Insights on Southern American lakes through diverse Space techniques: satellite imagery, radar and laser altimetry.

Rodrigo Abarca-del-Rio [(1)], **Jean-Francois Cretaux** [(2)], **M. Bergé-Nguyen** [(2)], **S. Calmant** [(2)], **A. Cazenave** [(2)], **L. Morales** [(3)], **M. Zambrano** [(1)]

[(1)] ***Departamento de Geofisica (DGEO)***
Facultad de Ciencias Físicas y Matemáticas
Universidad de Concepción
160C-Concepción-Chile
Email: roabarca@udec.cl

[(2)] ***LEGOS – UMR5566 (CNRS-IRD-CNES)***
Observatoire Midi-Pyrenees
14 Av Ed Belin
31400, Toulouse, France
Email:jean-Francois.Cretaux@legos.obs-mip.fr

[(3)] ***Facultad de Agronomia***
Universidad de Chile
Santiago-Chile

Abstract

In order to better understand the hydrologic cycle over some hydrological basins in South America, we investigate the variability over some lakes close to the Andes and dependent on its hydrological variability by different space techniques. These lakes are here separated into 3 different groups. These groups are not only representative of different climatic regimes but also represent different local conditions along the Andes. The first group is geographically named as “semi enclosed endorheic basin of the Altiplano” or officially known as TPDS (Titicaca – Poopo – Desaguadero - Salars) system which extends north to south over more than 1000 kilometers on the Altiplano. The second group of lakes are located along the western side of Los Andes Cordillera, i.e., along Chile and understands lakes alike Villarica, Panguipugui, Ranco, Rupanco, Todos los Santos, Llanquihue, which have been visited and GPS collocated during mission in 2005 and 2006. The third group is located over the western side of Los Andes Cordillera, and takes into account lakes alike Nahuelhuapi, General Carrera, San Martin, Viedma, Argentino, etc. We will show here some examples of how a combination of complementary space techniques applied on some lakes of these groups, which for the most are for the first time investigated through these space techniques, gives information on their hydrological cycle and interesting clues on its related climatic variability.

This work are ongoing results from the ECOS SUR C04U02 (Chile-France) project « continental hydrology from a combination of altimetry, gravimetry and in-situ data. Application to the Andean Region. »

INTRODUCTION

This resume intends to present some shots of the oral presentation shown at the second workshop of space hydrology held at Geneva, Switzerland. These results are under further development in work-papers under preparation. Some of this work is part of an ECOS SUR (Chile – France) (2005-2008) project. This projects aims to give new insights on the variability of South American lakes by the complementary use of new space techniques,.

The different South America lakes under study are divided into four different groups, which in fact mainly represent the diversity of its climates: The first group is located over the Altiplano region, say the TPDS (Titicaca- Popoo-Desaguadero-Salars) region encompassing the Titicaca (Bolivia/Peru), The Popoo (Bolivia) and the two salars of Uyuni and Coipasa (Bolivia) (fig. 1a). The second region is located in southern Chile, and takes into account the different lakes that are generally associated to the so-called Chilean “Region de Los Lagos” (fig. 1b). The third region is called the Patagonian lakes, that takes into account the lakes Carrera/Buenos Aires (Chile/Argentina), the Cochrane (Chile), and O’higgins/St Martin (Chile/Argentina) as well as the two southernmost great lakes (Argentino and Viedma) (fig. 1c). Finally, the fourth region is the region of say Caribbean lakes, in which two lakes are preferentially under investigation; the Nicaragua Lake (Nicaragua) and the semi open Lake Maracaibo (Venezuela) (figure 1d).

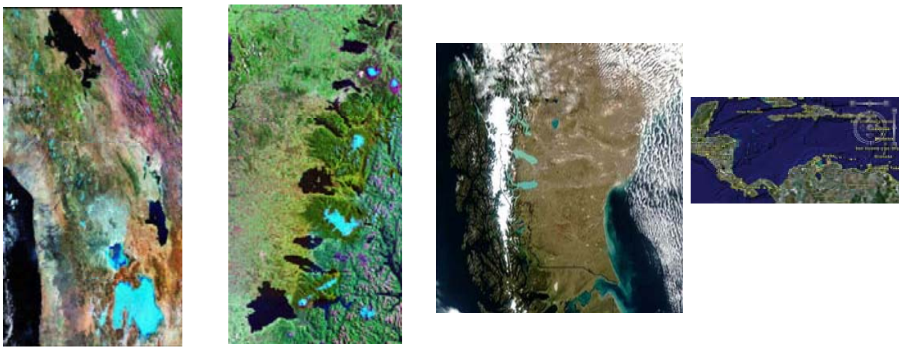

Figure 1: From left to right (1a) the TPDS region in the Altiplano, (1b) the “Los Lagos” region in Chile, (1c) The Patagonian region Lakes (Chile-Argentina) and (1d) the Caribean region.

