Water Optics and Water Colour Remote Sensing

Yunlin Zhang [1,*] **, Claudia Giardino** [2] **and Linhai Li** [3]

[1] Taihu Laboratory for Lake Ecosystem Research, State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[2] Institute for Electromagnetic Sensing of the Environment, National Research Council of Italy, via Bassini 15, 20133 Milan, Italy; giardino.c@irea.cnr.it
[3] Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093, USA; lil032@ucsd.edu
* Correspondence: ylzhang@niglas.ac.cn; Tel.: +86-25-8688-2198; Fax: +86-25-5771-4759

Abstract: The editorial paper aims to highlight the main topics investigated in the Special Issue (SI) "Water Optics and Water Colour Remote Sensing". The outcomes of the 21 papers published in the SI are presented, along with a bibliometric analysis in the same field, namely, water optics and water colour remote sensing. This editorial summarises how the research articles of the SI approach the study of bio-optical properties of aquatic systems, the development of remote sensing algorithms, and the application of time-series satellite data for assessing long-term and temporal-spatial dynamics in inland, coastal, and oceanic waters. The SI shows the progress with a focus on: (1) bio-optical properties (three papers); (2) atmospheric correction and data uncertainties (five papers); (3) remote sensing estimation of chlorophyll-*a* (Chl-*a*) (eight papers); (4) remote sensing estimation of suspended matter and chromophoric dissolved organic matter (CDOM) (four papers); and (5) water quality and water ecology remote sensing (four papers). Overall, the SI presents a variety of applications at the global scale (with case studies in Europe, Asia, South and North America, and the Antarctic), achieved with different remote sensing instruments, such as hyperspectral field and airborne sensors, ocean colour radiometry, geostationary platforms, and the multispectral Landsat and Sentinel-2 satellites. The bibliometric analysis, carried out to include research articles published from 1900 to 2016, indicates that "chlorophyll-*a*", "ocean colour", "phytoplankton", "SeaWiFS" (Sea-Viewing Wide Field-of-View Sensor), and "chromophoric dissolved organic matter" were the five most frequently used keywords in the field. The SI contents, along with the bibliometric analysis, clearly suggest that remote sensing of Chl-*a* is one of the topmost investigated subjects in the field.

Keywords: water optics; water colour remote sensing; bibliometric analysis; popular study topics; chlorophyll-*a*

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1. Water Optics and Water Colour Remote Sensing from a Bibliometrics Perspective

Bibliometrics, which was first introduced by Pritchard [1], has been widely used to quantitatively and qualitatively analyse scientific production and research trends at the decade to century scale with a large amount of data [2]. Using the Science Citation Index-Expanded (SCI-Expanded, where SCI is the multidisciplinary database of the Institute for Scientific Information, Philadelphia, PA, USA) database of the Web of Science and "bibliometric analysis" as the topic, 1502 papers could be searched by the end of 2016. The bibliography of all articles related to water optics and water colour remote sensing from 1900 to 2016, was compiled by searching, in the online version of SCI-Expanded, the following keywords: TS (Topic) = ("inherent optical propert *" or "apparent optical propert *" or "bio-optical propert *" or "remote sensing reflectance *" or "absorption coefficient *" or "scattering coefficient *" or

CDOM) or (("suspended matter *" or "particle matter *" or CDOM or chlorophyll or phycocyanin or "water colour *" or bloom * or macrophyte *) and "remote sensing *")) and TS = (lake * or reservoir * or ocean * or coastal * or estuary * or bay *). Keywords contain the most critical information in most papers whose frequency was used to discover study hotspots. Notably, only author keywords, not KeyWords Plus, were used for this analysis [3,4].

