ESA–MOST Dragon Cooperation

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Estimation of Ulva prolifera bloom biomass and areal coverage from space

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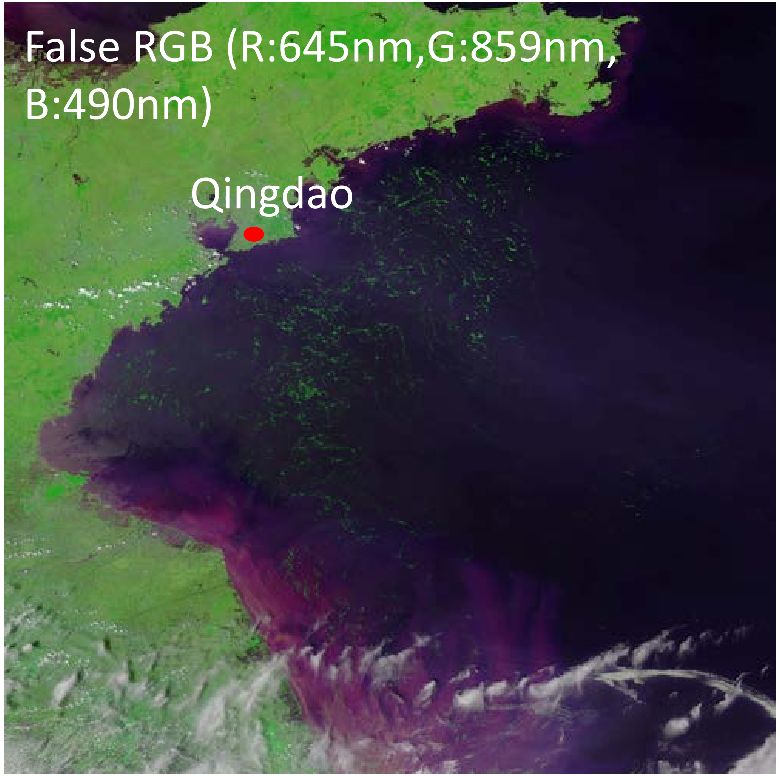
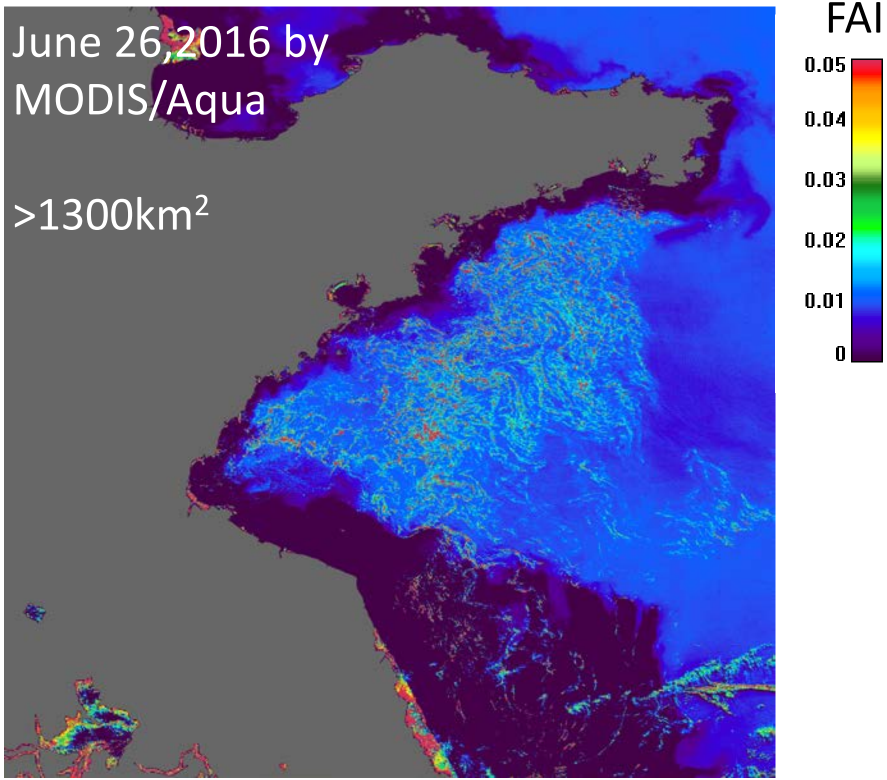
Ulva Bloom

Since 2008, *Ulva* macroalgae bloom have occurred in Yellow sea and landed in Qingdao every summer.

Ulva Bloom Monitoring





Ulva Prolifera biomass estimation from satellite observation

(Hu et al., RSE,2017)

Motivation

Many methods have been used with remote sensing data to estimate spatial distributions and temporal changes of *Ulva*, yet they all focused on the detection of presence and/or the area coverage of *Ulva*.

- NDVI *(Hu and He,2008,Liu et al, 2009)*
- NDAI (*Shi and Wang, 2009*)
- FAI (*Hu, 2009, Hu et al.2010, He et al,2011, Qi et al,2016*)
- SAI (*Keesing et al,2011,Garcia et al,2013*)
- IGAG (*Sun et al, 2013*)
- VB-FAH (*Xing and Hu, 2016*)

However,

- No study has estimated *Ulva* biomass at synoptic scale.
- Knowledge of biomass is important for ecology and management.

Objective

- Develop a model to estimate *Ulva* biomass from remote sensing
- Apply model to time-series MODIS data to study *Ulva* distributions.

Lab experiment

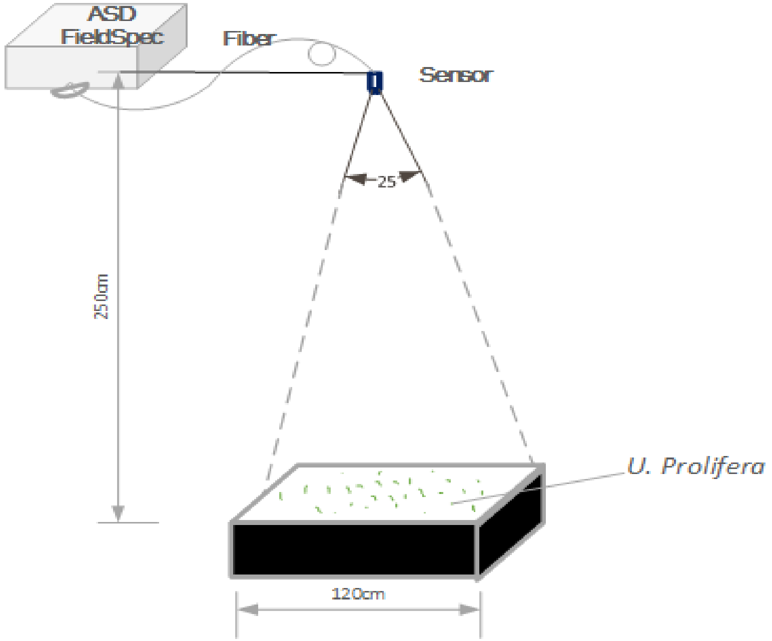
Water tank experiment was conducted to simultaneously measure the *Ulva* reflectance and biomass. Based on those data, a statistical model between biomass and reflectance was develop.

1. **Fill the water tank with seawater**

2. **Add 0.2 kg *Ulva* in the water tank;**

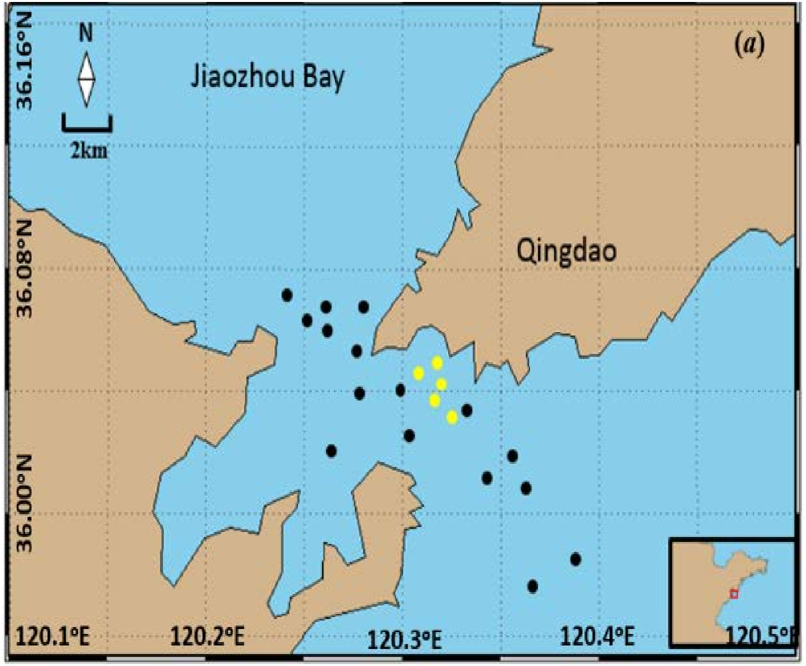
3. **Measure reflectance ten times**

4. **Repeat the above steps but each time with more *Ulva* added until reaching a total weight of 8.0 kg.**

