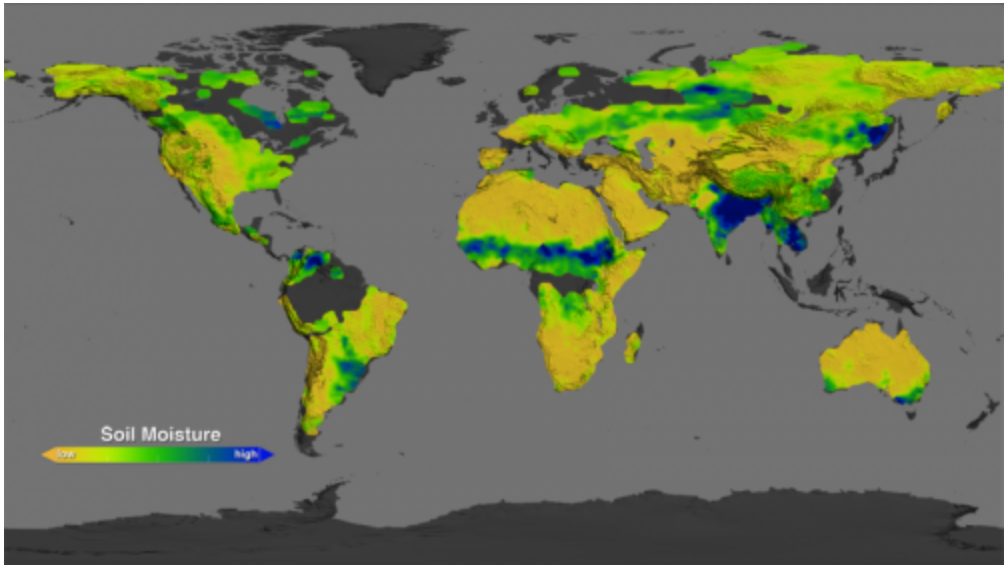
9th Aquarius / SAC-D
Joint Science Team
Meeting – 11-14 Nov
Seattle, WA, USA

Aquarius/SAC-D Announcement of opportunity

Aquarius, SMOS, and AMSR2 Soil Moisture Data Assimilation into Hydrologic Forecast Models



Bianchi, J.(1), Thibeault, M.(2), Lozza, H.(2), Uriburu Quirno, M.(2), Dadamia, D.(2), Goniadzki, D.(1)
1: Hydrological Warning System, National Water Institute (INA), Argentina. 2: National Space Agency (CONAE), Argentina.

Contact e-mail: jbianchi@ina.gov.ar

1. Introduction

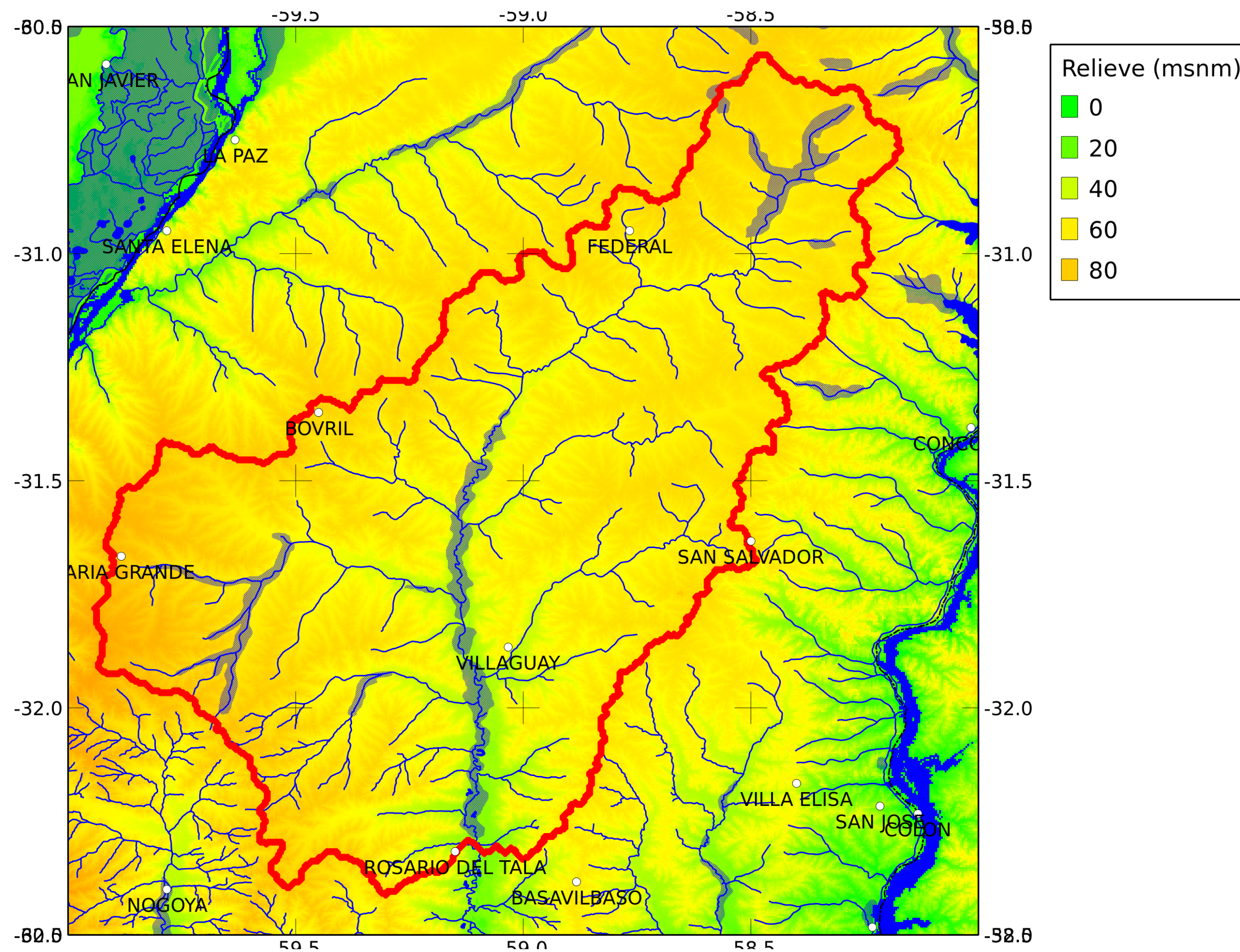
- The continuous simulation of the runoff-generating processes in a basin by means of conceptual models is known to be a useful tool for predicting floods and droughts.
- The real-time operation of such models requires the best available estimation of the system state variables at the beginning of the forecast lead-time, in order to minimize uncertainty.
- Thus, we propose correcting the simulated state variables with satellite surface soil moisture data assimilation.

Objective: **To assess the impact of passive microwave soil moisture data assimilation in hydrological modeling efficiency on the Gualeguay River Basin**

Study Basin

Gualeguay River @ Rosario del Tala

- Area ~ 16000 km^2
- Mean slope ~ 0.5 %
- Mean annual precipitation ~ 1131 mm
- Mean annual potential evapotranspiration ~ 1023 mm (according to Thornthwaite method)
- Mean discharge ~ 165 m^3/s
- Mean annual maximum discharge = 1816 m^3/s (1992-2013)
- Time of concentration ~ 6.2 days (according to Kirpich equation)



What do we understand by “Soil Moisture”?

- The ratio between the volume of the liquid phase and the whole volume of a soil sample, expressed as a percentage.

Which portion of the soil are we interested in?

- The top layer (a few cm deep).

Why it is important for operational hydrology?

- It is a key factor in the partition of rainfall between infiltration and runoff.

Estimación de humedad del suelo a partir de sensores remotos pasivos de microondas

- Los sensores remotos pasivos de microondas miden la temperatura de brillo dentro del rango de las microondas (longitudes de onda de centímetros hasta un metro) en diferentes bandas, con la ventaja de que la atmósfera es transparente para este rango del espectro electromagnético. Por otro lado, la energía emitida por unidad de superficie es muy baja (en comparación con el espectro óptico e infrarrojo, por ejemplo).

- La temperatura de brillo es función de las características de la superficie observada: la permisividad eléctrica del suelo, la densidad de la vegetación y la rugosidad del terreno, así como también del ángulo, frecuencia y polarización del sensor.

- A su vez, la permisividad eléctrica es función de la humedad del suelo. La profundidad que contribuye a la observación aumenta (siendo aproximadamente igual a ¼ λ), y la influencia de la vegetación disminuye con la longitud de onda.

- Por lo tanto, si conocemos las demás variables, invirtiendo las relaciones podemos "despejar" la humedad del suelo.

$$Tb=f(perm(sm),v,h,p,f,\Theta)$$

- Por último, se deben descartar aquellas áreas donde la vegetación es muy densa o bien el agua en superficie representa una porción significativa, ya que estas coberturas influencian mucho la señal.

