Water property monitoring and assessment for China's inland Lake Taihu from MODIS-Aqua measurements

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Outline

- Background
- Methods
- Results
- Discussion

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1. Background

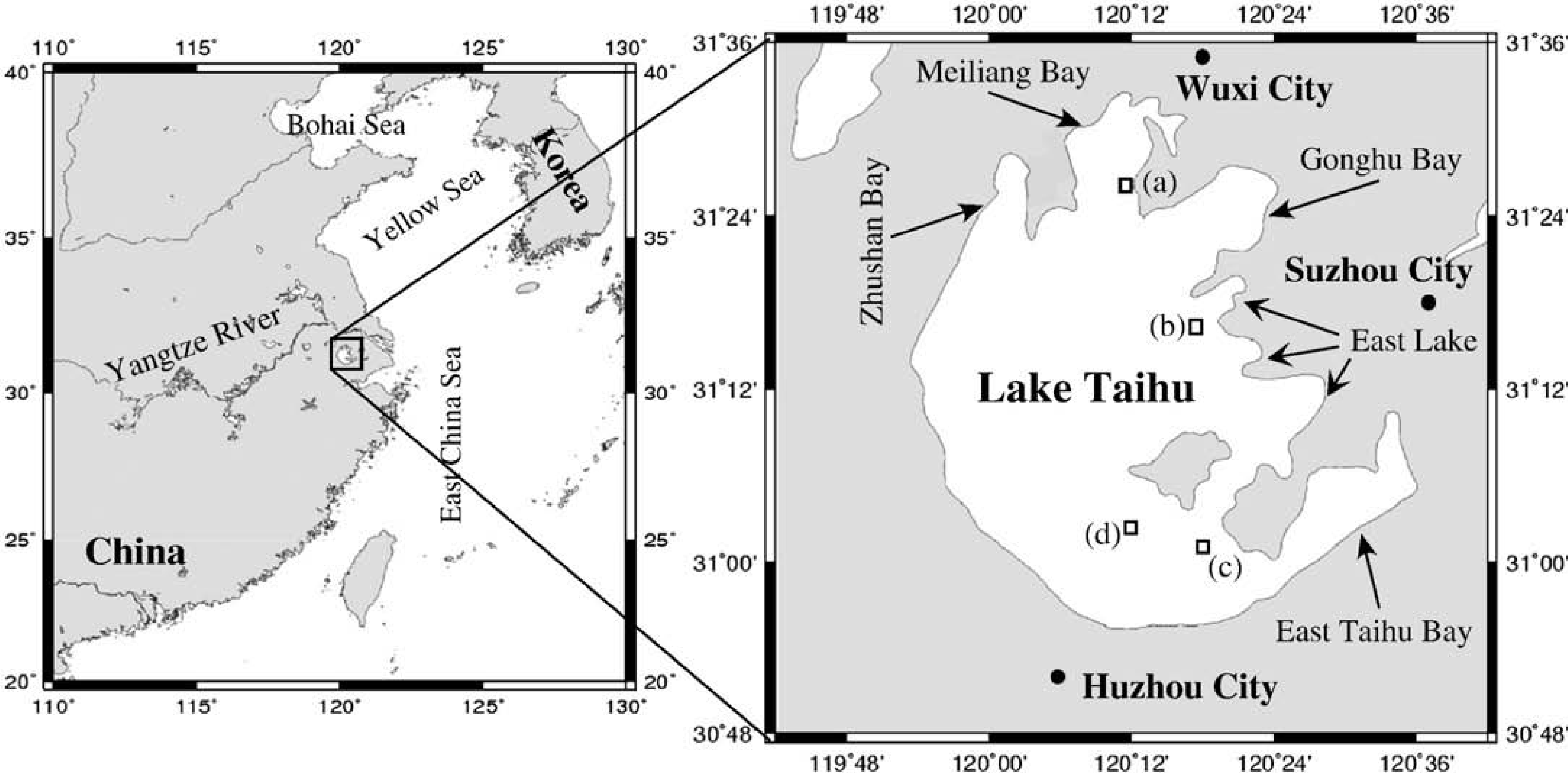

Fig. 1 Geo-location of Lake Taihu

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1.1 Why do we focus on water property in Taihu?

- Taihu locates in one of the world's most heavily populated regions with the rapidest economic growth.
- It helps irrigate millions of ha. of farmlands, also provides drinking water for more than 2 million people, and sustains one of China's most important fisheries (Guo, 2007) .
- Since 1980s, Taihu has became more and more eutrophic. In early June 2007, massive blue-green algae bloomed over Taihu, contaminating tap water for millions of Wuxi residents (Ding, *et al*., 2007; Hu *et al*., 2010).


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Table 1 Comparison between Remote Sensing (RS) and In situ measurement

	Remote Sensing	**In situ measurement**
Temporal coverage	High rate, long-term	Low rate, short-term
Spatial coverage	Broad field of view	Fixed locations
Characteristics	Rapid, synoptic, repeated, stable	Labor-intensive, confined to short period, restricted by external conditions

Spectral Resolution

Spatial Resolution

Temporal Resolution

MODIS measurements

Ma *et al*., 2009, 2010

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1.2 Basic knowledge for Lake Color RS

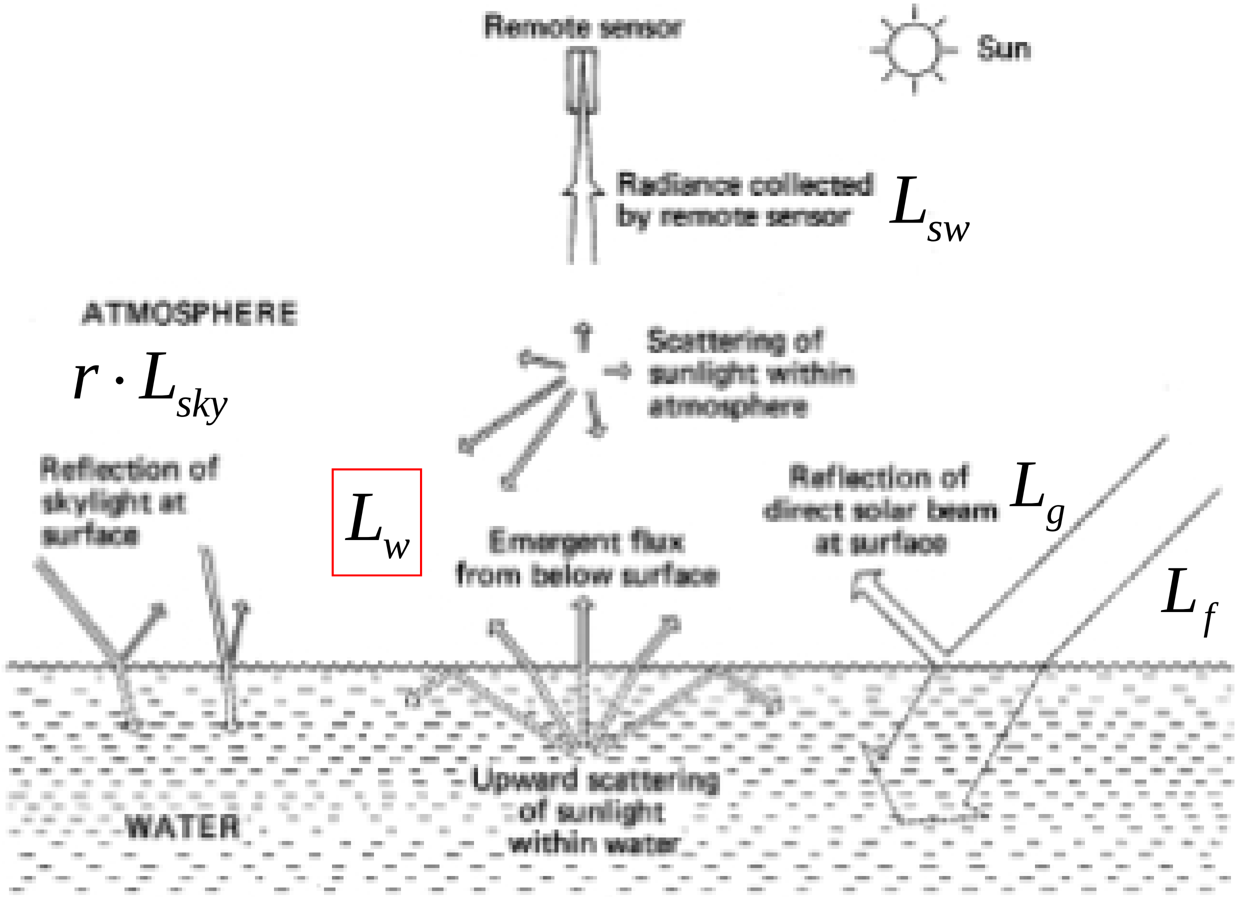

Fig. 1 Above water signal composition (Kirk, 2011)

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$$L_{sw} = L_w + r \cdot L_{sky} + L_f + L_g$$

$$nL_w(\lambda) = L_w \cdot \frac{F_0}{E_d(0^+)}$$

Ma *et al*., 2010

L_{sw} Radiance received by sensors

L_w Water-leaving radiance

r Reflectivity of water-atmosphere interface

L_{sky} Skylight radiance

L_f Radiance contributions of white cap

L_g Sunglint specular

nL_w Normalized water-leaving radiance

$E_d(0^+)$ Incident radiance above surface

F_0 Top of atmosphere radiance at mean Earth-Sun distance

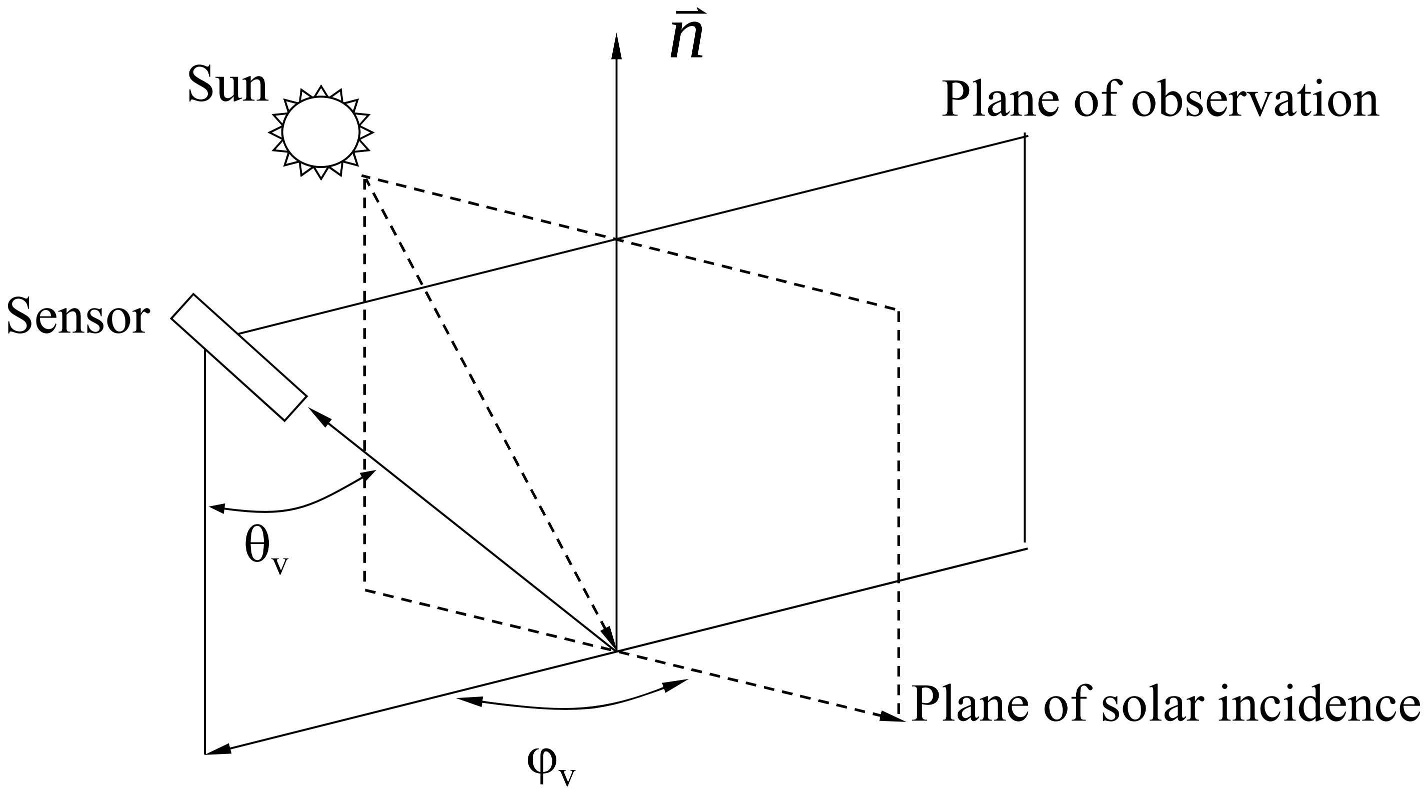

Fig. 2 Viewing geometry of above-water measurement (Tang *et al*., 2004)

