An overview of lake optics and remote sensing in Lake Taihu

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2012.12.12
Outline

1. Background
2. Study regions
3. Main progresses
1. Background
Solar radiation drives the lake ecosystem
Effect of increased UV-B radiation on lake ecosystem


The ozone hole in Arctic in 2011

Zooplankton irradiated by UV-B

Water waste event and frequent algal bloom urging water color remote sensing
Turbidity increase due to eutrophication causing the disappearance of SAV

SAV distribution with turbidity and nutrients increases (Scheffer, Nature, 2001)
CDOM plays an important role in the global carbon cycle and estimation.
Concept and theory framework of lake optics

AOPs: Secchi disc, reflectance, Kd, Zeu

IOPs: absorption, scattering, backscattering, etc.
Main contents and key scientific question

Investigation

- Optical parameters measurement
- Water color remote sensing
- Processes observation
- Laboratory simulation
- Numerical model

Spatial-temporal pattern:
1. Typical lakes
2. Large lake

Processes study:
1. Hydrodynamic process
2. SAV growth and death
3. Algal blooms process
4. Community succession

Results:
1. Spatial-temporal pattern and driven mechanism of lake optics
2. Coupling process and mechanism of optics, thermodynamics and hydrodynamic
3. Water color parameters, primary production and phytoplankton community remote sensing

Scientific question
2. Study regions
Total Lakes: 2742 (> 1 km²)
Total Area: 91020 km²
- Number of lakes (Area > 1 km²): 651
- Total area: 16558 km² (60% of total freshwater lake areas of China)
- Characteristics: shallow and eutrophication
Lake Taihu has multi-functions:
• Drinking water supply
• Tourism
• Flood control
Hydrography of Lake Taihu

- Area: 2338 km²
- Catchment: 36500 km²
- Mean Depth: 1.9 m
- Max. Depth: 2.9 m
- Lake Volume: 44x10⁸ m³
- Max. Level: 4.81 m a.s.l.
- Min. Level: 2.02 m a.s.l.
- Retention Time: 300 days
Characteristics 1: Diverse ecosystem types

Phytoplankton-dominated ecosystem

SAV-dominated ecosystem
Characteristics 2: Frequent algal bloom
Characteristics 3: Strong wind waves and sediment resuspension
3. Main progresses
1. Development and innovation of lake optics study methods

Absorption and relative contribution rate

Methanol soaked

NaClO bleaching

Zhang et al., 2007, Hydrobiologia
1. Development and innovation of lake optics study methods

Optimization model of tripton spectral absorption

\[ \ln a(\lambda) = a_1 - S_1 \lambda \]

\[ a_d(\lambda) = a_d(\lambda_0) \exp \left[ S_d(\lambda_0 - \lambda) \right] \]

\[ a_d(\lambda) = a_d(\lambda_0) \exp \left[ S_d(\lambda_0 - \lambda) \right] + K \]

\[ a(\lambda) = a_4 \left( \lambda / 440 \right)^{-S_4} \]
1. Development and innovation of lake optics study methods

**Phytoplankton numerical partition models**

\[ a_d(\lambda) = a_d(\lambda_0) \exp[S_d(\lambda_0 - \lambda)] \]

\[ a_{ph}(505): \ a_{ph}(380) = 0.99 \]

\[ a_{ph}(580): \ a_{ph}(692.5) = 0.92 \]

\[ a_d(\lambda) = a_d(\lambda_0) \exp[S_d(\lambda_0 - \lambda)] + K \]

\[ a_{ph}(490): \ a_{ph}(412) = 0.919 \text{Chl}a^{0.012} \]

\[ a_{ph}(510): \ a_{ph}(412) = 0.581 \text{Chl}a^{0.047} \]

With the determination coefficient larger than 0.9 and relative error less than 25%

Zhang et al., 2009, JPR
1. Development and innovation of lake optics study methods

**PAR diffuse attenuation coefficient prediction model**

\[ K_d(PAR) = \frac{a}{SDD} \]
\[ K_d(PAR) = b \cdot SDD^c \]
\[ K_d(PAR) = d \cdot C_{t-w}(PAR) + e \]

**Model calibration**

**Model validation**

\[ K_d(PAR) \]
 prediction model using, beam attenuation coefficient with the relative error less than 12%.

