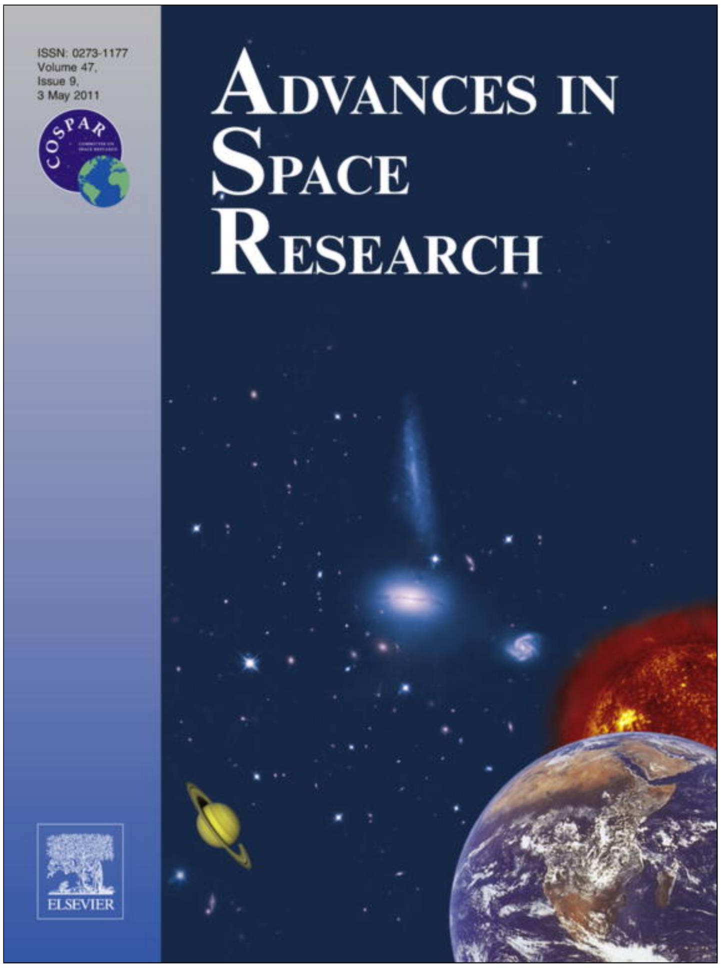
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SOLS: A lake database to monitor in the Near Real Time water level and storage variations from remote sensing data

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Abstract

An accurate and continuous monitoring of lakes and inland seas is available since 1993 thanks to the satellite altimetry missions (Topex–Poseidon, GFO, ERS-2, Jason-1, Jason-2 and Envisat). Global data processing of these satellites provides temporal and spatial time series of lakes surface height with a decimetre precision on the whole Earth. The response of water level to regional hydrology is particularly marked for lakes and inland seas in semi-arid regions. A lake data centre is under development at by LEGOS (Laboratoire d'Etude en Géophysique et Océanographie Spatiale) in Toulouse, in coordination with the HYDROLARE project (Headed by SHI: State Hydrological Institute of the Russian Academy of Science). It already provides level variations for about 150 lakes and reservoirs, freely available on the web site (HYDROWEB: http://www.LEGOS.obs-mip.fr/soa/hydrologie/HYDROWEB), and surface-volume variations of about 50 big lakes are also calculated through a combination of various satellite images (Modis, Asar, Landsat, Cbers) and radar altimetry. The final objective is to achieve in 2011 a fully operating data centre based on remote sensing technique and controlled by the in situ infrastructure for the Global Terrestrial Network for Lakes (GTN-L) under the supervision of WMO (World Meteorological Organization) and GCOS (Global Climate Observing System).

Keywords: Lake; Database; Radar altimetry; Satellite imagery; Essential climate variable

1. Introduction

The knowledge of the lake water storage variations in time over a long period is fundamental for understanding the impact of climate change and human activities on the terrestrial water resources. Variations in air temperature and precipitation have impact on the water balance of a lake, and in an extreme case a lake can entirely disappear. There are two main types of lakes: open lakes with outflow draining rivers, and in opposite, closed lakes with no outflow. In any cases they are very sensitive to climate change.

In some regions highly ephemeral lakes provide information on the events like severe drought or inundation. Closed basin lakes are sensitive to changes in regional water balance. Therefore a Near Real Time (NRT[1]) monitoring of this type of lakes is essential in the frame of such extreme events. For small lakes of this class, the sensitivity to a small change in inputs is proportionally

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[1] The NRT mode corresponds to a delay of the products delivery, in SOLS, of not more than one week when the satellite altimetry measurements were collected.

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higher, principally in terms of their level variations. In a given region covered with several lakes, if the records of their level variations are long enough, they could reveal recurrence of trends in a very reliable and accurate manner. In this way lakes can be considered as an excellent proxy for climate change.

For example the Andean chain in South America is covered with hundreds of lakes. They are located in region, which is under the influence of several climatic forcing: Southern Atlantic Oscillation, Pacific Decadal Oscillation, El Nino, Glacier melting, etc. (Garreaud and Battisti, 1999; Garreaud and Aceituno, 2001; Zola and Bengtsson, 2006). From North to South, over a distance of more than 4000 km, lakes are distributed in the Semi Arid plateau region (Peru-Bolivia) which receives extremely small rainfall and suffers from intensive evaporation, and in the boreal region (Patagonia) where inter-annual fluctuations of precipitation are high, and water release from glacier thawing has increased last century. Studying of these lakes in a continental framework would be therefore very useful for a better understanding of climate change impact on surface water resources, in particular for the big Andean cities fed in summer by the melt of water outpouring from the glaciers stocking the winter snowfalls and rainfalls. As illustration, for South America, the IPCC (International Panel for Climate Change) scenarios predict an increase of temperature going from 1 to 6 °C, and an increase of precipitation anomalies by about 20% before the end of the XXIth century (Bates et al., 2008). But the geographical distribution of these anomalies is not homogeneous: Most GCM (Global Climate Model) projections indicate larger (positive or negative) rainfall anomalies for the tropical region, and smaller for the extra-tropical part of South America. This will have an impact on the runoff of the rivers that feed the South American lakes.