Table 2 Optical properties of Lake water (Case Ⅱ Waters) (Ma *et al*., 2010)

Apparent optical properties (AOPs)	Water leaving radiance
	Normalized water-leaving radiance
	Reflectance
	Remote sensing reflectance
	Diffuse attenuation coefficient of water
	Diffuse attenuation coefficient of irradiance
Inherent optical properties (IOPs)	Absorption coefficient
	Scattering coefficient
	Scattering phase function
	Volume scattering coefficient
	Beam attenuation coefficient

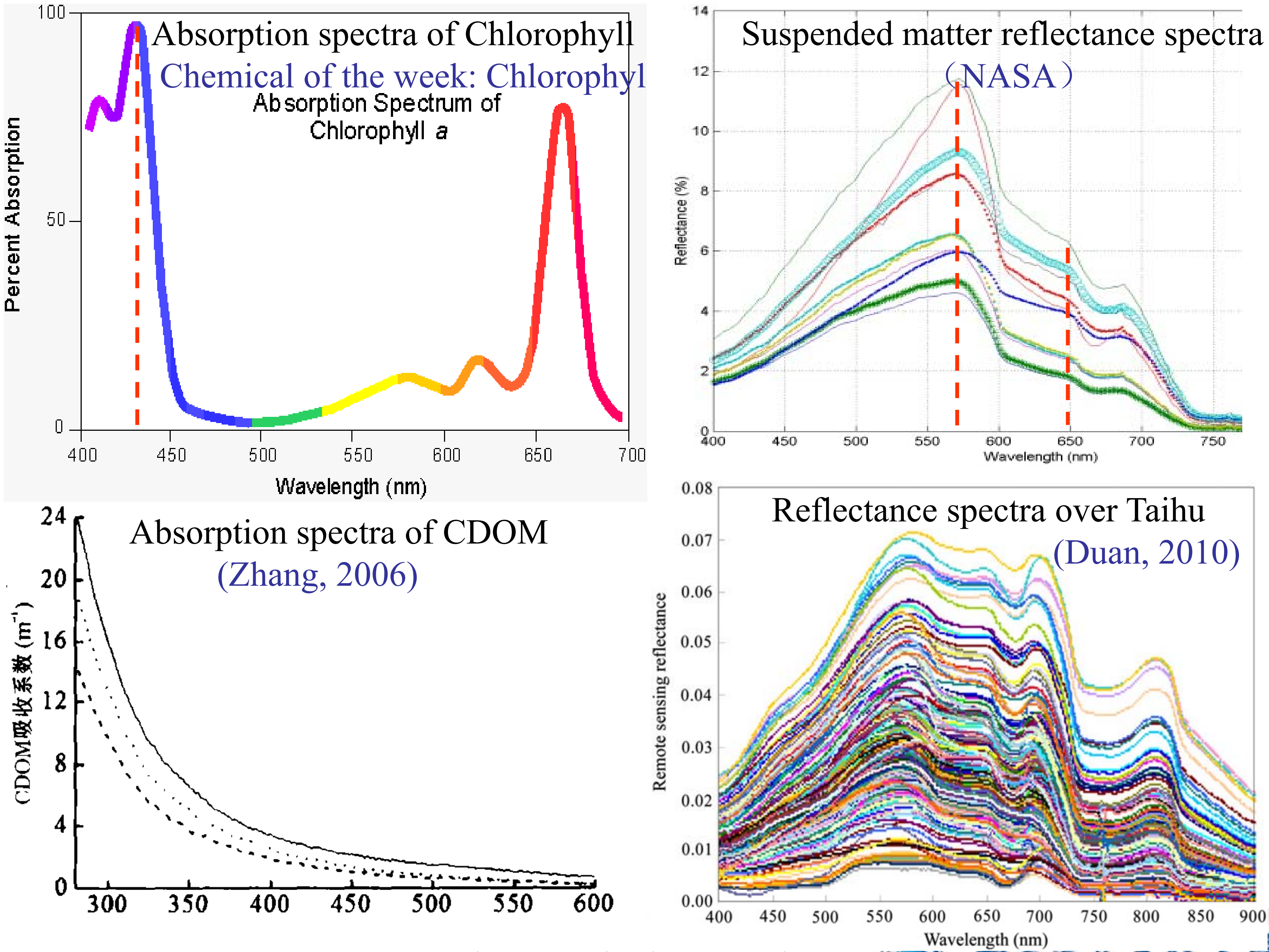

Fig.3 Typical spectral

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Table 3 Atmospheric correction algorithm suitable for Water Color RS (Ma *et al.*, 2010)

	Ocean Color RS	**Lake Color RS**
Characteristic	$L_{w,near-infrared} = 0$	$L_{w,near-infrared} \neq 0$
Algorithm	Gordon algorithm for CZCS (Gordon, 1993)	Principal component analysis (Neumann,1995)
	Gordon algorithm for SeaWiFs (Gordon and Wang, 1994)	Arnone iteration (Arone, 1998)
	Gordon algorithm for MODIS (Gordon and Voss, 1999)	Artificial neural network method (Doerffer and Schiller, 1998)
		Absorption coefficient iteration in near infrared (Aiken and Moore, 2000)
		Hu algorithm (Hu, 2000)
		Ruddick algorithm (Ruddick, 2000, 2001)
		Fixed remote sensing reflectance algorithm (He and Pan, 2003)
		Shortwave infrared (SWIR) algorithm (Wang and Shi, 2005)

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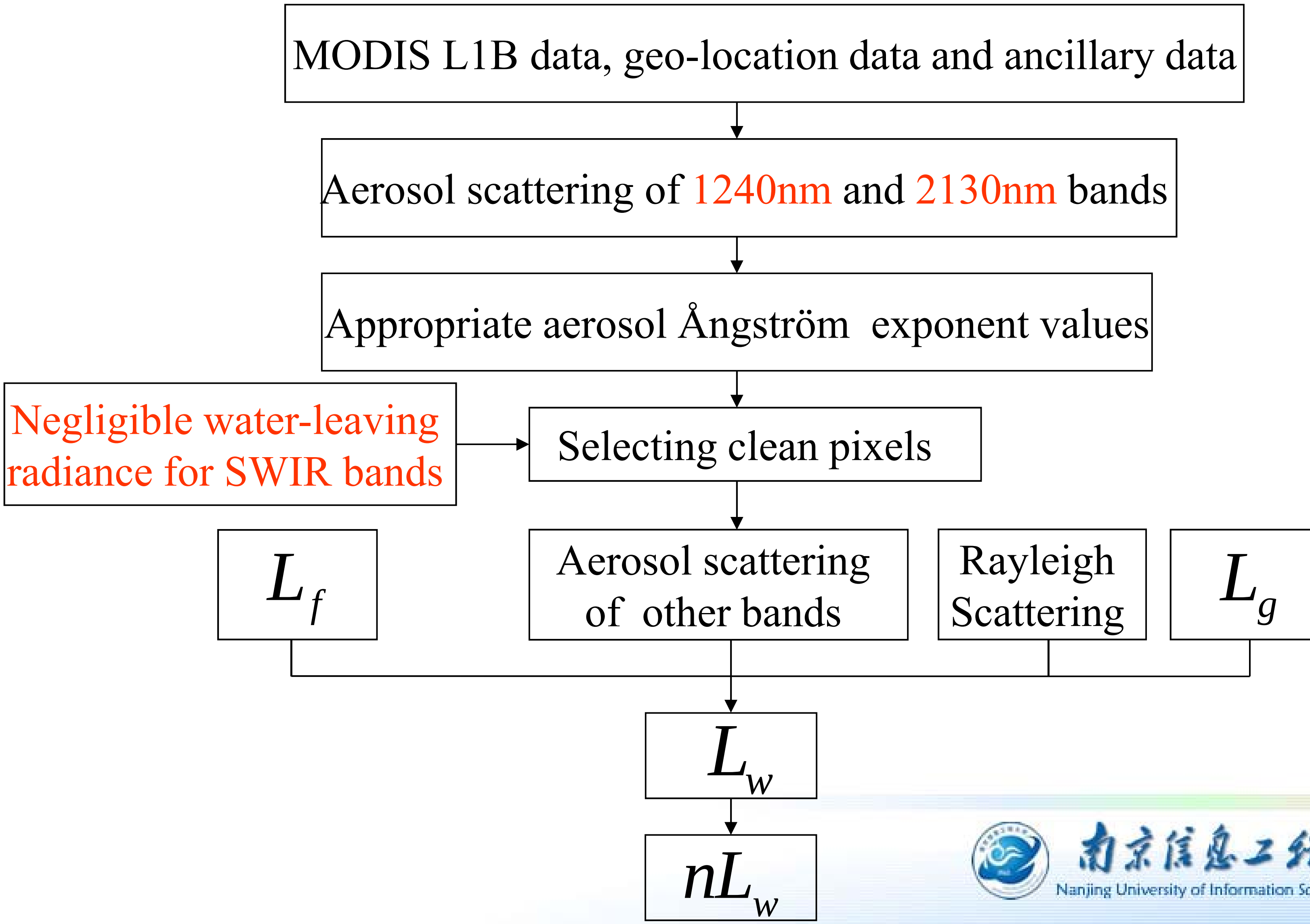
2. Methods

Table 4 Data set

In situ data	Water-leaving radiance spectral (10-18 June 2007） a (31.43° N, 120.20° E), b (31.27° N, 120.29° E) c (31.95° N, 120.31° E), d (31.06° N, 120.19° E)
MODIS-Aqua images	2002-2008 29 March, 19 April, 7 May, 14 May, 8 June 2007
Validation data (From CERN)	In situ Chl-a concentration 17 March (13), 15 April (13), 15-18 May (31), 15 June (13) 2007

Fig. 4 Flow chart of SWIR-based atmospheric correction algorithm



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Deriving Chl-a concentration and diffuse attenuation coefficient $K_d(490)$ from nL_w spectra

$$C_a = 10.0^{(0.366 - 3.067 R_{4M} + 1.930 R_{4M}^2 + 0.649 R_{4M}^3 - 1.532 R_{4M}^4)}$$

where $R_{4M} = \log_{10}\left(R^{443}_{550} > R^{490}_{550} > R^{530}_{550}\right)$ O'Reilly et al., 2000