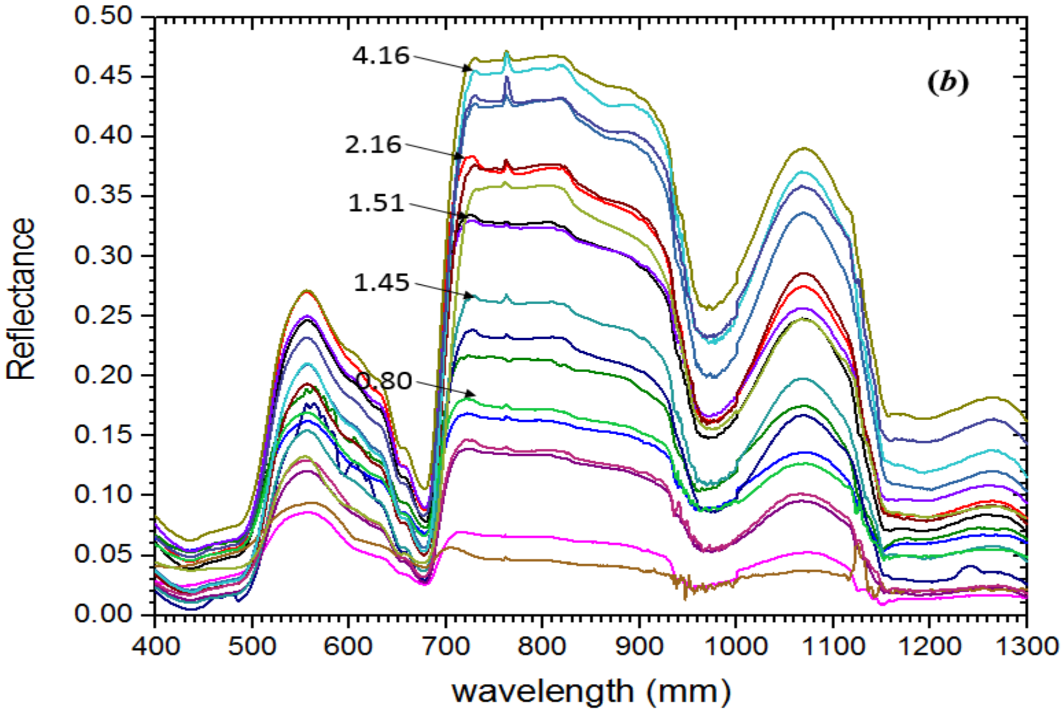


Field experiment

In situ experiments were conducted on 11 July 2013 and 16 July 2015, respectively, in coastal waters off Qingdao

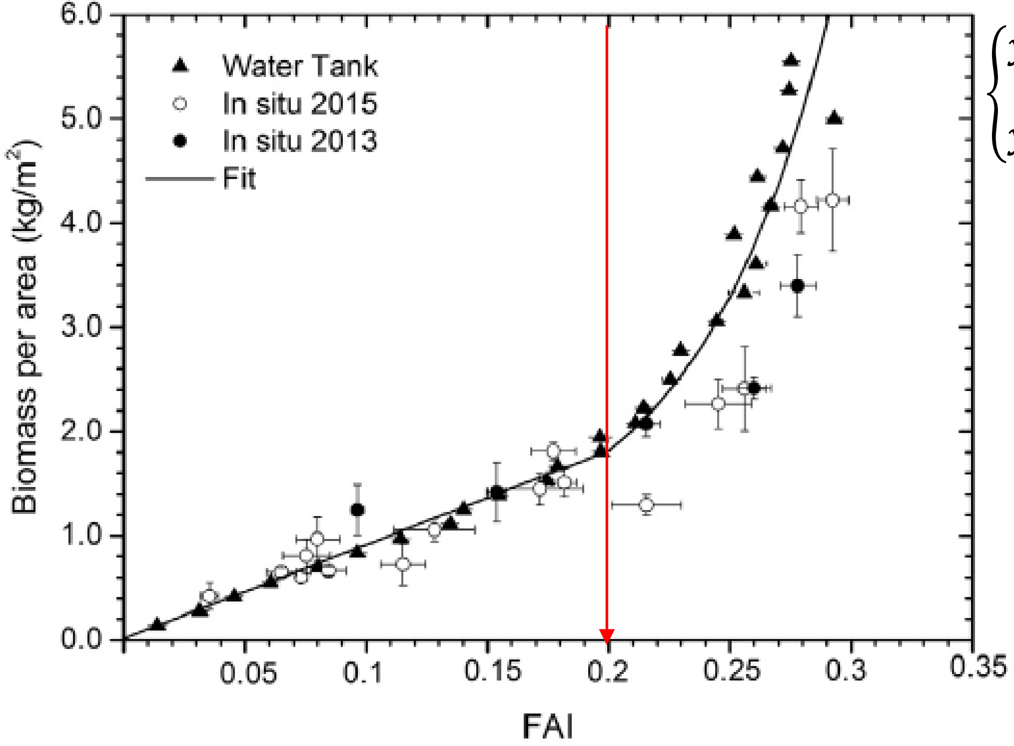


Field experiment



Reflectance spectra (dimensionless) collected from the *U. prolifera* macroalgae in the *in situ* experiment with total wet weight (kg/m^2) annotated for several selected spectra.

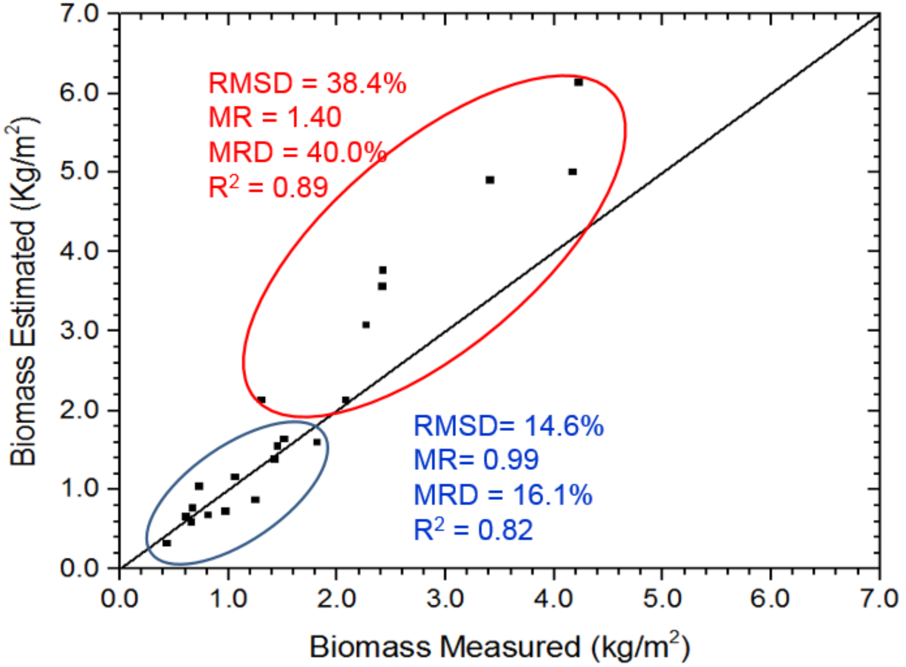
Model development

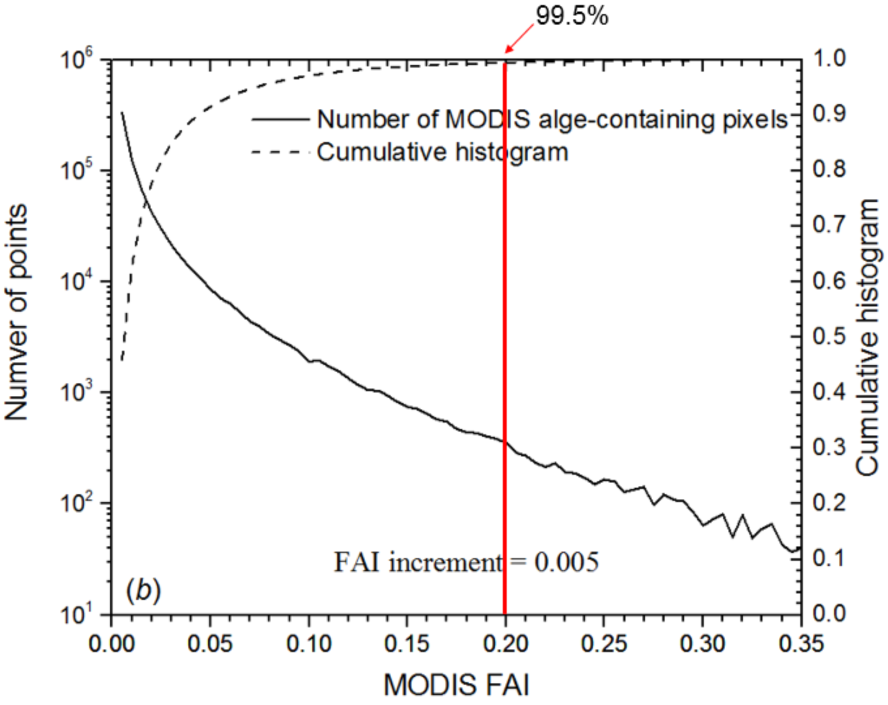


$$\begin{cases} y = 9x + 0.014 & -0.0015 < x \le 0.2 \\ y = e^{18.1(x-0.2)} + 0.814 & 0.2 < x \le 0.3 \end{cases}$$