De temperatura de brillo a humedad del suelo

$$T_{B_{p,f,\Theta}} = e_{p,f,\Theta} T + [1 - e_{p,f,\Theta}] T_{sky}$$

Brightness temperature (T_B) is a function of emissivity (e) and physical temperature (T).

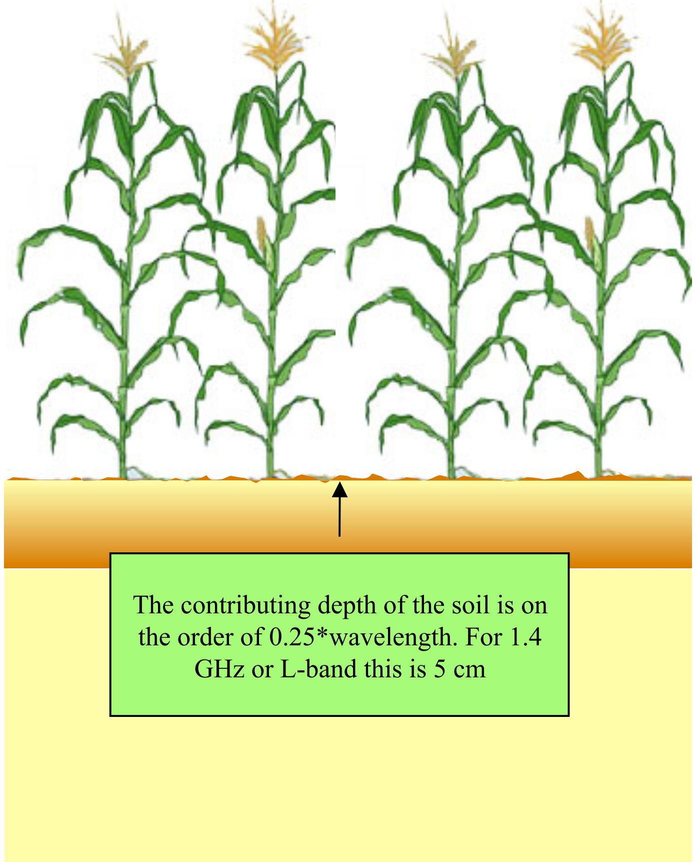
Observations are made at a specific polarization (p), frequency (f), and angle (Θ)

$$e_{p,f,\Theta} = \frac{T_{B_{p,f,\Theta}}}{T}$$

The second term is small resulting in a simple relationship for e

$$e_{p,f,\Theta} = [1-\omega_{p,f,v}][1-\gamma_{p,f,v,\Theta}][1+[1-e^{surf}_{p,f,\Theta}]\gamma_{p,f,v,\Theta}] + e^{surf}_{p,f,\Theta}\gamma_{p,f,v,\Theta}$$

The observed e is the result of contributions from the soil surface (e^{surf}) modified by the scattering (ω) and attenuation (γ) of the vegetation (v)



Incógnitas

$$e^{soil}_{p,f,\Theta} = 1 - [1 - e^{surf}_{p,f,\Theta}]\exp[-h_{p,f,g}\cos^2\Theta]$$

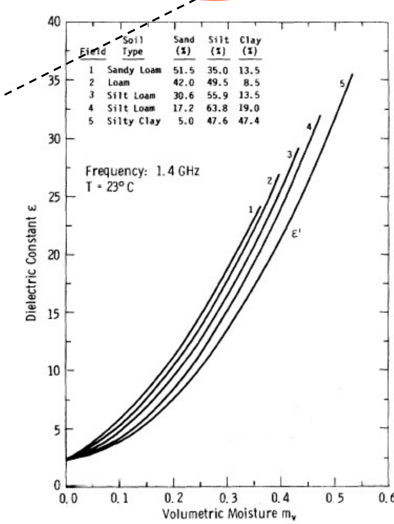
e^{surf} is the soil emission (e^{soil}) modified by the surface roughness (h)

$$e^{soil}_{H,f,\Theta} = 1 - \left|\frac{\cos\Theta - \sqrt{\varepsilon_r - \sin^2\Theta}}{\cos\Theta + \sqrt{\varepsilon_r - \sin^2\Theta}}\right|^2$$

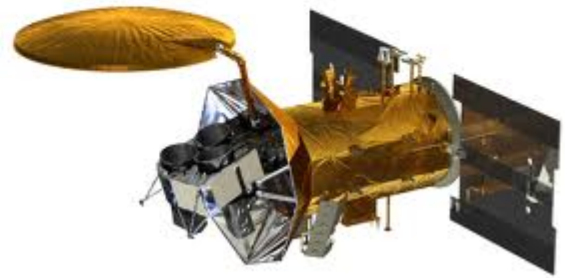
The contributing depth of the soil is on the order of 0.25*wavelength. For 1.4 GHz or L-band this is 5 cm

The e^{soil} is a function of the soil dielectric properties (ε_r)

A dielectric mixing model relates ε_r to soil moisture based on sand and clay fractions



Passive microwave remote sensors (at service today)

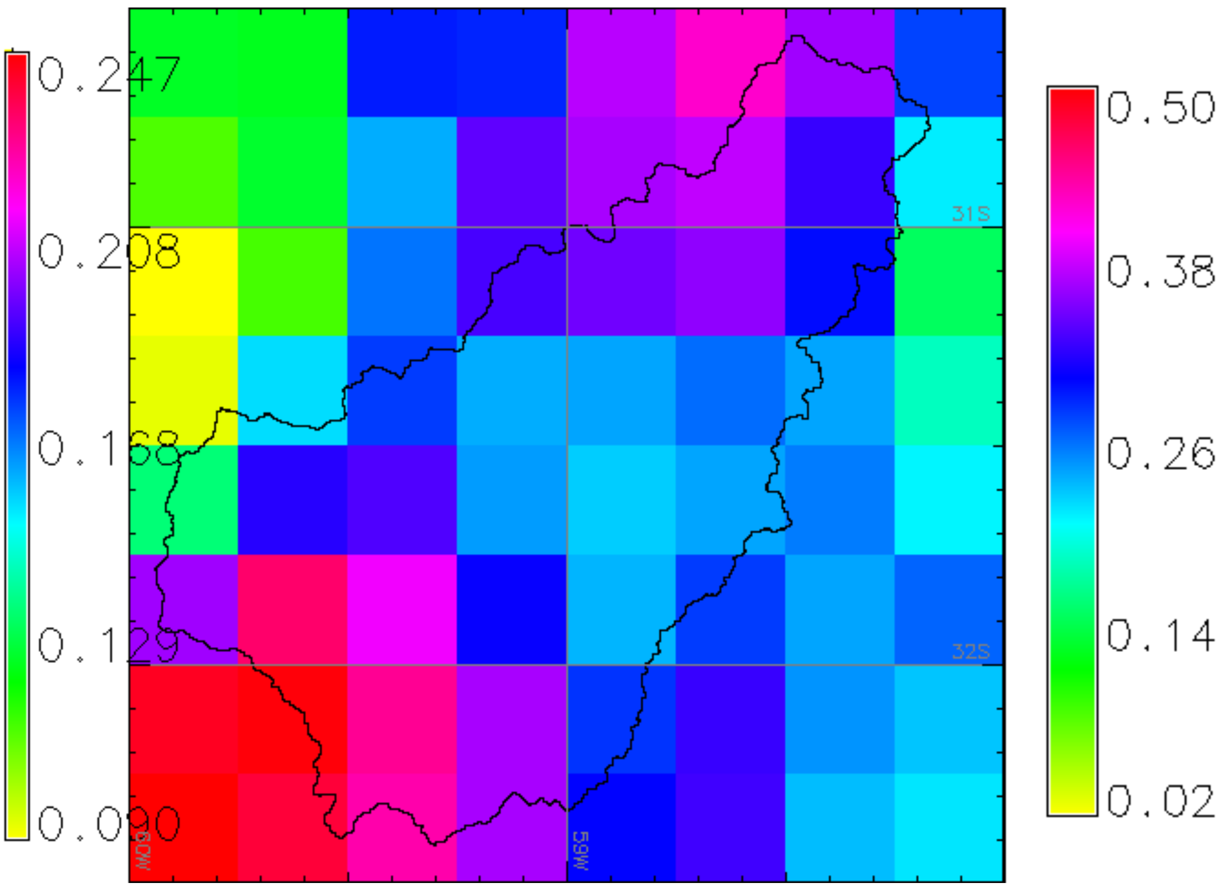




Instrument	MIRAS	AQUARIUS	AMSR2
Platform	SMOS (ESA)	SAC-D (CONAE/NASA)	GCOM-W1 (JAXA)
Revisit (mean)	1.15 / day	0.43 / day	1.6 / day
Spatial resolution	0.25°	1°	0.25°
Coverage	Global	Global	Global
Started	2010-01-15	2011-08-27	2012-07-03
Processing level	3	3	3
Bands(1)	1.4 GHz	1.414 GHz	6.9 GHz 10.65 GHz
Error (goal/max)	3%/10%	3%/5%	5%/10%

