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

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Outline

- Background
- Methods
- Results
- Discussion
1. Background

Fig. 1 Geo-location of Lake Taihu

Wang, 2011
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).
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Remote Sensing</th>
<th>In situ measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal coverage</td>
<td>High rate, long-term</td>
<td>Low rate, short-term</td>
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<tr>
<td>Spatial coverage</td>
<td>Broad field of view</td>
<td>Fixed locations</td>
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<tr>
<td>Characteristics</td>
<td>Rapid, synoptic, repeated, stable</td>
<td>Labor-intensive, confined to short period, restricted by external conditions</td>
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<tr>
<td>Spectral Resolution</td>
<td></td>
<td></td>
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<tr>
<td>Spatial Resolution</td>
<td></td>
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<tr>
<td>Temporal Resolution</td>
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Ma et al., 2009, 2010
1.2 Basic knowledge for Lake Color RS

![Diagram showing the composition of above water signals with labels: $L_{sw}$, $r \cdot L_{sky}$, $L_w$, $L_g$, and $L_f$.]

Fig. 1 Above water signal composition (Kirk, 2011)
\[ L_{sw} = L_w + r \cdot L_{sky} + L_f + L_g \]

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

- \( L_{sw} \): 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
- \( F_0 \): Top of atmosphere radiance at mean Earth-Sun distance
- \( E_d(0^+) \): Incident radiance above surface

Ma et al., 2010
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)

<table>
<thead>
<tr>
<th>Apparent optical properties (AOPs)</th>
<th>Water leaving radiance</th>
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<tbody>
<tr>
<td></td>
<td>Normalized water-leaving radiance</td>
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<tr>
<td></td>
<td>Reflectance</td>
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<td></td>
<td>Remote sensing reflectance</td>
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<td></td>
<td>Diffuse attenuation coefficient of water</td>
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<tr>
<td></td>
<td>Diffuse attenuation coefficient of irradiance</td>
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<tr>
<td>Inherent optical properties (IOPs)</td>
<td>Absorption coefficient</td>
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<tr>
<td></td>
<td>Scattering coefficient</td>
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<td></td>
<td>Scattering phase function</td>
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<td></td>
<td>Volume scattering coefficient</td>
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<td></td>
<td>Beam attenuation coefficient</td>
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</tbody>
</table>
Absorption spectra of Chlorophyll
Chemical of the week: Chlorophyll
Absorption Spectrum of Chlorophyll a

Absorption spectra of CDOM
(Zhang, 2006)

Suspended matter reflectance spectra
(NASA)

Reflectance spectra over Taihu
(Duan, 2010)

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ocean Color RS</th>
<th>Lake Color RS</th>
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<tbody>
<tr>
<td>Algorithm</td>
<td>$L_{w,\text{near-infrared}} = 0$</td>
<td>$L_{w,\text{near-infrared}} \neq 0$</td>
</tr>
<tr>
<td>Gordon algorithm for CZCS (Gordon, 1993)</td>
<td>Principal component analysis (Neumann, 1995)</td>
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<td>Gordon algorithm for MODIS (Gordon and Voss, 1999)</td>
<td>Artificial neural network method (Doerffer and Schiller, 1998)</td>
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<td>Ruddick algorithm (Ruddick, 2000, 2001)</td>
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<tr>
<td>Fixed remote sensing reflectance algorithm (He and Pan, 2003)</td>
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<td>Shortwave infrared (SWIR) algorithm (Wang and Shi, 2005)</td>
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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

MODIS L1B data, geo-location data and ancillary data

Aerosol scattering of 1240nm and 2130nm bands

Appropriate aerosol Ångström exponent values

Negligible water-leaving radiance for SWIR bands

Selecting clean pixels

\( L_f \)

Aerosol scattering of other bands

Rayleigh Scattering

\( L_g \)

\( L_w \)

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

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

where $R_{4M} = \log_{10}(R_{550}^{443} > R_{550}^{490} > R_{550}^{530})$  

O’Reilly et al., 2000

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

for $0.3 \text{ m}^{-1} < K_d(490) < 0.6 \text{ m}^{-1}$.  

Wang et al., 2009
3. Results

Fig. 5 Comparison of normalized water-leaving radiance spectra
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.
Fig. 6 MODIS-Aqua monitoring for 2007 algae bloom in Taihu
Fig. 7 Sampling locations distribution in Taihu
Fig. 8 Chl-a concentration comparison between MODSI retrieval and in situ observation (monthly).
Fig. 9 Chl-a concentration comparison between MODSI retrieval and in situ observation (every location).
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 $n_{L_w}(443)$
Fig. 12 MODSI-derived (2002-2008) monthly climatology $nL_w(555)$
Fig. 13 MODSI-derived (2002-2008) monthly climatology $nL_{w}(645)$
Fig. 14 MODSI-derived (2002-2008) monthly climatology $nL_{w}$ (859)

$nL_{w}$ (859) (mW cm$^{-2}$ μm$^{-1}$ sr$^{-1}$)
Fig. 15 MODSI-derived (2002-2008) monthly climatology $K_d(490)$
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.
Fig. 18 MODSI-derived climatology water property
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

- \( WS_{\text{DPK}} > WS_{\text{MLW}} \)
- \( TTS_{\text{DPK}} > TTS_{\text{MLW}} \)

Similarity

- Similar atmospheric conditions
- Similar incident irradiance

Reflected short-wave irradiance (DPK) > Reflected short-wave irradiance (MLW)

Albedo (DPK) > Albedo (MLW)

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

Thank you!