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Editorial

Remote Sensing of Floodpath Lakes and Wetlands: A Challenging Frontier in the Monitoring of Changing Environments

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Abstract: Monitoring of changing lake and wetland environments has long been among the primary focus of scientific investigation, technology innovation, management practice, and decision-making analysis. Floodpath lakes and wetlands are the lakes and associated wetlands affected by seasonal variations of water level and water surface area. Floodpath lakes and wetlands are, in particular, sensitive to natural and anthropogenic impacts, such as climate change, human-induced intervention on hydrological regimes, and land use and land cover change. Rapid developments of remote sensing science and technologies, provide immense opportunities and capacities to improve our understanding of the changing lake and wetland environments. This special issue on Remote Sensing of Floodpath Lakes and Wetlands comprise featured articles reporting the latest innovative research and reflects the advancement in remote sensing applications on the theme topic. In this editorial paper, we review research developments using state-of-the-art remote sensing technologies for monitoring dynamics of floodpath lakes and wetlands; discuss challenges of remote sensing in inventory, monitoring, management, and governance of floodpath lakes and wetlands; and summarize the highlights of the articles published in this special issue.

Keywords: floodpath lakes and wetlands; Landsat-LakeTime; Sentinel-1 SAR; Sentinel-2 MSI; Sentinel-3 OLCI; TanDEM-X; Poyang and Dongting lakes; Barguzin Valley Lake Baikal; Biebrza marshes

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1. Introduction

The needs for satellite-based observation of terrestrial aquatic ecosystem has for long received the attention of the world [1,2]. Timely measurements of water levels in the main channels of rivers, upland tributaries, and floodplain lakes are necessary for understanding flooding hazards, sediment transport, and nutrient exchange [3]. Affected by the seasonal variations of water level and surface area, floodpath lakes and wetlands are extremely sensitive to natural and anthropogenic impacts, such as climate change, human-induced intervention on hydrological regimes, and land use and land cover change [4–8]. Remote sensing from optical and active sensor systems, such as the Landsat, SPOT, MODIS, MERIS, AVHRR, and such as ERS, ENVISAT, J-ERS, PALSAR RADARSAT, COSMO SKYMED, and the TerraSAR-X, have been proven effective in monitoring the change of flooding and inundation conditions from global to local environments [9–20]. Satellite altimetry sensors have been applied in monitoring water extents, heights, and flows [21–36]. Rapid developments of remote sensing capacities have expanded their applications into ecological, hydrological, geomorphological, and societal interests in inundated situations [37–39]. SAR and InSAR from active sensors have been applied in water level and wetland mapping [40–46]. Hyperspectral remote sensing provides promising approaches in the monitoring of global tidal wetlands [47–49]. High spatial resolution satellite data have been effectively applied in water and wetland mapping and change analysis [50–54]. Sentinel satellites have demonstrated enhanced capacities in the monitoring of changing water and wetland environments, in recent years [55–60]. Database for the measurements of global water bodies derived from moderate resolution satellite sensors have been developed [61–64].

Remote sensing applications have been widely reported in lake and wetland mappings, in particular, for representative large lakes and associated wetlands. For example, the Poyang and Dongting lakes in the middle and lower reaches of the Yangtze River are among the representative floodpath lakes with dramatic spatial and temporal variation patterns in water surface areas and the associated wetlands. The lakes play a crucial role in the accommodation of flood water from its tributaries and the Yangtze, as well as for the regulation of sedimentation in the lower reach of the Yangtze [65]. Poyang Lake wetland is recognized to be among the most important wetlands of the world for its extraordinary biodiversity and conservation value. Different types of remote sensing data have been applied to reveal the spatial and temporal patterns of water extents and levels and the responses of vegetation and habitats, as well as the effects of sand dragging, sedimentation, and the contamination of this unique floodpath lake/wetland combination [66–79].

Remote sensing has been effectively applied in the monitoring of waters and wetlands around the world, for example, in the Amazon basin [80–82], in the African Great Lakes [12,83–89], in the greater Everglades [90–92], in coastal Louisiana [93–97], in Alpine lakes on the Tibetan Plateau [32,98–102], in tropical lakes [103], in river deltas [46,104], in Lake Baikal [105,106], and in large lakes in Europe and China [107–112].