However, in this short resume of the talk presented, we will mainly concentrate in the first and second group, and even within these, we will only present some of the results. The main idea of this resume is to show how by new space techniques, and taking the advantage of the complementarities of these, you can in fact follow the variability of all lakes over South America. It is presented in three parts, each of these developing shortly one of the techniques used.

<u>Results</u>

<u>First technique:</u> <u>Altimetry.</u>

The first appreciation of the lake variability is done through its level variability. We will first concentrate in the TPDS region, and Titicaca Lake. In fig. 2, are represented the Titicaca Lake and all the satellites traces (Topex, Envisat, Geosat F1 (GFO), ERS2) used for computing a combination which results in the lake level by altimetry presented in figure 3, along with the in situ variability, which fits exactly with the combined altimeter variability.

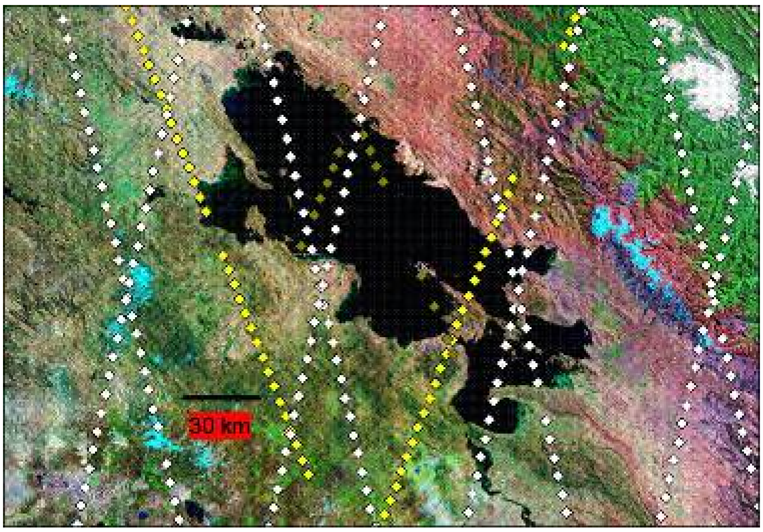

Figure 2: Titicaca Lake and the different satellite traces.

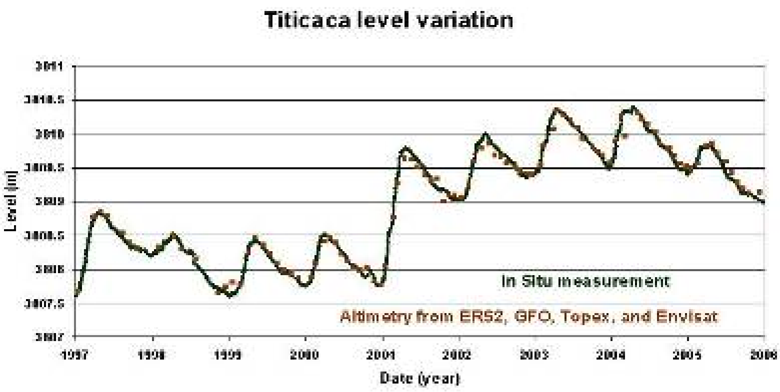

Figure 3: Titicaca lake level in meters, insitu data (solid bold line) and altimetry (red points).

The methodology will be of particular interest when applied over southern America, as some of its lakes do not present in situ measurements. For example along the "Los Lagos" region in Chile (Fig. 4) where unfortunately it is almost impossible to corroborate the variability detected by satellite altimetry with local data. The analysis of that variability's may give important insights on how climate variability affects the water cycle basin surrounding each of the basin catchments.