Another region with dense lakes coverage is the East African rift. Understanding of the climate variability in Africa, and therefore the tropical variability is one of the key goals for the climate research. Also African lakes themselves modify greatly local climate (Nicholson and Yin, 2002). Level records analysis of the Great East African Lakes such as Victoria, Tanganyika, and Nyassa-Malawi, and the regional climatic variability show synchronicity, which can be explained by a large-scale linkage (Ropelewski and Halpert, 1996). Several studies have investigated the effect of ENSO (Mistry and Conway, 2003) but also of the Indian Ocean Dipole (Richard, 1994), which is partly responsible for driving climate variability over eastern Africa (Marchant et al., 2007).

Global warming impact on lakes has ecological consequences that are not precisely predictable. For example, warming of the lake Tanganyka has lead to a reduction in photosynthesis productivity, following by drastic decrease in fish population with obvious societal consequences. In another region, the general reduction of water level of the Great Lakes of North America has several societal and environmental consequences: pollution on the rise in coastal areas, damage in transportation system, tourism, recreational, fishery and hydroelectricity industries. Finally, large open lakes can themselves affect local climate through evaporation and albedo effects.

Hence it is essential to build up global database on lakes and reservoirs worldwide providing information about level, surface and volume variations, ice cover duration and ice cover thickness, as well as surface water temperature variations. The availability of these datasets in NRT mode would also be beneficial worldwide, as it would increase the quantity and quality of information on water management, regional network enhancement, model assimilation, climate change's impact on the lake system and surrounding human activities, etc.

Yet, the existing gauge networks on a regional and a global scale are declining and observations are often nonexistent, particularly in developing countries. Long term change and inter-annual variability of water storage are also often lacking. When existing, data are neither harmonised nor expressed in the same reference frame. Remote sensing hence could offer an opportunity to improve this situation.

The main purpose of this article is to present the potentiality of remote sensing techniques, to fulfil the requirement of the lake data centre development in addition to the compilation of the in situ historical and current data. For this an initiative was taken in 2009 to setup such a data centre under the GCOS auspices with two main component, one, the HYDROLARE centre hosted by SHI, and two, a web portal under construction, SOLS (Service d'Observation des Lacs par Satellite: French acronym) hosted by LEGOS. Section 2 presents the different techniques that allow producing the ECVs (Essential Climate Variables) for lakes. Section 3 discusses the international institutional context and the SOLS component of the HYDROLARE data centre. Section 4 shows the prototype of the future web portal of SOLS. Conclusions are given in Section 5.

2. Remote sensing techniques and lakes survey

2.1. Satellite imagery as a tool for lakes surface monitoring

Satellite imagery is basically used to classify the Earth surface for several purposes: land use, ecology, sustainable development, agriculture, water management, farming development, urbanisation, fire monitoring, etc. Observations of the solar reflected energy at different frequencies, usually from visible to IR, allow discrimination between different types of land use. Several satellites carry instruments providing data that can be thus classified, with various spatial resolutions: usually from very high resolution of few decimetres for military applications, to kilometre resolution for global monitoring of the Earth.

Recent scientific literature is full of articles describing methodologies using remote sensing (optical and radar) for water extent monitoring, mainly with purpose of studying floodplains and wetlands (Töyrä et al., 2001; Töyrä and Pietroniro, 2005; Frappart et al., 2005a,b; Henry et al., 2003; Peng et al., 2005; Sakamoto et al., 2007).

Recently NASA has put on the Internet a complete set of high resolution landsat imagery covering the Earth over the last 20 years: http://edcsns17.cr.usgs.gov/EarthExplorer. The MODIS full database is also freely available on the web portal of NASA with regular up-to-date releases: http://edcimswww.cd.usgs.gov/pub/imswelcome/. The Brasilian space Agency (INPE) has done the same for South America with images from Landsat and CBERS-2 satellites, with spatial resolution of few metres: http://www.inpe.br/ingles/index.php. As for the European Space Agency it provides access to a database of the ASAR imagery from Envisat satellite: http://www.eopi.esa.int/esa/esa.

In the range of decametres to hectometres these data can be successfully used to detect water presence on the Earth, and if series of imagery over a specific lake are collected over a long period of time one can estimate the water surface at different level of those lakes, from low to high level stages. We hence use the different sources of satellite imagery to calculate surface variations of the GTN-L lakes.

It is worth noting that once pairs of both level and surface are available for a given lake ranging from the driest to wettest situations, rating curves can be established, and in case one of the two parameters is missing, it can be deduced from the rating curve in order to fill the gap in the series. All of these sources of data made available recently by space agencies will therefore allow us to reach one of the ECVs requested by GCOS, which are the lakes surface variations in time.

