Lakes, Climate and Remote Sensing

Towards an international multidisciplinary working group using remote sensing to assess the impacts of environmental change on lakes

J-F Cretaux and T. Pavelsky

Lakes and climate

All around the world, millions of lakes ranging in size from small ponds to inland seas dot the landscape. Scientifically, lakes are of great interest in the disciplines of hydrology, limnology, climatology, biogeochemistry, and geodesy. Often, these scientific communities operate independently, missing the potential benefits of cross-disciplinary collaboration. One of the most fruitful ways that lake scientists might collaborate is via the shared tool of remote sensing, which, through existing and planned sensors, can help to extend on-the-ground measurements to regional and global contexts. We have begun organizing a group of lake scientists from many countries in an effort to develop an international working group on integrating the study of lakes across many disciplines, and we invite interested colleagues from all disciplines to participate.

Lakes and enclosed inland seas are integrators of environmental and climatic changes occurring within their contributing basins. The factors that drive lake conditions vary widely across space and time, and lakes, in turn, impact their surrounding environments in important and diverse ways. As a result, lakes are important to our understanding of water resource availability, electricity generation (in the case of reservoirs), economic activity, and climate change. They constitute essential components of the hydrological and biogeochemical cycles due to their basic ability to store, retain, clean, and provide water. Lakes serve as sentinels of current and changing conditions, as actors in influencing their surrounding environments, and as integrators of human and environmental activities in their contributing basins. The geographical distribution of the world's lakes is very irregular, with most lakes located at high latitudes in the Northern Hemisphere and in currently or formerly glaciated areas**.** Their spatial distribution at the global scale provide opportunities for large-scale studies of environment, biodiversity, health (spread of water-borne diseases), agricultural suitability, climate change modeling, and for assessments of present and future water resources.

Despite the global significance of lakes, long-term sampling efforts have primarily focused on northern temperate sites. On-the-ground lake observations are scarce in many areas of the globe, especially geographically remote, lake-rich regions such as the Canadian and Siberian Arctic and subarctic regions, other less populated areas like the Himalayas, the Andes, and, in contrast, populated regions like the great lakes in Africa. Existing and forthcoming remote sensing technologies possess great potential to address this deficiency in several areas. Current satellite altimeters provide dense time series of water surface elevation measurements for the largest lakes, and multispectral optical and thermal sensors can be used to measure lake area, water color and quality, temperature, and ice cover. In the future, wide-swath satellite altimeters like the upcoming SWOT (Surface Water and Ocean Topography) mission can provide more robust measurements of water surface height for much smaller lakes.

Hyperspectral satellite imagers such as PRISMA (PRecursore IperSpettrale della Missione Applicativa), EnMaP (environment Mapping and Analysis Program), PACE (Plankton Aerosol Cloud and ocean Ecosystem) and HyspIRI (Hyperspectral InfraRed Imager) are expected to extend the range of water quality applications from what is currently achievable with multispectral optical sensors (e.g., particle size, phytoplankton functional types, harmful algal bloom species, phytoplankton health) and should improve retrieval accuracy by facilitating atmospheric corrections and the optical separation of the independent water constituents affecting water quality. Geostationary optical sensors, either multispectral or hyperspectral, (e.g., GeoCAPE) are also expected to enhance the temporal coverage of water quality (e.g., every 3 h) in dynamic regions. High-resolution thermal imagery will allow better quantification and the ability to extensively map lake water temperature. Much work remains, however, to realize a robust, global dataset biological, chemical and physical lake properties that can be used to understand how lakes are changing in response to climate and other human impacts, along with the feedback of lakes on their surrounding human and natural environments.

Essential Climate Variables for Lakes

The GCOS (Global Climate Observing System), in response to an invitation from the UNFCCC (United Nations Framework Convention on Climate Change), have identified "*required actions to reduce gaps in knowledge to improve monitoring and prediction, to support mitigation, and to help meet increasingly urgent needs for information on impacts, adaptation and vulnerability*" (implementation plan document of the GCOS).

To reach this goal, GCOS has defined a set of variables representative of the different components of the Earth system and its climate. These comprise the Essential Climate Variables (ECVs), long-term observations of the atmosphere, the continental surface and sub surface, and the ocean. For each of these compartments GCOS has identified the *data essential for climate analysis, prediction and change detection* (ibid).

Lakes are considered by GCOS as one of the main components of the water cycle linked to the climate system, and long-term as well as perennial lake observations have been identified as crucial in this context. Several variables have been defined with strict requirements. A list of 79 natural lakes has been established on which the following variables are required:

- Water level and extent changes from ground-based or satellite observations
- Water temperature
- Lake ice cover and thickness
- Water color

The general list of ECVs and their associated requirements in terms of resolution and accuracy is updated yearly in the GCOS annual report and implementation plan documents. Notably, all of these variables are amenable to remote sensing, and there is considerable potential to extend long-term climate data records for lakes beyond the current 79 using a global remote sensing approach.

