# Assimilation of SMOS Soil Moisture Estimates into Flow Forecasting Hydrologic Models


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## ABSTRACT

The present abstract outlines the advances of the project **Assimilation of Soil Moisture Estimates into Flow Forecasting Hydrologic Models** encompassed in the Aquarius / SAC-D Announcement of Opportunity. The project aims at developing assimilation techniques of SAC-D soil moisture retrievals into operational hydrologic models for simulation and forecast at catchments within the De la Plata basin.

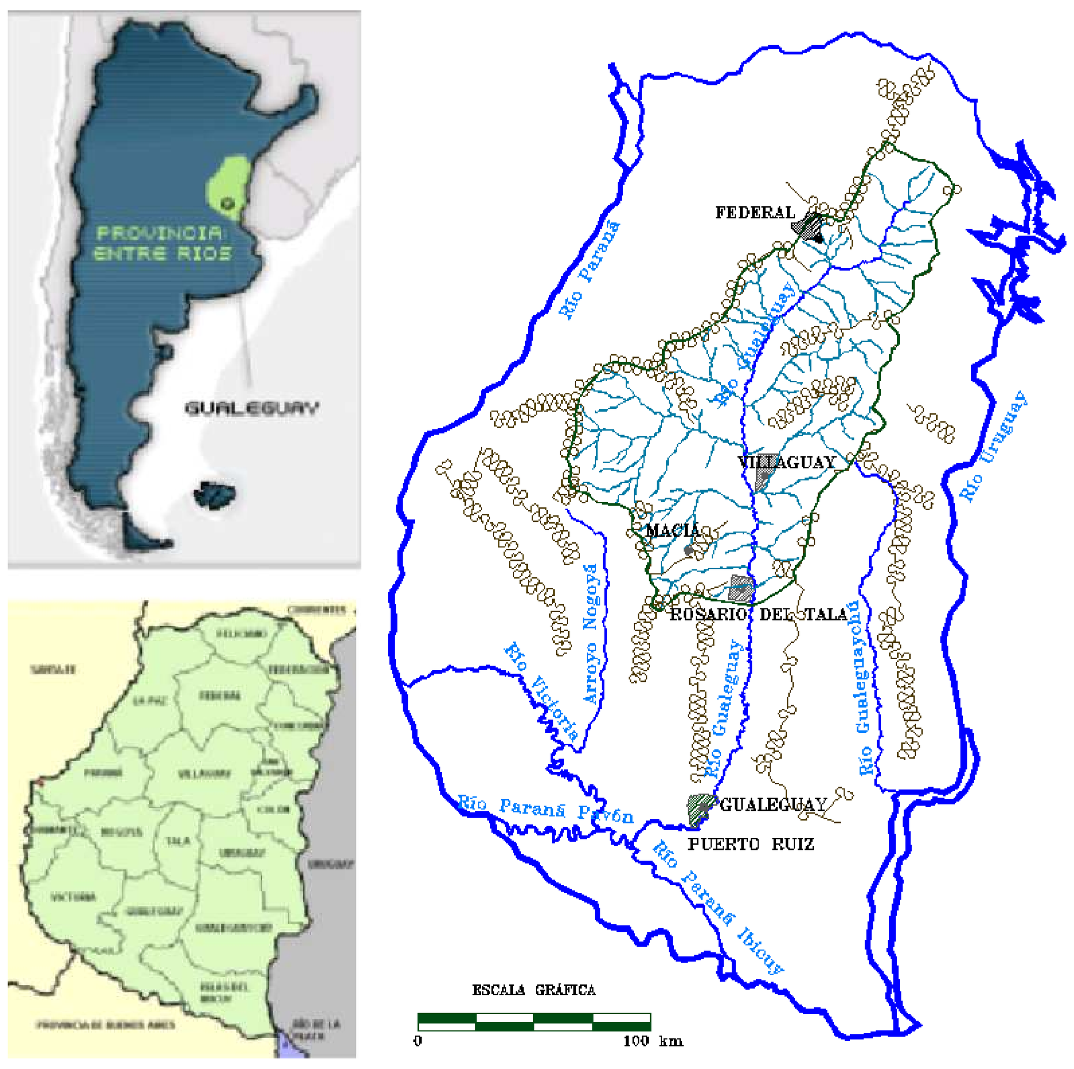
Since Aquarius soil moisture retrievals are to date not available, several essays with similar spaceborne sensors have been carried out. In previous work[3], assimilation of AMSR-E X-band soil moisture content product from NASA/JPL was essayed resulting in model effinciency loss, while efficiency gain was observed with outflow data assimilation for the same basin and time period. In this study, a product based on MIRAS L-band of SMOS mission was used in a similar manner. Daily series of SMOS mean areal soil moisture content, observed outflow, TRMM 3B42RT mean areal precipitation and rain gauge-derived mean areal precipitation have been produced for the Gualeguay river basin (Entre Ríos Province, Argentina).