2.2. Lakes water height inferred from radar altimetry

Despite some limitations, altimetry is a technique that has a proven potential for hydrology science since the data are freely available worldwide, and it is the only source of information for most lakes in remote areas. Water level measurement by satellite altimetry has been developed and optimised for open oceans. Several satellite altimetry missions were launched since the late 1980s: GEOSAT (1986–1988), ERS-1 (1991–1996), Topex/Poseidon (1992–2005), ERS-2 (1995–), GFO (2000–2008), Jason-1 (2001–) Jason-2 (2008–) and ENVISAT (2002–). ERS-1, ERS-2 and ENVISAT have a 35-day temporal resolution (duration of the orbital cycle) and 70 km inter-track spacing at the equator. Topex/Poseidon, Jason-1 and Jason-2 have a 10-day orbital cycle and 350 km equatorial inter-track spacing. GEOSAT and GFO have a 17-day orbital cycle and 170 km equatorial inter-track spacing. The combined global altimetry data set has more than two-decade-long history and is expected to be continuously updated in the coming decade with missions such as Altika, Jason-3, Cryosat-11, Sentinel-3 and SWOT. The technique is now applied to obtain water levels of inland seas, lakes, rivers, floodplains and wetlands (Aladin et al., 2005; Crétaux et al., 2005). Owing to the efforts of the scientific community, altimetry for continental water bodies has grown up and acquired a relative autonomy with respect to the altimetry for oceanography. Indeed, altimetry for continental water bodies has specific requirements, different from those for the oceanic domains. These differences include range estimates by algorithms tuned for echoes different from the ocean paradigm (Frappart et al., 2006), altitude-dependent dry tropospheric corrections wet tropospheric corrections from global meteorological models to replace the radiometer deficiency in the land environment (Cretaux et al., 2009), and use of high frequency (10 Hz, 18 Hz or 20 Hz depending on the mission) sample values and coordinates instead of 1 Hz averages.

Over the past 5 years the LEGOS has developed a web database (HYDROWEB: http://www.LEGOS.obs-mip.fr/soa/hydrologie/HYDROWEB) containing time series over water levels of large rivers, lakes and wetlands on a global scale.[2] Due to technical problems on the satellite, GEOSAT data are not suitable to estimate water height over continental water, and for ERS-1 and 2, the GDRs (Geophysical Data Records) provided by ESA are limited to ocean surface. Moreover the performances of Jason-1 and GFO satellites over narrow inland water are also poor, which has limited the use of these satellites to only big lakes where it has provided accurate lake height variations (see Figs. 2a and 2b). Therefore the lake levels are based on the merged Topex/Poseidon, Jason-1 and 2, ENVISAT and GFO data. Almost 150 lakes and reservoirs monthly level variations deduced from multi-satellite altimetry measurements are freely provided. (Figs. 1a and 1b). Potentially the number of lakes monitored could be significantly increased.

Operating at dual frequencies 13.6 GHz (Ku Band: Jason T/P) and 5.3 GHz (C Band) or 13.6 GHz and 3.2 GHz (S Band: Envisat), each altimeter emits a series of microwave pulses towards the nadir direction that are examined in the time domain. By noting the two-way time delay between pulse emission and echo reception, the surface height is determined by the difference of the satellite orbit and the altimeter range measurement. Depending on the size of the lake, it is necessary to correct for the slope of the geoid (or equivalently, the mean lake level) which is represented by a mean lake surface. The EGM2008 geoid is used as a priori but does not fit correctly short wavelength variations over a lake surface hence must be corrected. It is done by averaging the altimetry derived height levels from the whole cycles along each track. The water levels are further referred to this 'mean lake level'. If different satellites cover the same lake, the lake level is computed in a 3-step

[2] The US Department of Agriculture has developed a similar database for water level variations for almost 100 lakes monitored from the satellite missions T/P, Jason-1 and Jason-2. The data are available on the web site: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/. The European Space Agency, in cooperation with the De Montfort University in UK has also developed a database which provides instantaneous water level products for rivers and lakes in NRT mode at the following address: http://earth.esa.int/riverandlake/.

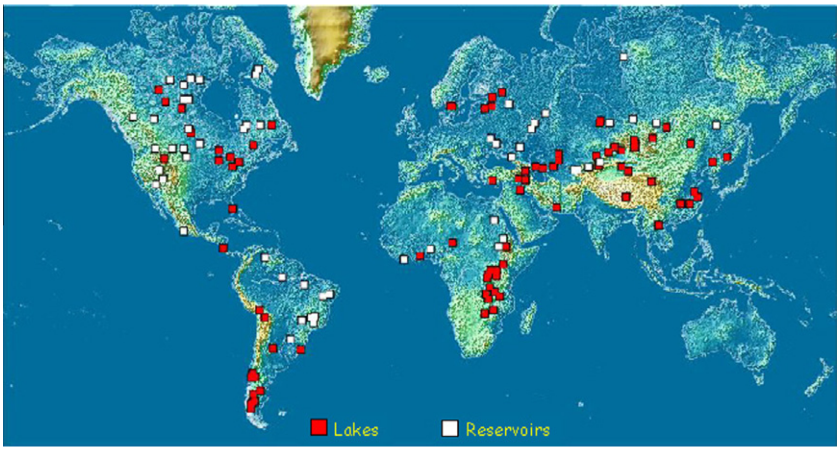

Fig. 1a. Map of the existing lakes and reservoirs of the HYDROWEB database.