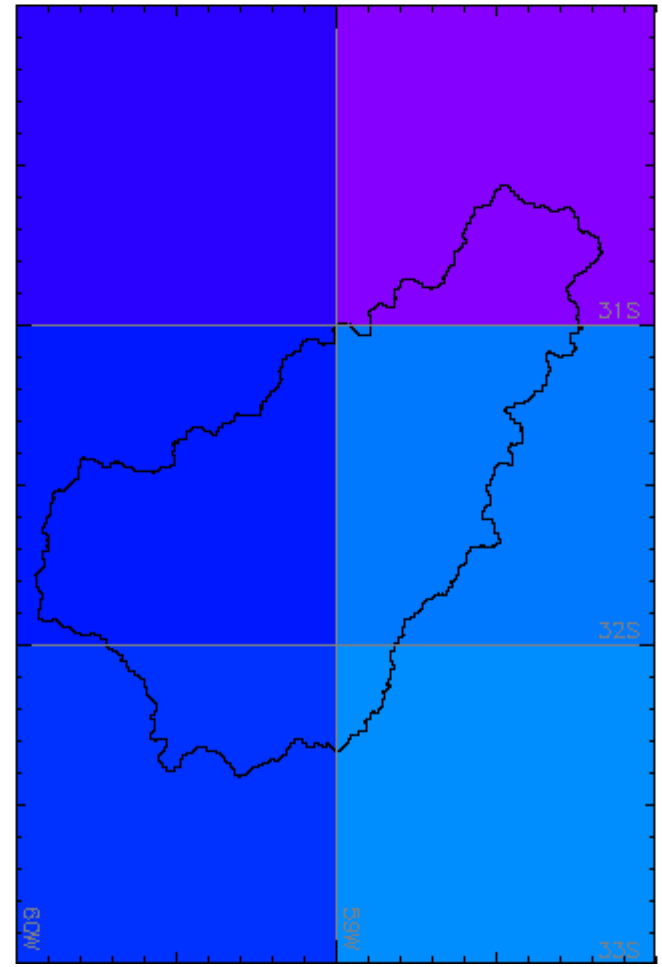
(1): used for soil moisture retrieval

Spatial resolution

SMOS/AMSR2



AQUARIUS



Mean areal soil moisture
Gualeguay River Basin

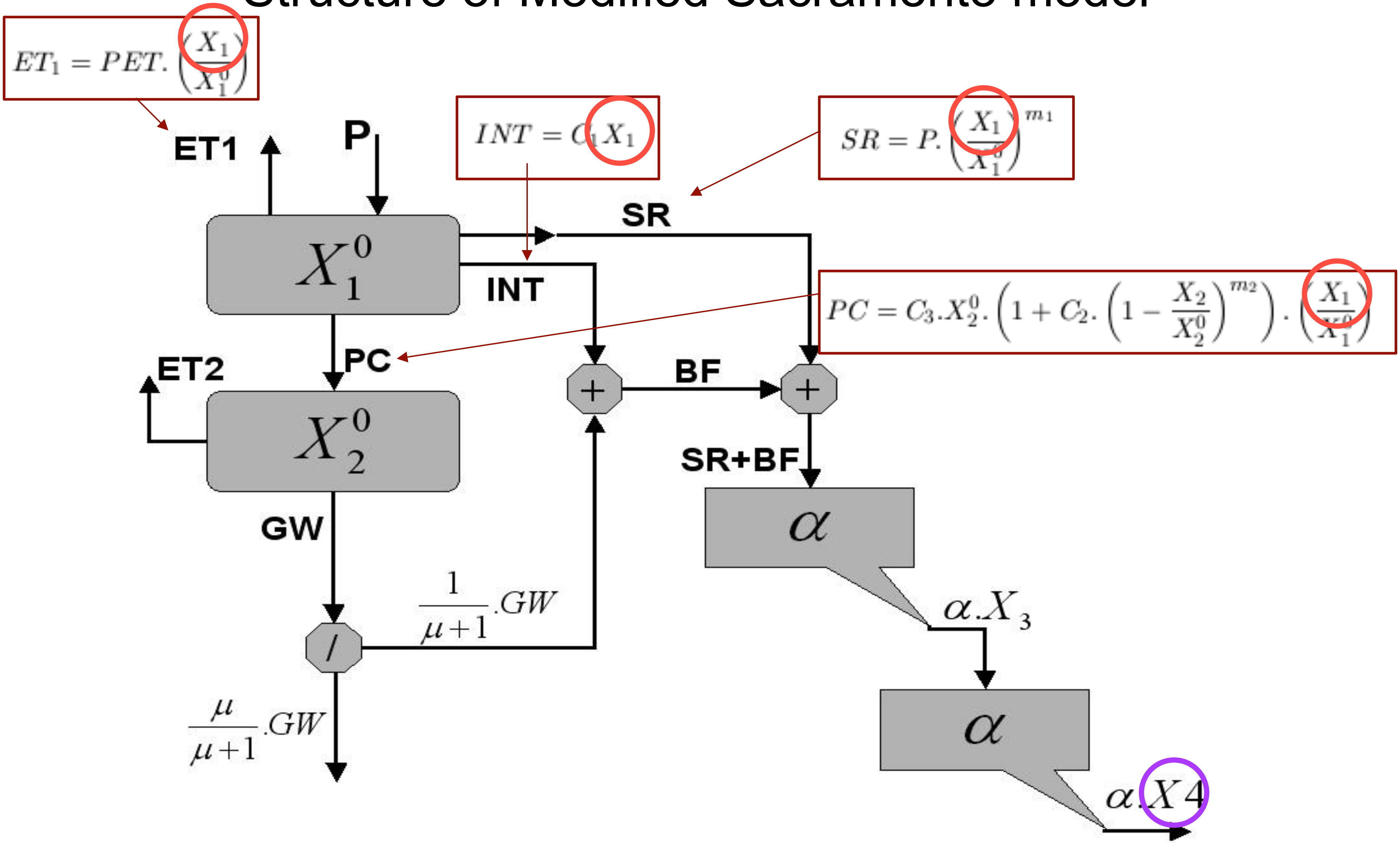
2.1 Methods: hydrological modeling

- Conceptual, physically-inspired, continuous, lumped, daily stepped.
- Forcings (input variables):
  - Daily mean areal rainfall from ground stations
  - Daily climatological potential evapotranspiration (Oudin et al., 2005) based on daily mean temperatures from one ground station, adjusted to sum up to the annual value calculated according to the Thornthwaite (1948) method.
- Two models where essayed:

Sacramento SMA – Modified (Georgakakos & Baumer, 1996)	GRP (Cemagref)
10 parameters	4 parameters

- Calibration and verification was performed against observed discharge at the basin outlet, calculated by transforming from gauge height by means of an empirical rating curve. Period 3/2000-5/2012