The total publication number was 4809 when the aforementioned search strategy was used. We presented the 20 most frequently used keywords of water optics and water colour remote sensing research (Figure 1). "chlorophyll-*a*" (Chl-*a*), "ocean colour", "phytoplankton", "SeaWiFS" (Sea-Viewing Wide Field-of-View Sensor), and "chromophoric dissolved organic matter (CDOM)" were the five most frequently used keywords of the study subject after excluding, for obvious reasons, the keyword "remote sensing". In particular, the frequency of "Chl-*a*" was as high as 532, which was much higher than the second frequently used keyword "ocean colour" (86). The result of SeaWiFS indicated the role played in the past from this sensor, while for recent years sensors such as Moderate Resolution Imaging Spectroradiometer (MODIS), Medium-Resolution Imaging Spectrometer (MERIS), and OLCI might be considered as improved successors. This result indicated that Chl-*a*-related study was the popular study topics in the field of water optics and water colour remote sensing.
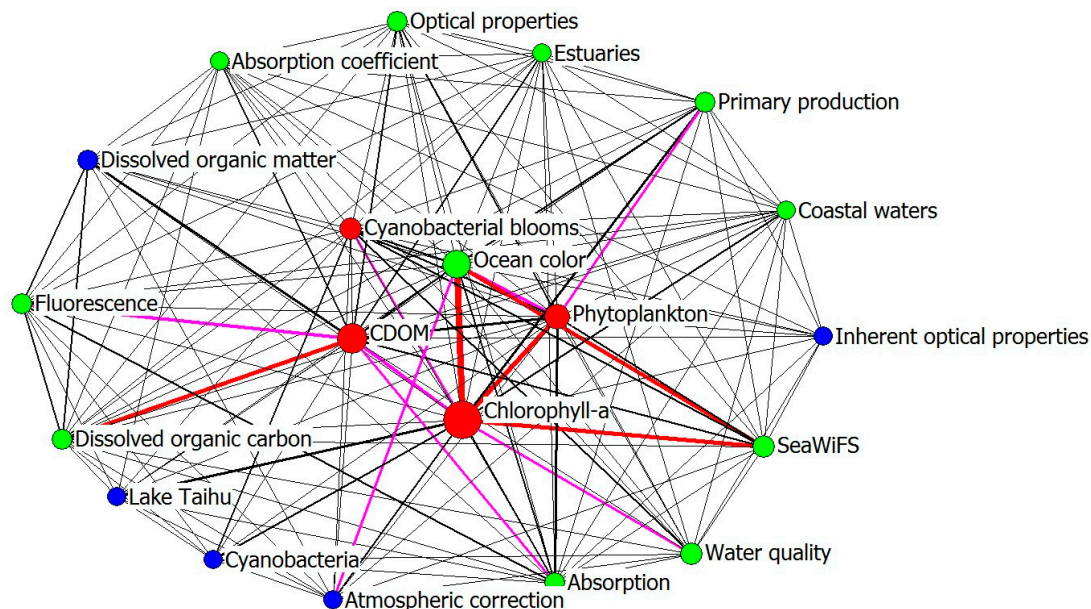

Figure 1. Co-word network of high-frequency keywords in water optics and water colour remote sensing research. The size of lines represents the number of co-occurrences. The colour of lines represents the group of the co-occurrences number: red $\geq$ 50; 25 $\leq$ magenta < 50; black $\leq$ 25. The size of nodes represents the keyword frequency; the colour of nodes represents the group of the number of connections to other nodes: red = 20; 15 $\leq$ green < 20; 10 $\leq$ blue < 15.

2. Overview and Scope of the Special Issue

Available water resources, including rivers, reservoirs, lakes, coastal waters, and oceans, are emerging as a limiting factor, not only in quantity, but also in quality, for human development and ecological stability. Declining water quality has become a global issue of significant concern as anthropogenic activities expand and climate change threatens to cause major alterations to the hydrological cycle. Thus, monitoring the physical, chemical, and biological status of those waters is immensely important. Remote sensing has the potential to provide an invaluable complementary source of data at local to global scales. However, accurate, cost-effective, frequent, and synoptic retrieval algorithms of in-water optical and biogeochemical parameters, as well as information on the biophysical properties of the monitored waters, have several challenges.

This Special Issue (SI) focusing on "Water Optics and Water Colour Remote Sensing" is specifically aimed at addressing: (1) issues on water optics including the characterisation of optical properties among rivers, reservoirs, lakes, coastal waters, and open sea, modeling the relationships between apparent optical properties (AOPs) and inherent optical properties (IOPs); and (2) challenges on retrieval algorithm developments, validation, and applications of remote sensing of rivers, reservoirs, lakes, coastal waters, and open ocean. This SI presents many of the recent progresses in this rapidly growing research area.

3. Highlights of Research Articles

The main topics of this SI concentrate on: (1) bio-optical properties (three papers); (2) atmospheric correction and data uncertainties (five papers); (3) remote sensing estimation of Chl-*a* (eight papers); (4) remote sensing estimation of suspended matter and CDOM (four papers); and (5) remote sensing estimation of other water qualities and water ecological parameters (four papers). Overall, Chl-*a* estimation-related study is a major topic in this SI, which is consistent to the previously described bibliometrics analysis.

There are three papers on bio-optical properties in this issue. Ma et al. [5] reported the spatial distribution of the diffuse attenuation coefficient of photosynthetic active radiation (PAR) (K_d(PAR)) and its main regulating factors in 26 lakes and reservoirs in Northeast China. The results showed that total suspended matter was the dominant factor in determining K_d(PAR) values and best correlated with K_d(PAR). Zhou et al. [6] presented a model to describe the polarisation patterns of celestial light, when refracted by wavy water surfaces. Scattering skylight dominates the polarisation patterns, while direct solar light is the dominant source of the intensity of the underwater light field. Wind speed has an influence on disturbing the patterns under water. To optimise atmospheric correction and bio-optical algorithms for the wide variety of lake optical conditions, Eleveld et al. [7] proposed two water type classification schemes through a cluster analysis of in situ hyperspectral remote sensing reflectance spectra collected around the world.

