HYDROLOGICAL VALIDATION OF SATELLITE WATER LEVEL MEASUREMENT OVER RIVER PO BASIN

C.Vittucci¹, F.Napolitano², J. Benveniste³

(¹) University of Rome “La Sapienza”, Via Eudossiana, 18-00185-Rome (IT)
mailto:Cristina.Vittucci@libero.it

(²) University of Rome “La Sapienza”, DITS (Hydraulic Transports and Roads Department) ; Via Eudossiana, 18-00185 Rome (IT)
mailto:Francesco.Napolitano@uniroma1.it

(³) Earth Observation Science, Application and Future Technologies Department, ESA-ESRIN, Via Galileo Galilei, Frascati, (IT)
mailto:Jerome.Benveniste@esa.int

ABSTRACT

“Illuminating” Earth’s inland water surfaces with radar altimeter, from both ERS-2 and ENVISAT, a global waveform analysis has shown that even over a “small river” such as river Po (if compared to Nile or Amazon basin) an hydrological validation is possible. Although altimeters were designed and optimised to operate over ocean, and although their ability to maintain lock on the rapidly varying of land surface is limited, their capability in retracking also “small target” is increasing. This work shows that if good results were obtained over river Po, (due to the fact that it is yet well ground monitored through the use of gauging stations) the future aim of satellite altimetry is to monitor and eventually forecast natural floods events even for ungauging basins over the entire world.

INTRODUCTION

The “River Po-Emergency dry weather” analysis, by APAT and ARPA Emilia-Romagna Scientific Committee for water level forecast, appeared on 2007, July 17th Italian newspapers ‘La Repubblica’ and ‘Il Messaggero’.

“[…] Last year 40 km of river body became shorter than 100 km. Maybe river Po will interrupts on Pontelagoscuro (Ferrara) where salty sea water will go up to the river. […] An ecosystem revolution is nearer than we expected,
suggestive wooded landscapes and their air fauna, that years ago made river Po sides a typically country background, will risk to die forever. […] In addition typical belts and natural products will disappear because of desert advancing.”

River Po discharge decreased about of 20-25% in the last thirty years, (nowadays it is about 1500 mc/s instead of the historical 1800 mc/s), every ten litres arriving at outpouring two litres are missed.

A real time monitoring will be an ideal condition to forecast floods events. For the most of earth gauging basins, like river Po, it is quite simple nowadays, but many river basins are marked by extensive wetlands and floodplains in which flow is diffuse and not flowing in a channel. Braided rivers are also problematic because their multiple, intertwined channels are constantly shifting, resulting in new channels with ungauged flows. Costs and logistics prohibit the installation of numerous gauges to characterize the flow dynamics in these environments.

Satellite remote sensing is being explored as one possible answer to such data acquisition problems, because of its facility in providing greatly improved space and time coverage of key hydrological variables. This spacecraft method offers a new hope that more homogeneous data may be collected from even relatively inaccessible or poorly developed regions of the world. The potential use of satellite system would be required to be operational rather than experimental. It might be argued however, that many hydrologists and engineers engaged on operational functions are not aware of the potential benefits of satellite technology.

**METHODS AND MATERIALS:**

A collaboration with the various Italian agencies allows us to collect meteorological data series (precisely ARPA PIEMONTE, ARPA LOMBARDIA, and ARPA EMILIA ROMAGNA) of both water levels and discharge of the interested target of river Po. For satellite measurement a contact at “De Monfort University” give us all data satellite collection at every flight over the river of both ERS2 and ENVISAT. On the track of these multi-satellite missions that involved Topex Poseidon radar over Amazon basin our efforts were involved in applying the same procedure over river Po, using these collected data sets (precisely referred from the year 1995 to 2005). So the first step was to represent the ground and satellite stations involved along the river.
Fig. 1 represents the ground and satellite capture sites. This image is a cut from an Italy image captured by Landsat 5, in false colours. Orange symbols represent ERS2 crossings over river Po, in red ENVISAT ones and in yellow in situ stations. The first step consisted in comparing satellite and terrestrial nearest station, in order to verify the reliability of satellite trends hypothesizing true ground station sets. An example of such results is illustrated here:

![Graph](image1.png)

Fig. 2 Casalmaggiore section and ERS nearest crossing represented in the same graph.