A modified Sacramento hydrologic model has been calibrated and validated for this basin using precipitation and outflow data. The modeled soil moisture is compared with SMOS soil moisture.

A data assimilation algorithm is incorporated into the hydrologic model. Retrieved soil moisture is assimilated through this technique.


**Comparison of SMOS and Aquarius soil moisture retrieval characteristics**

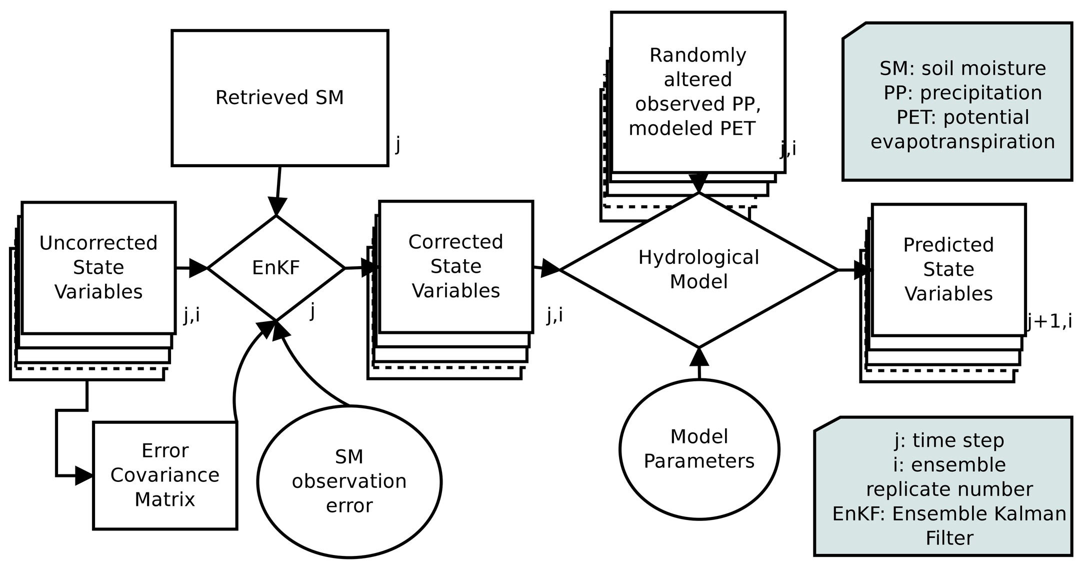
| | | |
|---|---|---|
| Instrument | MIRAS | Aquarius |
| Platform | SMOS | SAC-D |
| Center frequency | 1.4 GHz | 1.413 GHz |
| Spatial<br>Coverage<br>Resolution | <br>Global<br>25km | <br>Global<br>100km |
| Temporal<br>Coverage<br>Resolution | <br>2010-<br>1 to 3 days | <br>2012-<br>8 days |