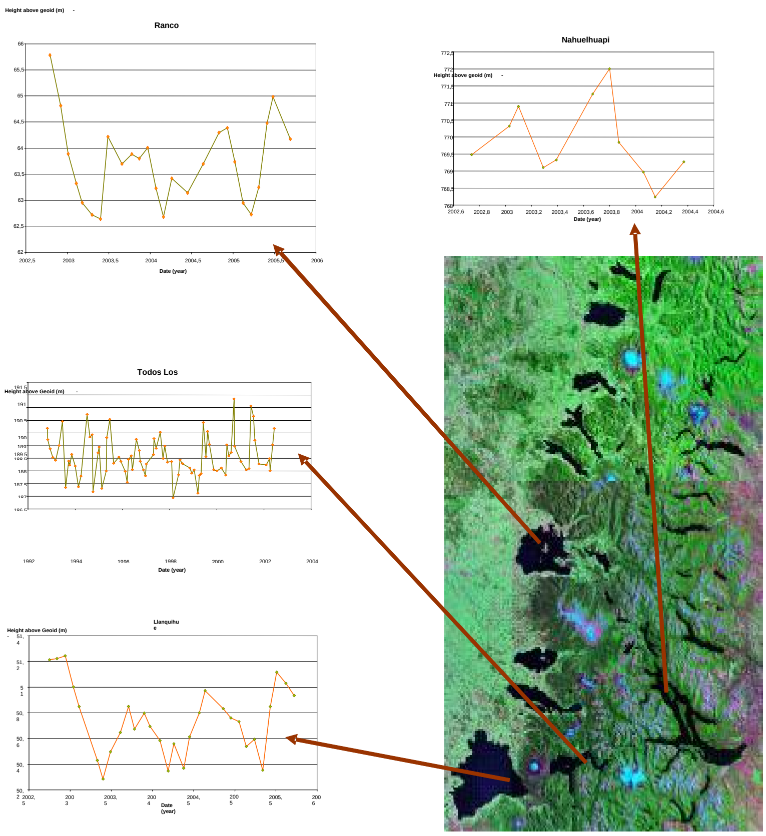

Figure 4: Lake Height level above the geoid of lakes Ranco, Todos los Santos, Llanquihue over Chile from up to bottom in the lefts and Nahuelhuapi (Argentina) over the right, joint with the satellite image of its localization.

Second Technique: Satellite Radiometry.

With the advent of satellite radiometer measurements at the end of 1979's, the sea surface temperature is in fact actually one of the best-known ocean parameters. The knowledge of the sea temperature is vital for most of the climatic processes. For example, part of the increase of global sea level is due to the steric sea level rise, say the effect the temperature may have on the volume of the whole water column. It is well know too, that the ocean surface temperature variations is an important tool for monitoring state of the global climate and henceforth in our case microclimates. The temperature of the oceans, as that of lakes, varies owing to the change of the different air-water processes, the water exchanging energy (heat and momentum) through the air –water interface. Investigating carefully the different fluxes that participates on to these flux exchanges may help in understanding better, not only of course the water cycle, but indeed the effect these may have on local biological communities, and finally the influence it may have locally on climate. This may be particularly true in the case of Titicaca Lake, which experiences approximately 90% evaporation values and influences the local climate. Taking advantage of the AVHHR estimates, at 5 km resolution, we show (Fig. 5) the lake surface temperatures over the Titicaca for different months representing the seasonality of year 1999. Interestingly one can note that the southern part of the Titicaca Lake present all the yearlong lesser surface temperature than the north, probably associated with a less pronounced depths, and lesser ventilation.

