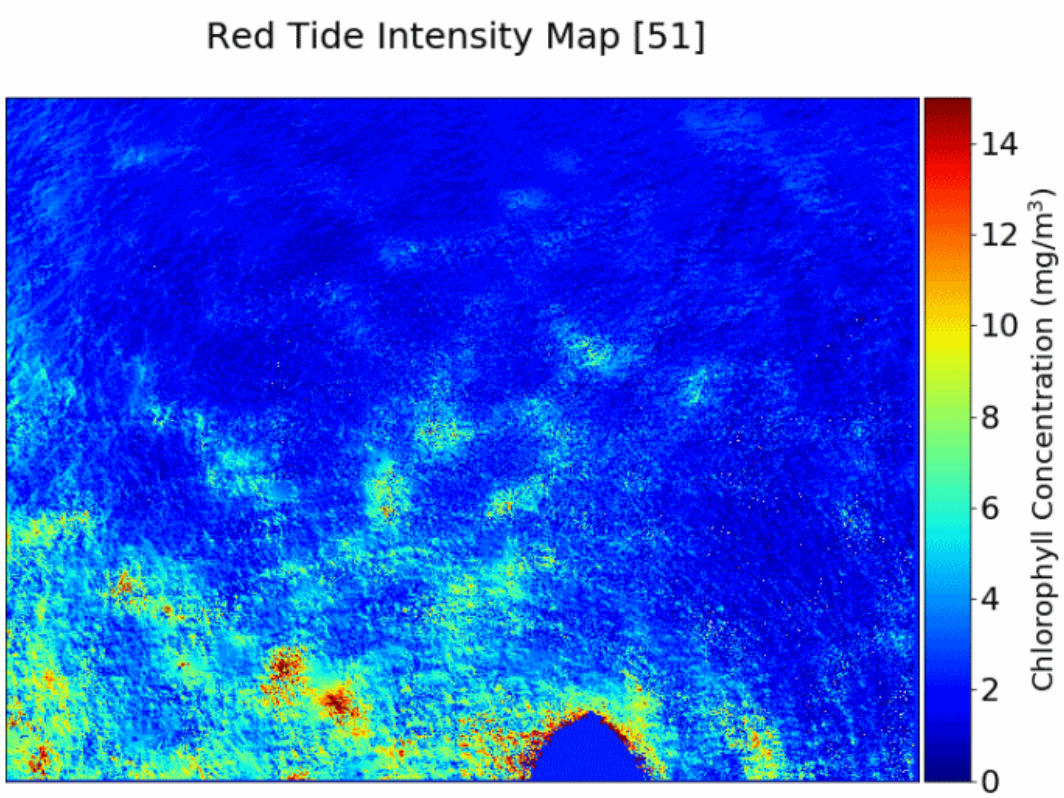


Red Tide Detection (by RBR algorithm)