Structure of Modified Sacramento model



Source: Uriburu Quirno, 2011

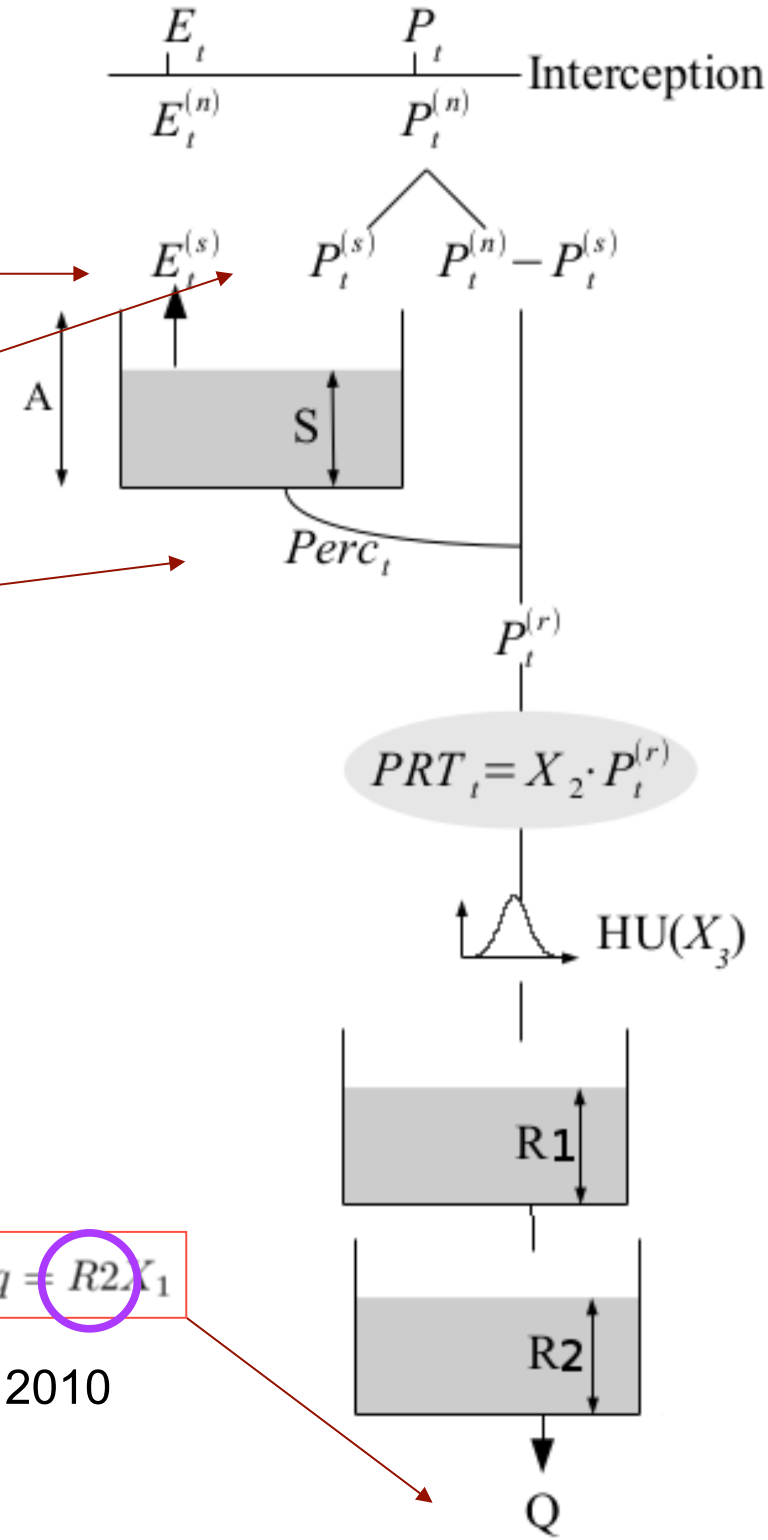
Structure of GRP model

$$e_s = s(2 - s/a)\frac{\tanh((ETP-P)/a)}{1+(1-s/a)*\tanh((ETP-P)/a)}$$

$$p_s = a(1-(s/a)^2)\frac{\tanh(p_n/a)}{1+s/a\tanh(p_n/a)}$$

$$Perc = (s - e_s + p_s)(1-(1+(\frac{4}{9}\frac{s - e_s + p_s}{a})^4)^{-1/4})$$

$$q = R2 X_1$$



Source: Modified from Berthet, 2010

2.2 Methods: Data assimilation

- Is the combination of simulated state variables with concurrent observations of variables conceptually linked to them, to produce an updated state variable vector
  - **Soil moisture** is linearly linked to the storage in the top soil reservoir of the model by

SAC: $\hat{s}m_{i,j} = \frac{X_{1,i,j}}{X_1^0} . (\theta_s - \theta_r) + \theta_r$ GR4P: $\hat{s}m_{i,j} = \frac{S_{,i,j}}{A} . (\theta_s - \theta_r) + \theta_r$

  - **Discharge** is linearly linked to the final reservoir of the cascade of the model by

SAC: $\hat{q}_{i,j} = \alpha X_{4,i,j}$ GR4P: $\hat{q}_{i,j} = X_1 R2_{i,j}$

- Data assimilation was performed though Kalman Ensemble filtering, which uses the ratio between observation error and the sum of observation and simulation errors as the updating gain factor:

$$S_{i,j}^{+} = S_{i,j}^{-} + KG_j . [(sm_j, q_j) + (v_{i,j}^{sm}, v_{i,j}^{q}) - H.S_{i,j}]$$

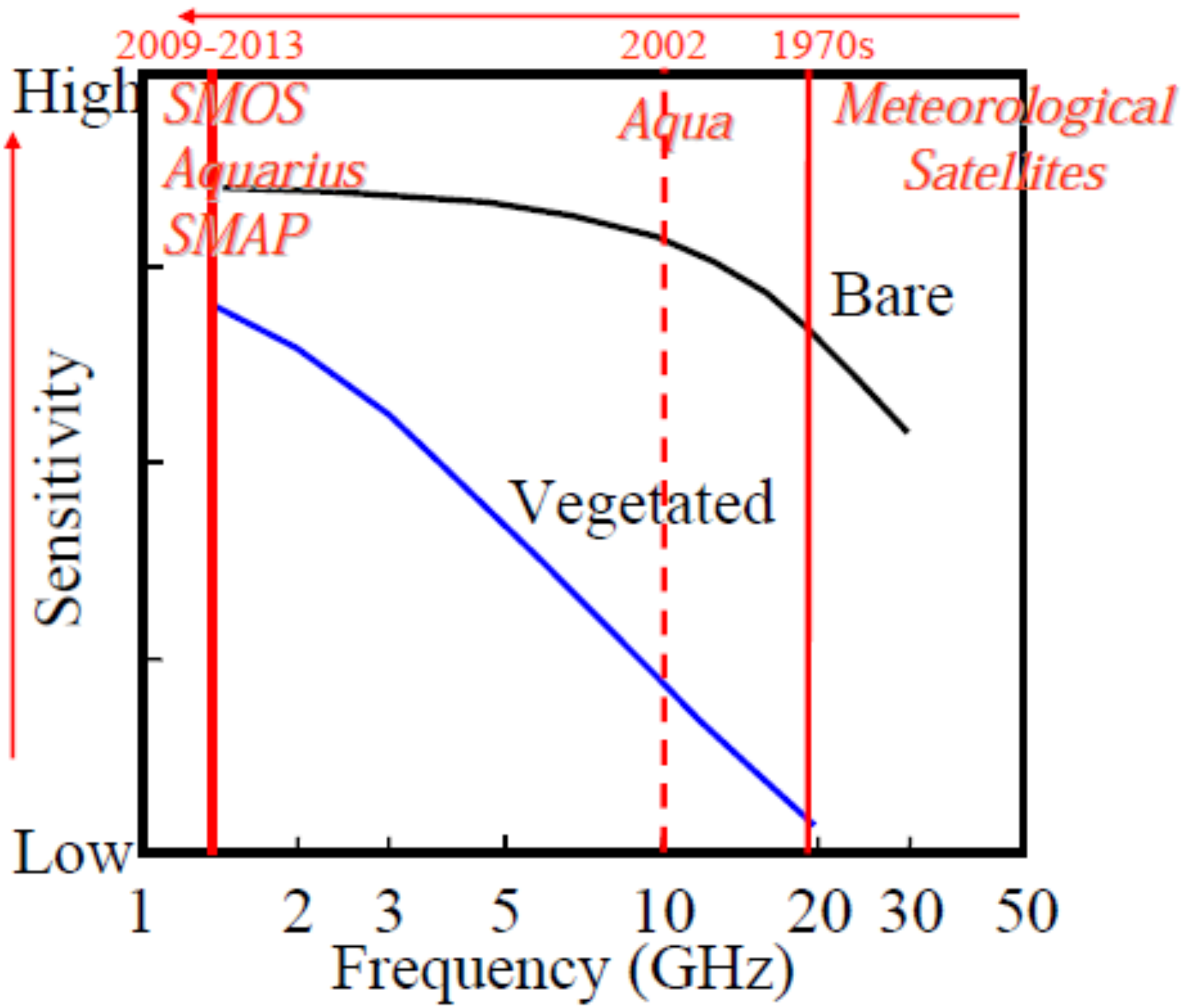
State updating equation

$$KG_j = [C_j . H^T] . [H.C_j . H^T + R]^{-1}$$

Kalman filter gain equation

Frecuencias menores proveen información de una capa de suelo más profunda y son menos afectadas por la vegetación

- La profundidad del suelo que contribuye a la observación se encuentra en el orden de ¼ la longitud de onda:
  - 1,4 GHz -> ~5 cm
  - 10,7 GHz -> ~0,5 cm