$$K_d(490) = -0.05256 + 1.3537 \frac{R_{rs}(670)}{R_{rs}(490)},$$

for $0.3\ \mathrm{m}^{-1} < K_d(490) < 0.6\ \mathrm{m}^{-1}$ Wang *et al.*, 2009

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3. Results

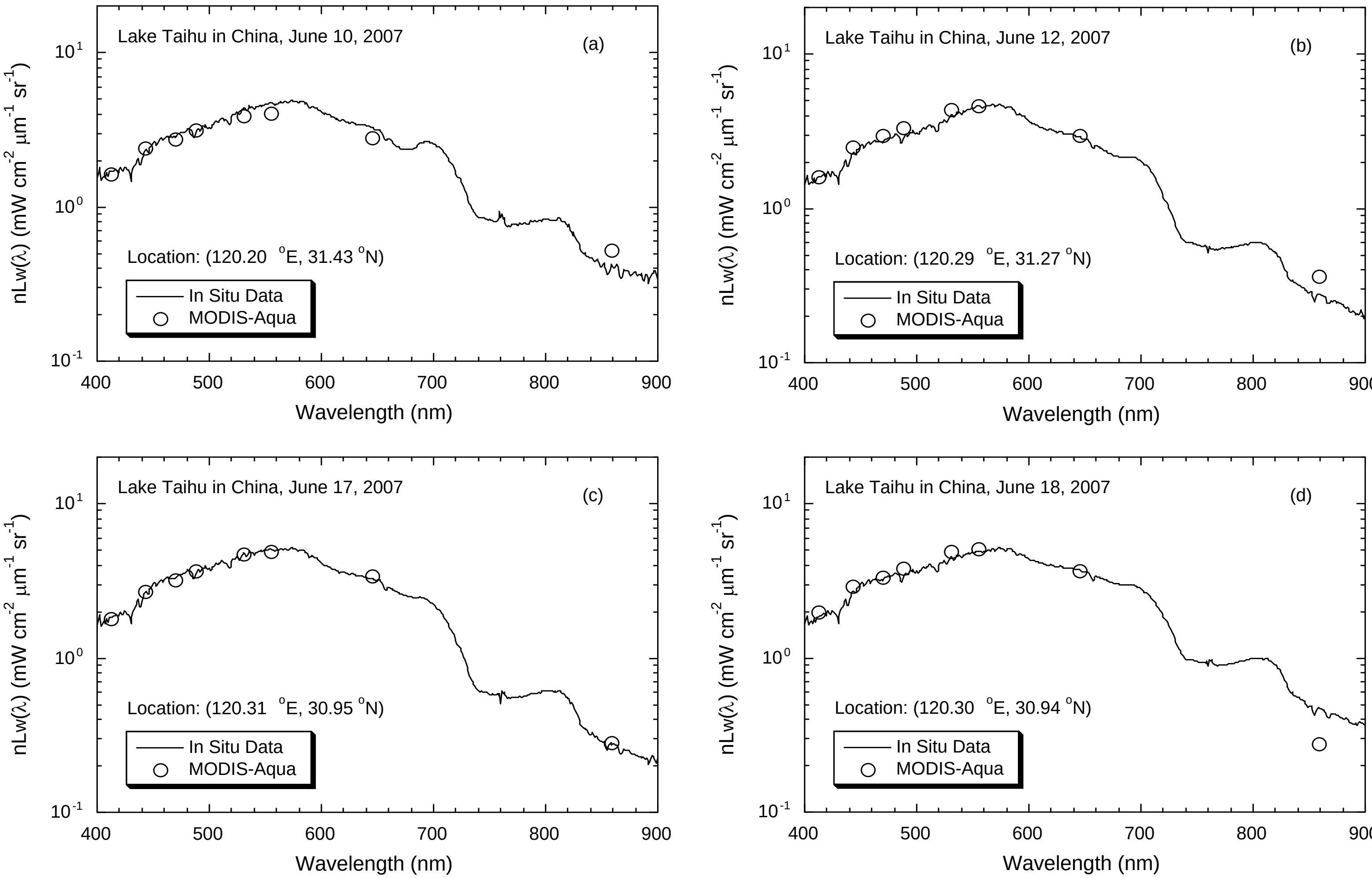

Fig.5 Comparison of normalized water-leaving radiance spectra

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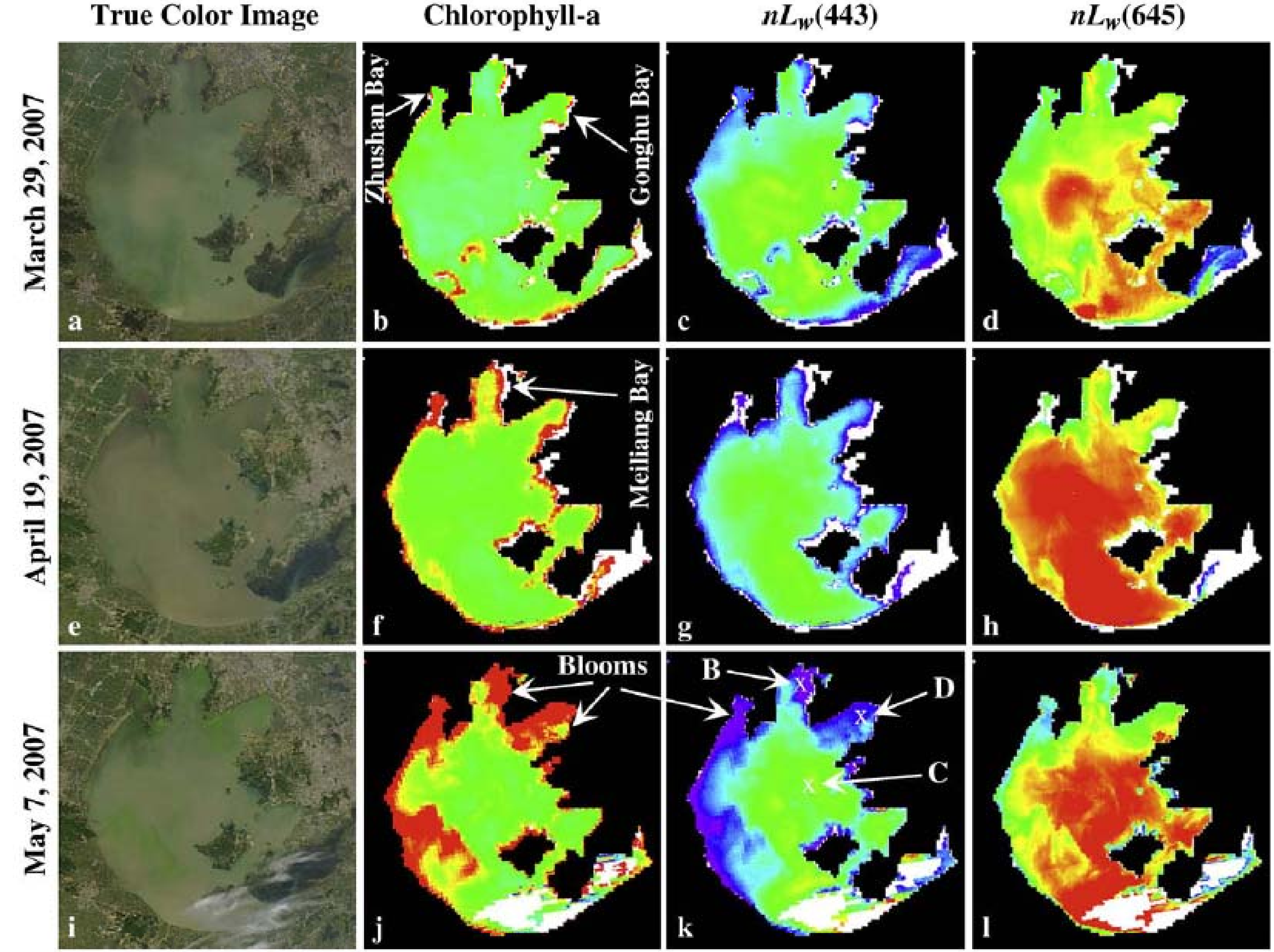
Importance of $nL_w(\lambda)$ for typical bands

- $nL_w(443)$: representing characteristic of algae absorption, low value corresponds to high algae concentration;
- $nL_w(555)$, $nL_w(645)$, $nL_w(859)$: representing variation of total suspended sediment (TTS), high value corresponds to high TTS concentration ;
- $K_d(490)$: water diffuse attenuation coefficient at 490nm, low value corresponds to high-clarity waters.



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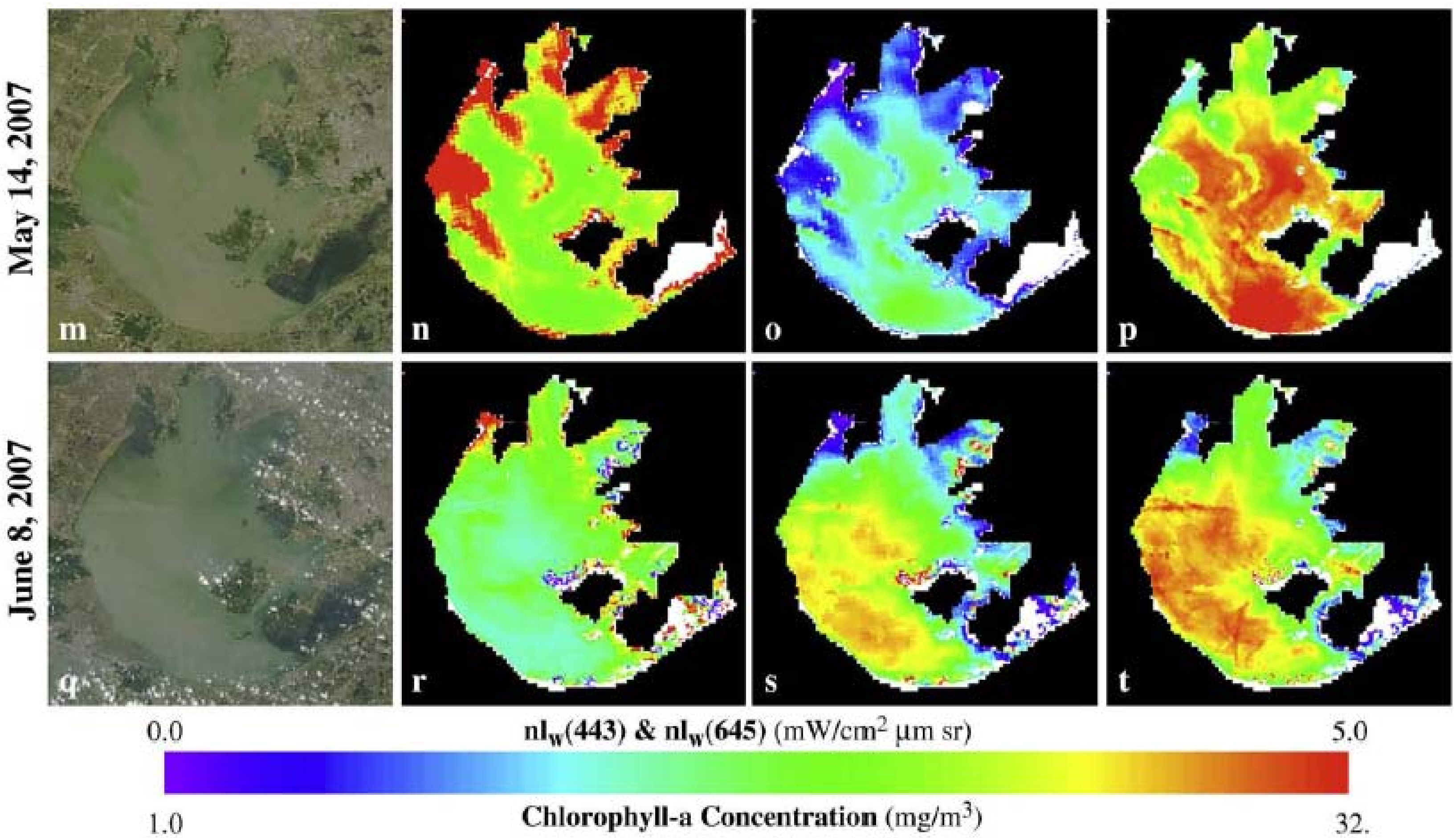