The difference in height that some of these graphs reported is due to the different calibration of ground hydrometer and space radar altimeters different references. Instead this graph evidences the smaller amount of satellite data respect to ground ones in the same ten years of gauging ERS2 and ENVISAT. They capture a measurement over the same point with a cycle of 35 days, for this reason it is not possible to compare these different data sets before to transform the daily ground series in a 35 days step series.

So, the second step consists in a series of scatter plots to compare ground 35 days step series and the corresponding 35 days satellite data series. An example is represented in the graph below:

![Graph](image2.png)

Fig. 3 An example of a simple scatter plot, it represents the comparison between ENVISAT crossing and Sermide ground station. The high value of correlation coefficient, even if the small number of observations, suggests ENVISAT
RA capability to look also at a small target such as river Po. Probably the flat region around and the unvariated regime of the river in these area, helps the interpretation of the signals, whose series trends are like to terrestrial ones.

This is the best results obtained, for the most part of the comparison correlation coefficients were quite small in value. A tentative to heighten them was experimented through the research of a coefficient depending of a certain lag. In particular the research was focused on the higher correlation coefficient between the satellite measurement and the day before or the day after the satellite date of each measurement, in order to discover if the factor distance between the relative position satellite and corresponding ground station can influence the results. So if satellite measurements were located upstream respect to ground corresponding station, we will expect that the higher correlation coefficient will be the one obtained using a comparison between the day after series. This issues were a completely failure, probably engineering structures change the flow of the river, so disappear the component relative position.

Another preceding in heighten correlation coefficient adopts the removing of outliers that often disturbs the general trend of a scatter.(Only 3 or 4 point in about 70 observations). In this case I obtained good result.

Then, to have a confirm that radars were looking at the same river of the ground hydrometers, another series of new scatter were constructed, in this way: we computed the series of increments both for satellite and ground, using a serialized time (expressed in a fraction of these ten years of observations). The next graph below shows best results:

Fig.4 Here for the comparison Sermide-ENVISAT, are represented the series of increments.

The use of the increments respect to the original series are a way to cancel a certain bias from the signals and a gave also to bad station to establish if the bad correlation coefficient was due to the fact that satellite are looking at another source of reflectivity that had more power that the river, or if external geographical causes influenced the comparisons.

The last part of the work would become an issue to retrieve a model of the river from satellite and another from the terrestrial ground data.

Using a statistical model, in particular an autoregressive model AR(4).every station was modeled.
Naturally best results were obtained for the best correlation coefficient before computed, an example is represented here:

![Graph showing Casalmaggiore-ERS comparison between satellite and terrestrial modeling.](image)

**Fig.5 Casalmaggiore-ERS comparison between satellite and terrestrial modeling.**

Good approximation was obtained for these models, are quite similar, even if the returned echo from satellite seems arriving in late respect to terrestrial ones.

The general equation of an AR(4) model is given by:

\[ z_t = \phi_1 Z_{t-1} + \phi_2 Z_{t-2} + \phi_3 Z_{t-3} + \phi_4 Z_{t-4} + \alpha_t \]

\( Z_t \) is the generic observation

\( \alpha_t \) is a white noise

\( \phi_{i,Z_{t,i}} \) represents the generic coefficient obtained solving the linear Yule Walker system (\( \rho = P \Phi \)).

At the end to test the reliability of such model we build a series of histograms, referred respectively to daily ground data series, to 35 days ground models, to 35 days satellite models. Using histogram is a way to evidence, if there are, a lot of outliers between the different probability distributions.

