Agricultural drought analysis in the Arrecife basin (Pampas region, Argentina) using the SWAT model

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Introduction

- Drought is a natural hazard (Mavi y Tupper, 2004). It occurs in in almost all regions of the world, whose intensity and frequency of occurrence depend on each region (Ravelo *et al*., 1999).

- **The agricultural sector is highly vulnerable to weather conditions, especially to extreme events. The expansion of agriculture into more fragile environments brought about an increase in water-related hazards (i.e. droughts or floods) in the Pampas region (Andrade *et al.*, 2009), especially in new production areas, which are exposed to extreme events as a result of climate change and changes in land use (Magrin *et al.*, 2007).**

- **Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time. An agricultural drought occurs when soil moisture and rainfall are inadequate during the growing season to support a healthy crop growth to maturity causing extreme crop stress and a drastic fall in yields (Das *et al.*, 2003). It is a complex phenomenon affected by a number of factors: Meteorological factors, Agricultural factors, Natural environment factors, Irrigation and anthropogenic factors associated with land use practices**

- The main aim of this study was to explore the reliability of the SWAT model combined with specific drought indicators (such as NDVI) to estimate soil water content (SWC) in a poorly gauged basin of the Pampas region. The specific objectives of this study were: (1) to develop a long-term record of SWC using SWAT; (2) to determine the correlation between the anomaly of SWC (aSWC) and the anomaly of NDVI-3g (aNDVI).

Material and Methods

Study area

- Arrecife basin: 10,700 km^2
- Drainage area above the gaging station: 8,740 km^2
- Level difference : 77.5 m
- Lenght of longest flow path: 176.9 km
- Slope: 0.4 m/m
- Main channel slope: 0.00043 m/m
- Watershed’s time of concentration: 4.3 days
- Landscape: low round-topped hills, rolling geomorphology

Land use:

- Arrecife basin is located in the most productive region.
- Oleaginous (soybean and sunflower) and cereals (maize and wheat).
- Livestock activity (Upstream and near streams).

Soil typ e- Soil Taxonomy (at subgroup level):

- Typic Argiudolls (75,4%)
- Typic Hapludolls (5,6 %)
- Abruptic Argiudolls (2,8 %)
- undifferentiated complex units (9,7 %)

Arrecife basin has a high land capability and a high productivity index.

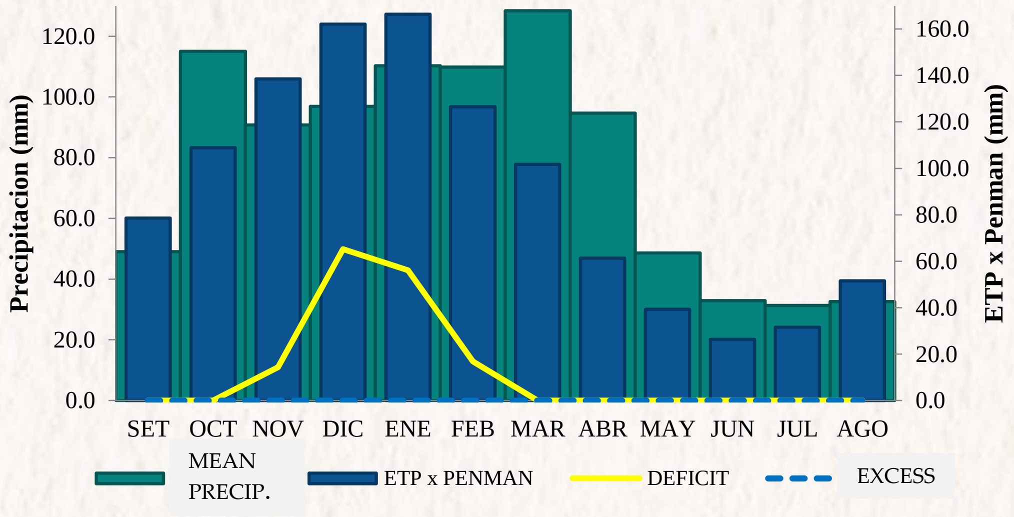
Exhibit moderate susceptibility to water erosion in the weakest sectors.

