Climate change effects on hydrological ecosystem services in a sub-tropical shallow lake used for drinking-water supply: Laguna del Sauce, Uruguay

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Celina Aznarez, Patricia Jimeno-Saez, Adrián Lopez-Ballesteros, Juan Pablo Pacheco & Javier Senent-Aparicio

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BC3 BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai

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ICTA Institute of Environmental Science and Technology-UAB

@celiaznarez

celina.aznarez@bc3research.org

Hydrological ecosystem services

- **Beneficial effects on people and their well-being** produced by the influence of the Earth's ecosystem on freshwater

- Existence of at least one **beneficiary** as a *sine qua non* condition to define the **ecosystem service**. Well-being has a **multidimensional** character (e.g. environmental, social, physical)

- Main classification groups: i) **improvement** of extractive water and in-stream **water supply**, ii) **natural hazard mitigation**, iii) water-related **cultural services provision** and iv) **water-related supporting services**




Brauman et al. 2007, 2015

Hydrological ecosystem services

- **Eco-hydrological processes →** transpiration, filtration, and fog interception, play a crucial role in shaping the **quantity, quality, location, and timing of water**, directly affecting its availability to meet **human needs**

- Linking **hydrological attributes** with the **HES** of interest, we can identify the **specific functions** that require monitoring for effective management

- Competitive impacts of functions on the same attribute or positive and negative effects of different characteristics of a specific HES → **trade-offs** between HESs and beneficiaries.

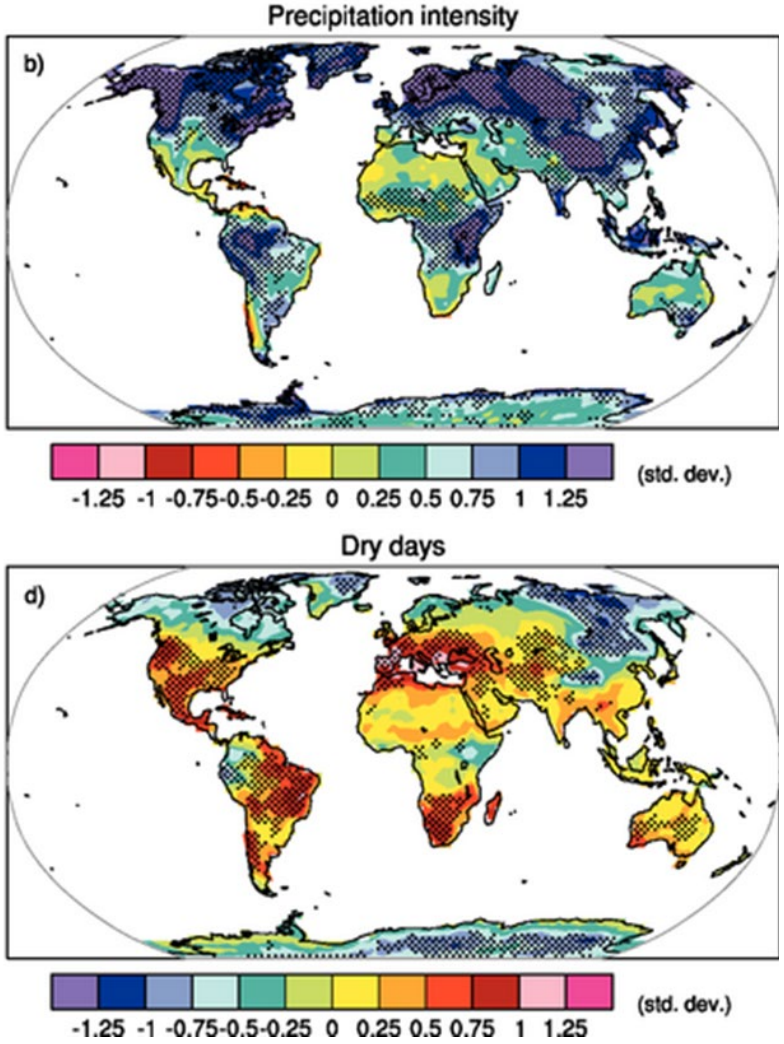
Ecohydrologic process (what the ecosystem does)		**Hydrologic attribute** (direct effect of the ecosystem)	**Hydrologic service** (what the beneficiary receives)
Local climate interactions Water use by plants	→	Quantity (surface and ground water storage, and flow)	**Diverted water supply:** Water for municipal, agricultural, commercial, industrial, thermoelectric power generation uses ***In situ* water supply:** Water for hydropower, recreation, transportation, supply of fish and other freshwater products **Water damage mitigation:** Reduction of flood damage, dryland salinization, saltwater intrusion, sedimentation **Spiritual and aesthetic:** Provision of religious, educational, tourism values **Supporting:** Water and nutrients to support vital estuaries and other habitats, preservation of options
Environmental filtration Soil stabilization Chemical and biological additions/subtractions	→	Quality (pathogens, nutrients, salinity, sediment)	
Soil development Ground surface modification Surface flow path alteration River bank development	→	Location (ground/surface, up/downstream, in/out of channel)	
Control of flow speed Short- and long-term water storage Seasonality of water use	→	Timing (peak flows, base flows, velocity)	