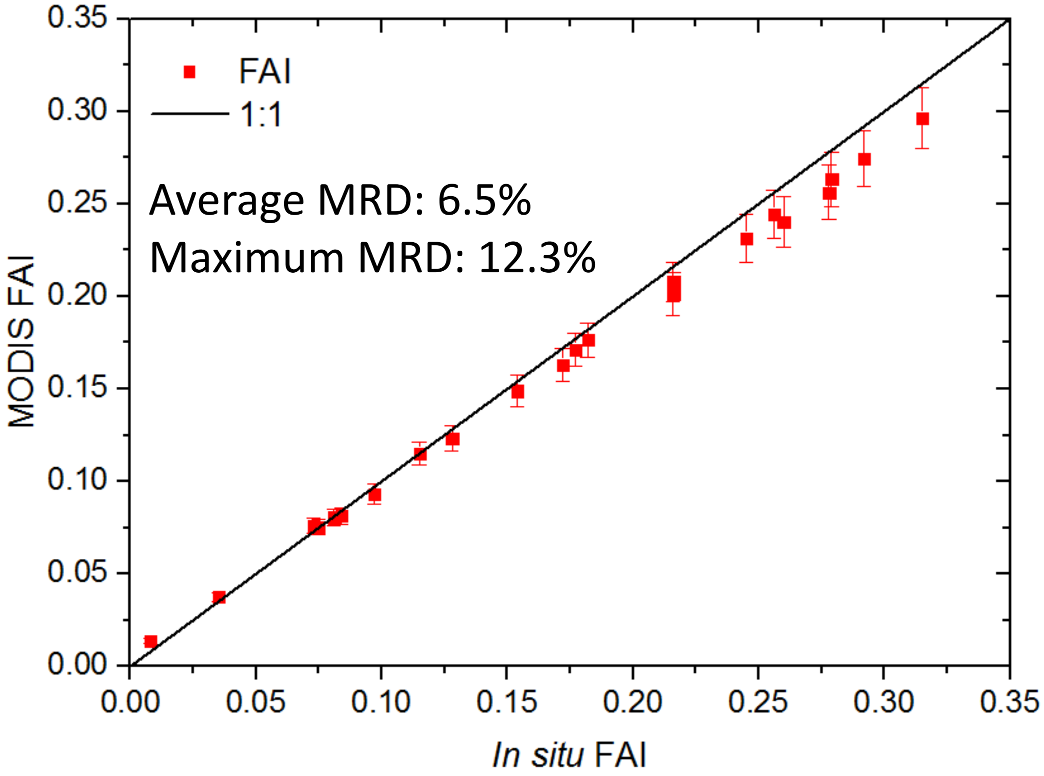
- Biomass linearly increases with FAI when FAI<0.2
- Biomass nonlinearly increases with FAI when FAI>0.2.

Model validation





Aerosol impacts



$$R_{rc}(\lambda) = R_a(\lambda) + t_0(\lambda)t(\lambda)R_{algae}(\lambda)$$

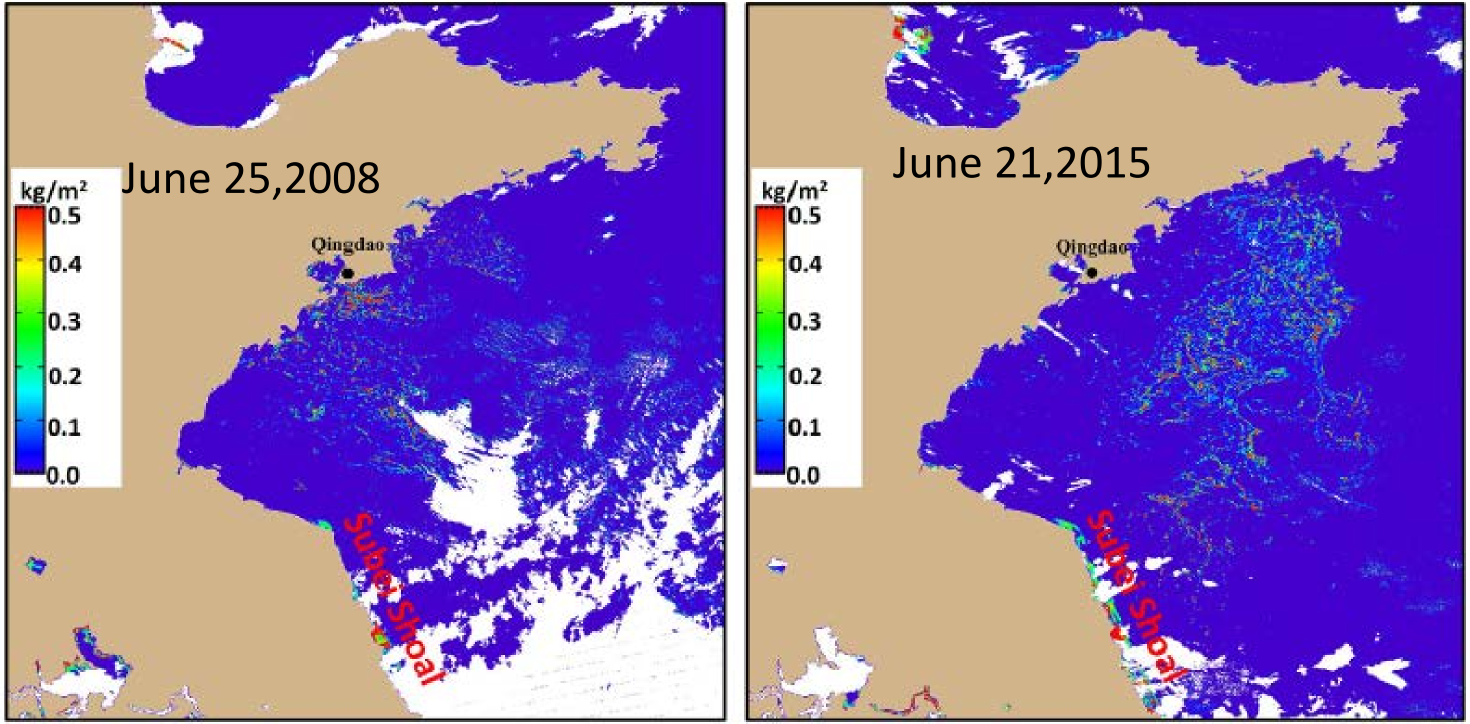
R_a: aerosol reflectance

t_0 : diffuse transmittance from sun to pixel

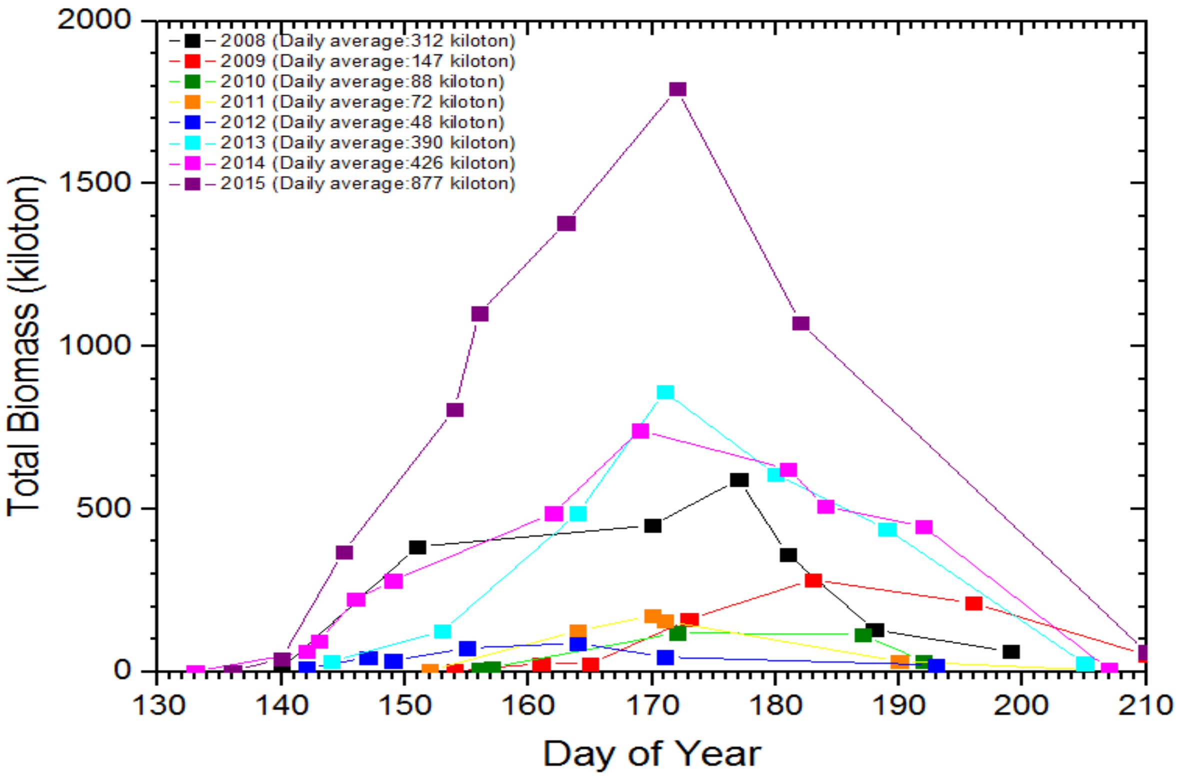
t : diffuse transmittance from pixel to sensor