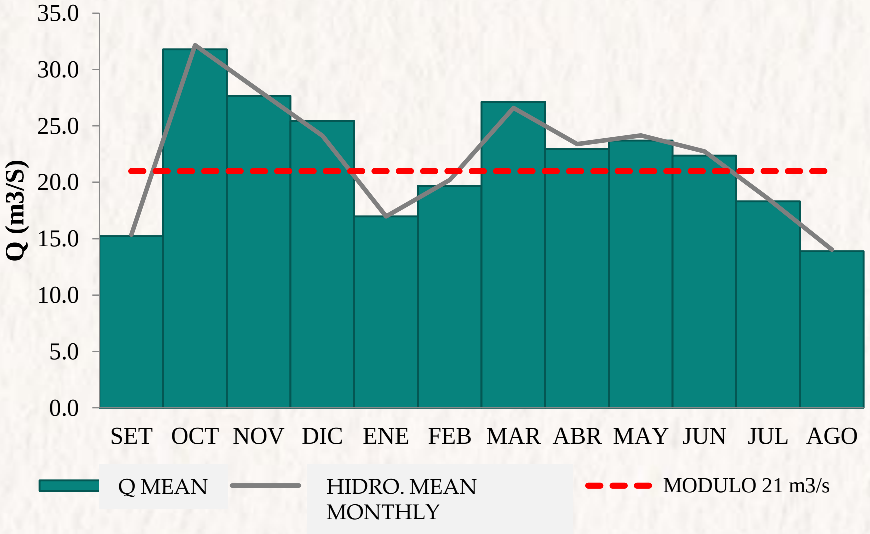
Climate

- Köppen climate classification: Humid subtropical climate
- Annual precipitation: 900 ~ 1100 mm
- Average winter temperature: 11°C
- Average summer temperature: 23°C
- The water deficit: late spring and early summer
- Evapotranspiration: 1000 ~ 1200 mm

Outflow

- Watershed outflow: “río Arrecifes” N° HL 4035 gage
- Discharge series (incomplete): 1963-2002
- Flow regime module: 21 m^3/s
- Average annual contribution: 579 Hm^2/year