Relationship between ecohydrological processes and HES

Brauman, 2015

Anthropic impacts, climate change and synergies

- **Anthropic impacts** on ecosystems diminish HES provision capacity
- **Damming, water storage and extraction + productive practices** → affect eco-hydrological processes, landscape attributes and HES provision
- **Synergistic effects with climate change:** changes in the quantity and timing of water movement throughout the landscape, alter nutrient and sediment transport dynamics → affect hydrological attributes such as water quality

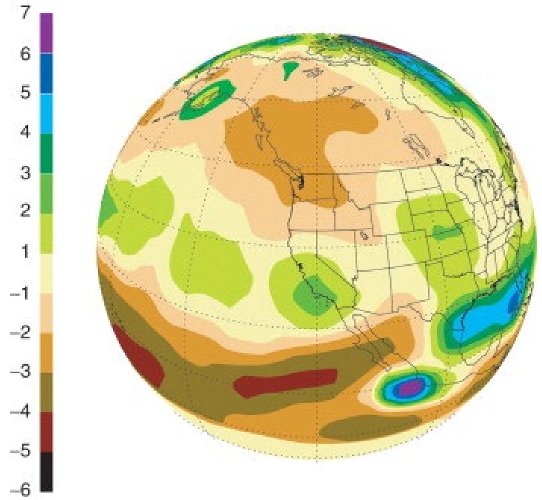


Changes in spatial patterns of precipitation intensity and dry days

Meehl et al., 2007

Hydrological models as a tool for water management

- Models for the biophysical assessment of functions that drive the water balance, linked to the production and distribution of hydrological ecosystem services
- SWAT + Climate scenarios (global climate models) → effects of climate change on freshwater ecosystems
- Scenario analysis: useful for evaluating possible futures → research and decision-making tools in environmental studies for adaptation to CC



Objetives

Assessing potential impacts of climate change on the hydrology of the Laguna del Sauce catchment and the provision of hydrological ecosystem services

We tested the applicability of remote sensing (SSEBOP real evapotranspiration) for the calibration of distributed hydrological models in ungauged basins → Contributing to the development and improvement of modelling in data scarce areas and in need for monitoring + management