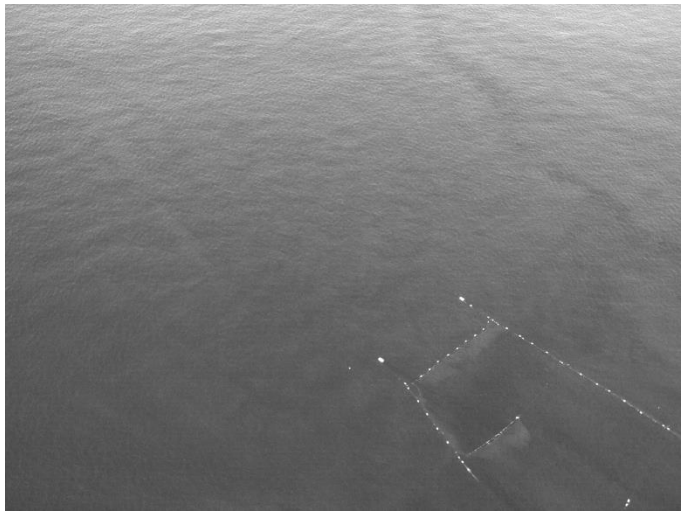
RGB Image



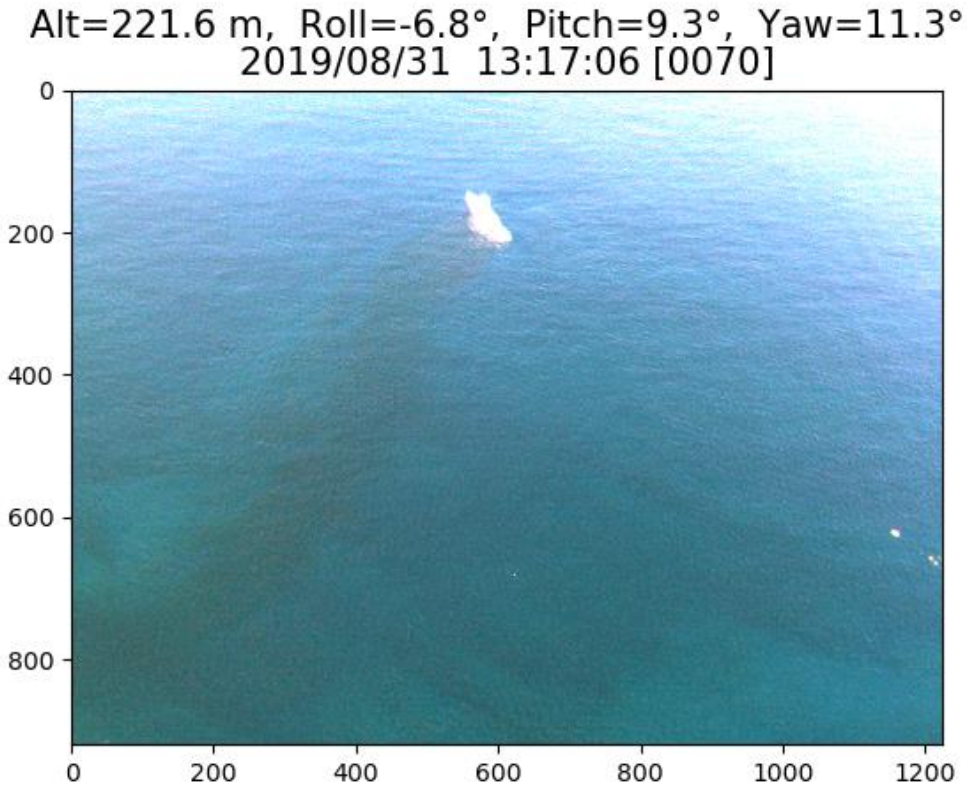
Red Tide Intensity (in Chlorophyll-a)