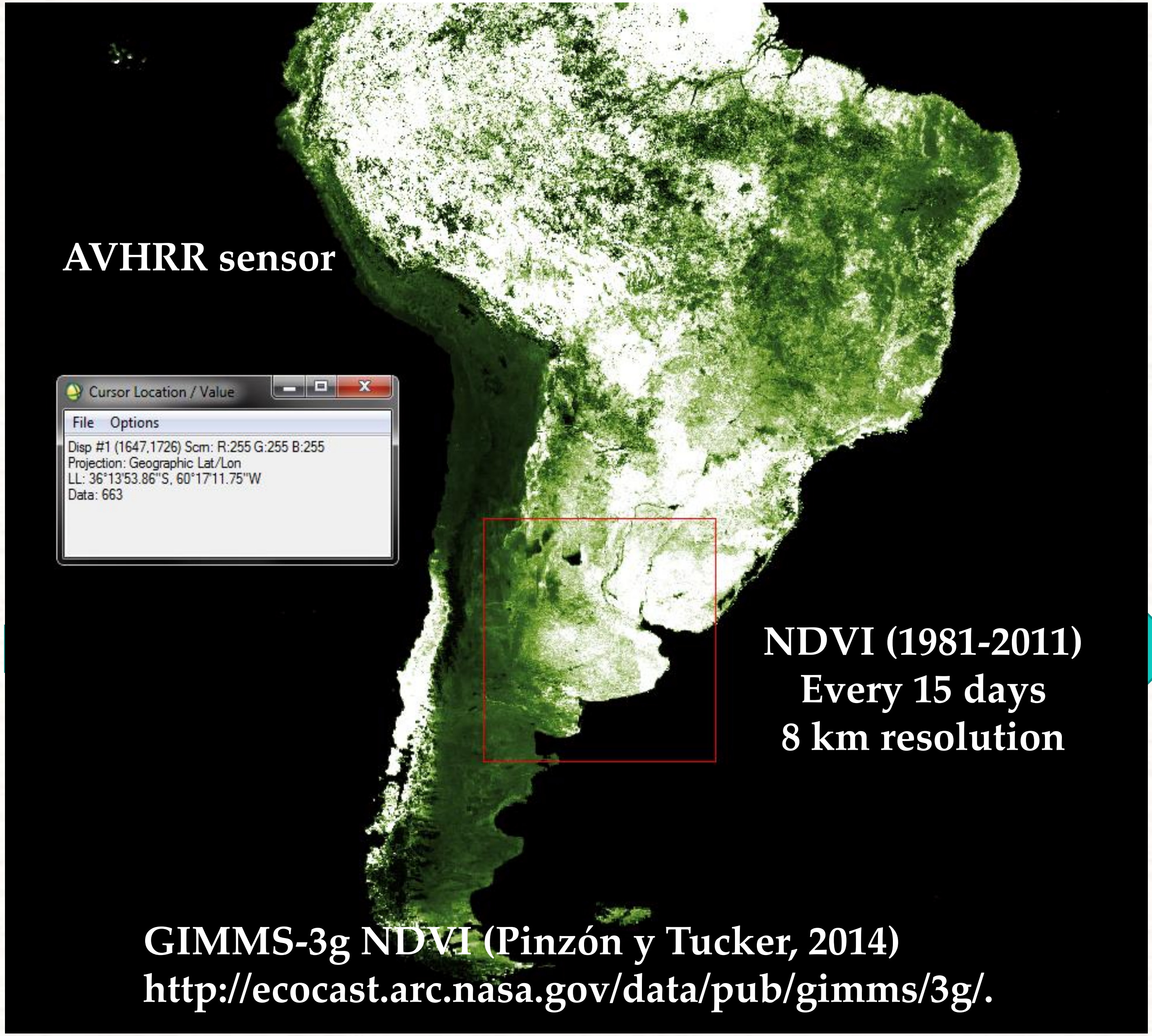
Input Data

SOIL

LAND USE

DEM SRTM

METEOROLOGICAL DATA



SOIL WATER CONTENT

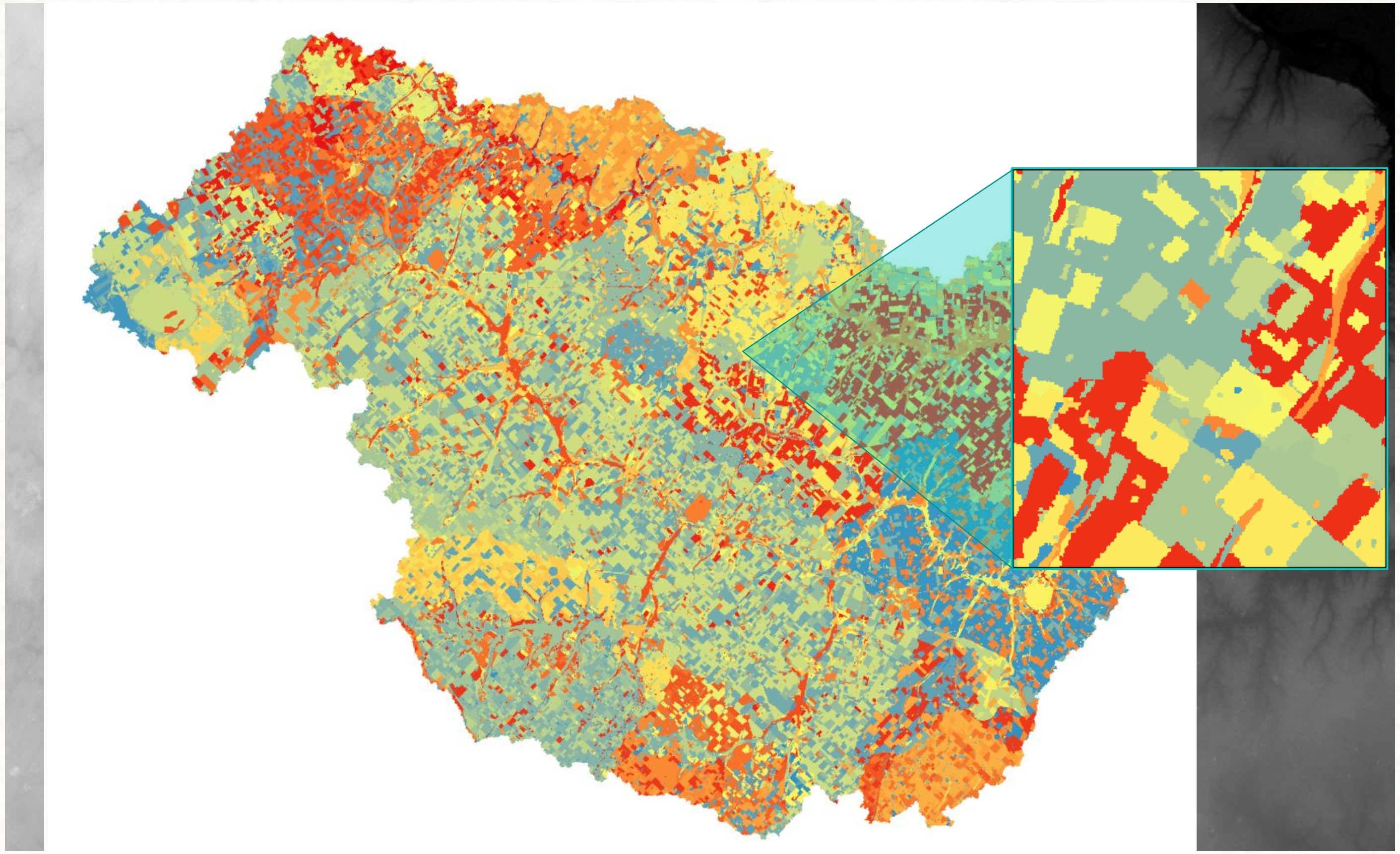
NORMALIZED DIFFERENCE VEGETATION INDEX

Hydrological modeling

- Discretization scheme: subwatershed