Remote sensing of floodpath lakes and wetlands has become routine in scientific research and in management practices, in flood and flood-prone areas [113,114]. Challenges remain to be addressed for the advancement of the science, technologies, and the management practices [115,116].

2. Challenges in Monitoring of Floodpath Lakes and Wetlands

A growing scarcity of fresh water resources and their security, under the changing environment, has long been recognized as a primary challenge [117,118]. For remote sensing, the challenges mostly exist in obtaining time sensitive data and generating precise and accurate information. Improvements of capacities in data acquisition and methodologies, in information extraction, are deemed necessary.

Significant efforts have been devoted to the development of time sensitive database and approaches for monitoring the dynamic nature of water level and storage variations, using remote sensing data [25]. Availability of open-access satellite data, for example the Landsat [119] and optical high-resolution Sentinel-2 data [120], created an unprecedented opportunity of converting the efforts and assets from a multi-decadal, time-series Earth observation for the use of societal benefits. The capacity and service from Google Earth Engine, for another example, open opportunities to address the challenges in satellite-data availability, cloud computing, machine learning, and change analysis [121]. However, there still exists the challenges and uncertainties, in data continuity and availability, which might be introduced by potential governmental action [122].

Among the challenges, there is a particular concern in the cloud-prone and rainy regions, for monitoring of the floodpath environments [123–125]. Active sensors have advantages, as cloud cover during the rainy season obscures optical observations [126–131]. This is, in particular, effective for event-driven critical time periods. Integration of multi-sensor data provides enhanced capacity to improve the needed data for monitoring. For example, integration of optical high-resolution imagery and altimetry data demonstrated an approach to determining the volume of water in small lakes [132]. The Sentinel-1 and 2 constellations provide data continuity for the ERS, ENVISAT, and SPOT satellites. With the most recent launch of the second Copernicus Sentinel-3 satellite, Sentinel-3A/3B sensors opened opportunities for remote sensing of coastal and terrestrial waters [133].

Water quality monitoring is deemed challenging because of complexities of water environments, in connection to their contributing tributaries within the watersheds. Remote sensing of inland waters has faced challenges in the retrieval of physical and biogeochemical properties [134–136]. In particular, the optical complexity of inland waters is typically characterized by high concentrations of phytoplankton biomass, chlorophyll-a (chl-a), turbidities with suspended materials that typically do not co-vary over space and time. The development and validation of atmospheric and in-water models for optically complex waters, can only be properly advanced through rigorous testing and refinement of candidate algorithms, across the full spectrum of optical water types [137]. Comprehensive validation studies in remote sensing of water quality are much needed through collaborative team studies. For example, approaches in integration of remote sensing and field-based monitoring have been constantly explored for improving the understanding of spatial and temporal patterns of water constituents [138,139], such as Chl-a concentration, colored dissolved organic matter (CDOM), dissolved organic carbon (DOC), total suspended materials (TSM), intensity of the sedimentation and effects of the human-induced hydrologic engineering projects on the water qualities for both inland and coastal waters [135,140–148].

Floodpath wetlands provide unique ecosystem services that are invaluable to the wellbeing of life on the planet Earth. Degradation and loss of wetlands are caused by land conversion, water eutrophication and pollution, the introduction of invasive alien species, and are indirectly fostered by economic development and population growth, as well [149]. Yangtze reaches and the connected lakes, such as Poyang and Dongting Lakes, are the most important wintering zones of waterfowl in East Asia, hosting significant proportions of the populations of cranes, geese and swans. The Yangtze floodplain hold the highest diversities of Anatidae in the world. About 80% of Anatidae in Eastern China's wetlands are in the Yangtze [150]. Challenges for monitoring of floodpath wetlands are associated with dynamics of water levels, extents, and quality. In particular, monitoring and explaining the spatio-temporal changes in wetland biodiversity caused by biotic and abiotic factors remain to be precisely mapped and understood. The timing of exposure of recessional vegetation lead to changes in the landscape composition and configuration patterns, which in turn affect the biodiversity, abundance, and habitats of the migratory wildfowl. Species that depend on seasonal submerged aquatic vegetation for their migratory foraging requirements have experienced challenges due to the impacts on variations of water level and extents. These impacts, in particular, include alterations of hydrological patterns from human activities, such as sand dredging and engineering measures of water control.