R_{algae}: *Ulva* reflectance

Applied to satellite data



Applied to satellite data



Ulva Prolifera areal coverage estimation from satellite observation

(submitted to RSE)

Motivation

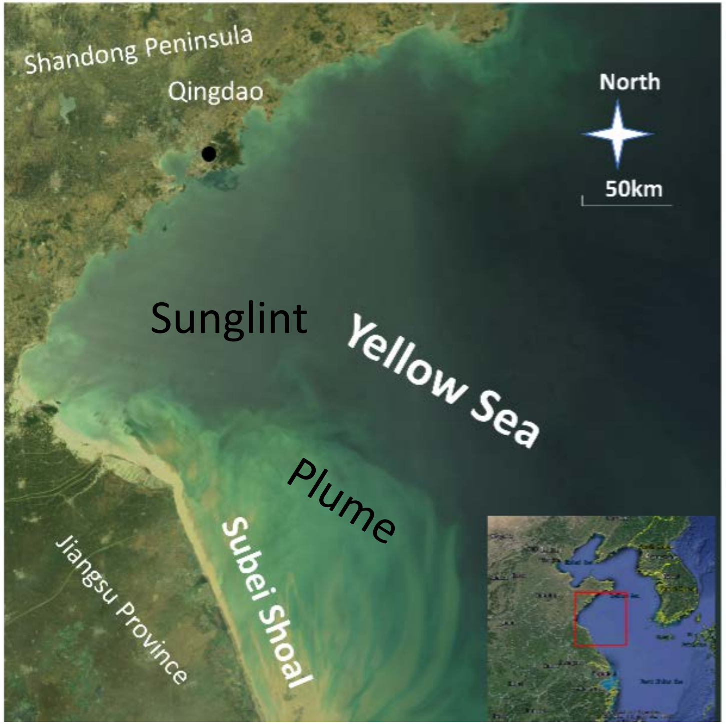
Date	Coverage(km^2)	Method	Sub-pixel coverage	Thresholds		Reference
				T_0	T_1	
2008-05-30	1200	NDVI	No	Fixed	-	Liu et al. (2009)
2008-05-30	2240	NDAI	No	Fixed	-	Shi and Wang (2009)
2008-05-30	3475	SAI(NDVI)	No	Local seawater	-	Keesing et al.(2011)
2008-05-30	1200	NDVI	No	Fixed	-	Xing et al. (2015)
2008-05-30	1500	FAI	Yes	0	0.02	Xu et al. (2014a)
2008-05-31	427.8-481.3	SAI (NDVI)	Yes	Local seawater	SAI_{max}	Garcia et al.(2013)
2008-05-30	219±30	snFAI	Yes	Local seawater	FAI_{algae}^{*}	This study
2008-05-31	257±35	snFAI	Yes	Local seawater	FAI_{algae}^{*}	This study

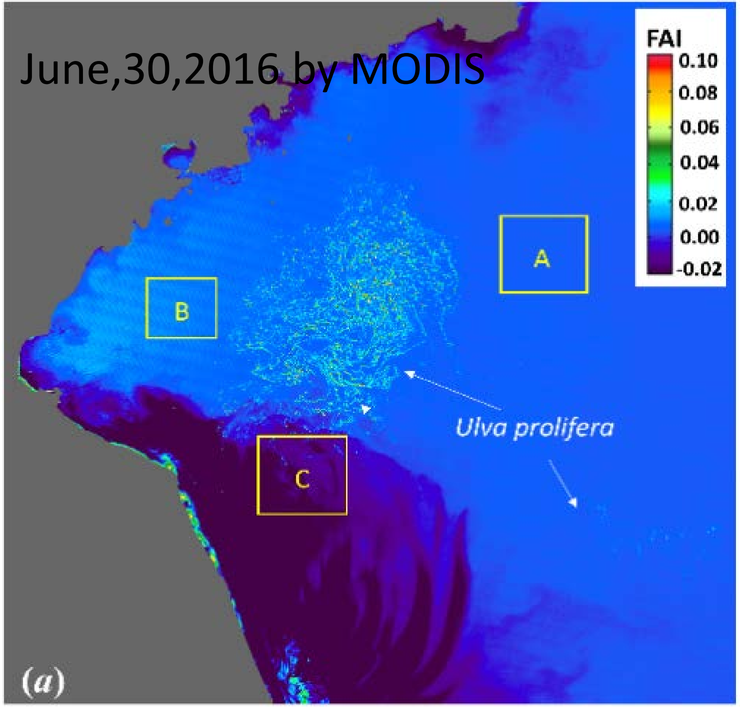
$$\alpha = \frac{FAI - T_0}{T_1 - T_0}$$

T_0: differentiate algae partial-covered pixels from sea water pixels

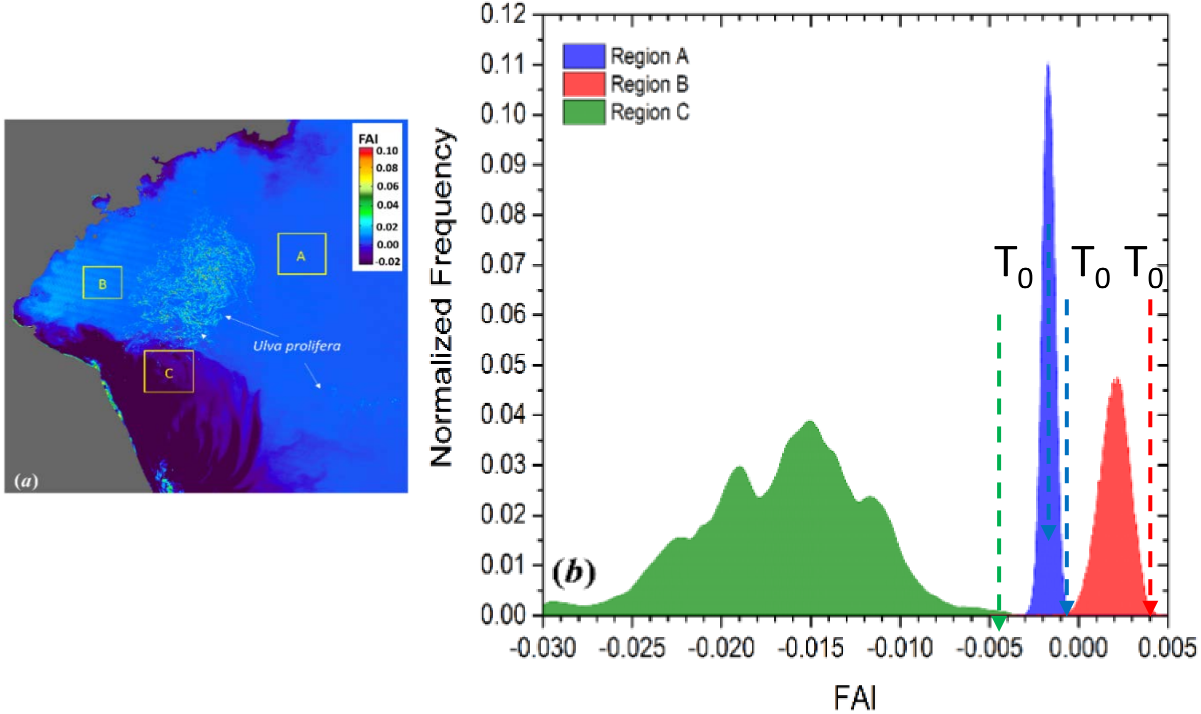
T_1: differentiate algae full-covered pixels from partial-covered pixels

Global-scene T_0





Global-scene T_0



Region A: -0.003 - 0.000
Region B: -0.001 - 0.005
Region C: -0.030 – -0.004

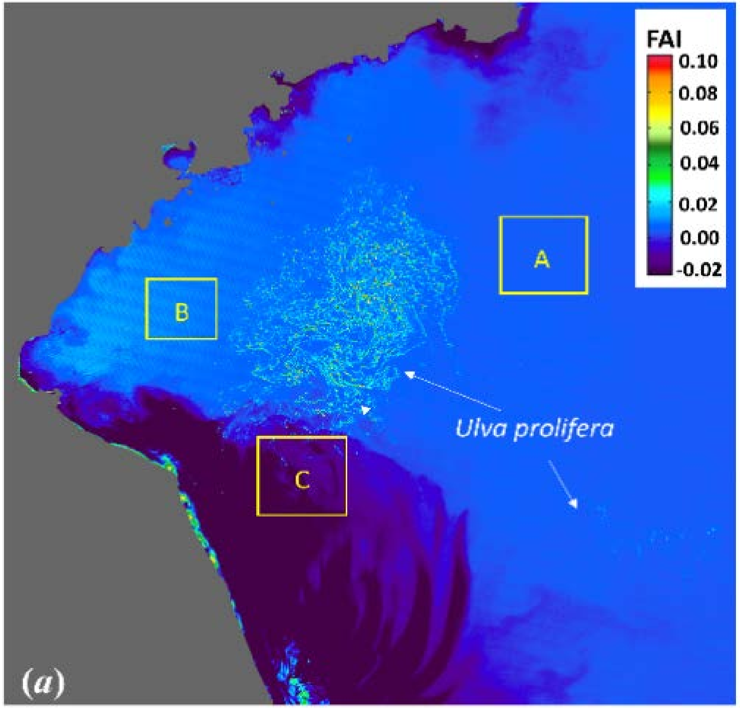
Area Coverage:

$320km^2$ if T_0=0.000
$130km^2$ if T_0=0.005

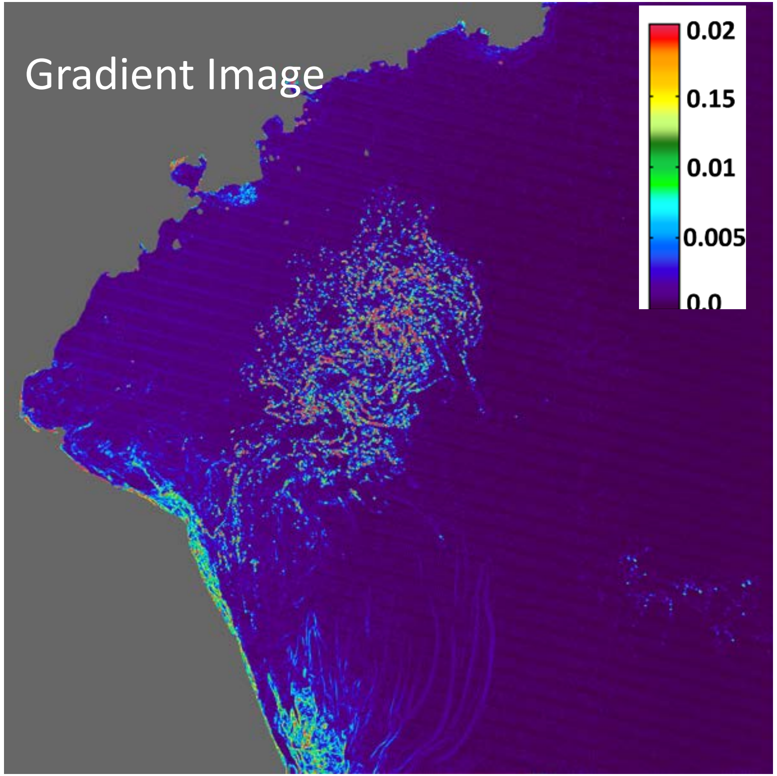
Determination of FAI_{water}

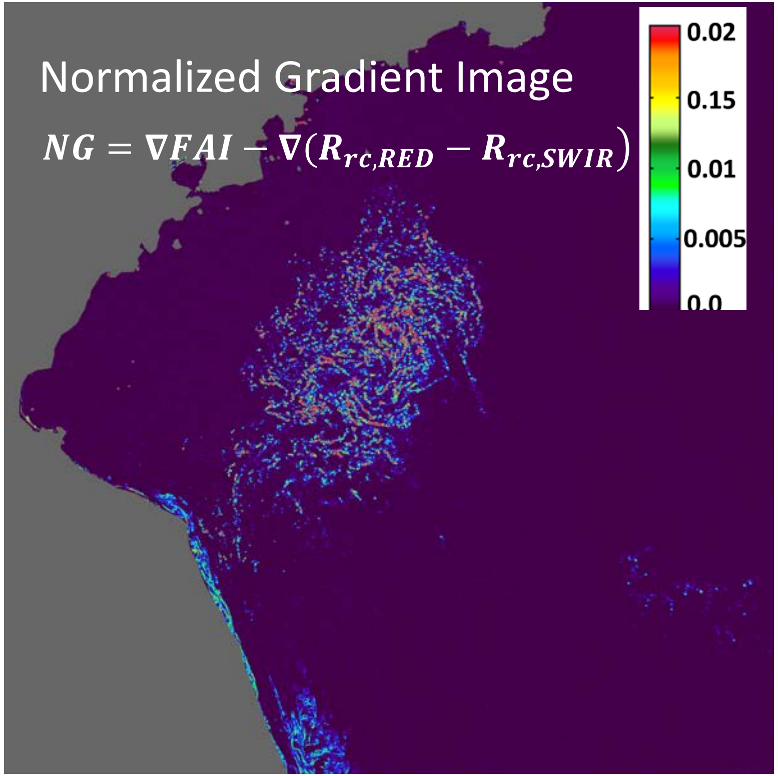
$$\alpha = \frac{FAI \quad - FAI_{water}}{FAI_{algae} - FAI_{water}}$$

$$\nabla y = \sqrt{\frac{1}{8}\sum_{j=0}^{8}\left(\frac{y_i - y_j}{x_{i,j}}\right)^2}, \quad j \neq i$$



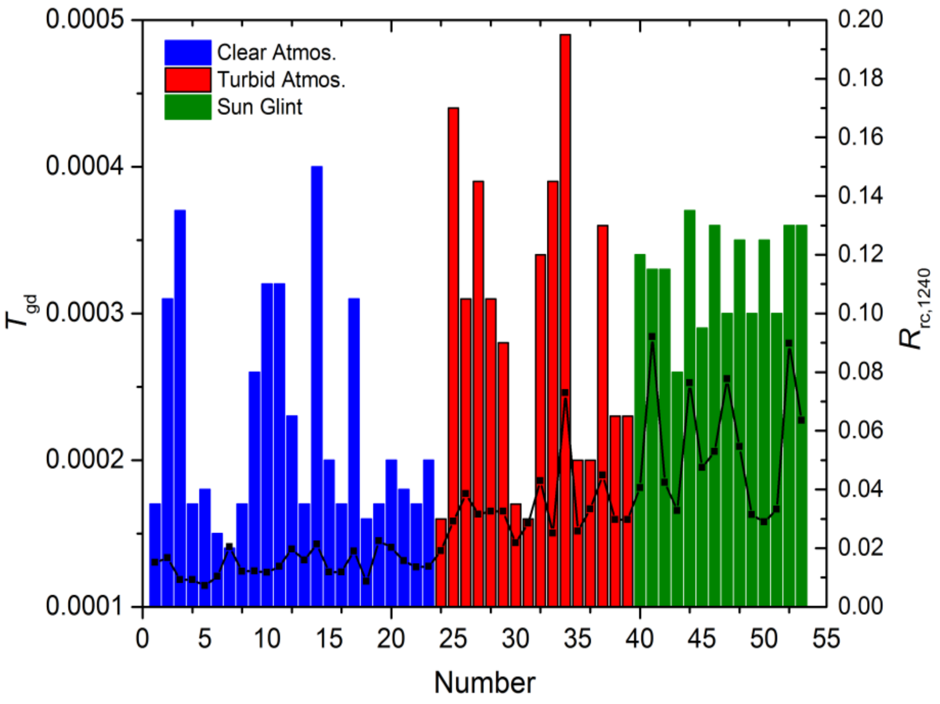
Normalized Gradient Image





Threshold T_{ng}

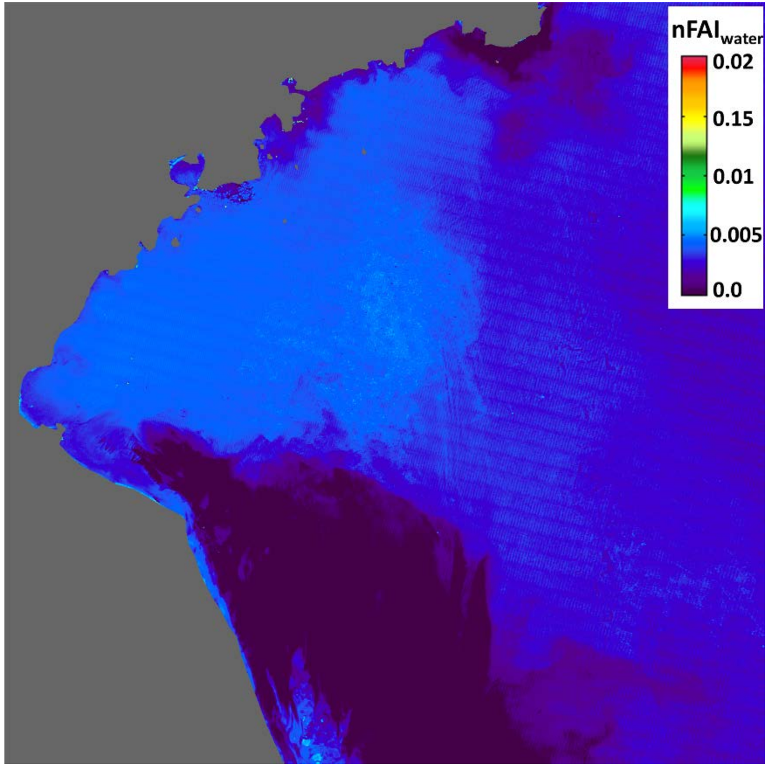
1. Select cloud-free and algae-free MODIS images
2. Calculate FAI images then NG images
3. Calculate histogram and cumulative histogram NG values of sea water pixels
4. T_{ng} is determined for each cloud-free image when cumulative histogram equals to 0.99