- Subbasin outlets: manual drainage points (the limits of the main soil series)
- Hydrological response units (HRUs): threshold percentage of 2% for land use, 5% for soil type, and a uniform slope.
- Total number of HRUs: 337

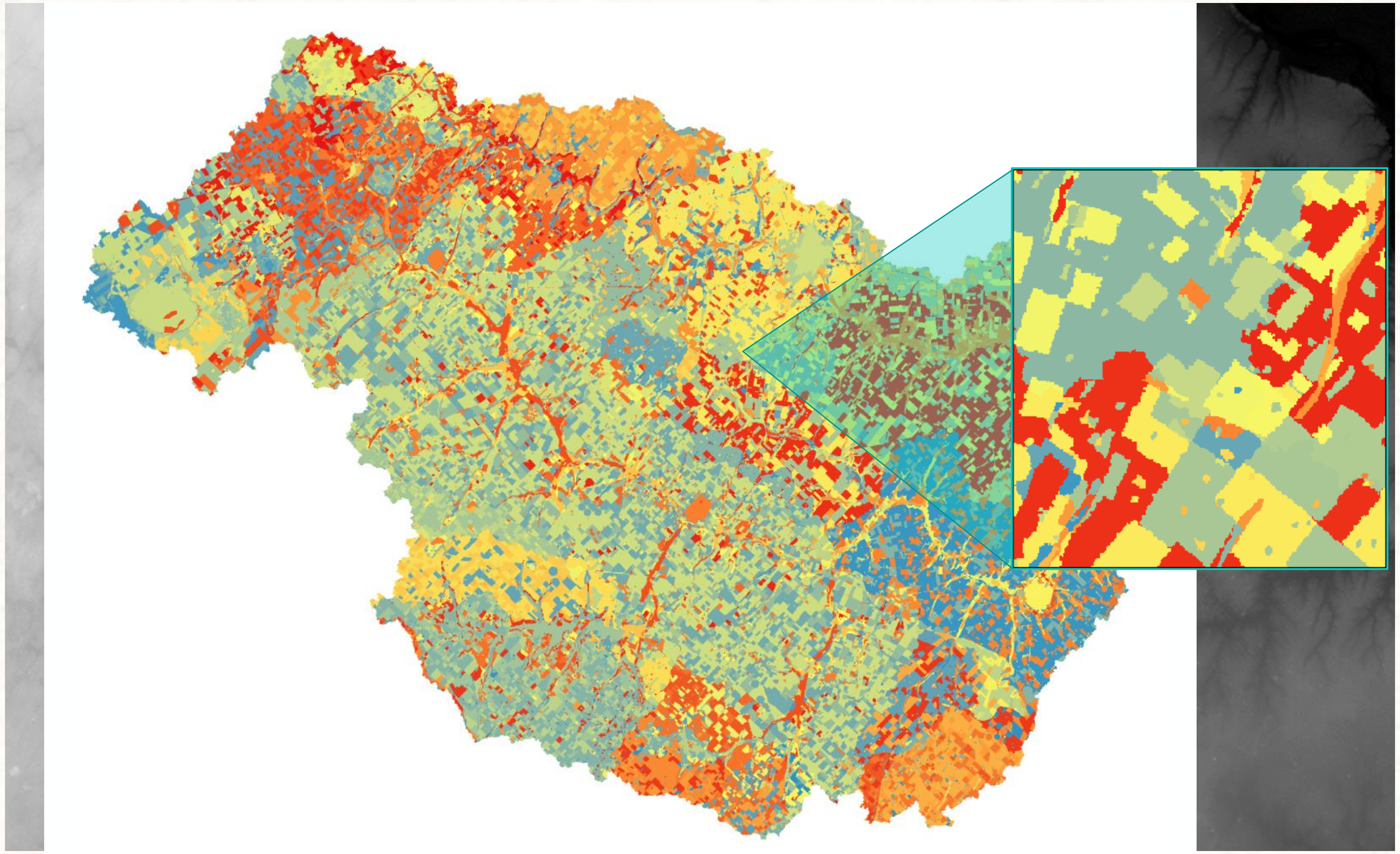
Management practices for each HRU:

I. only rainfed crops were considered;
II. plant growth was defined considering planting and harvesting;
III. minimum tillage practices were implemented by using disk harrow.



Hydrological modeling

- We assumed classic planting rotation with a duration of 3 years.
- Groundwater parameters: matched by calibration
- Simulation: January 1, 1975 ~December 31, 2011 (with 4-year equilibration period 1975-1978)
- Potential evapotranspiration (PET): Priestley-Taylor
- Daily CN: method of evapotranspiration of plants
- Channel routing: variable storage coefficient method



Model calibration and validation

- Model performance evaluation: SWAT-CUP4, Sequential Uncertainty Fitting ver. 2 (SUFI-2).
- Daily discharge series (1963-2002) was used to calculate monthly values.
- Calibration: period of 14 years (1979-1992)
- Validation: period of 6 years (1993-1998)
- Objective functions: Nash – Sutcliffe, NS

Series HSS y NDVI

- Run SWAT: period of 36 years (1975-2011).
- Extraction at subbasin level Soil Water Content from tables out : period of 30 years (1981-2011).
- Data were filtered by calculating the standardized anomaly (aSWC).
- NDVI: 15 days image was averaged monthly (for every sub-basin) by raster/vector layer operations for a period of 30 years (1981-2011).
- NDVI values were filtered using the standardized anomaly (aNDVI).
- Negative values of the anomaly mentioned above mean that (aSWC/ aNDVI) is lower than the mean value, whereas positive values indicate the opposite.