Zhang et al., 2012, *Hydrobiologia*
2. Lake bio-optical properties and affecting mechanism

Phytoplankton community succession in Lake Taihu

Chla-Specific absorption with Chla concentration

Zhang et al., 2012, OE
2. Lake bio-optical properties and affecting mechanism

Tripton was the dominant factor affecting $K_d$(PAR), SD and $Z_{eu}$ in Lake Taihu

$K_d$ variation with wind waves

Relationship between $K_d$(PAR) and wind speed

Zhang et al., 2006, SC-SDEC; Zhang et al., 2007, FLA
Tripton was the dominant affecting factor of $Z_{eu}$. SAV was distributed in these regions with the ratio of $Z_{eu}$ to water depth > 0.8.

Spatial pattern of SD, Zeu, and SAV distribution

Zhang et al., 2007, FLA
2. Lake bio-optical properties and affecting mechanism

CDOM controls UVR attenuation but tripton controls PAR attenuation in Yungui Plateau lakes. In contrast, tripton controls UVR and PAR attenuation in Yangtze River middle and lower reaches lakes.

Zhang et al., 2011, PPS
3. CDOM distribution, sources, composition and removal mechanism

CDOM absorption increase with trophic level but decrease with altitude increase

CDOM EEMs of different trophic level

Zhang et al., 2010, L&O
3. CDOM distribution, sources, composition and removal mechanism

Spatial pattern of CDOM in Lake Taihu

In the flood season, CDOM decreased from the river to the mouth and further to the open water.
3. CDOM distribution, sources, composition and removal mechanism

Correlation between Chla and CDOM absorption, fluorescence

CDOM increased during the phytoplankton degradation

Zhang et al., 2009, WR
3. CDOM distribution, sources, composition and removal mechanism

Photobleaching causes CDOM decrease as the first-order kinetics

Zhang et al., 2009, Hydrobiologia
3. CDOM distribution, sources, composition and removal mechanism

CDOM composition parameters change under natural solar radiation irradiation

Zhang et al., 2009, Hydrobiologia
4. Water color parameters and primary production estimation

Chla three-band model calibration

\[ C_{\text{Chla}} = 347.7[R_s^{-1}(690) - R_s^{-1}(703)] \times R_s(759) + 27.6 \]

\( r^2 = 0.94, p < 0.0001, n = 197 \)

Chla three-band model validation

RMSE = 15.1 \( \mu \text{g L}^{-1} \) (37.3%)
Mean RE = 44.2%

Zhang et al., 2009, IEEE TGRS

Chla spatial pattern
4. Water color parameters and primary production estimation
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Calibration and validation of PAR diffuse attenuation coefficient

Zhang et al., 2012, OE
4. Water color parameters and primary production estimation

Euphotic depth spatial-temporal pattern
4. Water color parameters and primary production estimation

\[ PP_{eu} = \cdot D_{irr} \]
4. Water color parameters and primary production estimation

Primary production spatial-temporal pattern
4. Water color parameters and primary production estimation

Monthly variation

Yearly variation

Comparison of empirical and VGPM models

Determination coefficient between empirical and VGPM models was higher than 0.80. The yearly mean phytoplankton primary production was 1172.6 mgC·m⁻²·d⁻¹ and the summer accounted for 43.0%.

Zhang et al., 2007, JPR
Summary

Development of physical limnology and lake optical remote sensing

Method development and innovation

- Underwater light climate and affecting mechanism
  - blue-green algae light competition
  - SAV spatial pattern

- CDOM distribution, source, composition and removal mechanism
  - Relationship with DOC
  - Carbon cycle
  - Characterizing DOM

- Water color and primary production remote sensing
  - Chla, TSM, CDOM, Kd, Zeu estimation
  - Primary production and SAV estimation
Thanks for your attention

Welcome to Lake Taihu