Fig.6 MODIS-Aqua monitoring for 2007 algae bloom in Taihu

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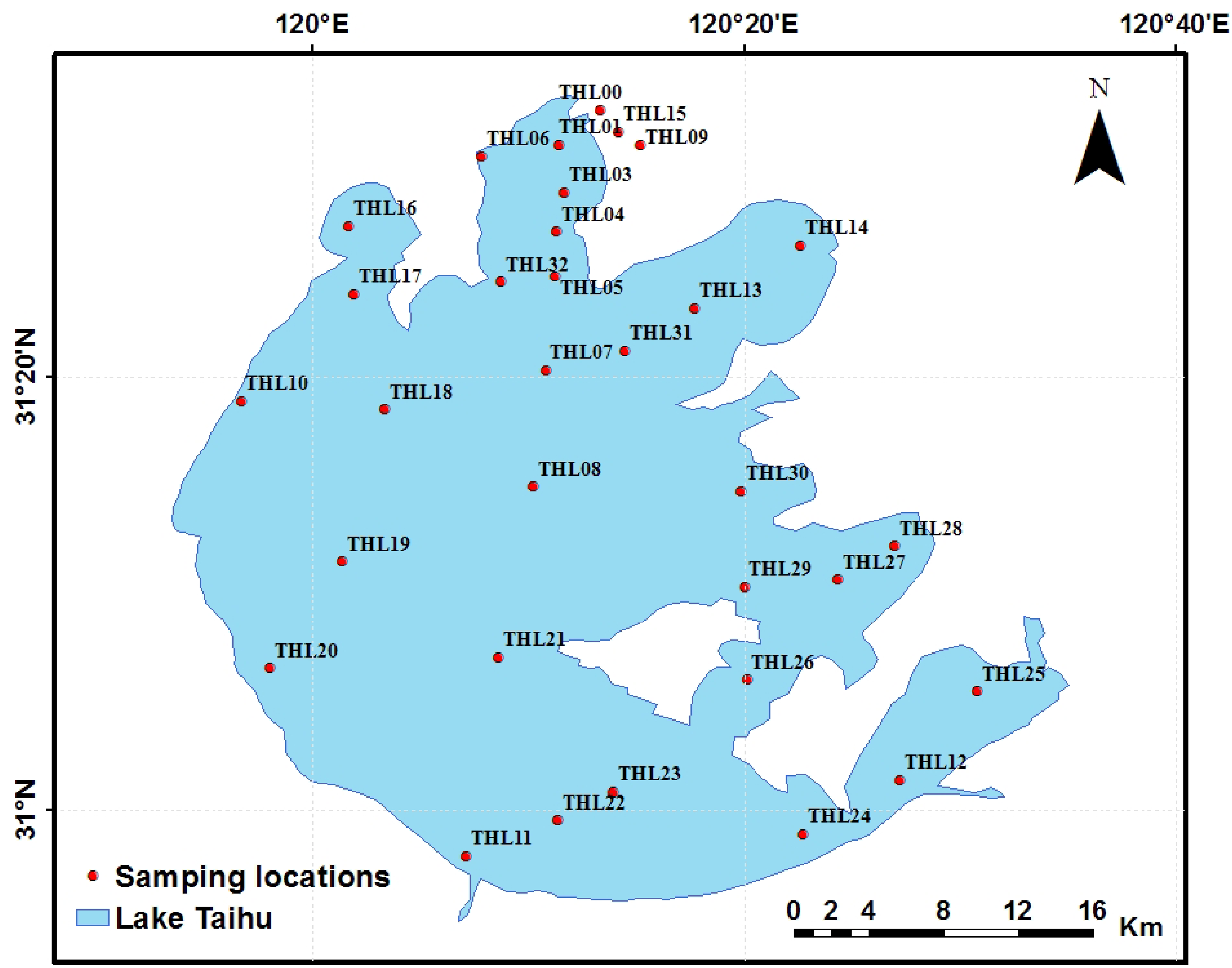

Fig.7 Sampling locations distribution in Taihu

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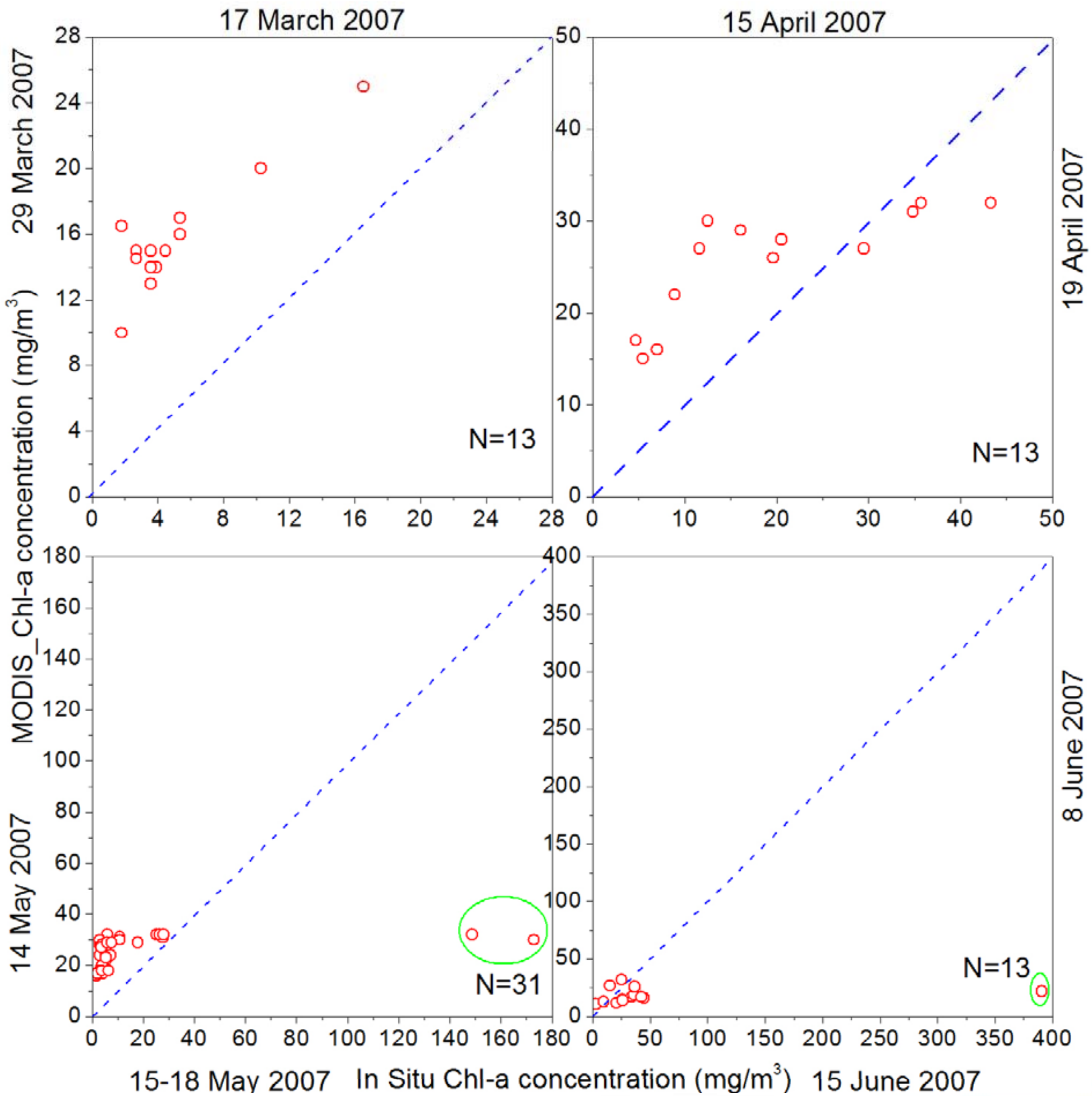

Fig.8 Chl-a concentration comparison between MODSI retrieval and in situ observation (monthly)

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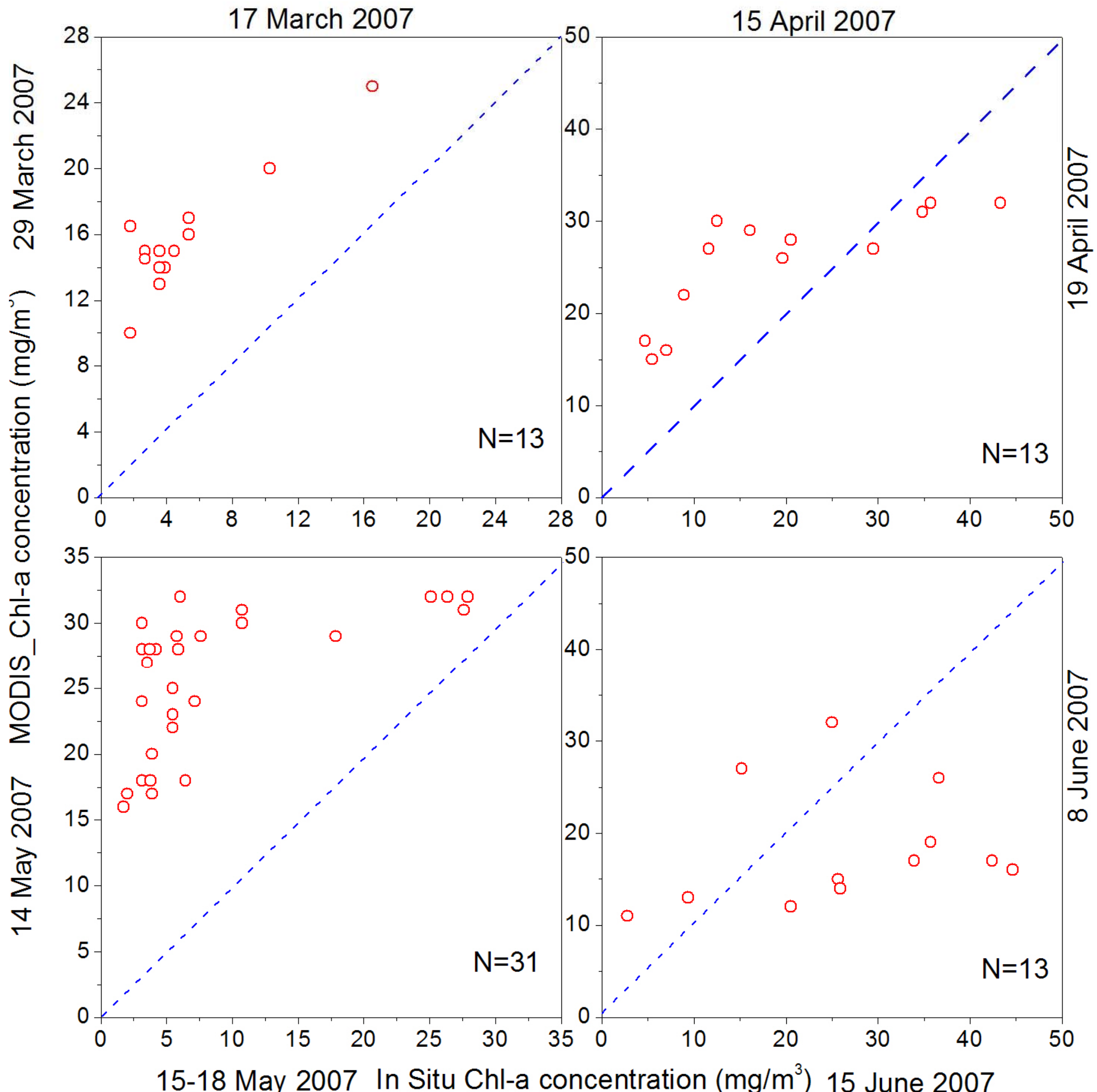

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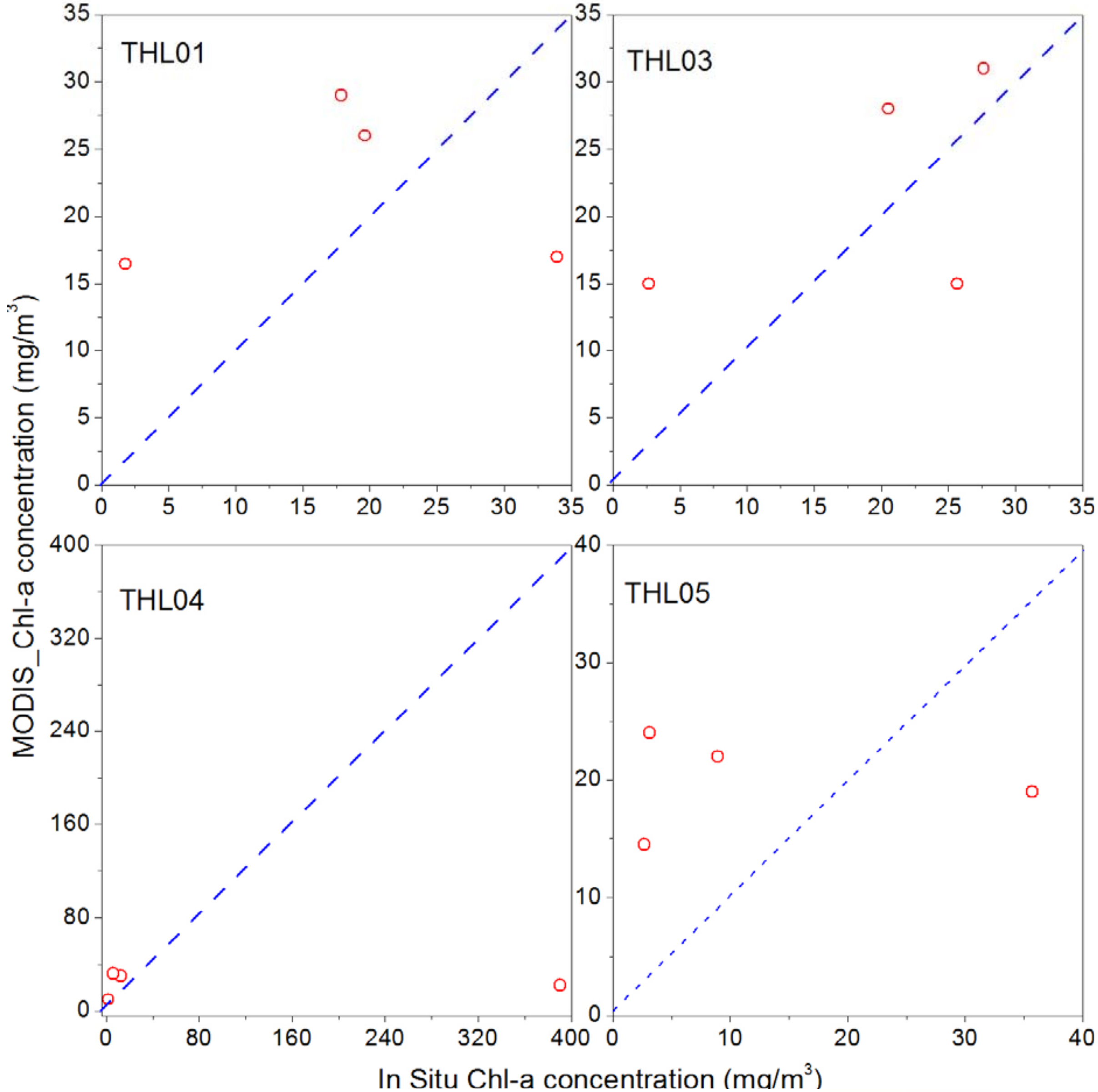