**Gualeguay river basin in Entre Ríos, Argentina**

## 1 Input Data and Methods

The product P11P of SMOS mission MIRAS microwave interferometric radiometer operating at 1.4 GHz (band L) was used. The product consists of a daily global soil moisture map and it is available in a morning ascending pass and an evening descending pass (http://www.catds.fr/Products/Products-access)[6]. The soil moisture value is expressed as volumetric water content over total soil volume [m3 /m3 ], and is considered representative of the soil layer between 0.2 and 5 cm of depth[4]. Each value is paired with a quality index, expressed in the same units. The areal mean for each pass was calculated by a weighted average of the non-null pixels with centroids inside the basin boundaries. The inverse of the squared quality index was used as the weighting factor. Additionally, an estimation of the error of the areal mean was calculated.
Sacramento is a continuous, lumped, soil moisture retrieval rainfall-runoff prediction model widely used in operational hydrology at a catchment scale for prediction/warning purposes[2]. It consists of four conceptual reservoirs (two representing soil horizons, the other two representing the drainage network) governed each by a differential equation. The moisture content of each reservoir (state variables) determines, together with the model forcings, the magnitudes of the fluxes between them and out of the system. Thus, having good estimates of the state variables is important in order to give more accurate predictions.
Observed values of runoff and soil moisture prior to the forecast horizon are considered to be useful to correct these state variables, not necessarily because these are expected to be more accurate than the model predicted states, but for the error structure of both data sources are different[8].
Thus, a combination of them may be less biased and with less random errors than any of them individually[5].
The model was calibrated, using daily observed outflow data and TRMM 3B42RT mean areal precipitation[7], by minimizing the sum of the squares of the differences between observed and simulated outflow. Potential evapotranspiration was modelled climatically using historical daily mean temperatures from a ground station[1]. Calibration period was set from March 2000 to January 2010. A global Nash-Sutcliffe coefficient of efficiency of 0.56 was achieved.
Retrieved soil moisture were assimilated into Sacramento model's first storage element (top soil layer) through a Kalman ensemble filter. This means correcting the simulated value according to the observed value, the observation error and the model error. Optionally, the other model state variables may be corrected taking into account the covariance between them. Thus, three model runs were performed with SMOS soil moisture assimilation: (1) updating only the first element, (2) updating both soil elements, and (3) updating all four state variables, and a run without assimilation (4). A series of efficiency indicators was calculated for each run and they were compared with those of the reference runs (without assimilation). In the assimilation runs, states were updated up to 3 days before the date of the predicted discharge.