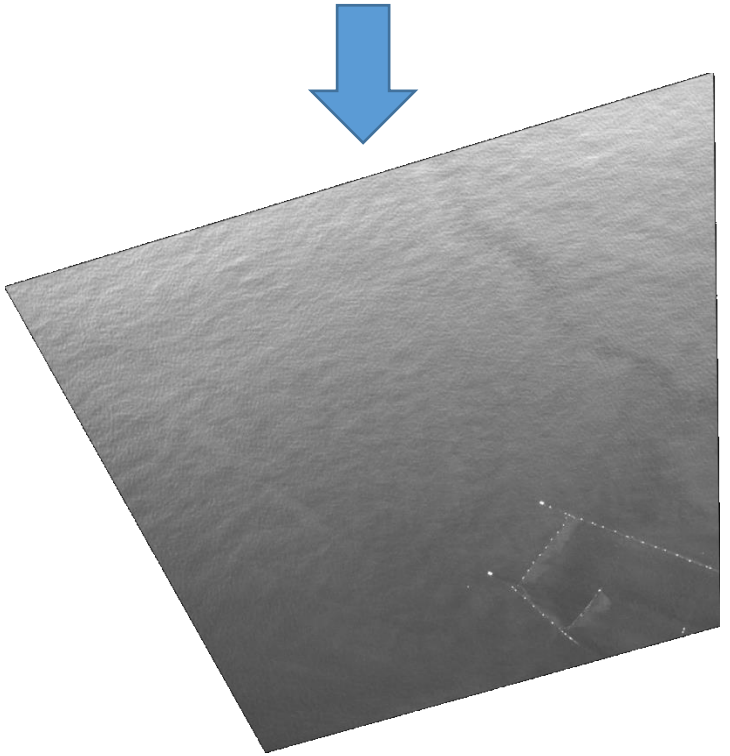


Geo-referencing image



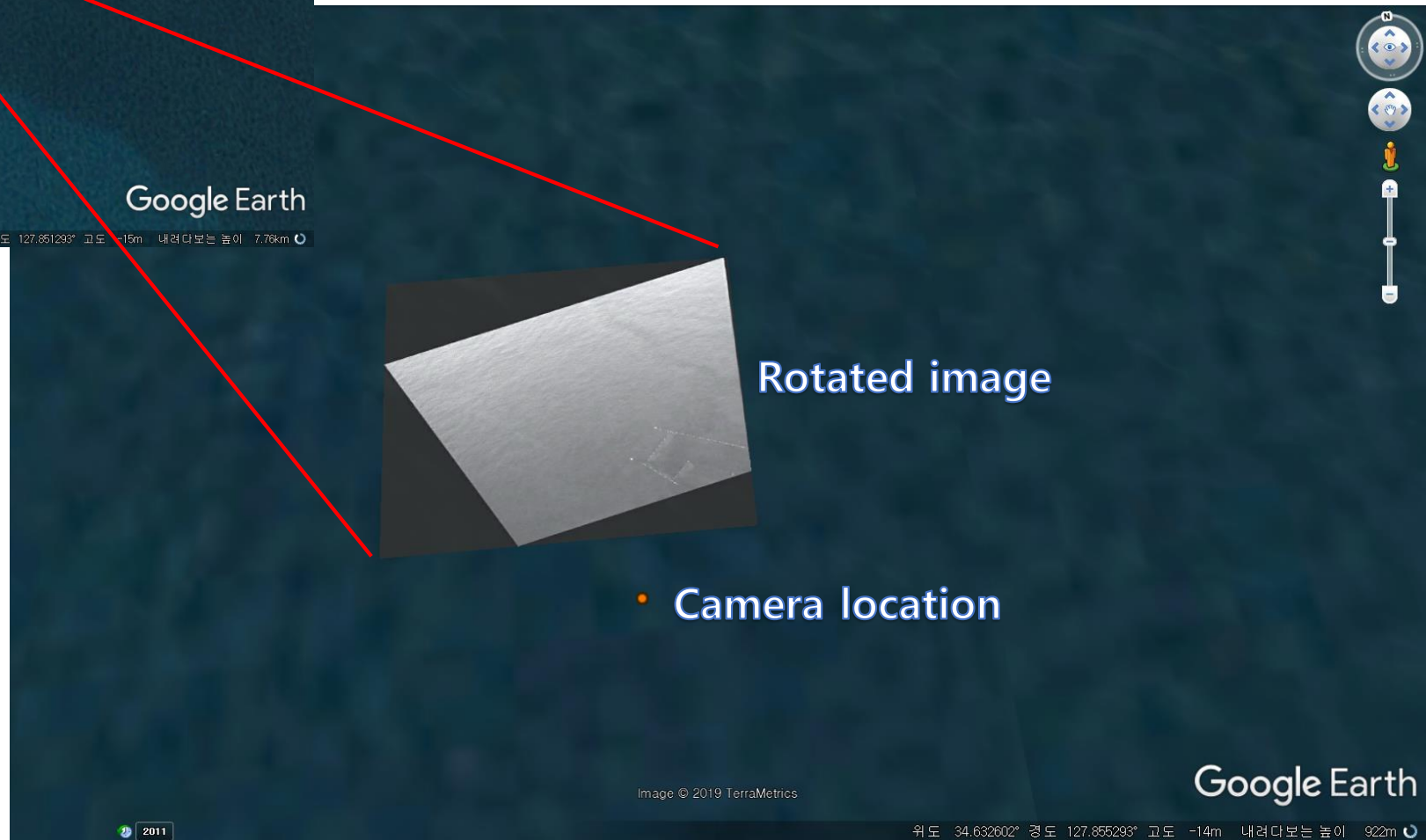
Raw image





Geo-referenced image

Image plotting in Google Earth Pro



Current Challenges in RS of HAB

- Differentiation of species
  - Distinguishing diatom blooms and harmful dinoflagellate blooms
  - Distinguishing harmful and non-harmful blooms
- Depth-resolved quantification
  - Algae are often submerged under the surface
  - Algae in the depth exhibit less-characteristic Rrs at the surface
- Extraction of pigment composition from a reflectance spectra
  - Breaking down the reflectance spectrum into the abundance of individual pigments