Fig.9 Chl-a concentration comparison between MODSI retrieval and in situ observation (every location)

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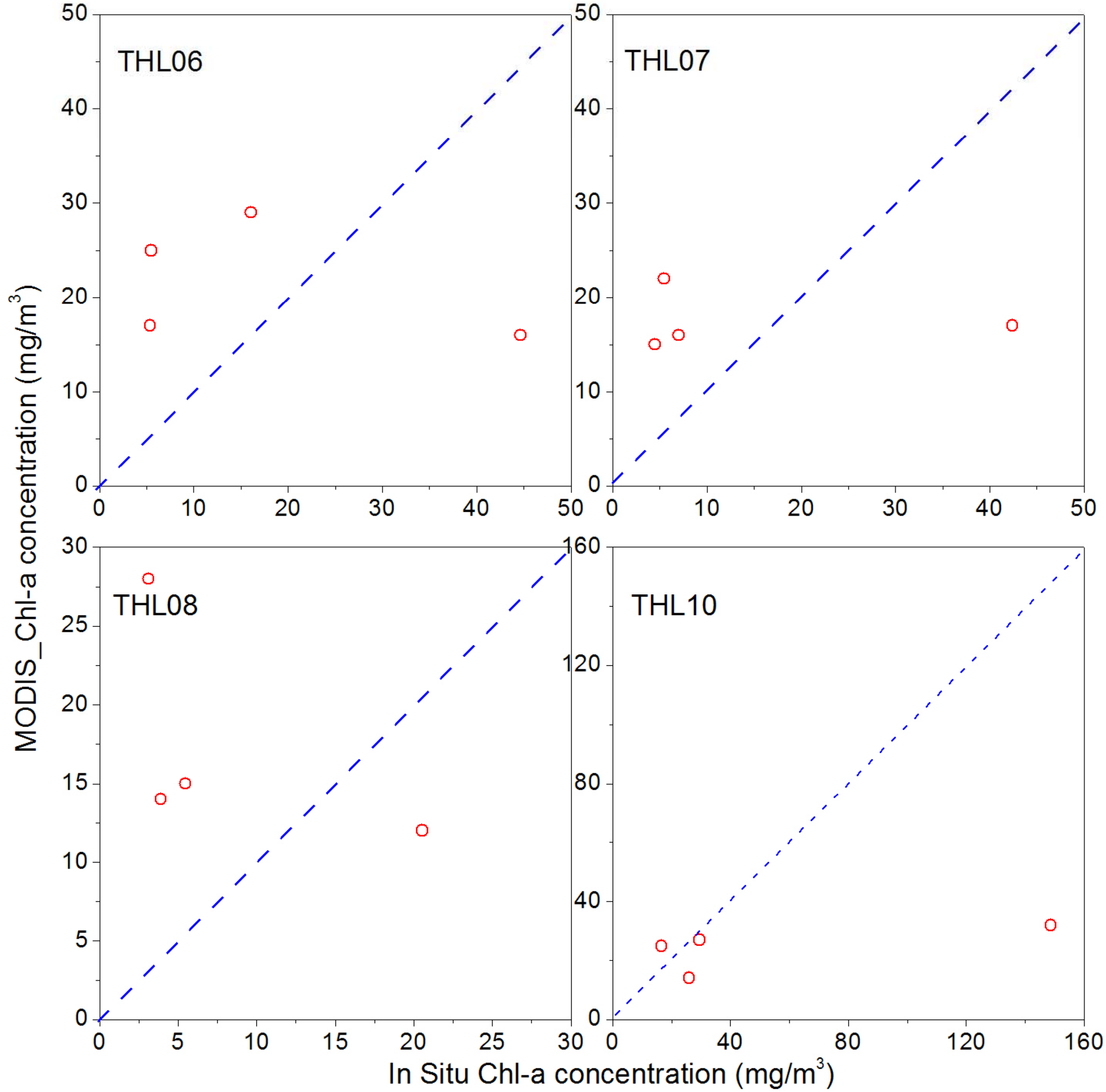
THL06
THL07
THL08
THL10
MODIS_Chl-a concentration (mg/m3)
In Situ Chl-a concentration (mg/m3)
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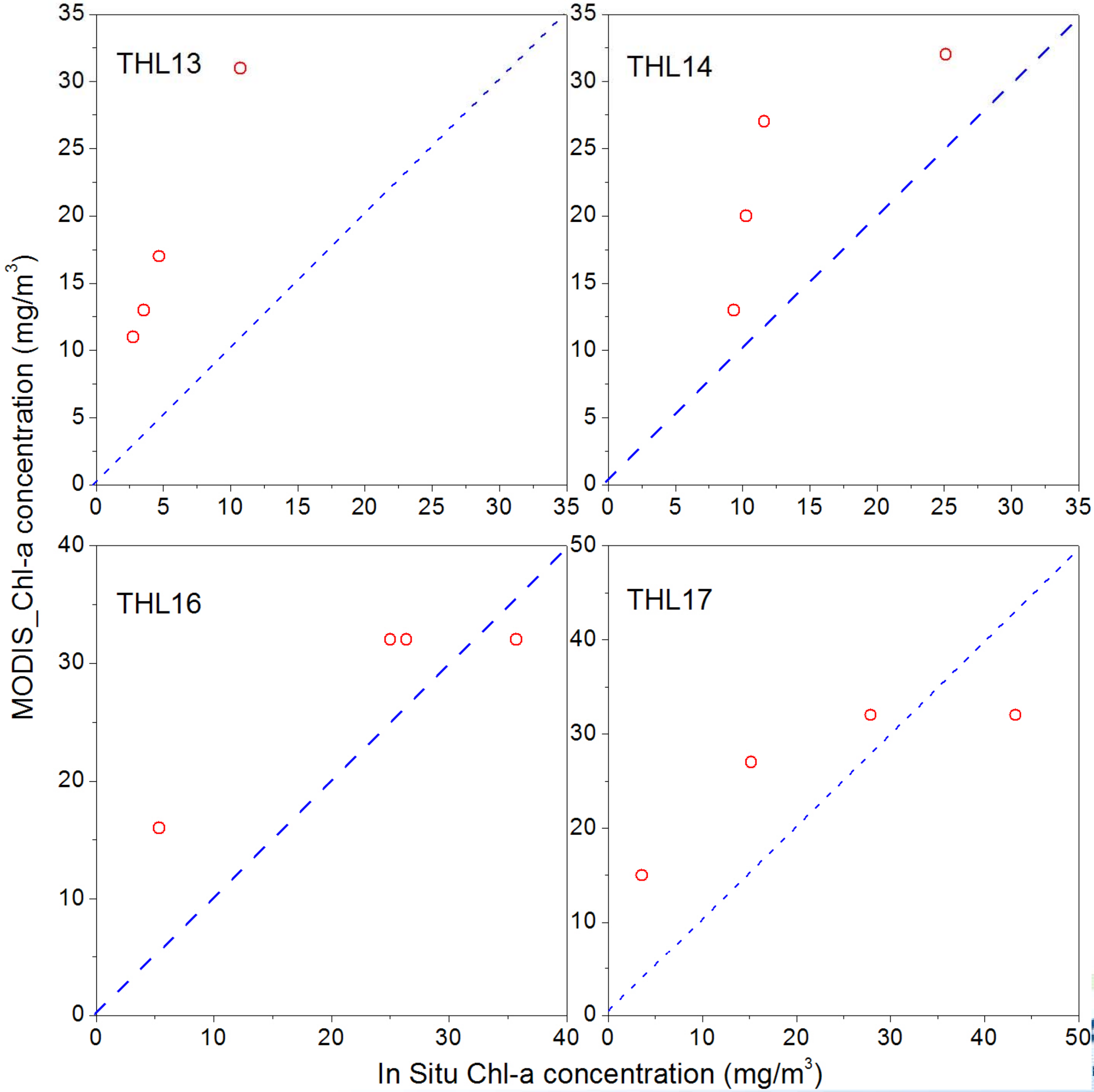

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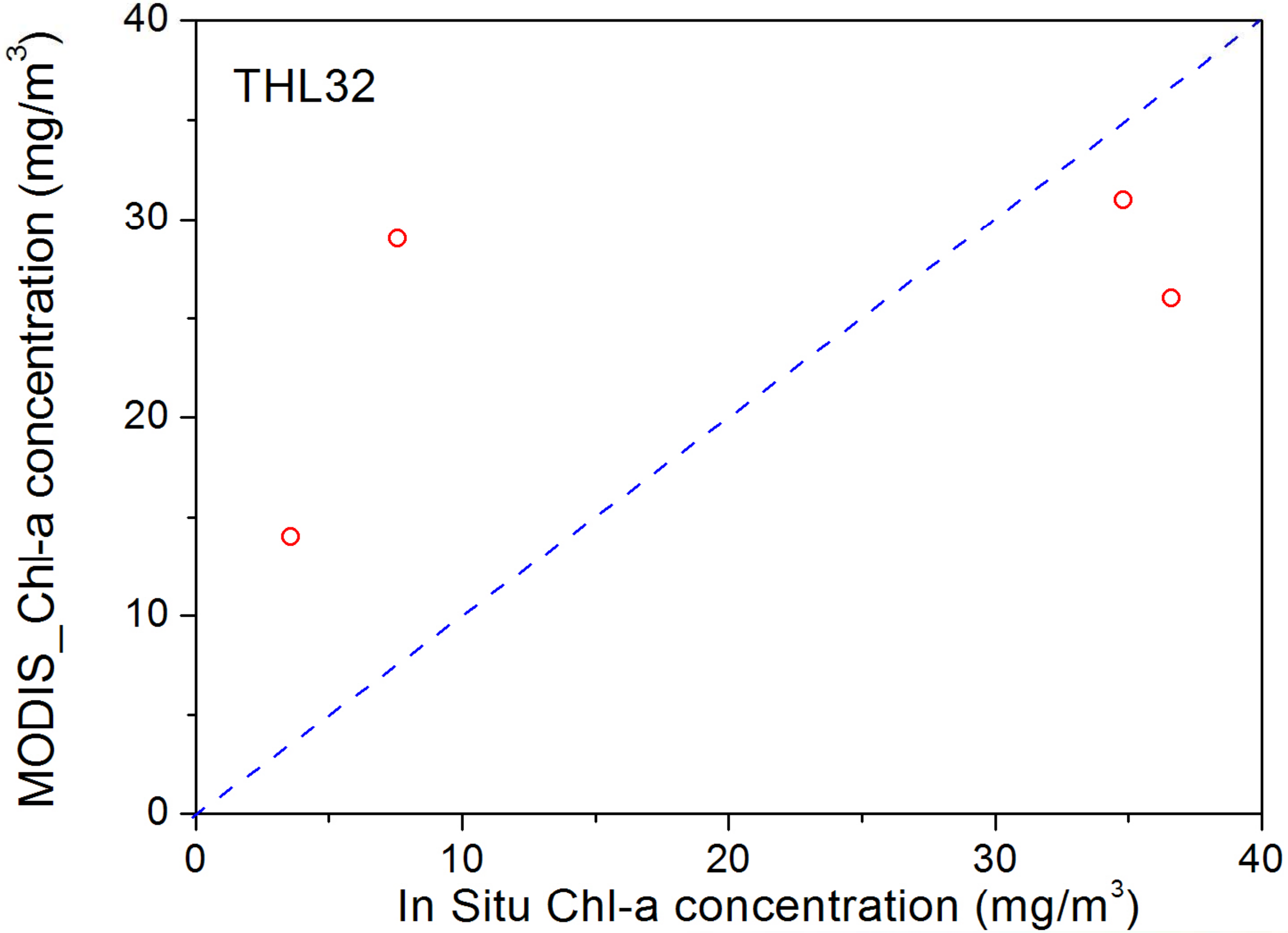