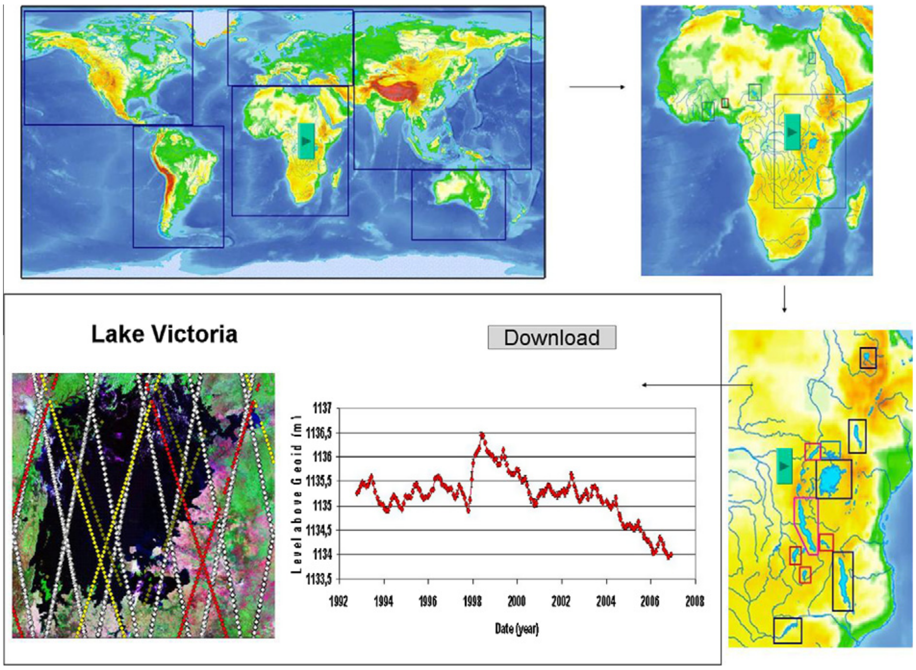

Fig. 1b. Schema of use of HYDROWEB.

process. Each satellite data are processed independently. Potential radar instrument biases between different satellites and geoid differences are removed using Topex/Poseidon data as reference. Then lake levels from the different satellites are merged on a monthly basis. We generally observe an increased precision of lake levels when multi-satellite processing is applied.

Hydrology is a growing field of application for satellite altimetry. However, very few studies have been dedicated up to now for checking the quality of the altimetry data over the continental waters. A lake database will be a unique opportunity for Calibration/Validation activities over the continental waters.

Comparisons of altimetry results with gauge data for the Great Lakes, for example, are accurate to ∼3–5 cm rms (Shum et al., 2003; Crétaux et al., 2010, Figs. 2c and 2d) For the Lake Victoria, comparison between Jason-1 inferred water level variations and in situ Gauges records, from September 2004 to March 2006 has given an RMS of differences of 2.6 cm and a correlation of both time series of 0.99 (Figs. 2a and 2b). For such a big lake, the altimetry clearly provides very accurate level data in a continuous manner (Figs. 2a–2d, Table 1).

Although the technique is less accurate for smaller lakes the derived level variations are generally an order of magnitude higher than the total error budget (Crétaux and Birkett, 2006). An ongoing research is examining the trade off between minimum target size observable and acceptable height accuracy for the various hydrological applications.

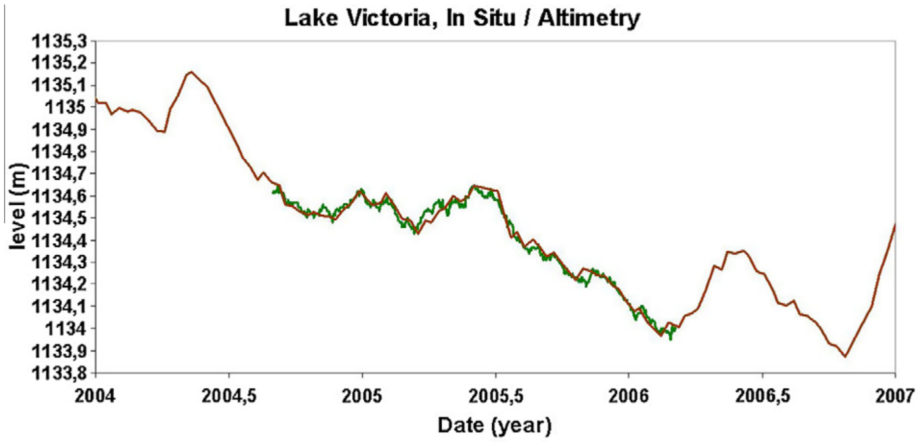

Fig. 2a. Comparison of water level of Lake Victoria from in situ gauges (green) and from radar altimetry (Red: Jason-1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

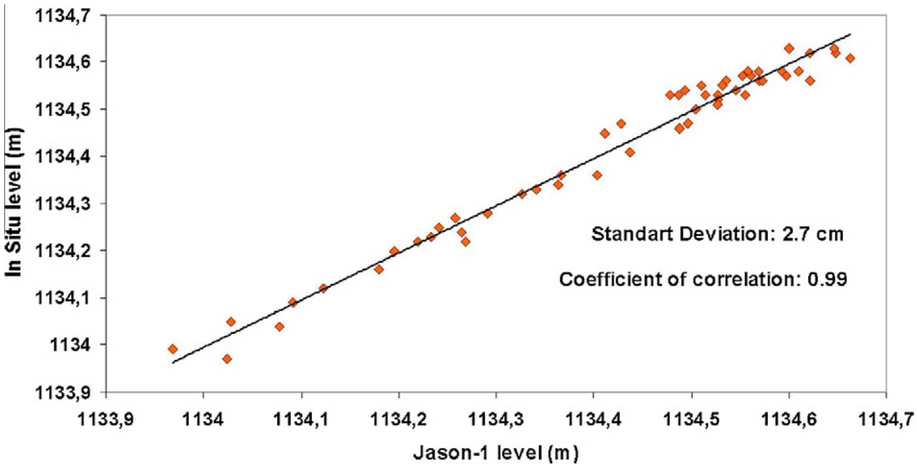

Fig. 2b. Scatter plot of in situ/Jason-1 level data over the Lake Victoria.