Existing Lake Databases

There are a number of databases already in existence that use remote sensing and serve a range of different lake-focused communities. Since 2004, several comprehensive worldwide lake datasets have been developed, containing information on location, extent and other basic characteristics of open water bodies and wetland areas at the global scale.

While these global databases of lake geography have, until very recently, been temporally static, other datasets focused on lake water level, temperature, and other variables deliver multitemporal data for a smaller number of large lakes. For example, the UK’s NERC GloboLakes and ESA’s Arclake databases deliver water color (including optically active water quality constituent retrieval) and water temperature information on a large set (~1000) of lakes worldwide. Similarly, the HYDROWEB, G-REALM, River&Lakes and DAHITI databases provide lake levels, areal extent, and volume variations over the last 3 decades for a few hundred lakes. HYDROLARE, which is hosted by the State Hydrological Institute (SHI) in St Petersburg, Russia collects and gathers in situ lake data worldwide in support to the GCOS implementation plan, under the umbrella of the World Meteorological Organization (WMO). The Global Surface Water database is a globally consistent, validated dataset documenting different facets of surface water dynamics (e.g. seasonality, recurrence, occurrence, transition, surface water history) and its long-term changes (1984-2015) at 30 m resolution.

In addition, space agencies have ongoing missions and programs to provide surveys of continental water from individual satellites, but the proliferation of sensors that can provide information on lake should lead to:

- Development of new tools in order to insure continuity and integrity of lakes database,
- Improved database accessibility and user friendliness,
- Enhanced interoperability of databases, especially those focused on water quantity and water quality.

Our Goal: an international working group on lakes, climate and remote sensing

In order to improve our holistic understanding of global-scale lake science, we are spearheading creation of a new international working group that brings together scientists from a range of disciplines to generate new ideas for applying remote sensing to lakes and coordinate a global response to changing lake environments. Principally, participants will be experts in remote sensing, hydrology, limnology, climatology, biogeochemistry, and geodesy, along with space agencies management. We held a first meeting of invited participants, hosted by the CNES (Centre National d’Etudes Spatiales, France) in June 2017 in Toulouse, France, gathering scientists from around the world, including France, USA, United Kingdom, Russia, Canada, Italy, Chile. Representatives of international organizations were also present, including the European Commission -Joint Research Center- of the European Union and ESA (European Space Agency) . A total of forty scientists from across lake-focused disciplines met to met to join force on advancing the use of remote sensing in the study of lakes and climate via a series of invited talks and a round table discussion. Through this meeting and follow-on discussions, we have identified key questions to be addressed by the lake science and remote sensing communities, principally divided into three groups:

(1) satellite instrumentation and data:
- What are the most needed satellite data sets in limnology and how do we develop long-term continuity in datasets across satellite platforms?
- Are current sensors adequate, or do we need new sensors with new capacities to measure environmental variables linked to lakes?
- What recommendations should we make to space agencies regarding relatively short-term funding & long-term observation plans related to lakes?

(2) international collaboration around lakes:
- How can we organize the international community of remote sensing data providers to make remote sensing data useful for lakes more accessible to the science and applications communities? Do we need a centralized thematic exploitation platform for data access? How can we inter-compare remote sensing products, and with in situ?
- What should be the complementarity and the forum of discussion between modelers (limnologist, climatologist) and the space community (agencies, engineers)?

(3) key questions on lake science:
- Can we understand climate change impacts on lake ice, lake temperature, lake hydrology, and lake biogeochemistry independently, or are changes only understandable through coupled analysis? How are these variables coupled?
- Is there a need to revise the definition of the ECVs defined by GCOS in order to provide the data necessary to advance lake science globally?

To begin with, there is a clearly expressed need to develop a global lake network with in situ instrumentation on a high range of variables to serve a diverse range of purposes, including:

- satellite data calibration and validation
- evaluation of models
- assimilation into models
- identification and tracking of long term changes across multiple variable and disciplines

Additionally, a global classification of lakes under different criteria, including morphology, climate, absence of anthropogenic pressure, mixing, salinity, and biogeochemistry, would help to guide future global lake studies. It is necessary to prepare such a classification based on a combination of satellite-derived and in-situ information. A global network of lakes representative of linkage between lakes and climate based on multi-disciplinary and multi-sensors approaches is therefore a necessity, together with the development of a database with inter-calibrated climate records.

To this end, we invite interested colleagues to join a working group, open to new participants, in order to address all of the question above, and to advocate for strengthened programmatic support for lake studies by international organization like UNEP, GEO, FAO, WMO, and towards national space agencies and ESA which is launching the Climate Change Initiative for elaborating a lake ECV. A more expansive paper providing details on lakes, remote sensing, and environmental change is in preparation, and we anticipate future workshops focused on developing a robust international community and providing timely input to space agency management. In the meantime, we invite interested colleagues to contact the authors.

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