$$aHSS = \frac{xi - \bar{x}}{St}$$

Results

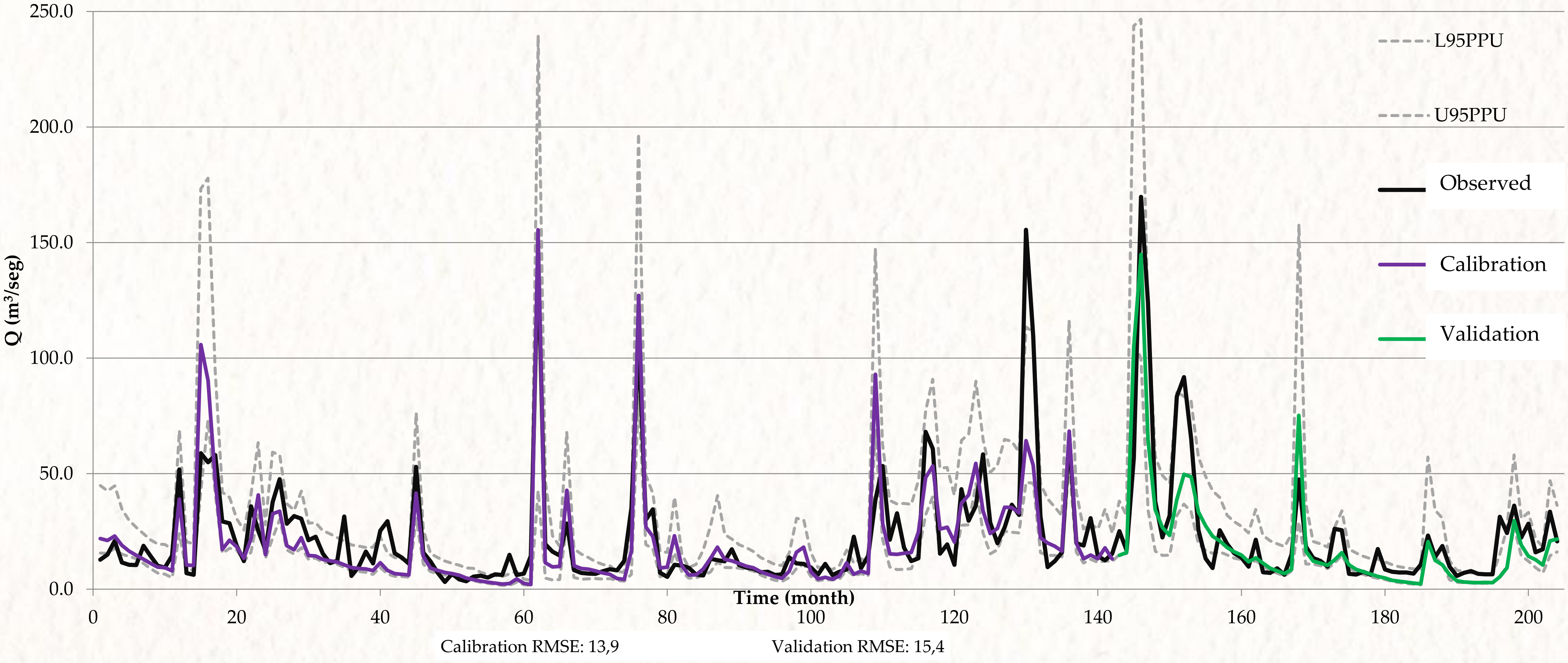
- The sensitivity analysis (*one-at-a-time*): 14 of the 25 initial parameters of the model were selected.
- First iteration, R^2 defined a value of 0.52, whereas NS defined a value of 0.41.
- The final optimization needed 8 iterations of 100 simulations.
- Calibration: R^2 :0.69 NS: 0.67 RMSE: 13.9

  P-factor: 0.70 R-factor: 0.54
- Validation: R^2 :0.75 NS: 0.72 RMSE: 15.4

  P-factor: 0.70 R-factor: 0.55

Rank: SURLAG, CH_N2, TRNSRCH, OV_N, CN2, ALPHA_BF

Processes	Parmeters/modification	Definition	Final Value	Rank
Evapotranspiration	EPCO (v_)	Plant uptake compensation factor (fraction).	0,92	12
	ESCO (v_)	Soil evaporation compensation factor (fraction).	0,79	9
Surface runoff and Time of concentration	SURLAG (v_)	Surface runoff lag coeficient (n/a).	0,50	1
	OV_N (r_)	Manning's value for overland flow.	0,023	4
	CN2 (r_)	Initial SCS runoff curve number for moisture conditions II (n/a).	-0.097	5
	CH_K (1) (v_)	Effective hydraulic conductivity in tributary channel alluvium (mm/h).	35,9	13
Lateral flow	LAT_TTIME (v_)	Lateral flow travel time (days).	75,6	7
Groundwater	ALPHA_BF (v_)	Baseflow alpha factor (days).	0,006	6
	GW_REVAP (r_)	Groundwater delay time (days).	0,095	
Soil Water	FFCB (v_)	Initial soil water storage	0,78	11
Chanel water routing	TRNSRCH (v_)	Fraction of transmission losses from main channel that enter deep aquifer (fraction).	0,48	3
	EVERCH (v_)	Reach evaporation adjustment factor (n/a).	0,69	14
	CH_N(2) (v_)	Manning's "n" value for main channel (n/a).	0,026	2
	CH_K (2) (v_)	Effective hydraulic conductivity in main channel alluvium (mm/h).	115	10