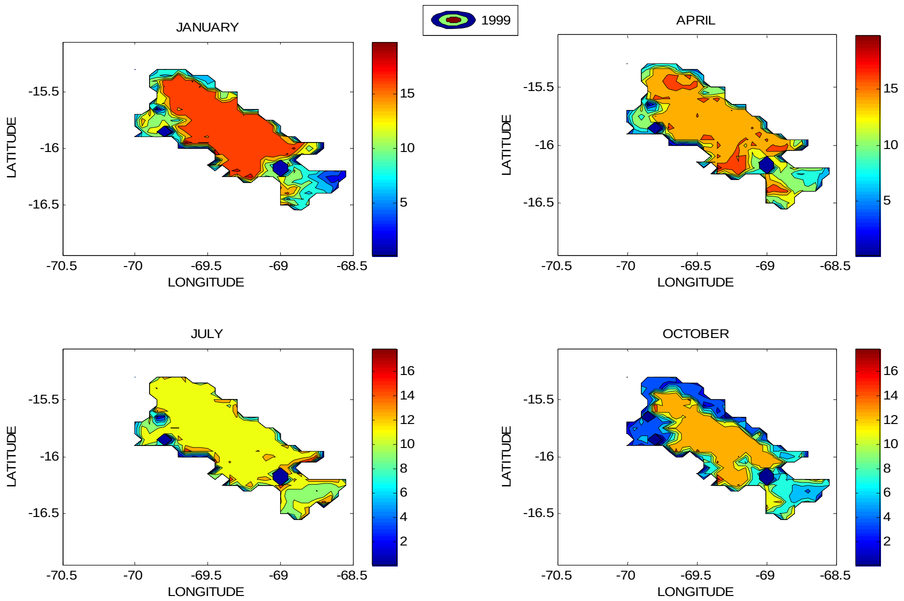

Figure 5: Lake surface temperature for January, April, July, and October of year 1999.

Third technique: By Satellite Imagery.

In cases in which either in situ measurements does not exist or is of poor quality, nor altimetry measurements are available, a recent technique, still under development-refinement by Legos, help in delimiting the watershed. For example, let us take the case of the Popoo Lake, which depth is so shallow (2.5 meters in average), and extensive that its variation in superficy are drastic from one season to another, and indeed at interannual time scales. This is very clear in a comparison of Landsat images: The lake lake is almost empty in October 1996 and full in February 2001 (respectively shown in Figures 6a and 6b).

Figure 6: Landsat visible images of Popoo Lake for October 1996 (left, Fig 6a) and February 2001 (right, Fig 6b).

The traces from the different satellite altimetry missions (Fig. 7) and the Popoo lake in Fig 6a, demonstrates that the follow on of Popoo Lake is almost impossible. Places in the world in which altimetry missions cannot resolve, should be by other means.

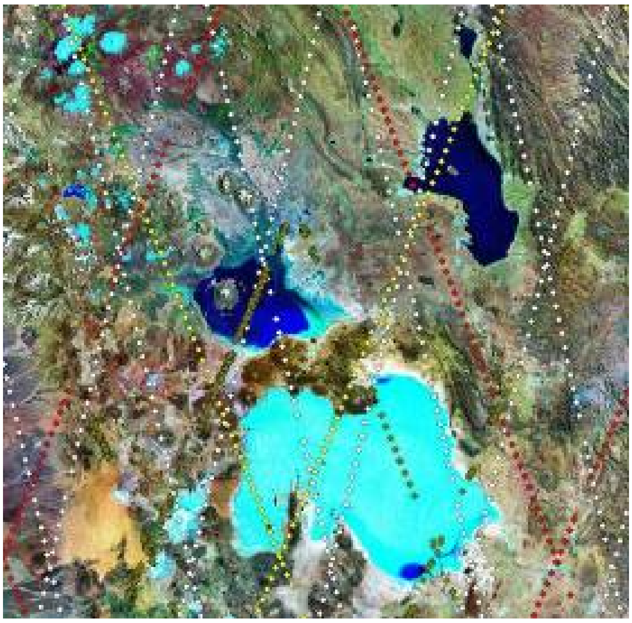

Figure 7: Southern part of the TPDS region, along with the traces of the different altimetry satellites

The availability of different frequency bands in satellite missions, for example Modis, allows, through the combination of these to compute the superficies covered by water. In this figure (Fig 8), the superficy covered by the water varies stoutly all over the year, agreeing with the climatology over the different places over the Altiplano, where high precipitation over the Salars takes place from November to April, and then diminished drastically over the rest of the year (Fig 9).

Figure 8: Superficies covered by water over the Coipasa Salar.

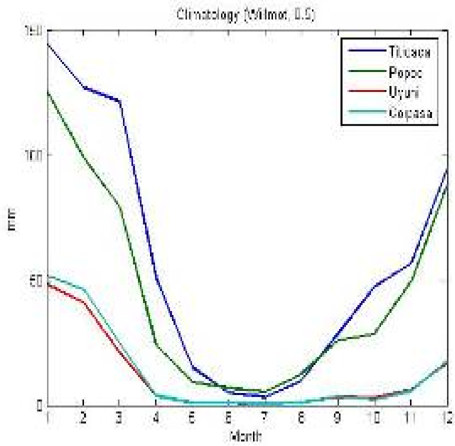

Figure 9: Accumulated precipitation per month over the TPDS region.