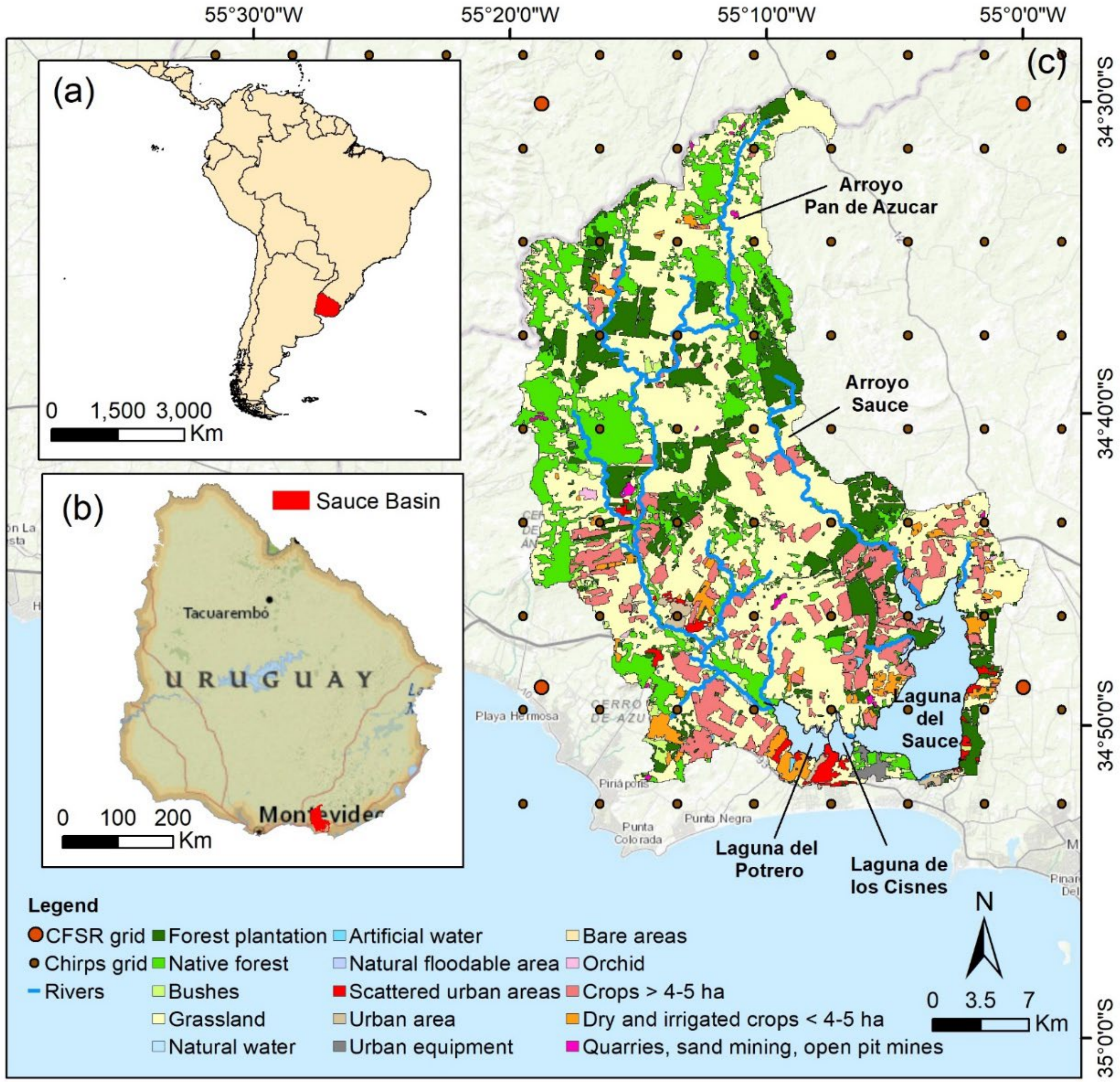
Case study: Laguna del Sauce catchment

- Primary water source for the Maldonado Province → supporting 95% of the permanent population (160,000) + 400,000 summer residents