250.0
200.0
150.0
100.0
50.0
0.0
Q (m³/seg)
Time (month)
0
20
40
60
80
100
120
140
160
180
200
L95PPU
U95PPU
Observed
Calibration
Validation
Calibration RMSE: 13,9
Validation RMSE: 15,4

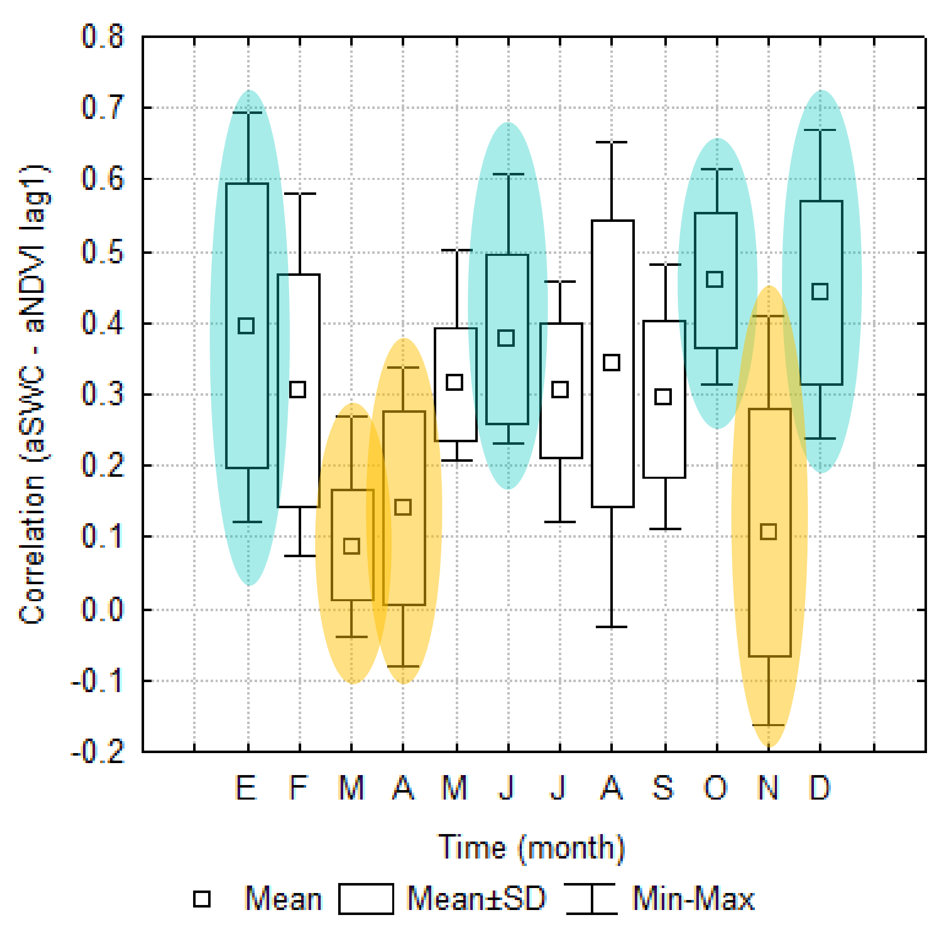
Correlation between aSWC and aNDVI

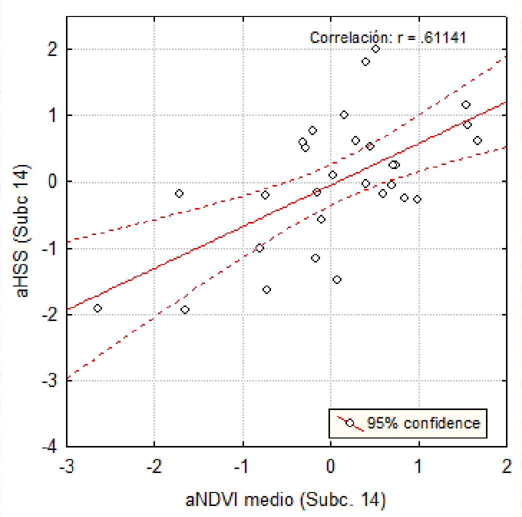
- Correlation between aSWC and aNDVI was at monthly level (20 correlations for every month.

