Water level fluctuations in the Plata Basin (South America) from Topex/Poseidon Satellite Altimetry

Caroline Maheu and Anny Cazenave
LEGOS-GRGS/CNES, Toulouse, France

Carlos R. Mechoso
Department of Atmospheric Sciences, University of California, Los Angeles, California, USA

Received 1 August 2002; revised 8 October 2002; accepted 16 December 2002; published 14 February 2003.

1. Introduction

The water level of rivers has traditionally been monitored at gauging stations. Estimates of river discharge obtained from those levels give useful insights on regional climate variability. Gauging stations, however, can be scarce or even absent in parts of large river basins because of limited access due to geographical or political factors. For such locations, information from satellite sensors can complement that of in situ observing systems. So far, the measuring of water levels using satellite altimetry has been developed and optimized for open oceans. Nevertheless, the technique can be applied to obtain water levels of inland locations, information from satellite sensors can complement that of in situ observing systems. So far, the measuring of water levels using satellite altimetry has been developed and optimized for open oceans. Nevertheless, the technique can be applied to obtain water levels of inland locations, information from satellite sensors can complement that of in situ observing systems.

2. The Plata Basin

The Plata basin (see Figure 1) is the second largest drainage basin in South America after the Amazon and the fifth largest in the world. There are three main sub-basins associated with the Paraná, Paraguay and Uruguay rivers. In the Upper Paraná, floods are geographically confined by mountainous terrain. In contrast, the Paraguay sub-basin with a north-to-south slope of only about 10 m km\(^{-1}\) includes the Pantanal, the world’s largest wetland. The Lower Paraná also has a small slope, while the Uruguay’ slope is more variable. Numerous storage dams regulate parts of the Paraná as well as their tributaries.

3. Altimetry Data Analysis

3.1. Topex/Poseidon Data

In this paper we use altimetry data from the Topex/Poseidon (T/P) satellite over the period 1993–2001 to examine the behavior of the Paraná, Paraguay and Uruguay, three major rivers of the Plata basin. Our motivation is to use the relatively dense dataset to provide a basin-wide view of water level variability and its links to climate variability.

[1] Time series of water level in major rivers of the Plata basin are examined using altimetry data from the Topex/Poseidon satellite over the period 1993–2001. Ten sites are selected on the Paraná, three on the Paraguay, one on the Uruguay and seven on wetlands. It is confirmed that the seasonal cycle of river levels decreases in amplitude with increasing latitude of the site. The normalized time series for sites along the same river differ mainly by a time-lag corresponding to propagation speeds of about 0.1 ms\(^{-1}\). The interannual variability of the Lower Paraná, with a strong peak in early 1998 and minima in early 1996 and 2000, shows the remote effects of El Niño/Southern Oscillation (ENSO). The variability of the Upper Paraná and Paraguay shows similar ENSO impacts with smaller amplitudes after 1995, and the effects of regional features climate variability before that date (e.g., the South American monsoon). The results support the usefulness of satellite altimetry for a dense and continuous monitoring of river water levels.


Copyright 2003 by the American Geophysical Union.
0094-8276/03/2002GL016033$05.00
for definition and technical details) by the onboard altimeter may be lost in areas with elevated topography, resulting in less valid data than over flat areas. The use of T/P data over rivers and wetlands was previously discussed by Birkett [1998] who compared altimetric heights computed by retracking radar echoes with those based on the nominal tracking mode (i.e., the geophysical data records, GDRs) in three regions (Paraguay, Amazon, and Zambezi rivers). The comparison demonstrated that GDRs are adequate for the construction of water level time series on rivers and wetlands.

For this study, we follow Birkett [1998] and select the most upgraded T/P GDRs made available by the Archiving, Validation and Interpretation of Satellite Data in Oceanography (AVISO) data center at the Centre National d’Etudes Spatiales (CNES). We use the 10 Hz data, which corresponds to along-track ground spacing of 580 m. In addition to the altimetric heights and radial orbit component, the GDRs include a series of environmental and geophysical corrections. We apply corrections for onboard instrumental drifts and biases, as well as the ionospheric, dry tropospheric, solid Earth and pole tide corrections, and neglect corrections for ocean effects. We also applied the wet troposphere correction computed by Mercier (in preparation, 2002), for the whole T/P mission, using air temperature and specific humidity fields from NCEP (National Centers for Environmental Predictions).

3.2. Water Level Time Series Construction and Validation

As a first step we identified intersections of T/P ground tracks with the rivers (see Figure 1) using the Generic Mapping Tool of Wessel and Smith [2001] complemented by the Times Atlas of the World [2000]. Next, for each 10-day interval (the temporal resolution of the T/P data at a given location), we averaged all valid 10 Hz GDR’s data over a distance corresponding to the T/P track-river intersection. Typical T/P track-river intersection are 5–7 km long, since in the Plata basin, tracks are highly oblique to the river directions. In some instances, track segments coincide with the river over large distances (up to 20 km in some cases). The spatially averaged 10 Hz data represent the basis for constructing water level time series at a given T/P track-river intersection. Water levels are expressed in reference to the ellipsoid surface provided with the GDRs.

Figure 1. Geographical map of the Plata basin showing Topex/Poseidon (T/P) tracks as red lines. Letters identify the sites with T/P-derived water level time series. Sites A–N (yellow labels) correspond to rivers, and sites O–U to flooded areas (purple labels).

Figure 2. Water level time series derived from the 10 Hz T/P data for site G (dots), in situ measurements at Forte Coimbra (solid line) and differences time series (dashed line) on the Paraguay River.