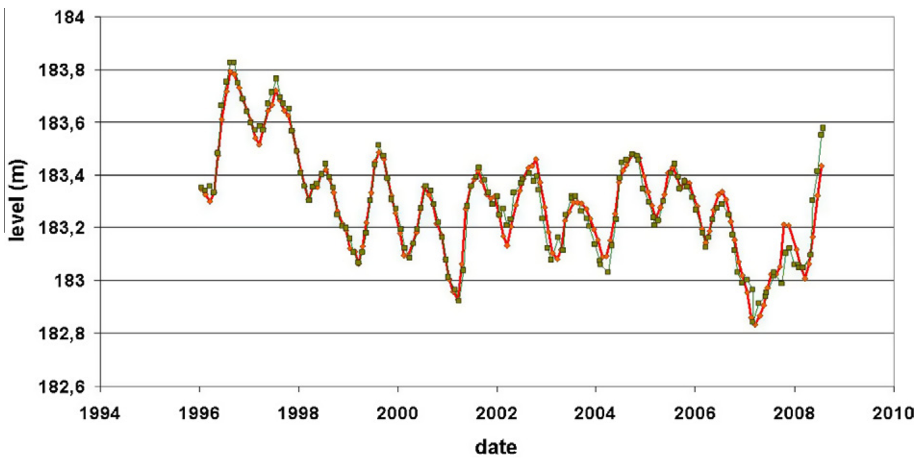

Fig. 2c. Comparison of water level of Lake Superior from in situ gauges (green) and from radar altimetry (Red: Jason-1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Lake ice monitoring from remote sensing data

Many boreal continental water bodies such as lakes or enclosed seas have seasonal ice cover. Ice dramatically affects the energy exchange between water and atmosphere, as well as various hydro physical and hydro biological processes (Kozhova and Izmest'eva, 1998). The presence of ice and its transparency affects the bloom of diatoms and

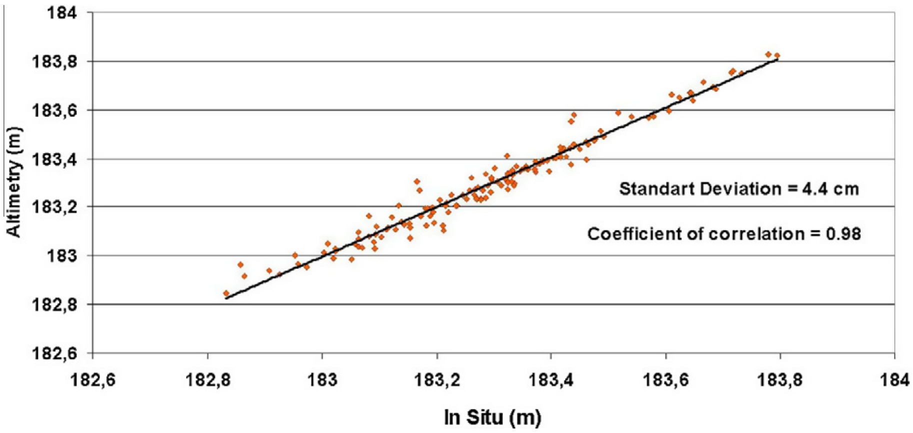

Fig. 2d. Scatter plot of in situ/Jason-1 level data over the Lake Superior.

Table 1
Some examples of comparison of lake level calculated from satellite altimetry data and measured by in situ gauges. Country and size of the lake are also indicated. For the biggest lakes (Victoria, Superior and Erie) the accuracy is better than 10 cm, the intermediate (Kariba, Mar de Chiquita, and Titicaca) the accuracy is at the decimetre level, while for some small water bodies, as Lake Powel it is closer to 1 m, particularly due to the fact that this lake is long but very thin. The Lake Issykkul, which is intermediate lake in size, presents surprisingly very accurate results.

Lake name	Country	Size of the lake (km^2)	RMS of the differences in situ/altimetry level (cm)
Erie	USA, Canada	25,821	5
Issykkul	Kyrgyzstan	6236	4
Kariba	Zambia, Zimbabwe	5400	24
Mar de Chiquita	Argentina	6000	13
Powell	USA	380	80
Superior	USA, Canada	82,367	4
Titicaca	Peru, Bolivia	8372	17
Victoria	Tanzania, Uganda, Kenya	68,800	3

primary productivity (Mackay et al., 2003). In spring, as soon as enough light can penetrate the ice, development of phytoplankton, zooplankton and benthos starts under the ice cover. Parameters such as timing of ice formation and break-up, ice cover extent and thickness, are good indicators of regional and large-scale climate changes and are widely used for various climatic studies, relating ice conditions with global climatic variability (Livingstone, 1999). Ice dynamics influences transport and navigation, fisheries and other industrial activities. Temporal and spatial variability of ice processes in seas and lakes is influenced not only by meteorological conditions (mainly by thermal regime), but also by wind and currents, bottom morphology and other factors (Wüest et al., 2005). Studies and monitoring of ice cover conditions are thus providing valuable information for climate research, maritime safety and sustainable environmental management (Mackay et al., 2005).

The studies of ice and snow cover of continental water bodies can benefit from the synergy of more than 15 years-long simultaneous active (radar altimeter) and passive (radiometer) observations from radar altimetry satellites complemented by SSM/I passive microwave data to improve spatial and temporal coverage. An ice discrimination approach based on a combined use of the data from the four altimetry missions and SSM/I was developed and validated (Kouraev et al., 2008). Although not included initially by GCOS in the ECVs for lakes, the SOLS/HYDROLARE data centre will include lake ice parameters for boreal lakes inferred from remote sensing data (radar altimetry and SSM/I) but also from in situ measurements when available. Fig. 4 shows the product that may be delivered through SOLS/HYDROLARE on this topic.