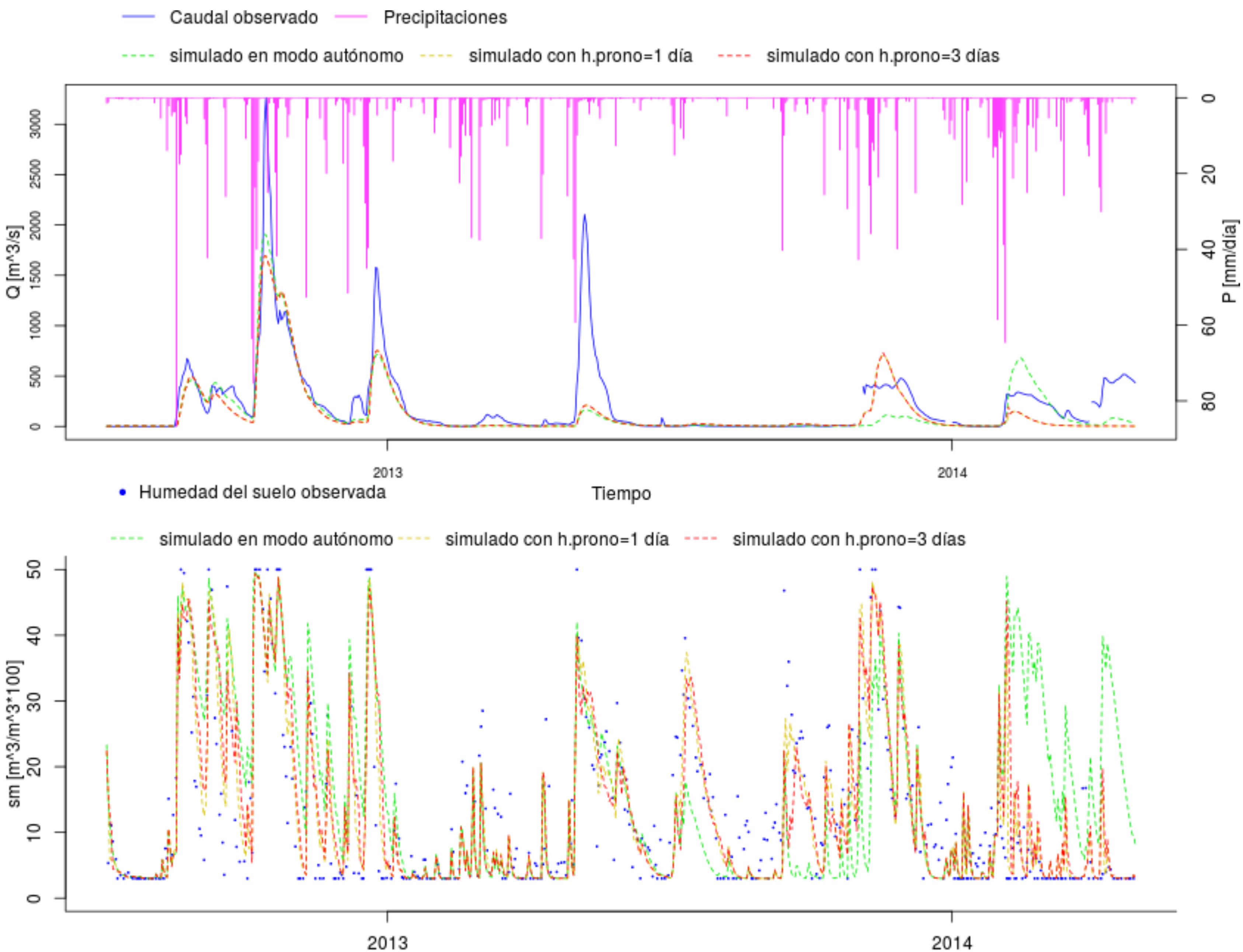
Fuente: Jackson, 2008

3.1 Results

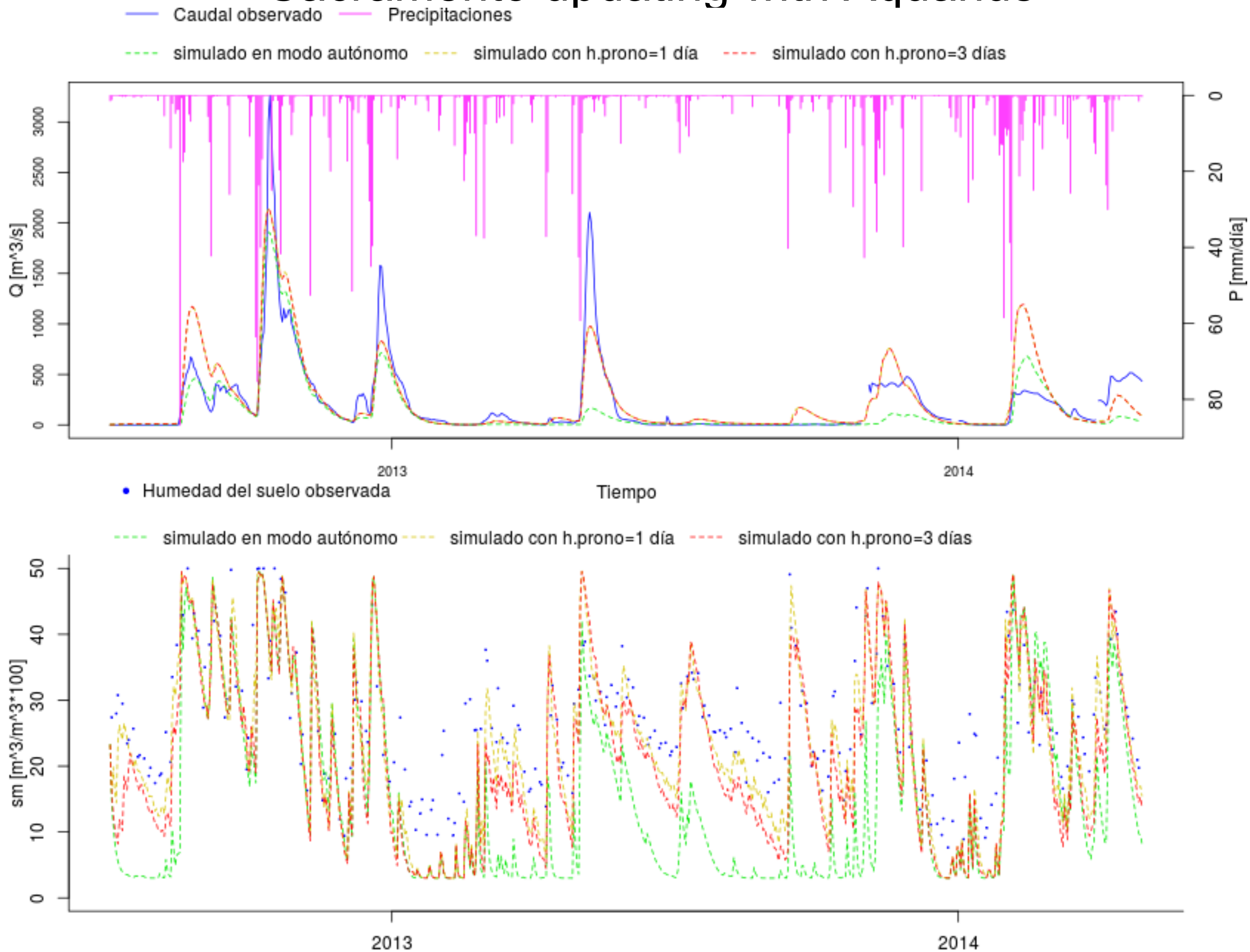
- Nash-Sutcliffe efficiency coefficients of each model with and without assimilation, with 1 to 3 days lead-times using observed rainfall for the lead-time (5/2012-4/2014)

	Sacramento			GRP		
Lead-time	1 day	2 day	3 day	1 day	2 day	3 day
Upd. with SMOS	0.59	0.59	0.59	0.65	0.64	0.62
Upd. with AQUARIUS	0.70	0.70	0.70	0.63	0.63	0.62
Upd. With AMSR2	0.68	0.68	0.68	0.60	0.59	0.59
Upd. With discharge	0.95	0.88	0.80	0.96	0.89	0.84
No updating		0.59			0.70	