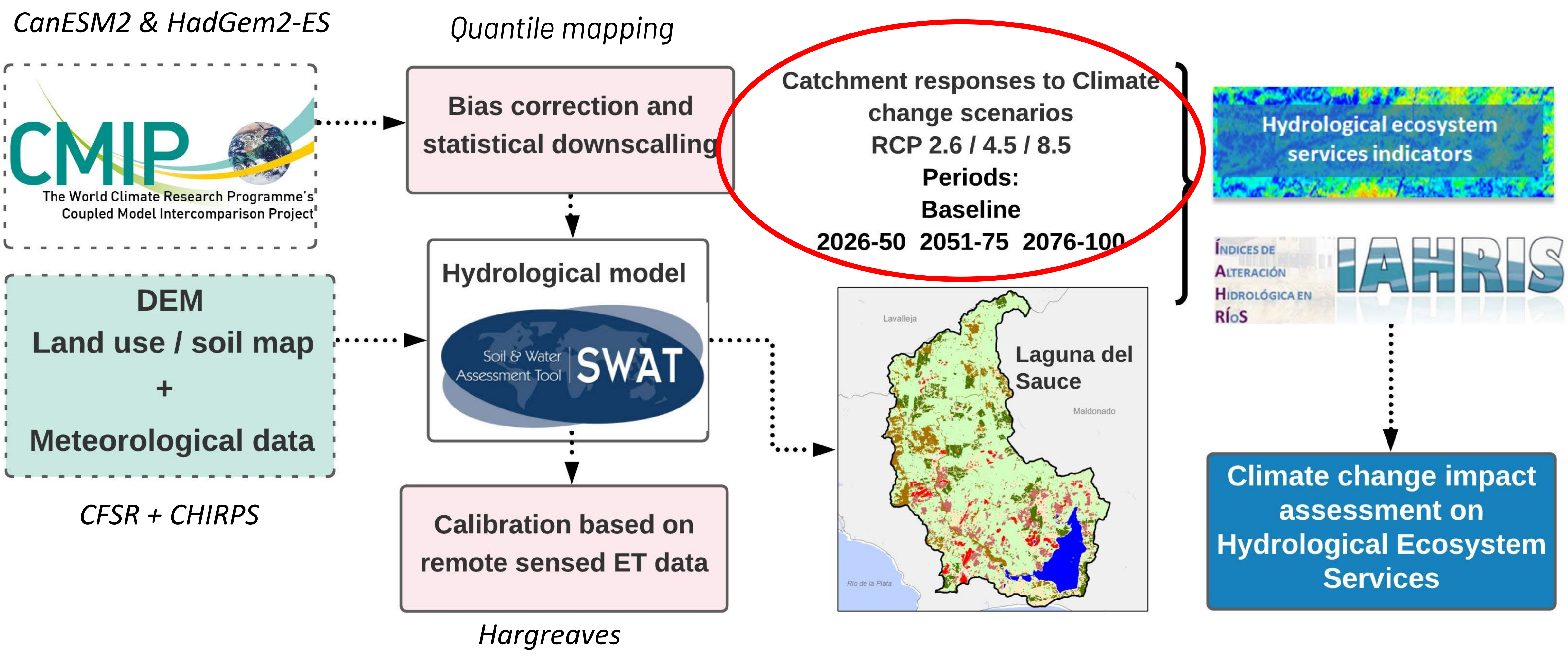
- 2nd largest freshwater source in Uruguay and the only system defined by the national water code (decree 253/79) with classification 1 (water for human consumption).

- Eutrophic system with recurrence in cyanobacterial blooms mainly during the summer season

- Forest priority land (48.4% of the basin categorized) + land uses for agriculture (main use)



Research design



Selection of hydrological ecosystem services indicators

- Projection of local effects of climate change on precipitation, evapotranspiration, temperature and sediment load

- Effects of CC on floods → daily water flow from SWAT outputs and estimation of indicators of hydrological alteration in rivers (IAHRIS) software

Table 2. Indicators based on SWAT output parameters (Adapted from [71,72]).

HES	Description	SWAT Indicator	Outputs
Water supply	Freshwater availability for consumptive use and in situ water supply	Water yield [mm] at the sub-subbbasin level	WYLD
Water flow regulation	Maintaining water cycle features through green and blue water	Green Water (flow and storage): Evapotranspiration [mm]; Soil water content [mm] Blue Water: Water yield [mm]; Deep aquifer recharge [mm]	WYLD DA RCHG ET SW
Soil erosion control	Sediment retention service provision	Sediment yield [t/ha] at thesub-basin level	SYLD
Natural Hazard protection	Flood, storms and climatic extreme events mitigation	Daily streamflow [m^3/s] + IAHRIS	FLOW OUT

Kandziora et al. 2013
Schmalz et al. 2015

Indicators of hydrological alteration in rivers (IHARIS)

- Level of alteration between historical vs. future flow data → 25 parameters from which the IHA are obtained
- These IHAs are related to the usual extreme maximum values (floods) and extreme minimums (droughts)
- We classified the parameters in terms of **magnitude and frequency**, **variability**, **duration**, and **seasonality**

Table 3. Parameters used in this study for flood analysis.