Improved remote sensing capabilities in data acquisition and processing facilitate precision and accuracy of change detection. The focus is on specific vegetation dynamics and their influence on sensitive wetland areas in floodpath environments.

Real-time remote monitoring of water environments demonstrated the advancement of sensor network for automated in situ data acquisition, wireless data transmitting, and information extraction [151,152]. Remote sensing practices need support from in situ data observed from field-based monitoring. Integration of automated in situ data acquisition, with space-born and airborne remote sensing data, can improve the validation requirements in dynamic water environments from GPS-guided field survey, GPS-based wildlife telemetry, and time series field-based observations.

Unmanned Aerial Vehicles (UAVs) extend the capacities and potentials for in situ water quality measurement and integration with remote sensing, for improved spatial resolution, flexibility, and frequency in data acquisition [153,154]. Seamless integration of UAVs data, with remote sensing and field-based observations, presents technical challenges to streamline the process.

3. Highlights of the Special Issue Articles

The articles in this Special Issue include applications of using data from multiple sensor systems to address the mapping and change analysis in floodpath lakes and wetlands, from global to local interests.

To address the common and critical issue in satellite data searching for monitoring of lake and wetland dynamics, Lyons and Sheng [64] present an automated method for selecting images for global scale lake mapping, to minimize the influence of seasonality, while maintaining the long-term trends in dynamics of lake surface area. Using historical meteorological data and a water balance model, this approach defined the most stable period after the rainy season, when inflows equaled outflows, independently, for each Landsat tile and select images acquired during that ideal period, for lake surface area mapping. The images selected provided nearly complete global area coverage at decadal episodes for circa 2000 and circa 2014, from Landsat ETM+ and OLI sensors, respectively. This method is being used in regional and global lake dynamics mapping projects, and is potentially applicable to any regional/global scale remote sensing application.

Suspended particulate matter (SPM) is one of the dominant water constituents in inland and coastal waters. SPM concentration (CSPM) is a key parameter describing the water quality of floodpath lakes. Liu et al. [155] reports a study that used in-situ spectral and CSPM measurements, as well as Sentinel 2 Multispectral Imager (MSI) images, to develop CSPM retrieval models and to estimate CSPM values of the Poyang Lake, China. The study involved in situ hyperspectral measurements and relative spectral response function to simulate Sentinel 2 MSI spectra. The developed models were then applied to two Sentinel 2 MSI images, captured in the wet and dry seasons, and the derived CSPM values were compared with those derived from MODIS B1 (λ = 645 nm). Results showed that the Sentinel 2 MSI B4–B8b models achieved acceptable to high-fitting accuracies. The validation showed the Sentinel 2 MSI-derived CSPM values were consistent in spatial distribution and magnitude, with those derived from the MODIS. This study demonstrated the applicability of Sentinel 2 MSI for CSPM retrieval in the Poyang Lake, and the Sentinel 2 MSI B4 and B7 are recommended for low and high loadings of SPM, respectively. The Ocean and Land Color Imager (OLCI) sensor on board Sentinel-3A satellite is important to the expansion of remote sensing monitoring of inland waters. With the successful launch of Sentinel-3A in 2016, Shen et al. [156] developed a dual band ratio algorithm for the downwelling diffuse attenuation coefficient at 490 nm for the waters of Lake Taihu in China. The results revealed a high consistency between the OLCI and MODIS data products. The study suggested that OLCI product possess smoother spatial distribution and finer textural characteristics. The higher spatial resolution and dynamic range of spectral bands of OLCI are in particular suitable for mapping of large or small inland water areas. The availability data from Sentinel-3B in 2018, teamed with Sentinel-3A, provide a significant improved capability in monitoring of inland waters with complex optical properties.