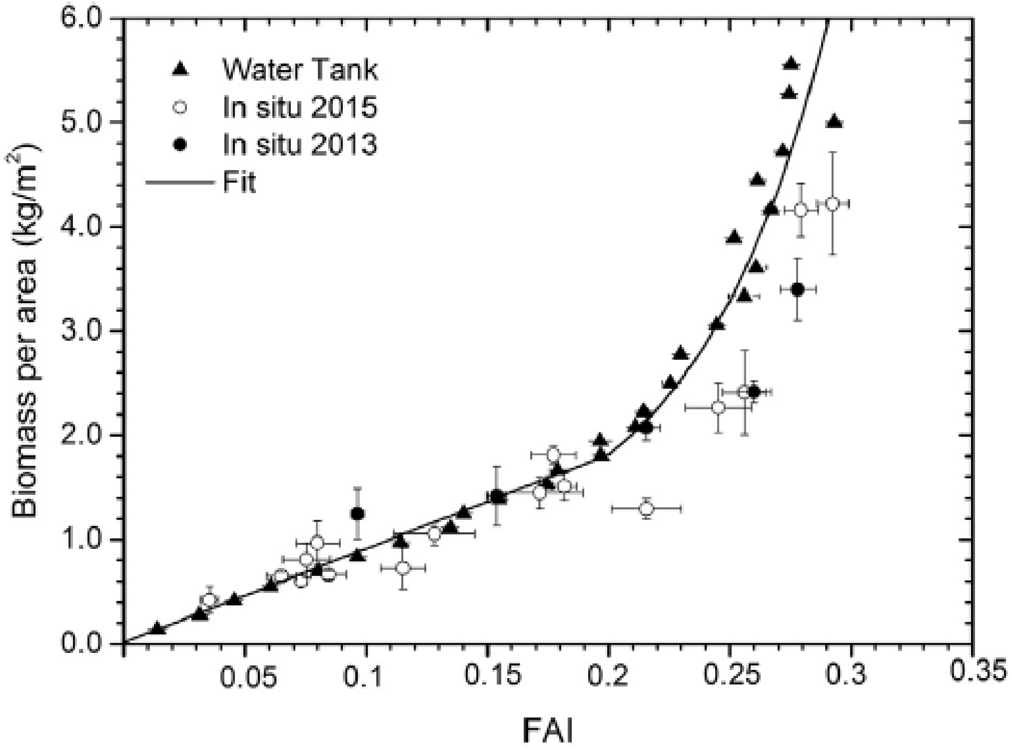
Determination of FAI_{water} Image

1. Using threshold T_{ng} to segment sea water pixels and algae-containing pixels in NG images.

2. FAI values of algae-containing pixels were filled with neighboring sea water pixels.



Determination FAI_{algae}



Hu et al, RSE, 2017

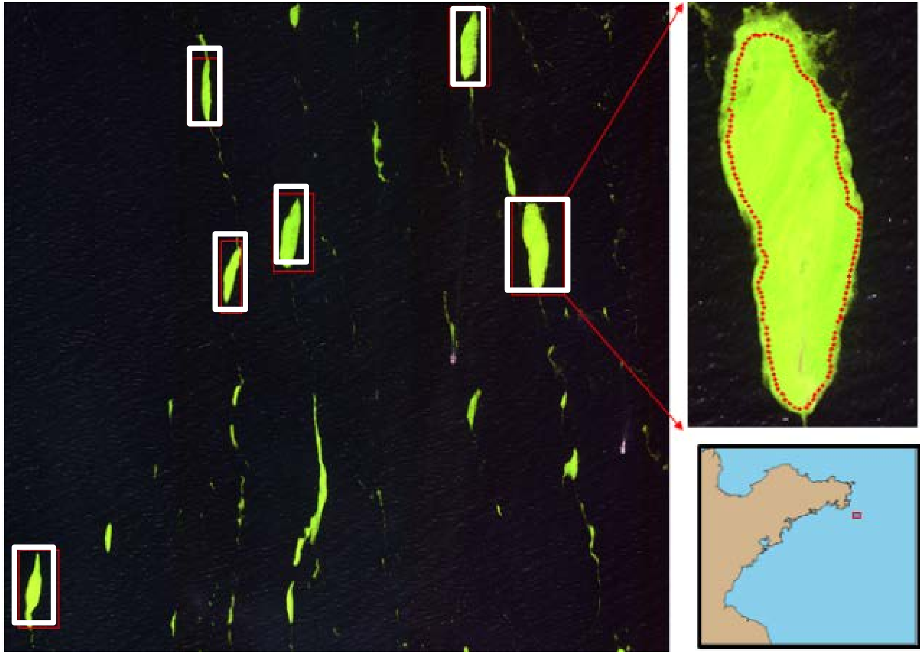
- Biomass linearly increases with FAI when FAI<0.2
- Biomass saturates with FAI increase when FAI>0.2

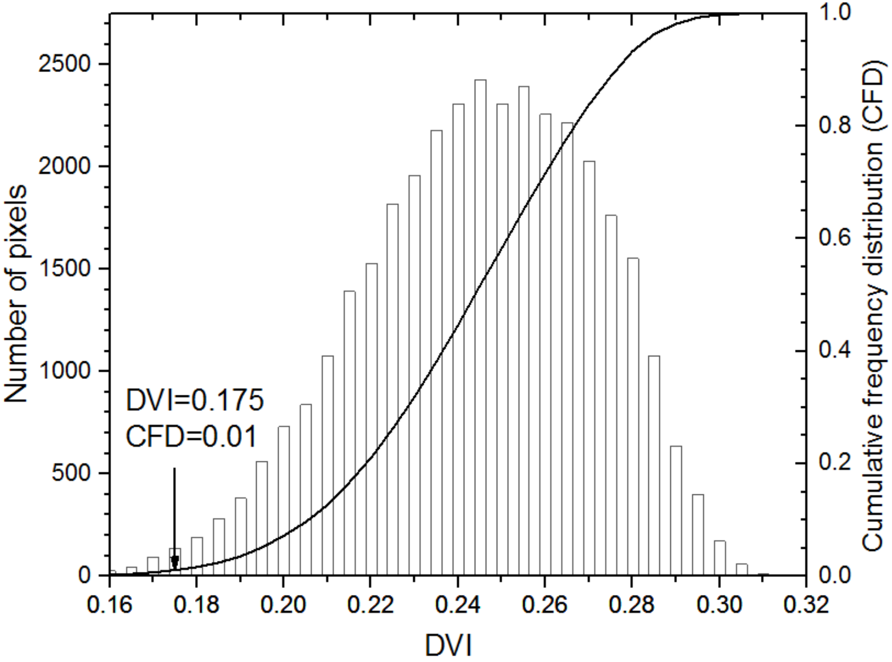
Determination FAI_{algae}

Sensor	Index	λ(nm)	$VZA = 4°$			$VZA = 57°$		
			$\tau_{a,859}$=0.03	$\tau_{a,859} = 0.16$	$\tau_{a,859} = 0.4$	$\tau_{a,859} = 0.03$	$\tau_{a,859} = 0.16$	$\tau_{a,859} = 0.4$
MODIS	FAI	645,859,1240	0.198 (0.192)	**0.194** (0.167)	0.185 (0.127)	0.199 (0.185)	0.190 (0.146)	0.172 (0.089)
VIIRS	FAI	640,865,1610	0.191 (0.185)	0.187 (0.162)	0.179 (0.123)	0.193 (0.180)	0.184 (0.143)	0.167 (0.086)
OLCI	FAI	665,865,1020	0.162 (0.123)	0.158 (0.107)	0.151 (0.081)	0.162 (0.096)	0.154 (0.075)	0.140 (0.045)
OLI	FAI	665,865,1610	0.199 (0.193)	**0.195** (0.169)	0.186 (0.128)	0.200 (0.187)	0.191 (0.147)	0.173 (0.090)
WFV/GF-1 WV-2	DVI	660,830	0.197 (0.192)	**0.192** (0.167)	0.181 (0.125)	0.198 (0.186)	0.187 (0.145)	0.166 (0.085)