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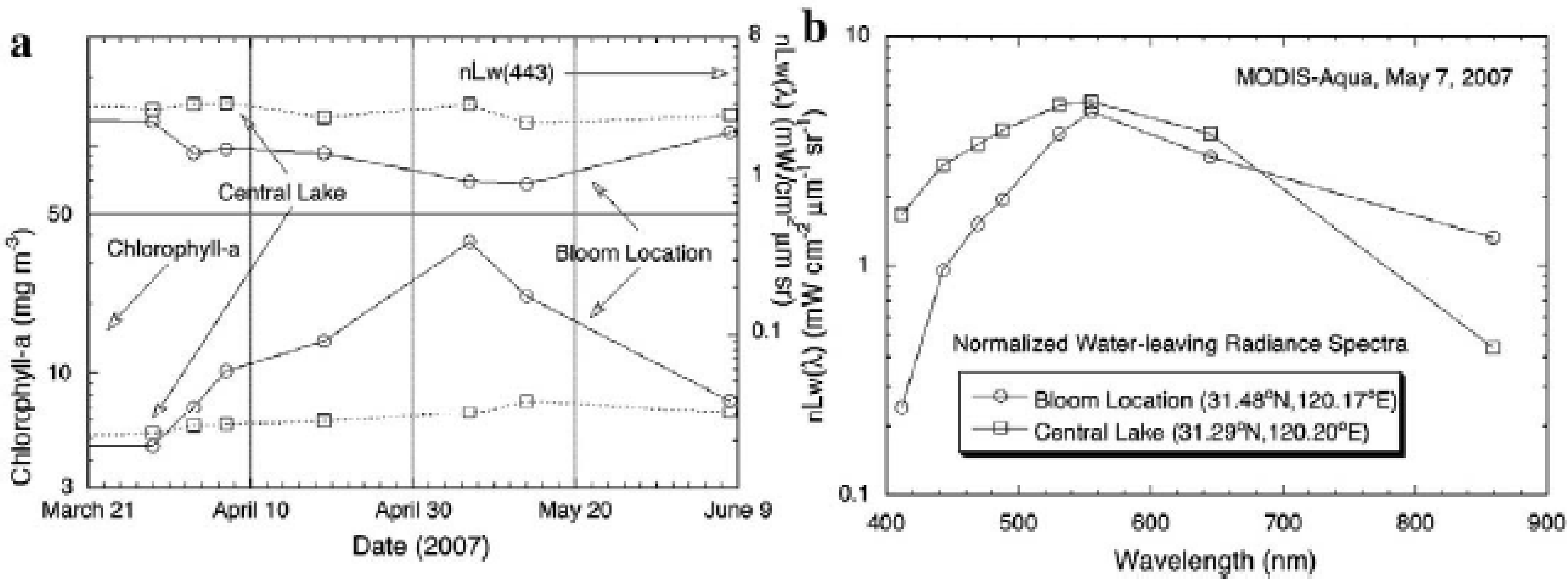

Fig. 10 (a) MODIS derived time series (29 March to 8 June 2007) for Chl-a and $nL_w(443)$, (b) $nL_w(\lambda)$ spectral on 7 May 2007 for algae contaminated and non-contaminated waters.

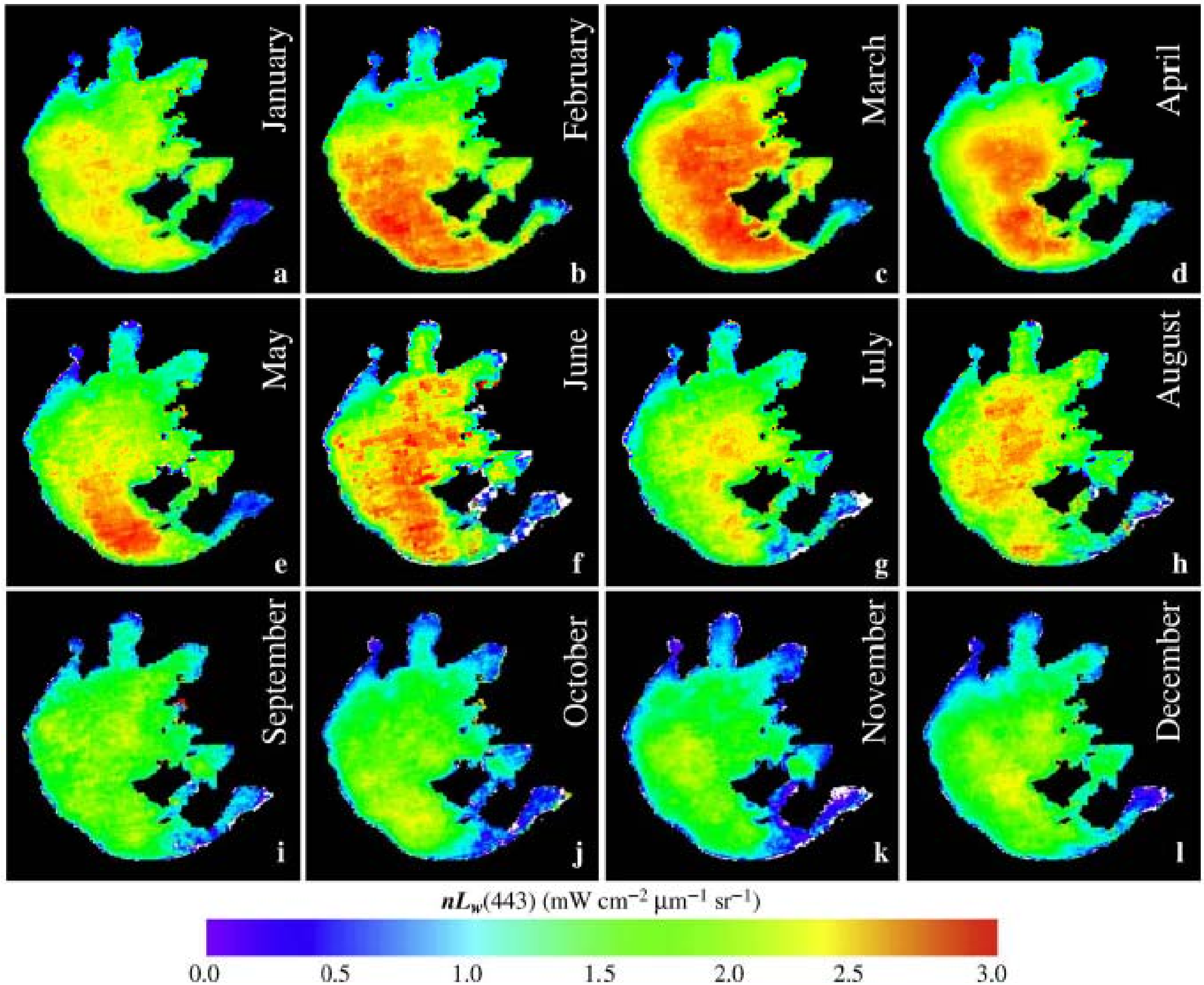

Fig. 11 MODSI-derived (2002-2008) monthly climatology $nL_w(443)$

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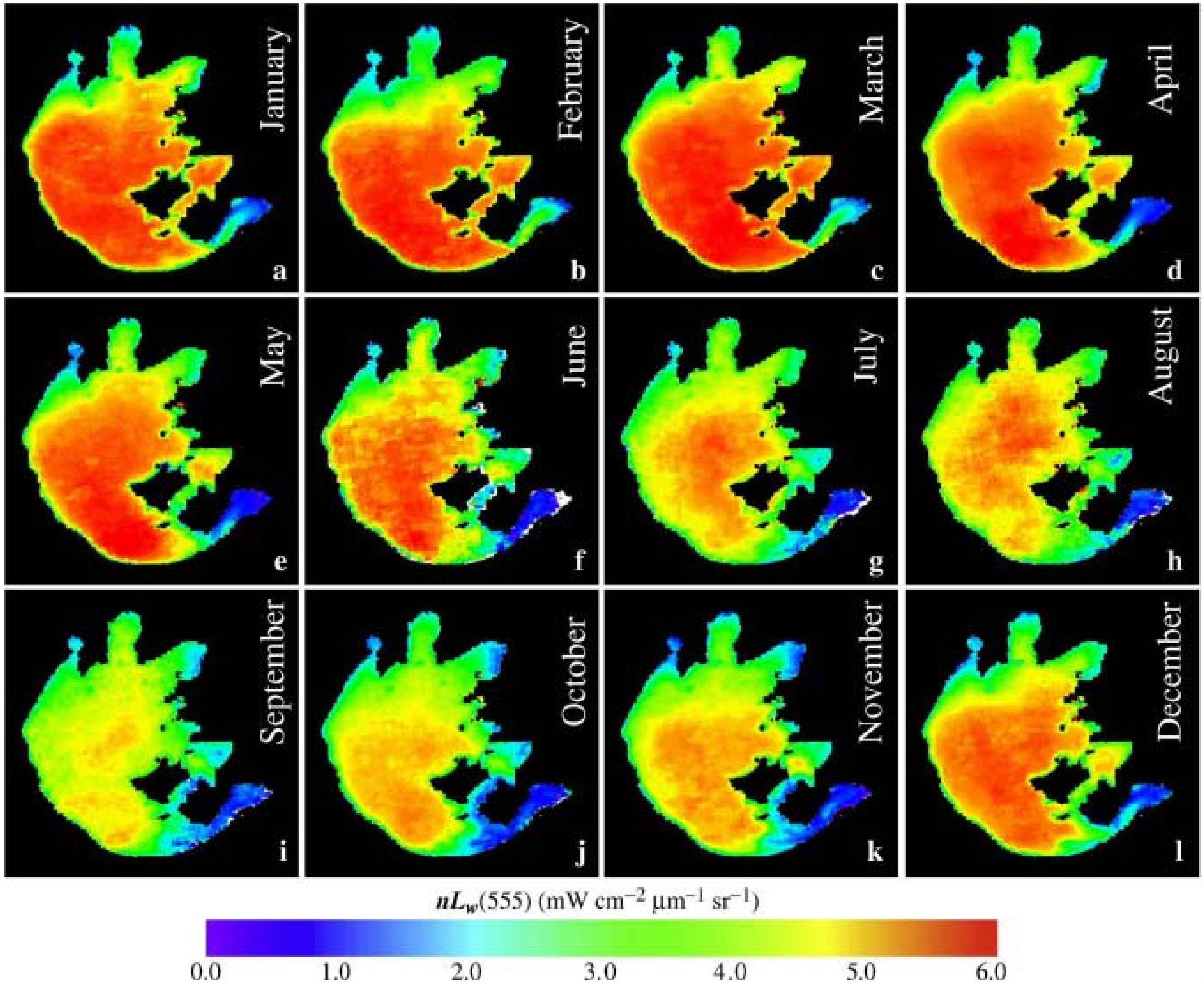