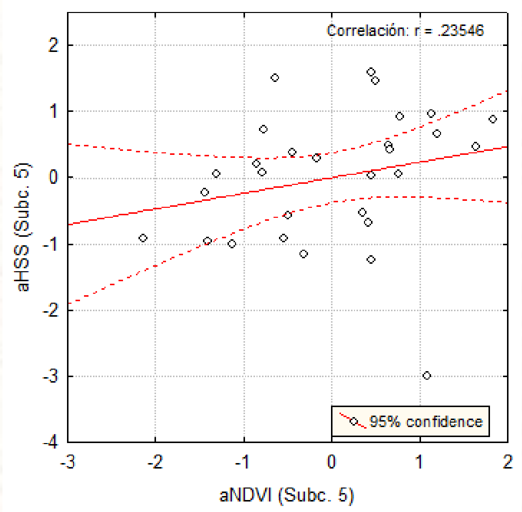
- Analisis with 0, 1 and 2 months of NDVI's lag: Higher values were derived when aNDVI was lagged one month.

- Box Plot:

I. r values were low
II. the highest correlations (> =0.4) were distributed throughout the year: coincide with times of crop growth of winter / summer as well as the planting period in June (at which almost 100% of all soils are bare or stubble)
III. the lowest correlations (<0.2) were observed in the months of March, April and November, coinciding with the time of maturity (end of growing season) and harvesting crops summer / winter..







Discussion and Conclusions

- For the first time in Argentina, a continuous record of monthly SWC (1981-2011) was obtained in a region with data shortage.

- Objective functions used during the calibration and validation of the SWAT model defined reasonably good values, could be improved increasing the availability of precipitation and flow data (i.e., precipitation and flow).

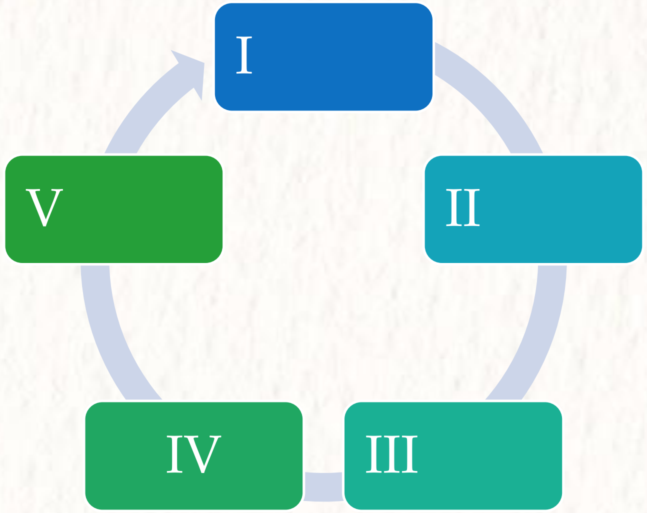
- Reliability of simulated SWC derived from SWAT was tested establishing the correlation between this parameter and aNDVI.

- The statistical relationship between aSWC and aNDVI showed low results and allowed assessing agricultural drought events partially.

- It is advisable to study homogeneous subbasins for each type of crop. NDVI is strongly conditioned by :

  I. Rooting depth, Land use in each subbasin ,
  II. Intense rainfall events within a drought context
  III. Soil type.

Discussion and Conclusions



- With a proper parameterization, SWAT could be applied to obtain accurate SWC time series in other watersheds of the Pampas region without any significant reduction in performance.
- The application of SWAT to estimate SWC at subbasin level contributes to the study of drought in the Pampas region. Also, the results obtained have important implications at the management level because the study would provide a new tool for drought monitoring.
- We propose to continue with the assessment of the Soil Water Content simulated by SWAT in Arrecife basin:

I. exploring the use of other indicators of drought and NDVI with a better spatial resolution,
II. reducing the size of subbasin to homogeneous crops areas,
III. modeling with current data (period 2009 to present) and 4 new gauging stations, 4 new weather stations
IV. improving the model with current land use
V. improving the model with current practical managment

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