DVI=$R_{rc,NIR}$-$R_{rc,RED}$

Determination FAI_{algae}

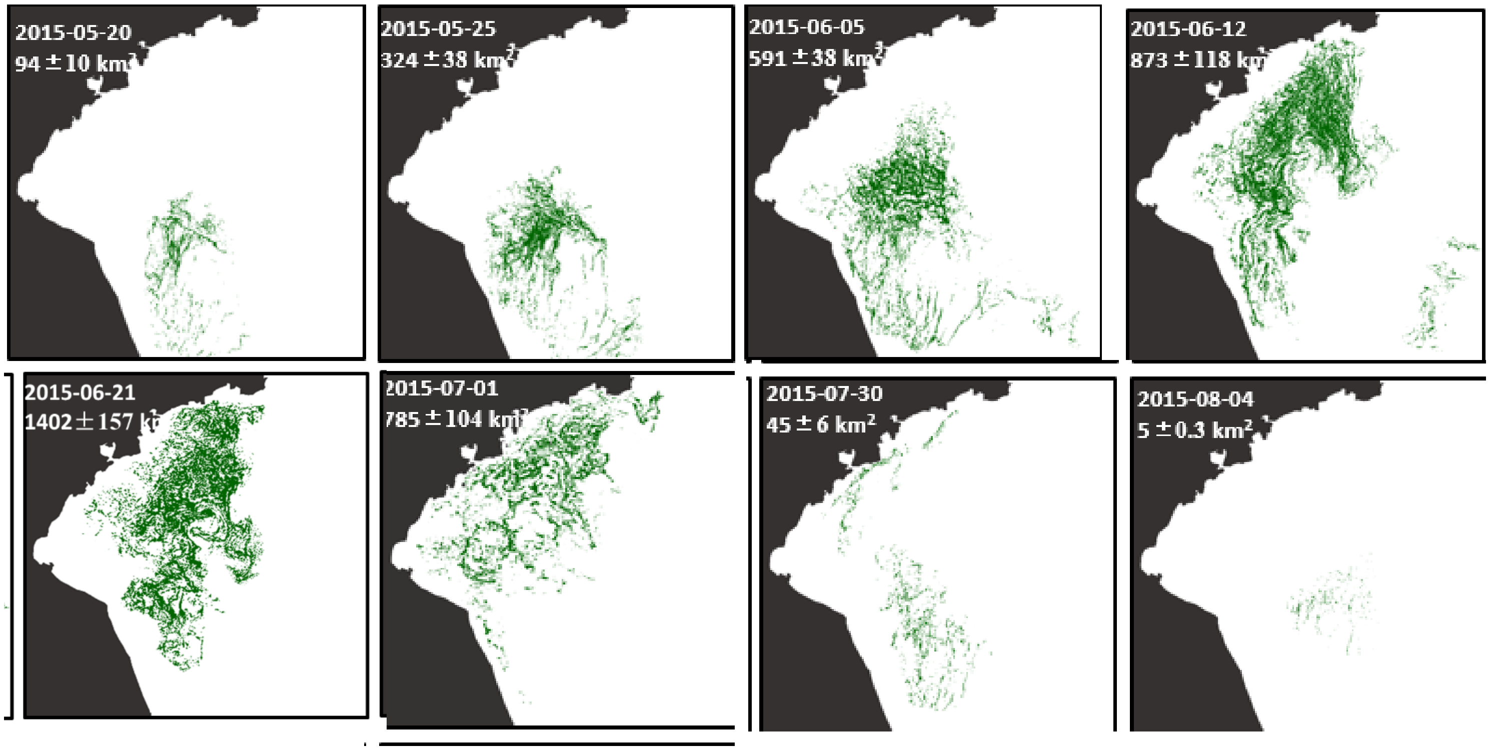




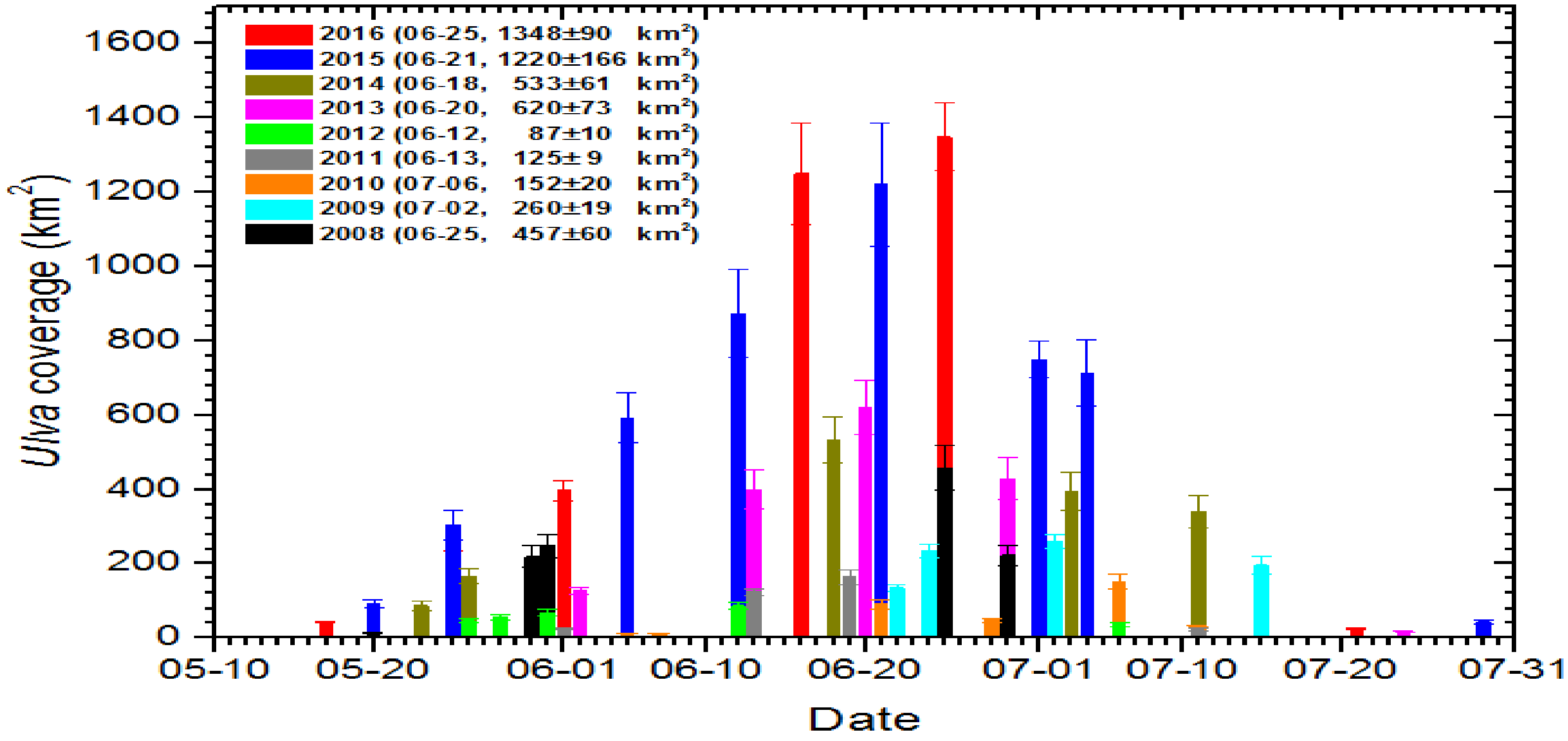
Validation

Date	Region	Ulva Coverage (km^2)				VZA		$R_{rc,1240}$	
		OLI	Resampled OLI	MODIST	MODISA	MODIST	MODISA	MODIST	MODIA
2016-06-25	35.357-35.935N,120.561-121.437E 35.215-36.612N,121.425-122.170E	225 262	245 298	201 (-10.6, -14.3) 227(-13.4, -21.1)	247 (9.6, 0.8) 298 (13.4, -0.3)	62 64	12 19	0.022 0.021	0.026 0.020
2016-06-25	34.525-35.450N,120.378-121.453E	267	271	213 (-12.3, -15.9)	259 (-2.9, -4.2)	63	11	0.017	0.020
Date	Region	WFV	Resampled WFV	MODIST	MODISA	MODIST	MODISA	MODIST	MODIA
2013-06-13	34.735-35.043N,120.487-120.987E	86	92	86 (0.7, -5.5)	85 (-1.0, -7.1)	45	48	0.019	0.018
2014-06-18	35.426-35.652N,120.015-120.588E	14	15	13 (-6.2, -13.0)	15 (9.6, 1.6)	58	29	0.017	0.013
2014-06-18	34.518-35.242N,120.483-121.385E	192	206	215 (12.0, 4.0)	214 (11.6,3.7)	56	32	0.017	0.015
2015-05-24	34.141-34.486N,121.042-121.555E	71	68	62 (-12.4, 4.0)	-	55	-	0.010	-
2015-06-06 **2015-06-27**	35.003-35.668N,120.865-122.156E 36.539-36.793N,121.686-122.291E	136 42	154 46	133 (-2.0, -13.2) 50 (19.1, 9.1)	- 46 (9.9,0.7)	14 42	- 24	0.096 * 0.014	- 0.043
2015-06-27	34.879-35.342N,120.648-121.091E	35	38	39 (10.9, 3.8)	-	40	-	0.016	-
2015-07-04	35.619-36.339N,120.927-122.155E	250	274	293 (17.0, 6.7)	301 (20.5, 9.9)	49	18	0.014	0.164*
2015-07-08	36.328-36.669N,121.285-121.774E	72	75	71 (-2.1 -6.0)	74 (2.9, -1.3)	11	51	0.137*	0.015
2016-06-01	34.490-35.138N,121.074-121.464E	85	91	95 (11.7, 4.8)	78 (-8.5, -14.1)	1	59	0.060*	0.031