3. SOLS/HYDROLARE data centre

3.1. Institutional context

Over the last decade several countries joined in an international treaty, UNFCC (United Framework Convention on Climate Change) to investigate the issue of the global warming reduction. An Implementation Plan has been developed by the GCOS endorsed by UNFCCC, to elaborate appropriate policies on climate change. To face these challenges, UNFCCC emphasises the crucial need to setup a global system capable of acquiring the earth observations required for these different components: terrestrial, atmospheric, oceanic. The Global Terrestrial Observing System (GTOS) and its various technical panels are in charge of the development of the required observing strategy. One of the main goals is to provide systematic, continuous, global, harmonised and reliable observations. GCOS has emphasised in its successive reports the difficulties encountered with respect to these requirements in the terrestrial domain, which remains the least well-developed component of the climate observing system.

The Terrestrial Observing Panel for Climate (TOPC) is a joint panel of GTOS and GCOS. Its main objective is to define and assess the availability of the ECVs in order to improve the knowledge of the terrestrial component of the climate system, the causes and impact of its changes.

The GCOS implementation plan identified 13 terrestrial ECVs including lake levels (T04) for which it has proposed actions towards the development and operation of an international lake and reservoirs data centre.

Lake levels are currently measured by numerous organisations worldwide. Despite the clear and long established requirement for such a centre, it does not exist yet and, at present, only two global databases exist for lakes (from International Lake Environment Committee: ILEC) and reservoirs (from International Commission Of Large Dams: ICOLD) that maintain a database with a limited set of information (lake name, morphometry, average level depth and surface, etc.). Nothing about water level dynamic and storage is provided.

3.2. SOLS/HYDROLARE data centre

However in 2008 The WMO has signed an agreement with the SHI to establish the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE), hosted by the SHI, in support of the GCOS implementation plan.

The objective of the Centre is to establish, develop and regularly update an international database on hydrological regime of lakes and reservoirs. One main requirement of GTOS is to develop "*basic processing and presentation tools for lakes and reservoirs data for distribution to stakeholders*", to conduct "*analysis and assessment of spatial and temporal tendencies of hydrological elements of lakes and reservoirs*" and also to "*establish agreed methodologies and standards*" (Biennal report 2008 of the GTOS[3]). The objective is to bring together observations (mostly lacking for lakes and reservoirs), prediction, and decision-support systems and establish links to climate and other types of data. A list of products for the T04 ECVs is proposed for large open lakes, highly ephemeral lakes and closed basin lakes in the frame of the GCOS implementation plan:

Products T1.1: maps of the lakes on the GTN-L: Grids of georef maps of 250 m spatial resolution on monthly basis for about 100 lakes with a requested accuracy of 5%.

Products T1.2: level of all the lakes on the GTN-L list: The requested accuracy is 10 cm on a weekly/monthly basis, in the form of time series based on satellite radar altimetry and in situ gauges.

Products T1.3: surface temperature of all the lakes on the GTN-L list: Daily temperature with accuracy of 0.2° and a stability of 0.1° with 1 km spatial resolution.

The HYDROLARE data centre seeks to provide the product T1.2 and T1.3 from an in situ database for lakes having permanent stations in terms of historical observation, and current records regularly updated.

Last year CNES developed a prototype for a data centre for lakes and reservoirs exclusively based on Remote sensing data: satellite radar altimetry and satellite imagery: SOLS. CNES is involved in the Committee on Earth Observing Satellite (CEOS) in charge of the international civil space missions' coordination in Earth observation. As body representing users, GCOS meets CEOS to ensure "*continuity of satellite measurements, systematic data generation, safeguarding of the records, data access and international coordination addressing future measurements needs*" (Biennal report 2008 of the GTOS). Under this framework, one of the CNES contributions (under the responsibility of the LEGOS) will be the participation in HYDROLARE in cooperation with SHI.

This will be done through the extension of the HYDROWEB database to the GTN-L lakes and by adding information from the satellite imagery to determine surface variations in time for each of the selected lakes.

Satellite radar altimetry provides level variations in time for a given lake. Satellite images collected at different dates from low to high water stage will allow determining a surface variation of each lake in the database (see Section 4.1).

It is also planned to apply the methodology developed by LEGOS for large seasonally-frozen lakes and enclosed seas and to derive from this approach time series of specific dates of ice events (the first appearance of ice, the formation of stable ice cover, the first appearance of open water and the complete disappearance of ice) for each water body or its sub-region.

Currently, HYDROWEB is updated every year for lake products (water level variations). The SOLS project will manage two complementary data sets:

- A reliable, long-term series based on the GDR data (Geophysical Data Record), computed using the best quality orbit, but available only 5–6 weeks after data acquisition) currently used by HYDROWEB.
- An intermediate-quality but rapidly available time-series based on the IGDR dataset (the interim GDR, based on the preliminary computation); typically, data can be delivered in ca. 3 days after acquisition.

This two-mode database can then be used to tackle both the long-term trend analysis and the NRT applications that require a high reactivity of the decision makers. Furthermore, the automation of data collection and time-series calculation procedures make the interactive download of

[3] http://www.fao.org/gtos/doc/pub50.pdf and http://www.fao.org/gtos/doc/ECVs/T04/T04.pdf.

the products possible. As for HYDROWEB, the SOLS/HYDROLARE data policy along with the ancillary data (e.g. lake images from remote-sensing images) bundled with the on-line data will be made available. Open – free of charge access to ECVs for the GTN-L lakes will be given on the SOLS/HYDROLARE.

Based on this principle, lake level and surface variations have already been calculated for almost 20 lakes and reservoirs. They will constitute the basic input for the prototype of a lake data centre, which is described in this manuscript. In the following pages we describe an overview of the future products for two selected lakes (Mar de Chiquita and Baikal) that will be delivered through the SOLS project.