For best stations we can notice that even if there aren’t big outliers between the probability distribution of models AR(4) from satellite and ground, a big difference is in representing a daily measurement respect to 35 days ones.
a) Fig. 6 Probability distribution of a ground daily data set of water levels for Sermide-ENVISAT comparison

b) Fig. 7 Probability distribution of 35 days step ground data set of water levels for Sermide-ENVISAT comparison

c) Fig. 8 Probability distribution of 35 days step satellite data set of water levels for Sermide-ENVISAT comparison

**CONCLUSIONS:**

This work started with the intention to overcome experimentally past radars altimetry mission. It is born with very little hopes to success in estimation a small target as river Po (never estimated before using ESA satellite), and confirms ERS2–RA and ENVISAT-RA1 excellent quality to operate also in such limited conditions. Even if only about 40% of satellite and ground station comparison measurements are defined well, the efforts were successfully thinking at:
1. The big dimension of both RA footprints (about 20 km of resolution), for a small river as Po if compared to the Amazon, or the Nile, where both ERS and ENVISAT RA has obtained great success.

2. The difficulties choosing an appropriate algorithm retracking code over inland waters, in such industrialized zone, where disturbing ground noises often didn’t allow finding the real returning echoes. (I have obtained few satellite measurements that in optimal topographic and meteorological conditions would be collected as a continuous world coverage series).

3. The most part of ground and satellite nearest measurements are several kilometres far, and between them different important river Po tributaries merged into the river itself between them.

4. Estimation of inland water was made using no appositely build instruments, but using them as experimental tests.

On the other hand, it can be confirmed that using such ESA instruments, scientific committee for small targets (river Po is an example) is quite far from reconstructing a useable forecasting satellite river model. It was necessary to integrate satellite measurements with ground ones because space borne measurement were not enough, in number and in time, and in order to validate river Po data were taken away different measures—So ‘Rivers and Lakes’ PUB (that stands for Prediction in ungauged basins) ESA project, for which I have worked to test over river Po satellite technologies during the last seven month, needs others scientific supports to overcome difficulties in:

1. Algorithm retracking models
2. Discharge estimation using only satellite technologies
3. Ground scientific committee able to well modelling
4. Reduction of the 35 days data sets of observations

Such difficulties probably will be overcame with the one of the several next altimetry missions, just presented at ‘Symposium on 15 Years of Progress in Radar Altimetry’ (on march 2006 in Venice), whose intention is

1. To best map in higher across- track resolution,
2. Using less time to collect an entire world coverage (in ten days)
3. Using also GPS technologies as support.

Finally I wish these efforts and testing would be a starting point for further scientific missions and not let to be shelved.

ACKNOWLEDGEMENTS

I’m grateful to my professor PhD. Francesco Napolitano, for kindly giving me the opportunity to spend my training period at ESA/ESRIN.

To my agency tutor PhD. Jerome Benveniste, he always encouraged me to make better everything (overall speaking in an acceptable English).

To Mr Richard Smith, for kindly sending me ENVISAT-RA2 and ERS-RA files from ‘De Montfort University’.

To PhD. Stefano Casadio, my light in desperation times.

To Danilo, Maria, Andrea for reserving me a lot of their working time and even more.

REFERENCES

Amazon River Discharge Estimated From TOPEX/Poseidon Altimetry, Elena A. Zakharova, Alexei V. Kouraev, Anny Cazenave, Frederique Seyler, C. R. Geoscience, available online at www.sciencedirect.com

Automated River Monitoring From Multi-Mission Satellite Radar Altimetry: Results From The Amazon ‘Natural Calibration Zone’ P.A.M. Berry, J.D. Garlick, J.M. Harrison, Earth And Planetary Remote Sensing Laboratory, De Montfort University, Leicester, Uk

Brat (Basic Radar Altimetry Toolbox), ESA and CNES

Characterizing The Quality Of River Water Level Time Series Derived From Satellite Radar Altimetry: Efforts Towards A Standardized Methodology, Nicolas Bercher, Pascal Kosuth, Jerome Bruniquel

ENVISAT Symposium, Montreux Switzerland 23-27 April 2007, Abstracts

ENVISAT RA-2 And MWR Products And Algorithms User Guide, Jerome Benveniste And P.M. Milagro, ESA/ESRIN

Global Inland Water Monitoring From Multi-Mission Altimetry, P.A.M. Berry, J.D. Garlick, J.A. Freeman, And E.L. Mathers, Earth And Planetary Remote Sensing Laboratory, De Montfort University, Leicester, Uk