4. Water Level Time Series Analysis

Figure 3 presents the time series of water level for sites A–N in Figure 1 (solid lines), together with the interannual anomalies obtained by removal from the records of the mean seasonal cycle (dotted lines). Note that
4.1. Lower Parana (A, B, C, D, E) and Uruguay (N)

The time series for the Lower Parana sites strongly resemble one another. The result of computing lag correlations between each time series and the one at site E suggests that disturbances on water level propagate downstream at a speed of about 0.1 m/s. The seasonal cycle has small amplitude of about 3 m. The higher elevations are in 1998 and the lower in late 1999-early 2000. There are also secondary maxima, for example in early 1995 and 1997.

4.2. Paraguay (F, G, H)

The Paraguay shows a strong seasonal cycle with amplitude that decreases from north to south (see Figure 3). This feature is consistent with effects of the South American monsoon on this river basin during the warm season. The range of amplitudes is about 5 m. A downward trend is observed for sites F and G. A lag-correlation analysis indicates that disturbances on water level propagate downstream at a speed of about 0.1 m/s. As in the Lower Parana, there are secondary maxima in 1995 and 1997 for sites F and G.

4.3. Middle Parana (I, J) and Upper Parana (K, L, M)

There is a clear difference in behavior between the time series for the sites on the Upper Parana (K, L, M) and on the Middle Parana (I, J). Sites L and M show a marked downward trend in the 20 m range from early 1993 to late 2001 and a substantial seasonal cycle. Sites I, J and K show smaller interannual amplitudes as well as a weaker seasonal cycle. All sites show a local minimum in late 1999-early 2000.

5. Interannual Variability in Water Level

To highlight both temporal and spatial variability of river water levels, we apply an Empirical Orthogonal Function (EOF) analysis to the time series for the 21 sites after removal of an average seasonal cycle, application of a 6-month running mean for removal of the intraseasonal signal, and normalization of the residual time series (normalization is based on the variance of the residual time
series over the 9-year time span). Figure 4 shows the leading modes (EOF1) of water level variability for sites in the Lower Paraná, Paraguay and Upper Paraná (which explain 85%, 61% and 53% of the total variance, respectively) and the corresponding principal components (PC1). All PC1s have a minimum around late 1999–early 2000, approximately three months earlier in the Upper Paraná than in the other rivers. PC1 for the Lower Paraná has small amplitude until 1996, a minimum in 1996, and a strong peak around March 1998. PC1 for the Upper Paraná has a minimum in 1996. PC1 for the Paraguay has a strong maximum in mid 1995 and a weaker one in 1997. All PC1s hint a decreasing trend towards the end of the period. Similar results were obtained after excluding sites I, J and flooded areas, which confirms that their variability is similar to that of the main rivers.

To address the climate variability in the Plata basin we use the gridded precipitation fields compiled by Xie and Arkin [1997] for the period 1993–2001. Again we apply an EOF analysis after removal of the annual and semi annual components of the annual cycles and application of a 6-month running mean. Figure 4 shows EOF1 of precipitation variability in the basin (which explains about 42% of the total variance) and the corresponding PC1. EOF1 resembles the structure in the Plata basin of the leading mode of summer rainfall over South America found by Zhou and Lau [2001] using data for the period 1979–1995. These authors also show that this mode represents the dominant influence of ENSO on summer rainfall variability over the continent on interannual time scales. The decade of the 90’s started with a series of weak El Niño events (1991–1992, 1993 and 1994), followed by a weak La Niña in 1995–1996 and strong El Niño and La Niña events in 1997–1998 and 1998–1999, respectively. Consistently, PC1 for precipitation over the Plata basin has a strong maximum by late 1997–early 1998 and weak minima in mid 1995, and early 2000.

The correlation between PC1 of precipitation in the Plata basin and water level for the Lower Paraná is high and positive (0.77) while those for the Upper Paraná and Paraguay are much weaker (0.33 and 0.01, respectively). This is consistent with the Lower Paraná increasing its level in response to increased precipitation during the 1997–1998 El Niño, and decreased its level in response to decreased precipitation during the 1995–1996 and 1998–1999 La Niña. The Upper Paraná and Paraguay after 1995 show similar signatures with decreasing magnitude. The variability of these rivers before 1995, on the other hand, cannot be directly attributed to ENSO effects. We found out that PC1 of precipitation over the Paraguay sub-basin also has a maximum in early 1995 (the corresponding EOF1 explains 48% of the total variance). This suggests that the Paraguay increased its level during 1995 in response to an enhancement of the South American monsoon.

6. Discussion

The power of altimeter-derived information is illustrated by finding the spatial and temporal signature of climate variability on the water levels in the Plata basin. Studies of this sort have generally been based on a single in situ gauging station per river, while with satellite altimetry, we can consider multiple sites that also provide information on the propagation of surface height anomalies.

The 10-year T/P time series will be soon extended with data from the Jason-1 and ENVISAT satellites, launched on December 7, 2001 and March 1, 2002 respectively. Combining Jason-1 and ENVISAT data for land water monitoring will take advantage of the 10-day temporal resolution of Jason-1 and the 4 times higher geographical coverage of ENVISAT.

Acknowledgments. One of us (CRM) was partially supported by NOAA grant NA06GPO511. This research also benefited from support of CNES and CNRS in France.

References


A. Cazenave and C. Maheu, LEGOS-GRGS/CNES, 18 Ave. E. Belin, Toulouse, France. (anny.cazenave@cnes.fr.)

C. R. Mechoso, Department of Atmospheric Sciences, University of California, Los Angeles, California, USA.