4. Examples of the SOLS/HYDROLARE ongoing web pages

In the following two paragraphs we show what will be the future web pages of HYDROLARE data centre for ECVs inferred from the remote sensing data. The purpose of this section is not only to demonstrate the capacity of the remote sensing techniques to produce suitable information in the field of hydrology, but also to introduce the data centre to users. For details on the radar altimetry applications on lake monitoring, see Birkett, 1995, 2000; Mercier et al., 2002; Coe and Birkett, 2005; Crétaux et al., 2005; Crétaux and Birkett, 2006; Kouraev et al., 2007, 2008; Medina et al., 2008; Swenson and Wahr, 2009; Becker et al., 2010.

4.1. Mar de Chiquita

Mar de Chiquita is the largest closed saline lake in South America, located in the central plain of Argentina. This lake is a remarkable target to study current and past environmental changes in a saline lacustrine basin as its water storage variability is purely natural and well documented. It is a shallow lake with maximum depth of 10 m. Given the flatness of the surrounding ground, it exhibits a highly variable extent with a level range from 5000 km^2 for the low level of the dry period to 6500 km^2 at high stages during the wet season. The daily in situ levels are available and can be compared to the remote sensing data, making this lake a possible site for continuous – although delayed – check of the altimetry products. The large variations of the surface extent can be monitored with multi-spectral medium resolution sensors like the Modis/Terra instrument. It can also be compared with an extent determined using High Resolution image (Landsat, CBERS: Fig. 3). Finally, a precise hypsometric function can be calculated and used to compute continuous variations of the level, surface and hence volume for this lake. The web page of the future SOLS/HYDROLARE database will include lakes as shown in Fig. 3, three types of variables for each: monthly level variations from the in situ gauges and radar altimetry data, the hypsometry curves parameters, and monthly surface variations. The re-processed images at a different epoch from low to high stage will also be available directly from the data centre.

4.2. Lake Baikal

There is an example of the products to be delivered on the SOLS/HYDROLARE for the lake ice phenology. The Lake Baikal, located in Siberia, is completely frozen every year (from late December to May) due to continental climate conditions with long and cold winter.

From the methodology described in Kouraev et al. (2008), three parameters can be derived from remote sensing data: time series of ice formation, break-up and duration from year to year, starting from 1992 when the T/P satellite was launched. Fig. 4 shows the time series of these

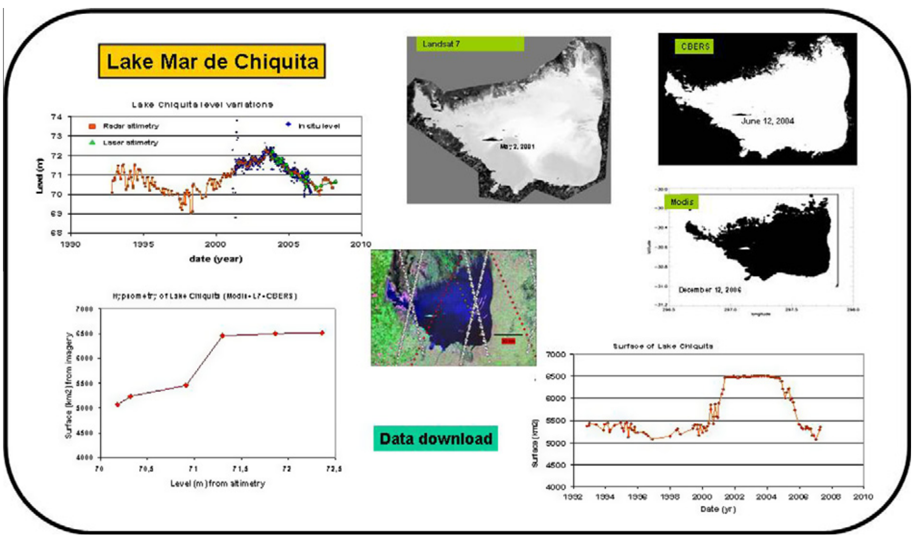

Fig. 3. Mar de Chiquita future web page. For some lakes the relation dh/dS (hypsometry) is not linear. This explains why the time series of level and surface variations have different slopes.