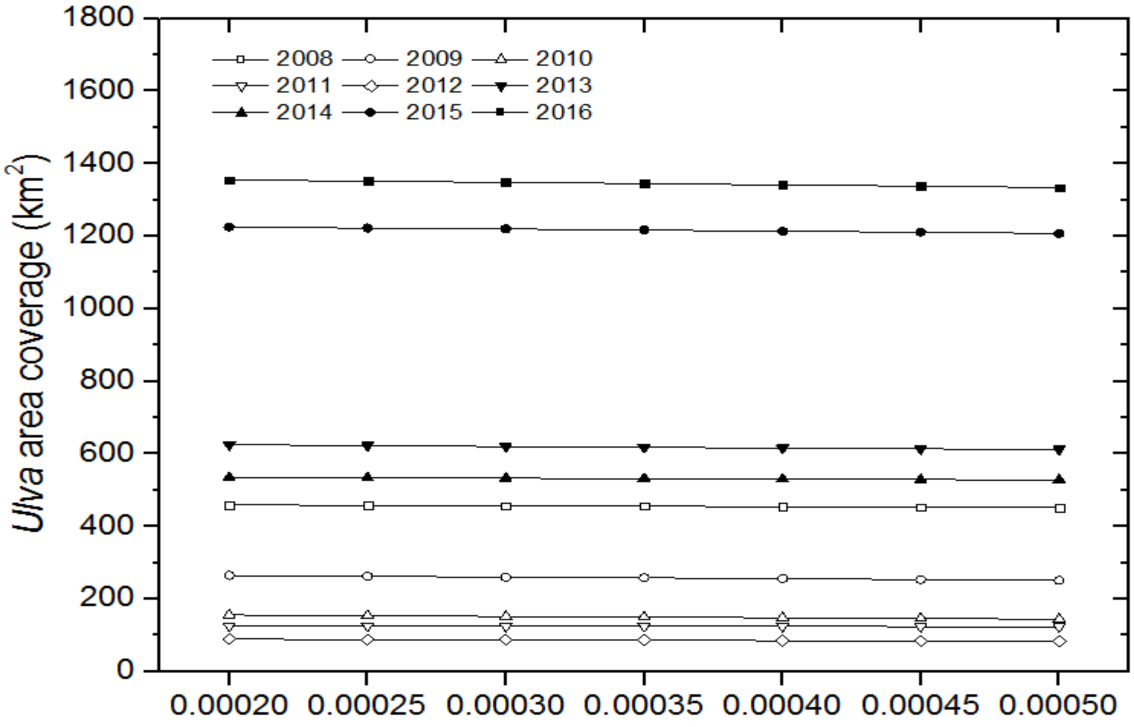
Applying to satellite sensor



Applying to satellite sensor



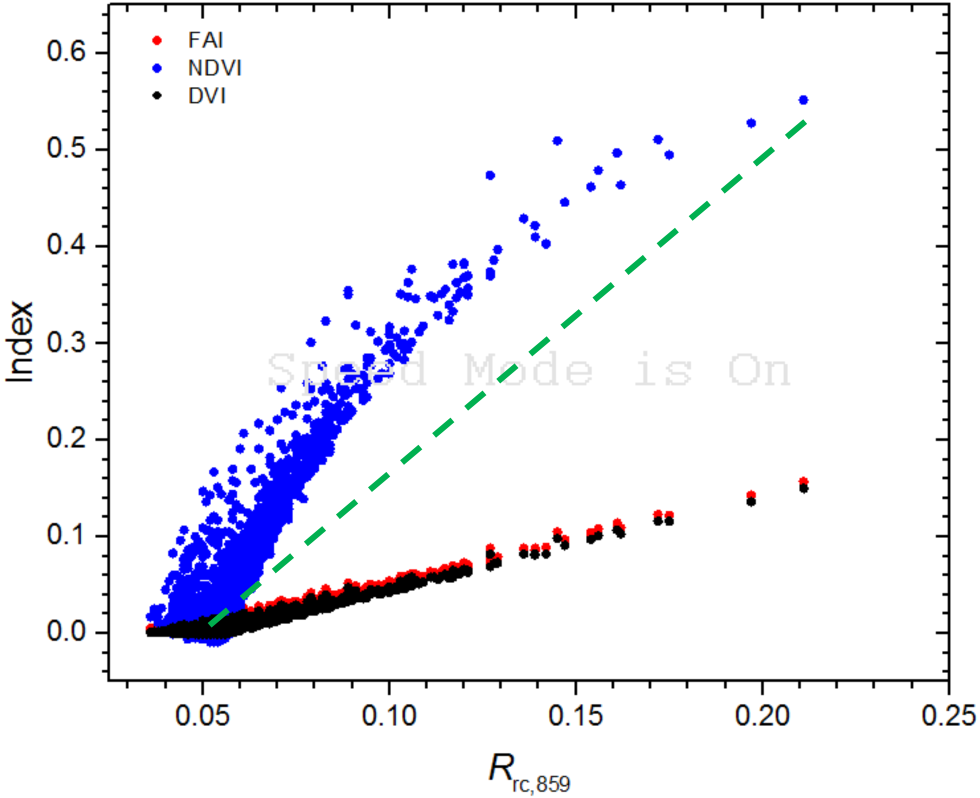
Sensitivity analysis of T_{ng}



T_{ng}

Coverage decrease 1.5% in 2015 and 2016 when T_{ng} varying from 0.0002 to 0.0005.

Algae index selection



$$\alpha = \frac{FAI \quad - T_0}{T_1 - T_0}$$

Impacts of sensor viewing angle, atmospheric conditions

Groups	Date	Sensor	Coverage(km^2) and APD (%)		VZA	$R_{rc,1240}$	Atmos. Cond.
Group-1	2010-06-21	MODIST MODISA	77 78	1.0	47 45	0.008 0.009	Clear Clear
	2013-06-29	MODIST MODISA	363 374	2.7	45 48	0.012 0.013	Clear Clear
	2013-06-20	MODIST MODISA	547 531	3.0	34 53	0.013 0.013	Clear Clear
	2015-05-25	MODIST MODISA	285 264	7.3	32 56	0.006 0.009	Clear Clear
	2013-06-02	MODIST MODISA	119 86	28.1	16 63	0.019 0.015	Clear Clear
	2016-06-25	MODIST MODISA	1042 1258	17.2	63 16	0.02 0.02	Clear Clear
Group-2	2009-07-15	MODIST MODISA	103 172	40.4	59 29	0.016 0.011	Fog Clear
	2014-05-26	MODIST MODISA	91 147	38.1	60 22	0.022 0.016	Fog Clear

Groups	Date	Sensor	Coverage(km^2) and APD (%)		VZA	$R_{rc,1240}$	Atmos. Cond.
Group-3	2014-06-18	MODIST MODISA	416 471	11.6	56 33	0.025 0.016	Fog Fog
	2009-05-31	MODIST MODISA	217 221	1.9	35 40	0.049 0.036	Sun glint Sun glint
	2014-05-27	MODIST MODISA	78 54	30.7	3 59	0.056 0.047	Turbid Atmos. Turbid Atmos.
Group-4	2008-05-20	MODIST MODISA	13 25	47.2	54 12	0.041 0.102	Thin cloud Sun glint
	2009-07-01	MODIST MODISA	106 190	44.3	60 7	0.025 0.047	Thin cloud Sun glint
	2014-05-28	MODIST MODISA	81 116	30.3	59 3	0.018 0.046	Turbid Atmos. Sun glint
	2015-07-01	MODIST MODISA	676 646	4.4	4 58	0.056 0.028	Sun glint Thin cloud
	2016-06-01	MODIST MODISA	369 328	11.1	4 58	0.073 0.030	Sun glint Thin cloud
	2016-06-17	MODIST MODISA	855 759	11.2	6 58	0.085 0.025	Sun glint Thin cloud

Impacts of sensor viewing angle, atmospheric conditions

There are three findings:

1. Ulva areal coverage derived between MODIST and MODISA agree each other very well with the APD<3% in clear days even under sun glint area if two scenes are with the similar VZA.

2. Ulva areal coverage will be underestimated with the increase of VZA for all atmospheric conditions. The higher VZA, the more coverage would be underestimated.

3. Ulva areal coverage will be underestimated in both turbid atmosphere and sun glint conditions. Turbid atmosphere especially fog significantly underestimate *Ulva* coverage . In worst scenario (high VZA, fog), the areal coverage can be underestimated more than 45%.

Summary

1. A remote sensing model has been developed and validated to estimated *Ulva* biomass using reflectance (FAI). Relative uncertainty is 16% for FAI<0.2 .
2. The model was applied to MODIS time-series data to derive the total biomass of *Ulva* in the Yellow Sea between 2008 and 2015. The model can be applied to other satellite sensors with similar RED, NIR, and SWIR bands such as Sentinel-3/OLCI, Chinese FY-3A&B/MERSI and NPP/VIIRS.
3. A robust sea water pixels extraction method was developed using the FAI normalized gradient image. The pure algae FAI (100% cover) was carefully determined from in situ experiment and radiative transfer simulation. The estimated Ulva areal coverage were validated with high spatial resolution data with uncertainty less than 25%.
4. The impacts of sensor viewing angle, fog and sun glint on the Ulva areal coverage were discussed.


Thank you!