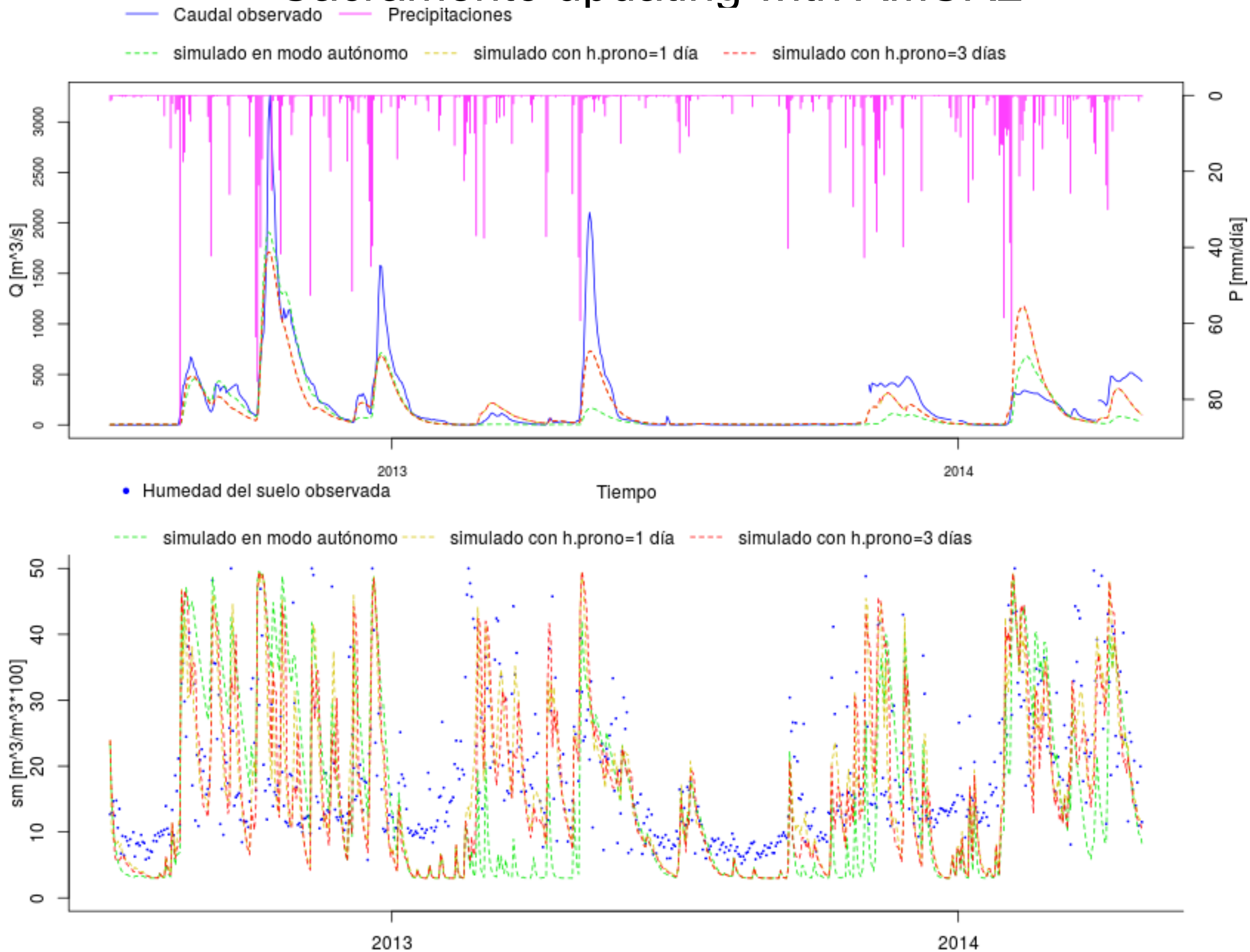
Sacramento updating with SMOS



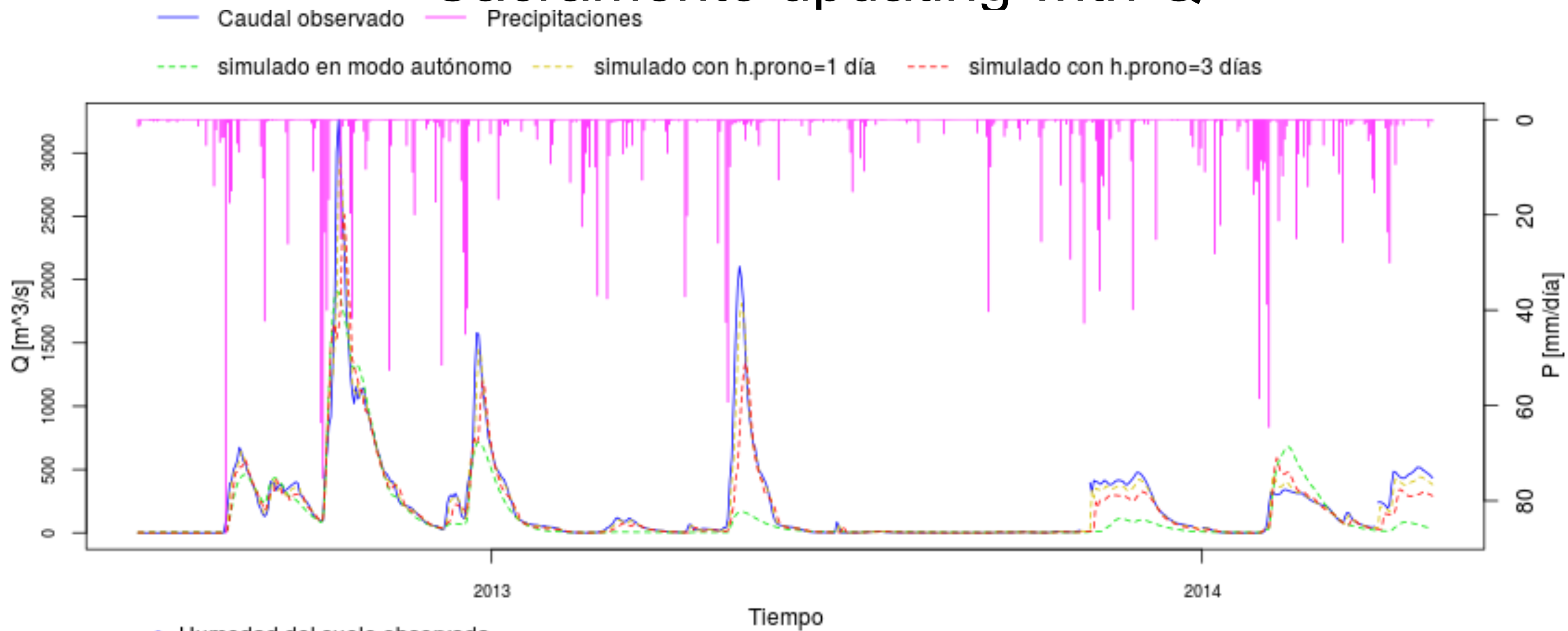
Sacramento updating with Aquarius

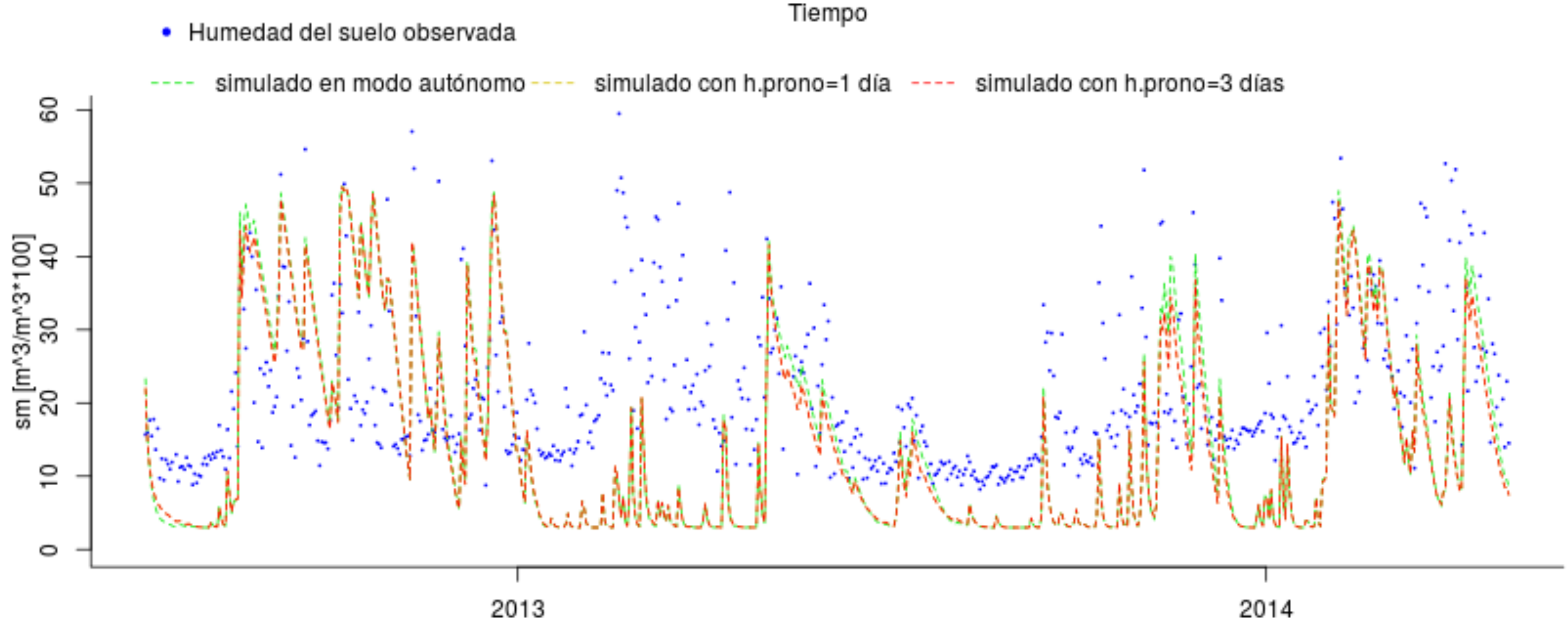


Sacramento updating with AMSR2

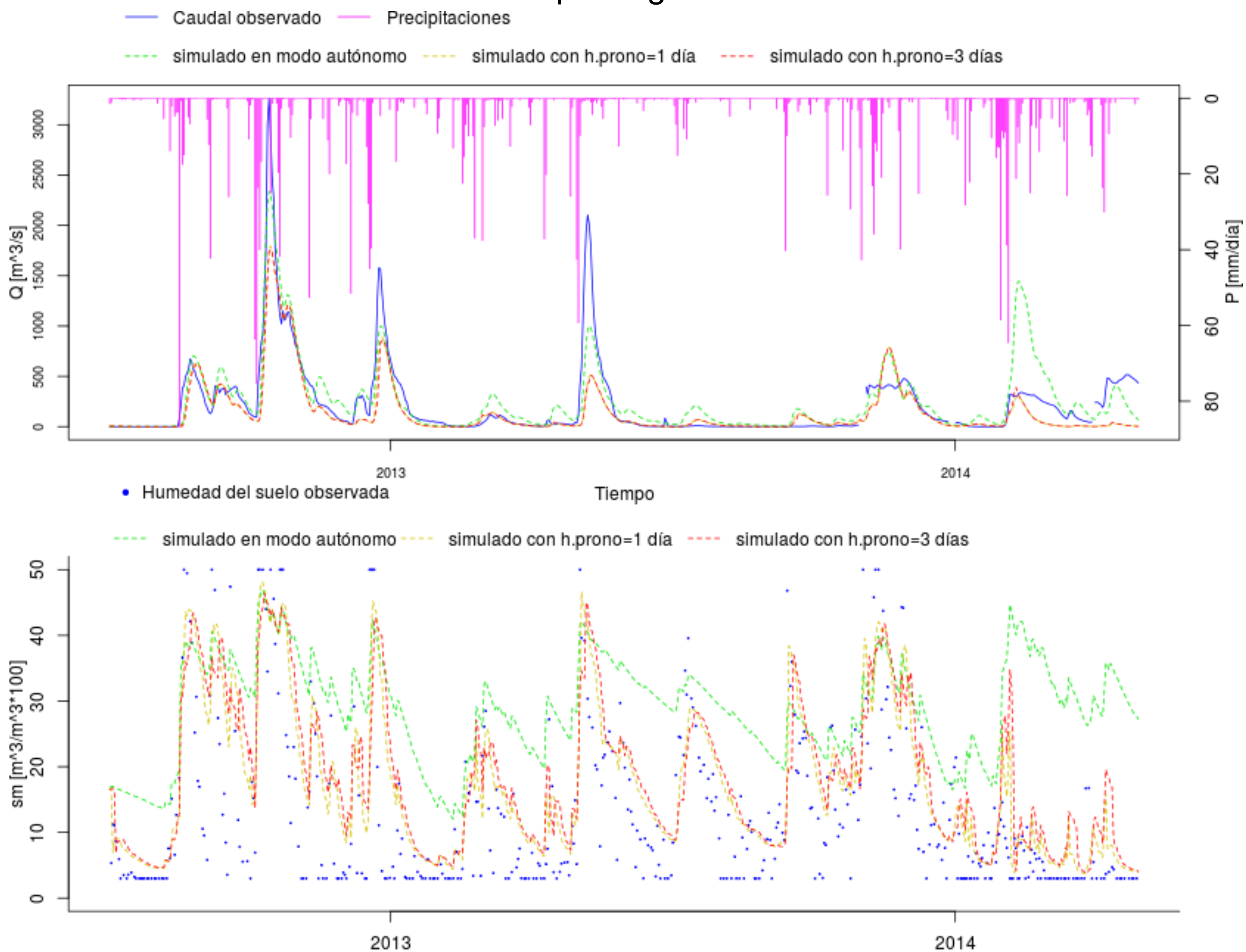


Sacramento updating with Q

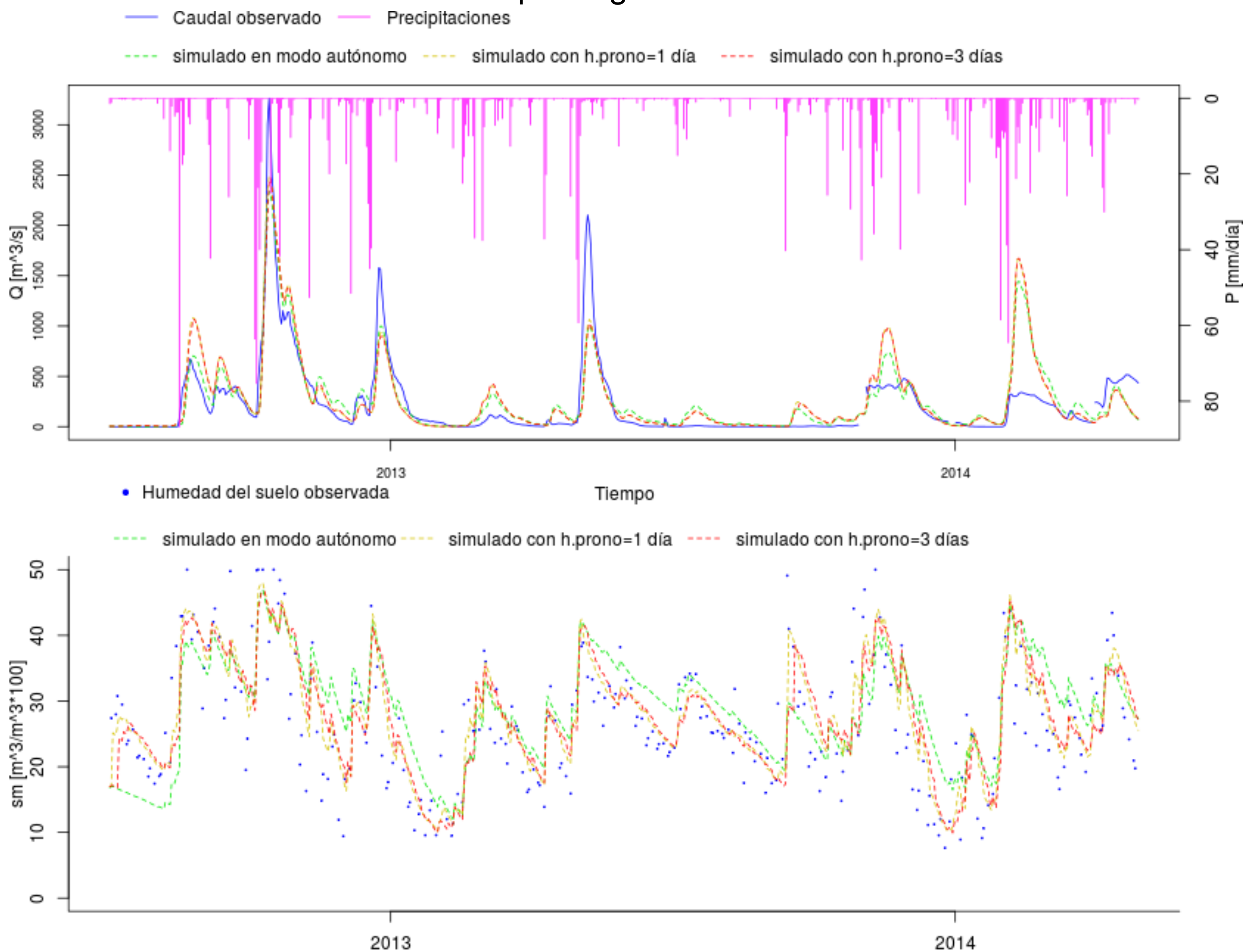




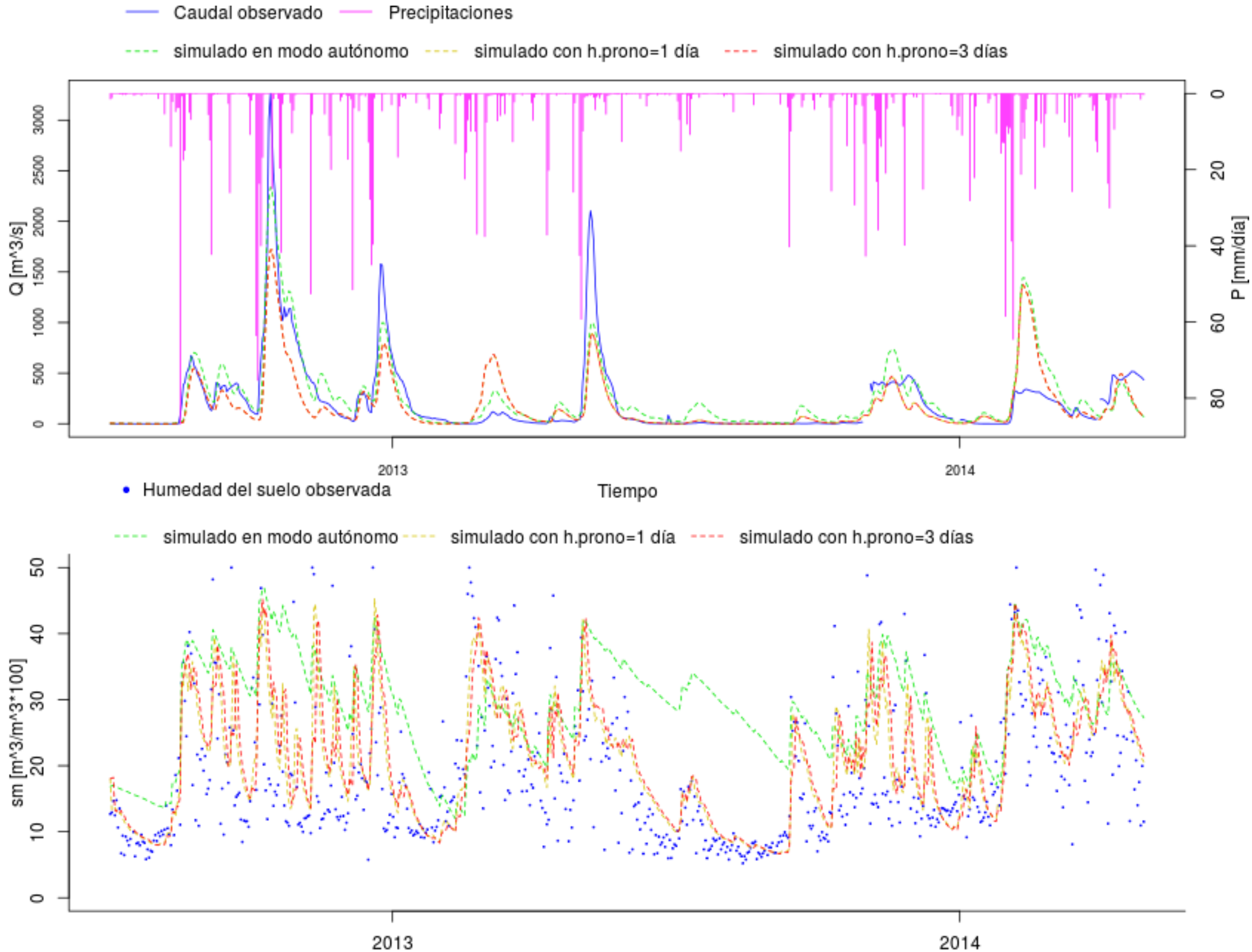
GRP updating with SMOS



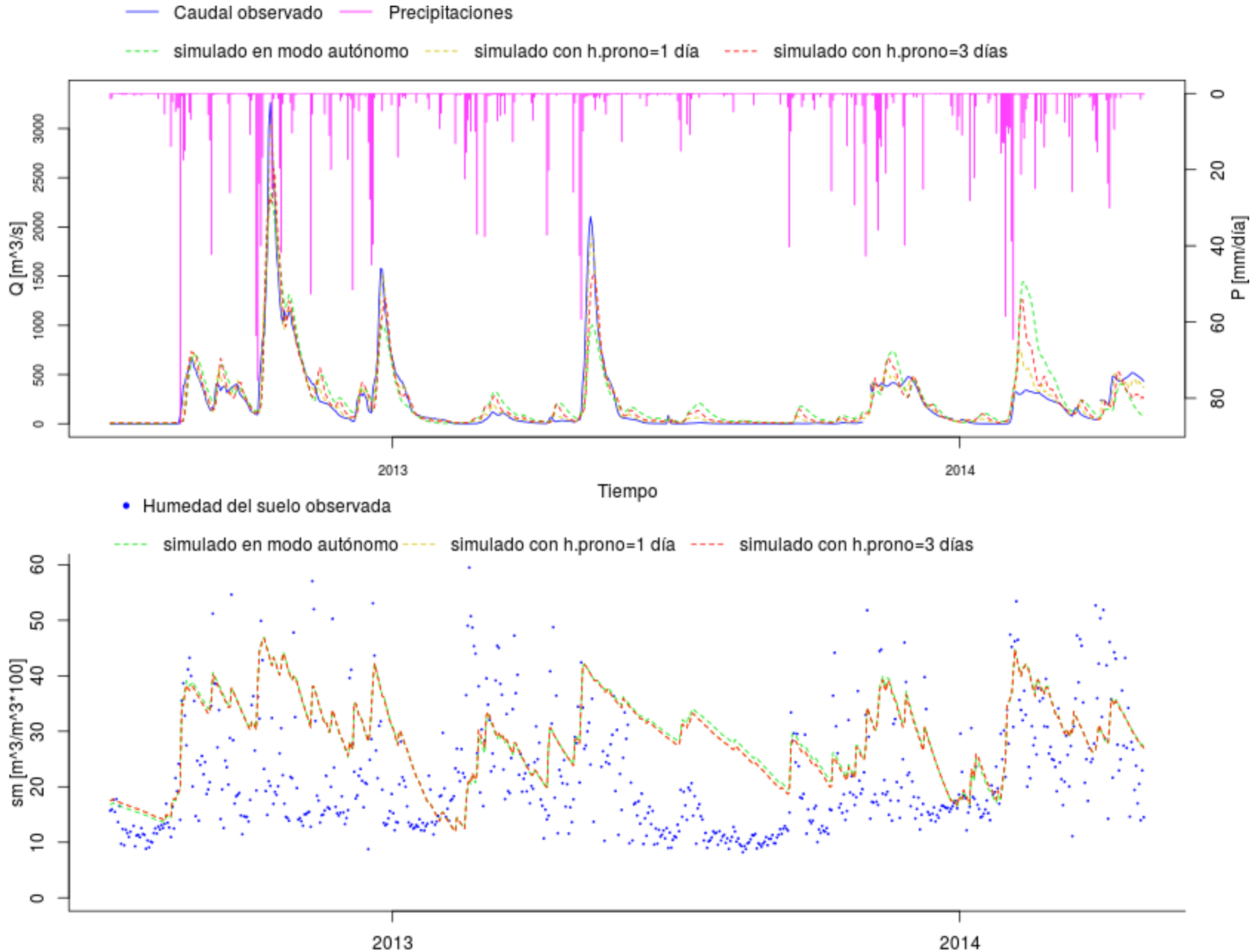
GRP updating with AQUARIUS



GRP updating with AMSR2



GRP updating with Q



3.2 Results analysis

- The results of the model runs show no significant gain in efficiency when updating the state variables with remotely-sensed soil moisture products, whereas they do when updating with discharge data. In most cases, soil moisture assimilation tends to even up flood waves, giving underestimated discharge values during large flood waves and overestimated values during minor flood waves.