**Ensemble Kalman Filter data assimilation scheme**

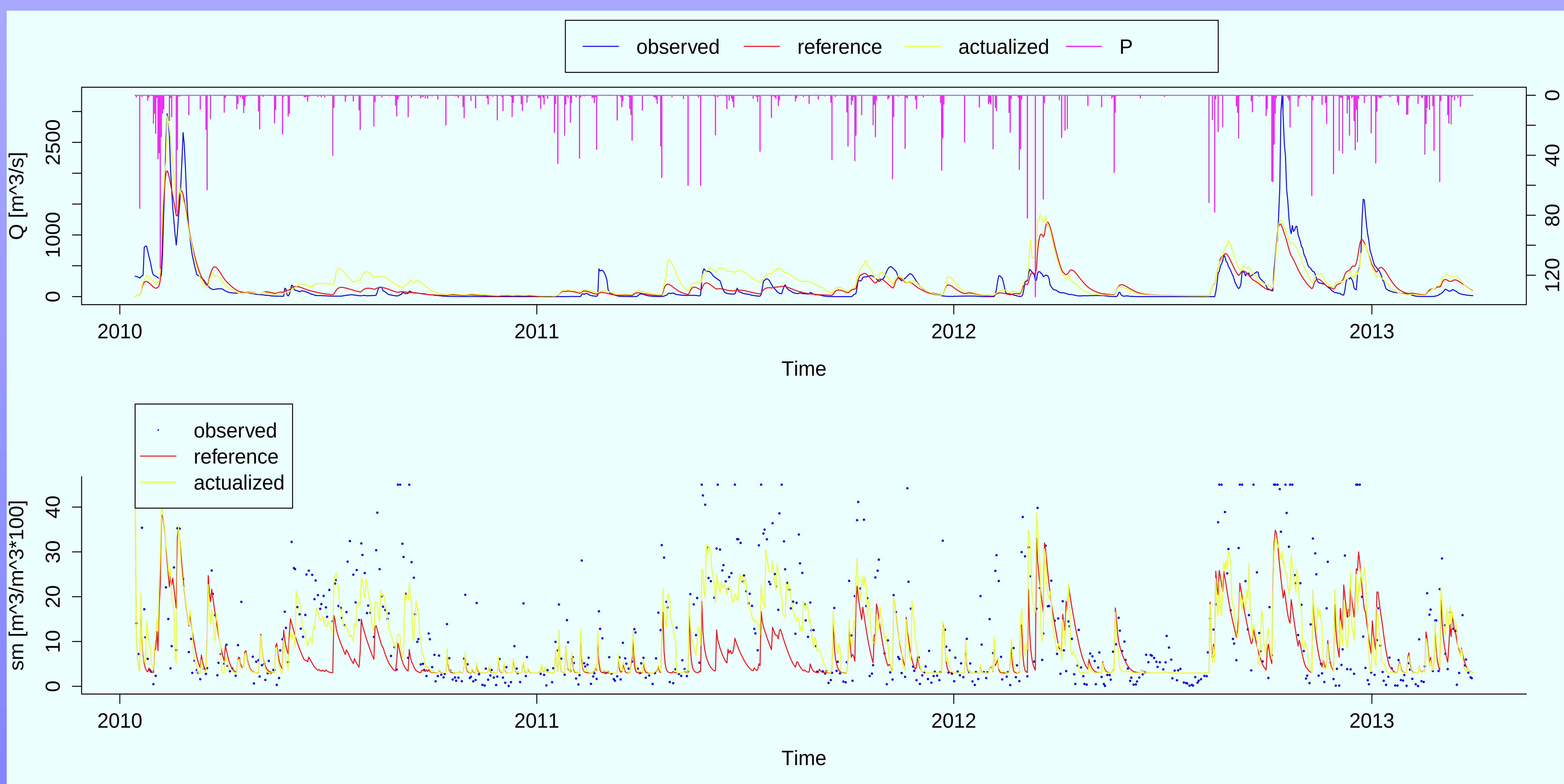
## 2 Results

### 2.1 Data Series Comparison

Daily areally averaged soil moisture content for Gualeguay river basin from SMOS was compared with modelled top layer soil moisture content from Sacramento hydrologic model. Comparison gave a correlation coefficient of 0.47 and SPEDS of 77.8% , showing significant differences in the behaviour of both data series. This differences may be due to model structure errors, sub-optimal model parameter estimation, soil moisture retrieval model error, or to the fact that both estimates do not necessarily represent the same physical variable since the depth of the top soil layer of the model (a model parameter) may exceed the depth of the remote observation.

### 2.2 SMOS Data Assimilation

Between the three state updating alternatives, (1) performed better that the other two, but still gently below the performance of the model run without assimilation (4).




Sacramento model run with (1) and without (4) SMOS data assimilation.

| | dif. mean | dif. stdev | RMSE | $r_{Pearson}$ | $R_{Nash}$ | SPEDS |
|---|---|---|---|---|---|---|
| 1 | 48.3 | -13.9 | 237.0 | 0.81 | 0.602 | 74.5 |
| 2 | 48.8 | -14.3 | 238.4 | 0.81 | 0.597 | 74.6 |
| 3 | 83.1 | 3.9 | 257.2 | 0.85 | 0.531 | 73.6 |
| 4 | 0.138 | -0.228 | 213.3 | 0.83 | 0.678 | 77.8 |

## 3 Discussion

No significative global model efficiency improvement is observed with SMOS soil moisture assimilation. While underestimation of hydrograph peaks gently decreases, overestimation of some hydrograph recessions increases (specially during winter), to average a gentle decrease in efficiency.
Nevertheless, before generalizing the results of this study, the experiment must be extended to other periods and other basins, since the hydrograph of the studied period has only 4 important rises, and the degree of fit of the simulation over these periods has a very stong weight in some of the used efficiency indicators (like RMSE y $R_{Nash}$).

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