The article by Li et al. [157] introduces a coupled modeling approach to improve the understanding about the influence of water temperature on the rates of ecosystem processes, in large floodplain lake systems that are subjected to multiple stressors. The approach was based on the coupling of physically-based hydrodynamic model, with a transport model to examine the spatial and temporal behavior and primary causal factors of the water temperature, within the floodplain of Poyang Lake. Model performance was assessed through comparison with field observations and remote sensing data. The daily water temperature variations within the Poyang Lake were reproduced, well, by the hydrodynamic model. The modeling results indicated that the water temperature exhibits distinct spatial and temporal variability. Although the degree of spatial variability differs considerably between seasons, the water temperature generally decreases from the shallow floodplains to the main flow channels of the lake. The study presents a first attempt to use a coupled model approach, which provides a useful tool to investigate the water temperature behavior and its major causal factors for a large floodplain lake system. It would have implications for improving the understanding of Poyang Lake water temperature and supporting the planning and management of the lake, its water quality, and ecosystem functioning.

Mleczko and Mróz [58] reported a study in wetland mapping, using SAR data from the Sentinel-1A and TanDEM-X Missions, as a comparative study in the Biebrza Floodplain, Poland. This research was related to the eco-hydrological problems of the herbaceous wetland drying and biodiversity loss in the floodplain lakes of the Middle Basin of the Biebrza River. The main goals included (1) mapping the vegetation types and the temporarily- or permanently-flooded areas, and (2) comparing the usefulness of the C-band Sentinel-1A (S1A) and the X-band TerraSAR-X/TanDEM-X (TSX/TDX), for mapping purposes. The study made efforts to address wetland mapping, using S1A multi-temporal series and fully polarimetric TSX/TDX data, to compare wetland mapping using dual polarization TSX/TDX subsets and the S1A and TSX/TDX data, based on the same polarization (VV-VH), to assess the contribution of interferometric coherence, for wetland classifications. The experimental results showed limitations of the S1A dataset, the accuracy using TSX/TDX data, as well as practical outcomes for management practice using SAR.

Berhane et al. [158] conducted pixel- and object-based image analyses (OBIA), using parametric and non-parametric (random forest, RF) approaches in the Barguzin Valley, a large wetland in the Lake Baikal drainage basin. The study analyzed Quickbird multispectral bands, plus various spatial and spectral metrics (e.g., texture, Non-Differentiated Vegetation Index, slope, aspect, etc.) using field-based regions of interest. The study evaluated the performances of combinations of classifiers, using different spectral bands and compared the pros and cons of the tested approaches for wetland mapping in the subject wetland area.

Yang et al. [159] conducted a study in the hydrological changes in Tian-e-Zhou Oxbow Lake in an ungauged area of the Yangtze River basin which is an important habitat for endangered wetland species. Remote sensing data acquired between 1992 and 2015 were employed to obtain the historical water levels, based on the water boundary elevation integrated with a topographic data (WBET), as well as the level-surface area relationship curve (LRC) methods. The results indicated that the hydrological regime of the oxbow lake has experienced a significant change after a major levee construction in 1998. The study revealed the changed hydrological pattern of the oxbow lake, which could bring disadvantages to the habitats of the two endangered species.

Lakes in arid and semi-arid regions have an irreplaceable and important role in the local environment and wildlife habitat protection. Liang and Yan [160] reported a study that used three hundred and thirty-six Landsat images from 1988–2015 and the Modified Normalized Difference Water Index to extract monthly water area and lake island area, in the Hongjian Lake in China. The study site is the only critical habitat option of the Relict Gull (Larus relictus), which is listed as a "vulnerable" bird species in the Red List of the International Union for Conservation of Nature (IUCN). The lake and wetland have been severely threatened by persistent lake shrinkage. The results showed that the lake area exhibited large fluctuations and an overall downward trend of $-0.94\ km^2/year$. The cumulative anomaly analysis diagnosed the lake variations as two sub-periods, during 1988–1998 and 1999–2015, with different characteristics and leading driving factors. The study concluded with suggestions to management practice for the conservation of Relict Gull.

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