4 Conclusions/Discussion

Overall, we reason that updating with soil moisture data is not rendering good results because there is a **mismatch between the observed and simulated soil moisture**. However, in the absence of in-situ data, there is no evidence to suggest which one describes better the reality. Some known sources of uncertainty are:

- limitations in the instruments (limited soil profile penetration),
- limitations in the retrieval algorithms (vegetation density, surface roughness and surface water influence), and/or
- limitations in model conceptualization, since state variables do not correspond necessarily to physical magnitudes.

Nevertheless, among the available soil moisture products the one from Aquarius seems to better match the simulated variable, and shows mean values and a distribution which are closer to what theory prescribes.

In order to address these issues, further tests can be made by rescaling and/or transforming the data as to match observed and simulated distributions prior to their use for model updating. A similar strategy would be using anomalies of soil moisture rather than absolute values. Additionally, the experiments can be replicated in other basins with similar or different characteristics so as to have a more encompassing view of the problem.

Thanks!

Asimilación mediante filtro de Kalman en ensamble

$$S^{-}_{i,j+1} = S^{+}_{i,j} + \Delta S_{i,[j,j+1]}(S^{+}_{i,j}, P_{i,[j,j+1]}, ETP_{i,[j,j+1]})$$

$$)) - H.S_{i,j}]$$

$$ETP_{i,[j,j+1]} = ETP_{[j,j+1]} + N(0, \sigma^{2}_{ETP})$$

Ensamble de estados del modelo

Correción de la variable de estado mediante asimilación de valores observados