Fig. 12 MODSI-derived (2002-2008) monthly climatology $nL_w(555)$

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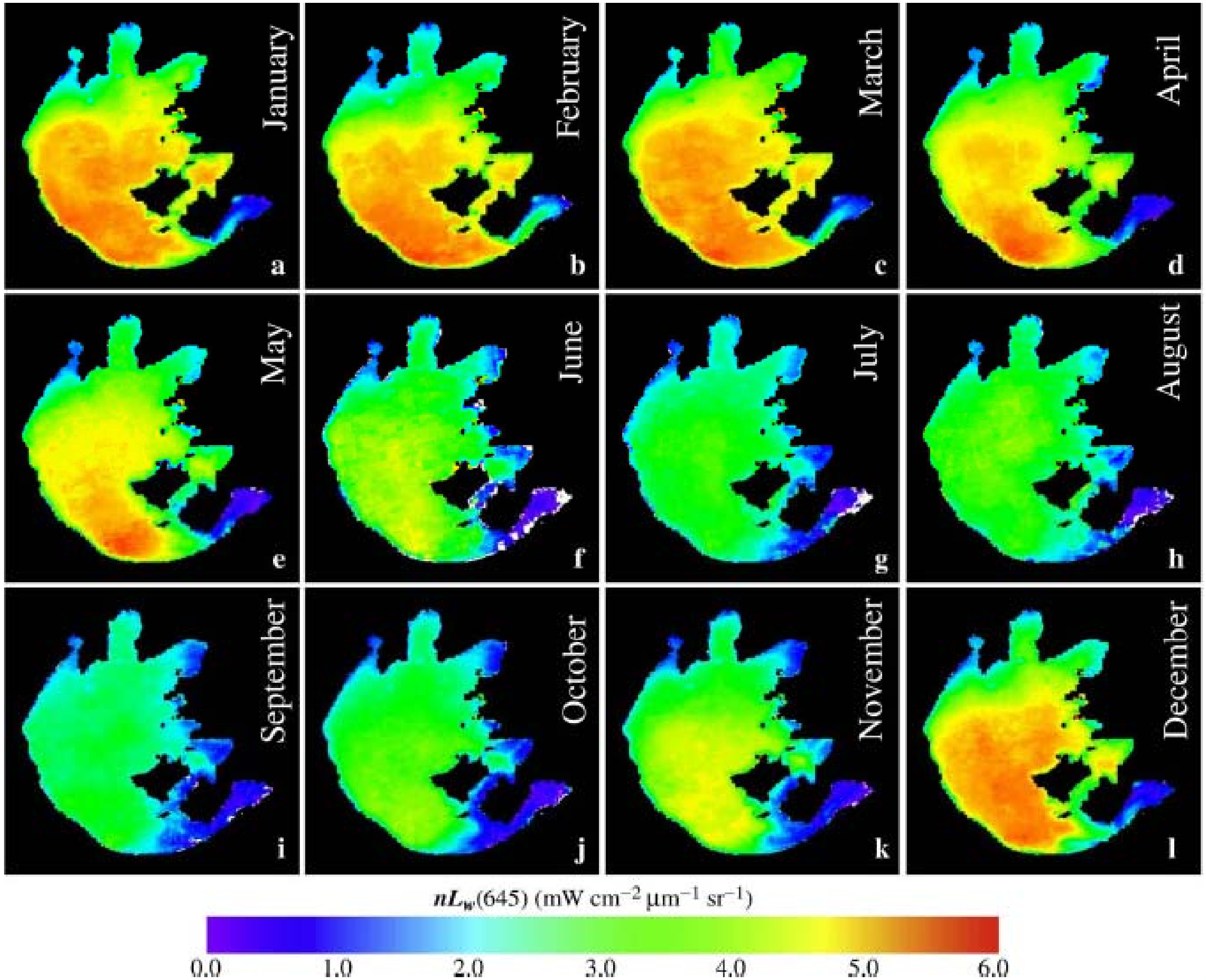

Fig. 13 MODSI-derived (2002-2008) monthly climatology nL_w(645)

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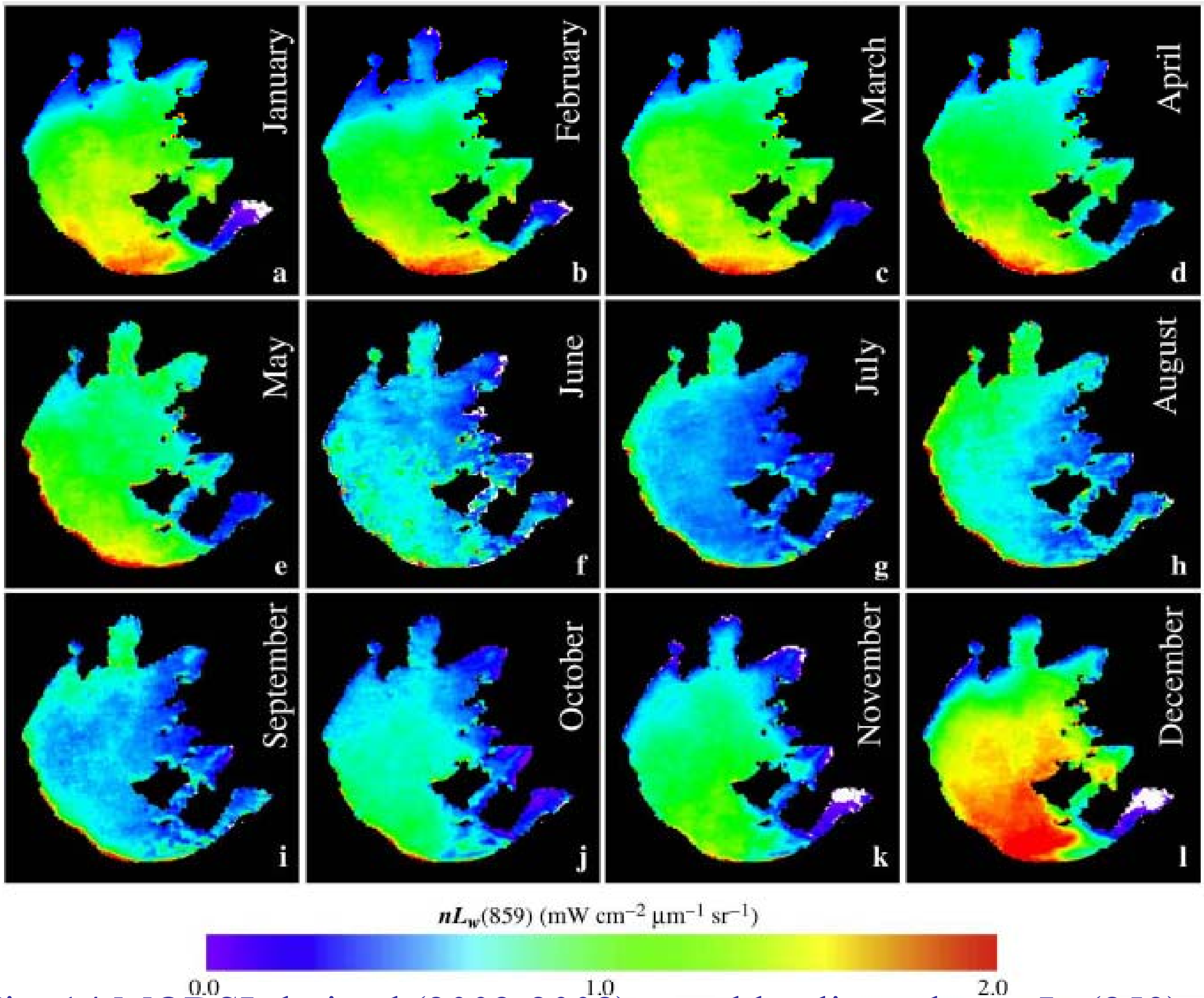

Fig. 14 MODSI-derived (2002-2008) monthly climatology $nL_w(859)$

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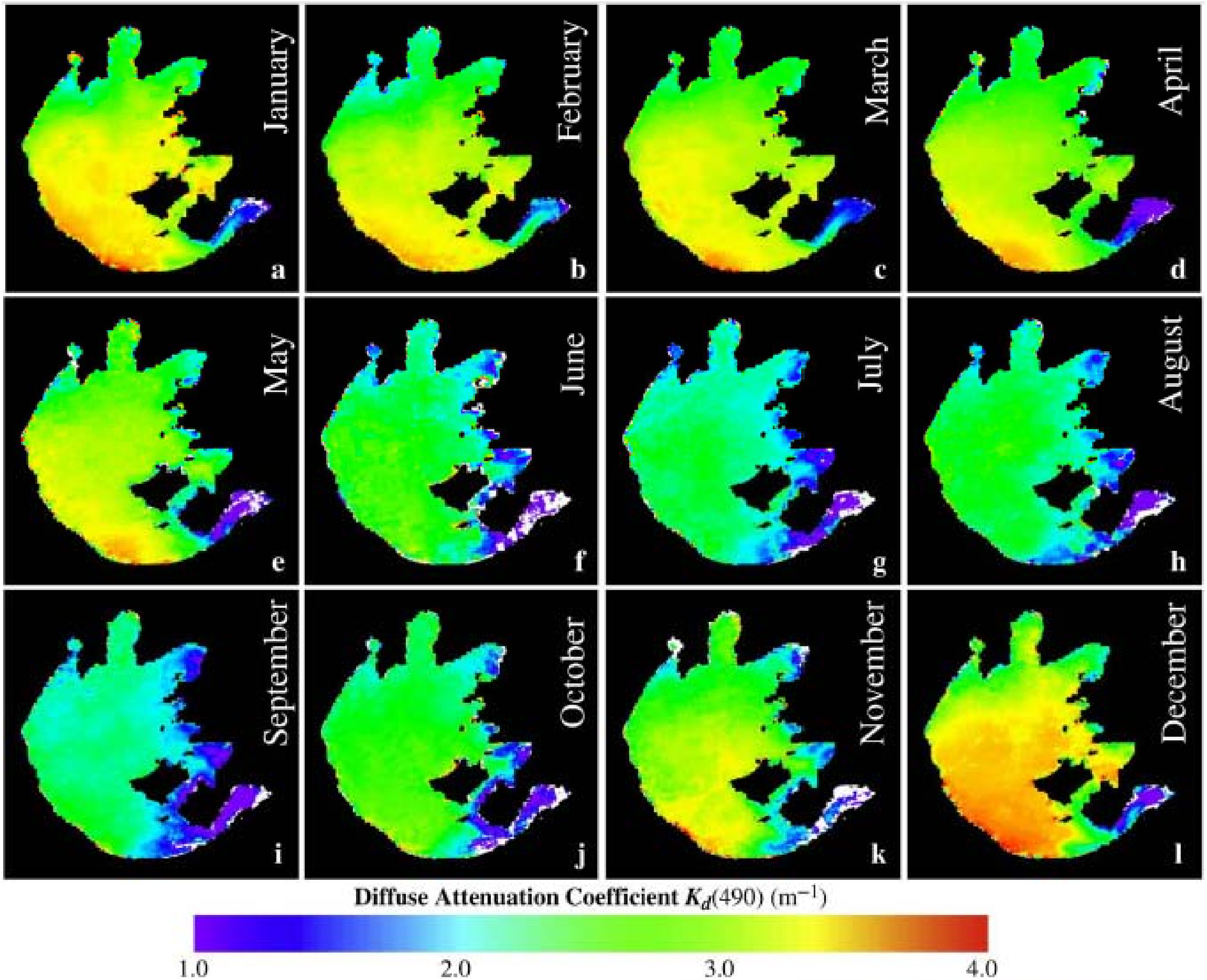