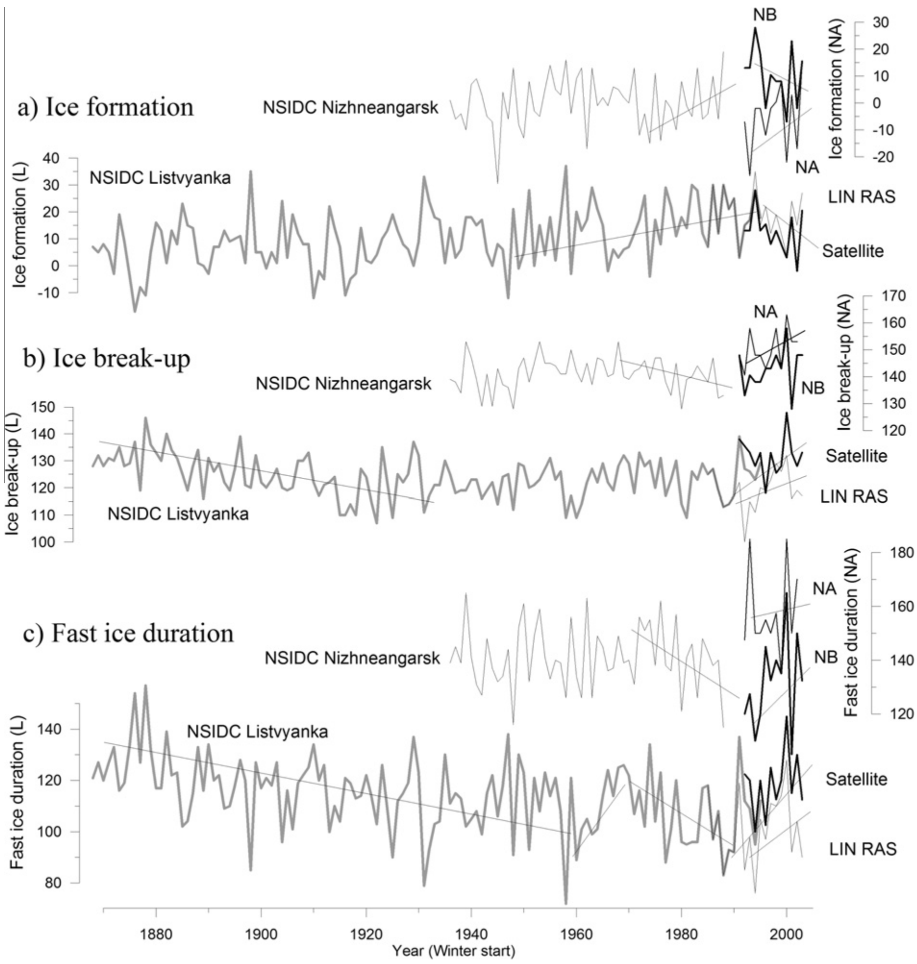

Fig. 4. Time series of historical and satellite-derived observations of (a) ice formation (days since 31 December), (b) ice break-up (days since 31 December) and (c) fast ice duration (days). Southern Baikal: thick grey line – NSIDC/ LIN RAS, data for Listvyanka, thick black line – satellite-derived estimates for region near Listvyanka. Northern Baikal: thin black line – NSIDC data for Nizhneangarsk, satellite-derived estimates are for the whole Northern Baikal (NB, thick line) and for sub-region near Nizhneangarsk (NA, thin line). Note that all vertical scales are identical. Straight lines indicate positive and negative tendencies discussed in the text – they are not statistically significant and do not represent calculated trend lines, but merely serve as a visual aid. The future users of SOLS/HYDROLARE will have access to both figures like these one and the associated historical and remote sensing data.

parameters for the c. This will be extended to all lakes in the northern hemisphere that are under similar climatic conditions (lakes of Siberia, Aral Sea and Caspian Sea, Ladoga, Onega, and all lakes in Canada). We will update the database for these products (plots as in Fig. 4 and ASCII files with the corresponding data) every year after winter time. As for many continental water bodies, the observations of ice regime for the Lake Baikal started in the end of the 19th–to beginning of the 20th century at coastal stations. Later on, mainly between 1940s and 1970s, field trips and aerial surveys made it possible to significantly extend the research from a point of observation to lake wide spatial scale. On the SOLS/HYROLARE, both the remote sensing data (radar altimetry and SSM/I) and these in situ data will be supplied to users as shown on Fig. 4.

5. Conclusion

For the next few decades, there will be a need to a continuous and automatic survey of lakes worldwide as addressed by UNFCCC. In the frame of the GCOS implementation plan, few ECVs were identified, among them, the water level and surface variations for a group of 100 lakes located throughout all continents. Some of them are already operationally monitored by national agencies (Russia, United States or Canada). Others are not equipped with the in situ gauges yet, or when they are, for different reasons the data are not available. Those two ECVs when they measured allow estimating the water storage variation which depends on many factors: climate change forcing and anthropogenic stress in the lake basin watershed (through irrigation, dam construction, water consumption, etc.)

Over the last 10–15 years, new satellites techniques have demonstrated their capabilities to fulfil the GCOS requirements. Satellite radar altimetry can provide lakes level variations for hundreds of lakes (they just need to be under the track of the satellite) with an accuracy ranging from centimetres to decimetres depending on their size, and also in a lesser extent on their location (mountain lakes for examples are more difficult to track). To be able to calculate a lake's water surface variation, one needs complementary information, which usually is quite impossible to derive from ground measurements Lately, national space agencies such as NASA, ESA and INPE have setup free public web data bases that provide imagery of satellites instruments like Landsat or CBERS optical and IR sensors, Terra/MODIS, SRTM or Envisat/ASAR. They all have different spatial and temporal resolution, but depending on the size and on the magnitude of water surface variability of each target, a large panel of instruments can now provide surface variations of hundreds of lakes worldwide.

With current progress in information technology, the processing power and storage capacities of research laboratories are sufficient to cope with data volumes, which were manageable only by large data centre 10 years ago. Leveraging this processing power with knowledge sharing made possible with an open source software, a pre-operational lake database can be created with a modest effort, and act as a proof-of-concept to build up the dynamics necessary to create a next-generation international fully operational database and making possible the rapid distribution of the key ECVs and metadata with the NRT updating, cross calibrated with in situ measurements and dedicated field campaigns.

An agreement was signed in 2008 between the SHI and WMO to develop such a lake data centre, called HYDROLARE, which will collect and distribute in situ lake level variations, surface temperatures and metadata. The remote sensing techniques that are mature enough to complete the requested information (lake level, surface and volume variations, lake ice regime) will be under the responsibility of LEGOS, in coordination with SHI. In the last 6 years LEGOS has developed a lake and river database, with water level variations for a group of 150 lakes and reservoirs fully derived from current satellite altimetry. Algorithms of radar and optical satellite imagery processing were developed by LEGOS in order to complete this database with information on lake's surface and volume variations that will be added to the database. It will result in an international lake data centre, in cooperation between SHI and LEGOS, under the auspices of WMO.

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