There are five papers on atmospheric correction and data uncertainties in this issue. In each of the three atmospheric correction papers, one or more atmospheric correction strategies were evaluated. The commercial ATCOR4 code was applied to airborne imagery [8], a series three of methods (i.e., ACOLITE NIR, ACOLITE SWIR, and MACCS) based on the use of short-wave infrared (SWIR) spectral bands was applied to satellite data of turbid coastal waters [9], and again three atmospheric correction methods (ACOLITE, 6SV, and Sen2Cor) were applied to Sentinel-2 images of lakes [10]. Two data uncertainties papers discussed the impact of the Signal-to-Noise Ratio of sensor design on the Chl-*a* and total suspended matter algorithms in four lakes located at Mamirauá Sustainable Development Reserve (Amazonia, Brazil) [11], and sensors selection, near-coincident data determination, and potential limitations of remote sensing measurements for surface and near-surface conditions [12].

There are eight papers on the remote sensing estimation of Chl-*a* in this issue. These papers presented Chl-*a* remote sensing estimation models including the height of the 810 peak of remote sensing reflectance [13], the comparison of four empirical models (Blue-Green Ratio Model, Two-Band NIR-Red Ratio Model, Three-Band NIR-Red Model, and Four-Band NIR-Red Model) [14], a coupled atmosphere-hydro-optical model [15], the combination of AisaFENIX sensor and ATCOR4 in image-driven parametrisation [8], iterative stepwise elimination partial least squares regression based on field hyperspectral [16], and an improved baseline fluorescence approach [17]. In addition, long-term spatial and temporal variabilities of Chl-*a* from MODIS and SeaWiFS observations in the Bohai Sea (2000–2012) [18] as well as from MERIS images in Lake Erie (2004–2012) [19] were elucidated.

There are five papers on the remote sensing estimation of suspended matter and CDOM in this issue. Kutser et al. [13] found that the height of the 810 peak was in good correlation with suspended matter and assessed the application of this finding on Landsat 8 and Sentinel-2 images. Wang et al. [20] developed an algorithm using the slope of R_{rs}(490) and R_{rs}(555) to estimate particle cross-sectional area concentration from the Geostationary Ocean Colour Imager (GOCI). An iterative stepwise elimination

partial least squares regression based on field hyperspectral was used to estimate water total suspended matter concentration in irrigation ponds in Japan [16]. Campanelli et al. [21] developed an empirical band ratio model using $R_{rs}(667)/R_{rs}(488)$ to estimate CDOM using MODIS ocean colour sensor images and data collected on the North-Central Western Adriatic Sea (Mediterranean Sea).

Lastly, there are four papers on the remote sensing estimation of other water qualities and water ecological parameters in this issue. Turbidity climatology over an eight-year period (2004–2011) in Apalachicola Bay was investigated based on remote sensing estimation from Landsat 5 TM and Landsat 8 OLI imagery using a single-band empirical relationship of band 3 [22]. Deng et al. [23] tested the applicability of the Vertically Generalised Production Model (VGPM) to estimate phytoplankton primary production by comparing the model-derived and the in situ results, investigated the long-term temporal-spatial variations in primary production using MODIS data, and further discussed the potential affecting factors in Lake Taihu. Liang et al. [24] developed a new cyanobacteria and macrophytes index (CMI) based on a blue, a green, and a shortwave infrared band to separate waters with cyanobacterial scums from those dominated by aquatic macrophytes. Deng et al. [25] employed 1375 seasonally continuous Landsat TM/ETM+/OLI data scenes to evaluate the lake water area changes from 1987 to 2015, and found a loss of 241.39 km^2 (10.67%) from 1987–2002 to 2005–2015 in Wuhan Urban Agglomeration, China.

4. Conclusions

This SI presents the state-of-the-art and represents the progress in the field of "Water Optics and Water Colour Remote Sensing". The 21 papers published in this SI present a variety of studies mainly related to bio-optical properties measurement and modeling, atmospheric correction and data uncertainties, remote sensing algorithms for Chl-*a*, suspended matter and CDOM, as well as water quality and water ecology applications. The SI covers a variety of applications at the global scale (with case studies in Europe, Asia, South and North America, and even the Antarctic), with different remote sensing instruments, ranging from hyperspectral field and airborne sensors, to ocean colour radiometry, geostationary platforms, and multispectral sensors such as Landsat and Sentinel-2. In particular, both the bibliometric analysis and a major number of articles in the SI suggest a popular and important research topic in the field—remote sensing of Chl-*a*, a parameter with a global relevance (phytoplankton is a prolific primary producer occurring in oceans and the world's freshwater sources) and one of primary interest for water quality authorities.

Conflicts of Interest: The authors declare no conflict of interest.

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