Fig. 15 MODSI-derived (2002-2008) monthly climatology $K_d(490)$

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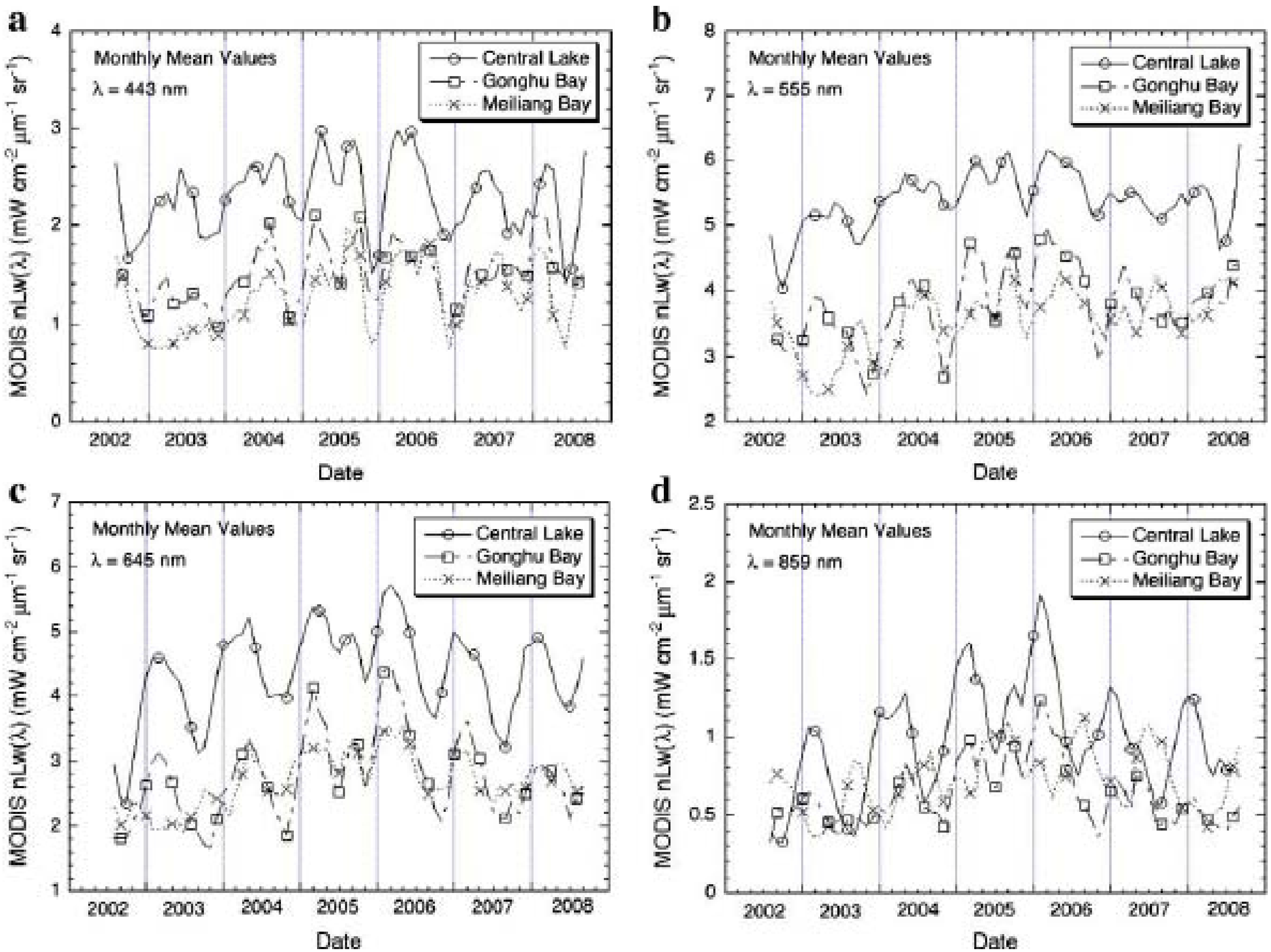

Fig. 16 MODSI-derived $K_d(490)$ for central lake, Gonghu Bay and Meiliangwan Bay

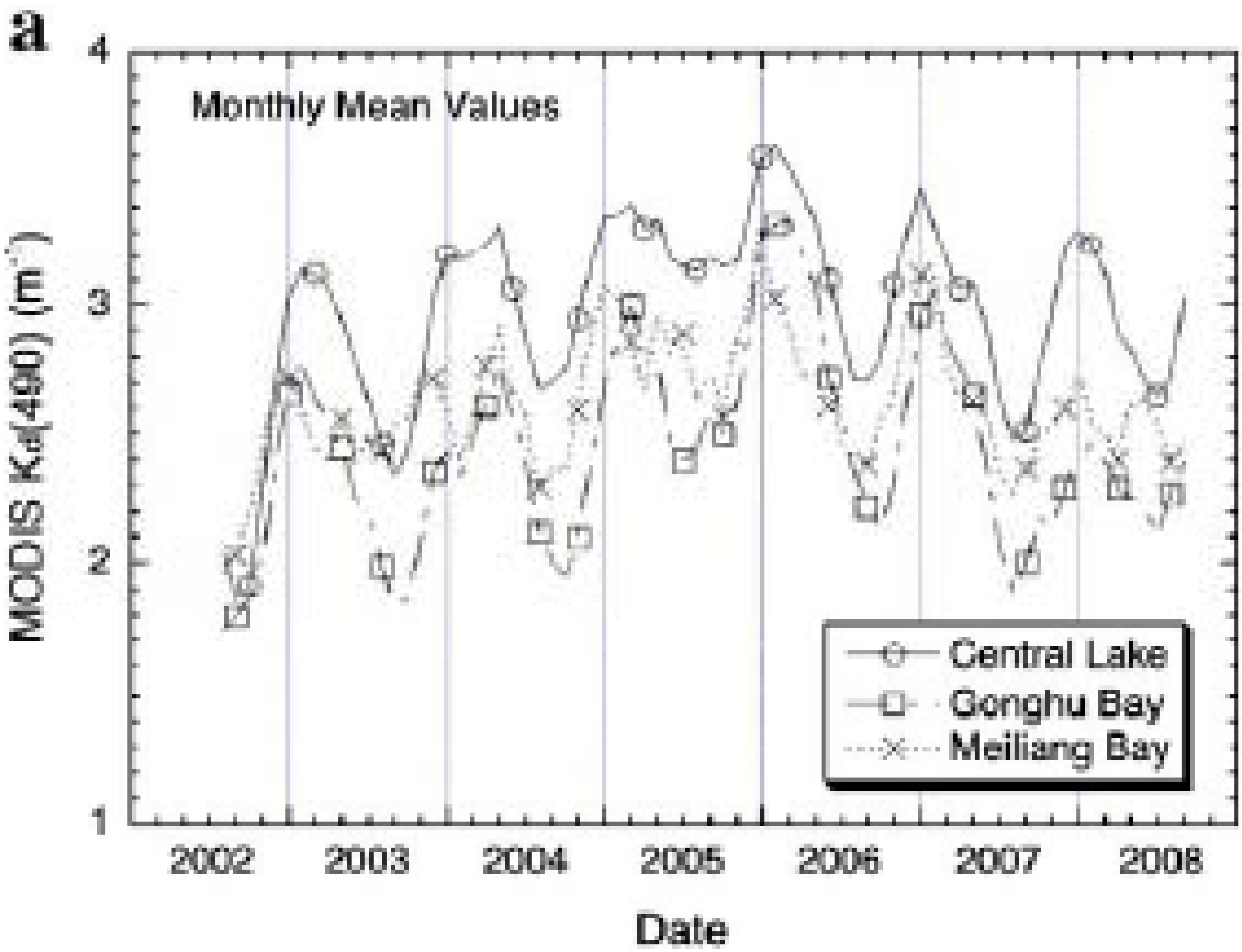

Fig. 17 Seasonal variability of MODSI-derived $K_d(490)$ for the central lake, Gonghu Bay and Meiliangwan Bay

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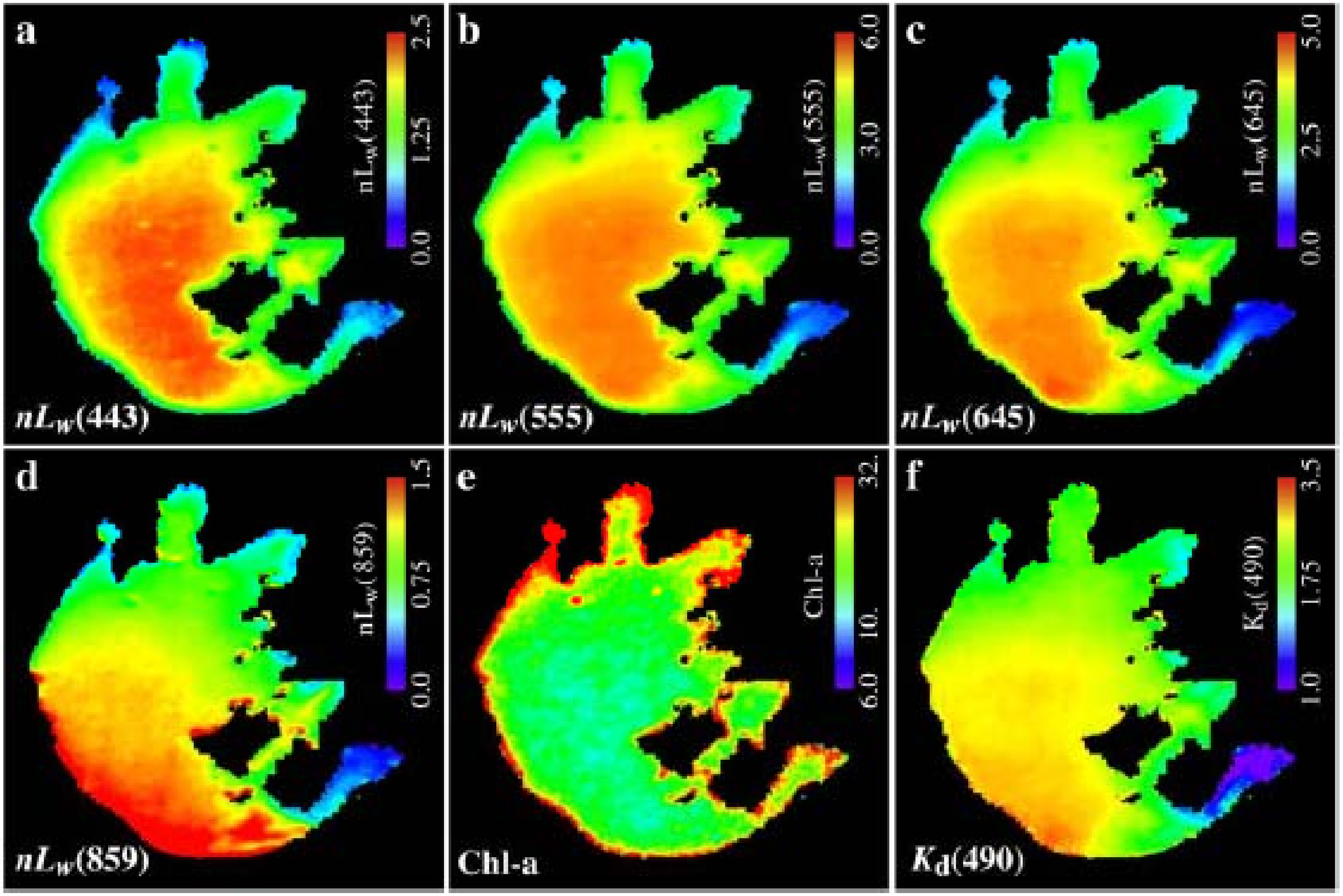

Fig. 18 MODSI-derived climatology water property

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Main conclusions

- Modified SWIR-based atmospheric correction algorithm is suitable for highly turbid inland Lake Taihu;
- Algae usually appears in the bay regions (Meiliangwan Bay, Gonghu Bay and Zhushan Bay), and high Chl-a concentration were often observed during late spring to early summer;
- Waters in Taihu are consistently highly turbid all year around, TTS concentration, driven by wind is high in winter-spring seasons and low in summer-fall seasons;
- Inland freshwater optical and biological properties, as well as water quality can be monitored and evaluated quantitatively by RS measurements (MODIS).

4. Discussion

Hypothesis for daily mean water surface albedo analysis

Difference

- $WS_{DPK} > WS_{MLW}$
- $TTS_{DPK} > TTS_{MLW}$
- Reflected short-wave irradiance (DPK) > Reflected short-wave irradiance (MLW)

Similarity

- Similar atmospheric conditions
- Similar incident irradiance

→ Albedo (DPK)> Albedo (MLW)

The spatial pattern of daily mean albedo may be similar to TTS distribution pattern on local scale.

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Difficulties for validation of lake color RS

- Reflection of bottom sediment in optical shallow regions;
- Asynchronism between RS measurement and in situ observation;
- Aerosol changing and fast variation of water color driven by wind;
- Spatial non-uniformity of water property in Lake Taihu.

Wang, 2011

Look forward to your suggestions.

Thank you!