Aspect	Parameter	Acronym	Unit
Magnitude and frequency	Average of yearly maximum daily flow	MMDF	m^3/s
	Effective discharge	ED	m^3/s
	Connectivity flow	CF	m^3/s
	Flushing flood (5% exceedance percentile)	FlF	m^3/s
Variability	Coefficient of variation of yearly maximum daily flow	CV_MMDF	-
	Coefficient of variation of flushing flood series	CV_FF	-
Duration	Consecutive days in a year with a percentile above 5%	CD_Q5	days
Seasonality	The average number of days per month with a percentile above 5%	AD_Q5	days

RESULTS

Calibration and validation

- In the absence of observed flow data we used real ET - Simplified Surface Energy Balance model (SSEBOP; USGS)
- Warm up 4 yr (2001 – 2004) + Calibration (2005 – 2009) + Validation (2010 – 2013)
- The CN2 parameter (curve number for soil moisture conditions) was manually reduced by 10% + ESCO (soil evaporation) adjusted by 0.8 and EPCO (plant absorption) by 0.95
- Performance was based on monthly values of NSE and R2 for calibration (0.74, 0.64) and validation (0.79, 0.84)

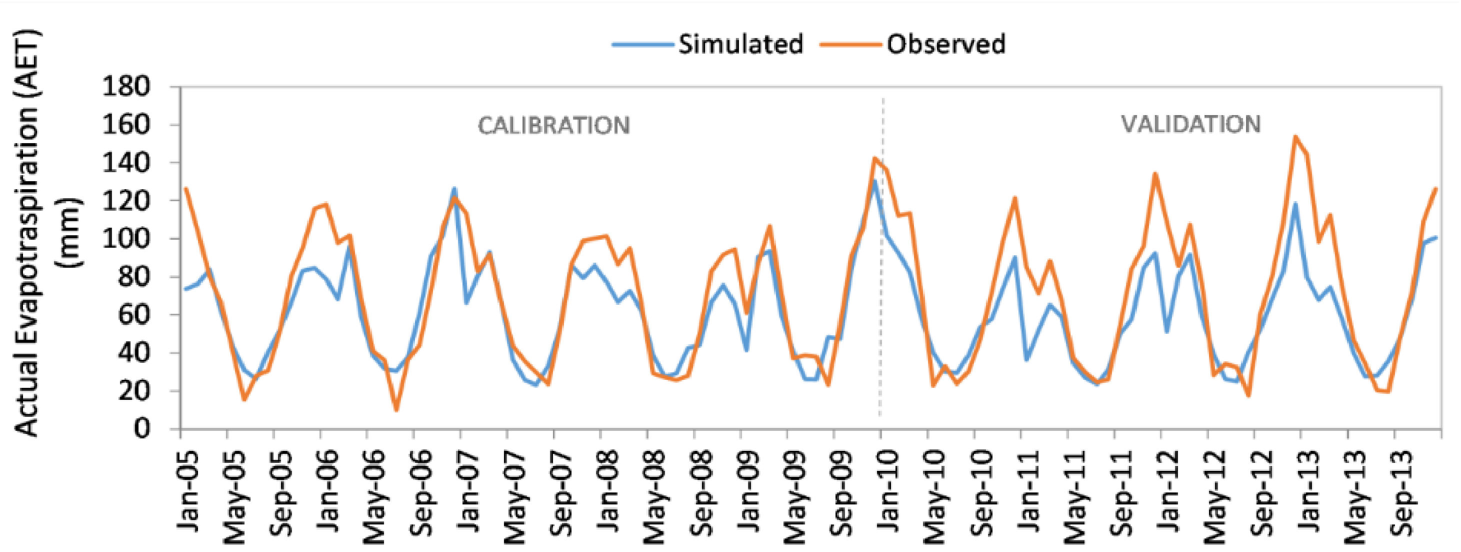
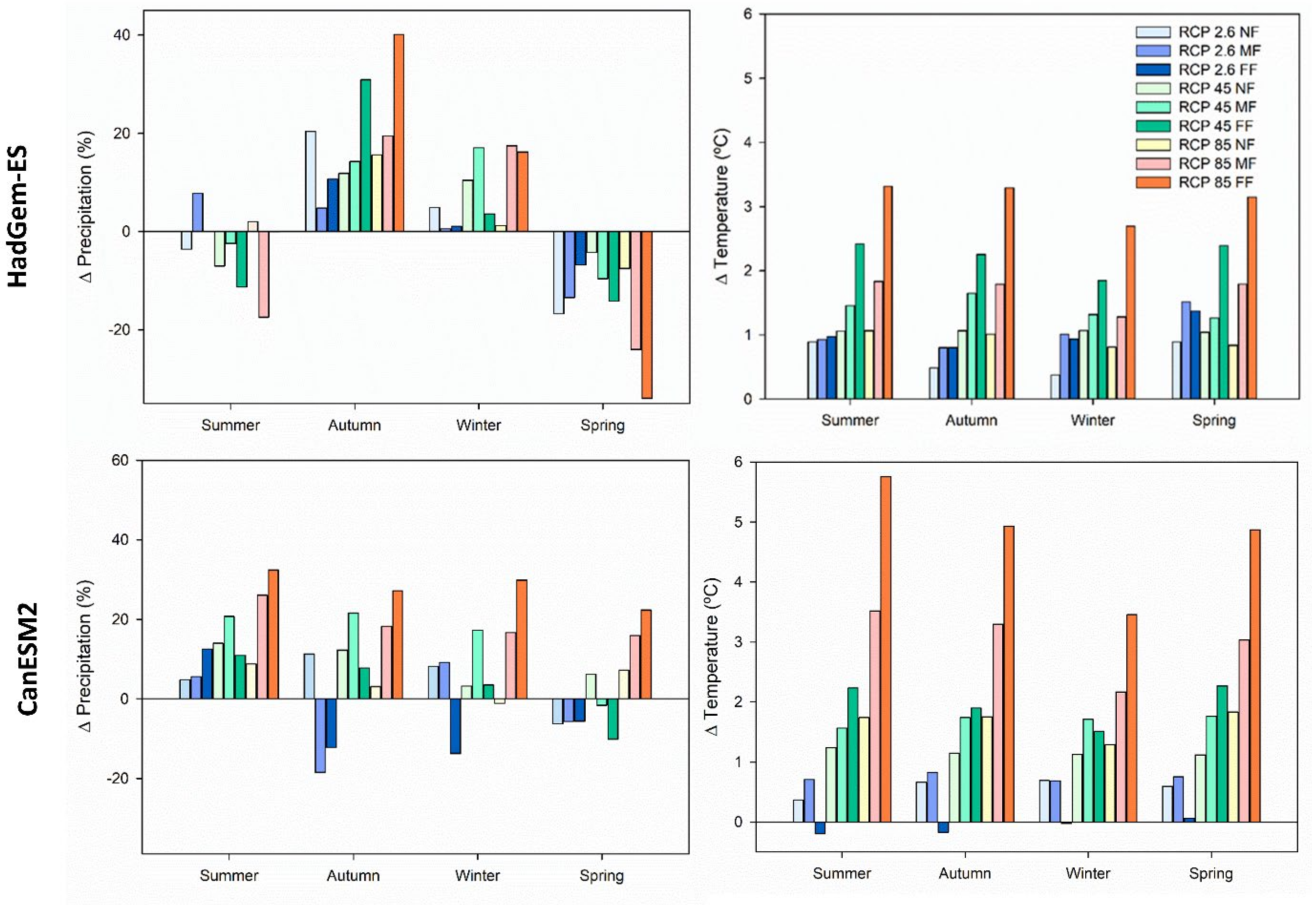


Figure 2. SWAT model calibration and validation for the period 2005–2013. Evapotranspiration data from SSEBOP compared to the obtained data from our simulated model.

CC impacts on precipitation and temperature

- Predictions of T and future alteration of PCP for: NF (2026-2050), the M F (2051-2075) and the FF (2076-2100)
- Accentuated T increase in spring and summer → moderate for RCP 2.6 and high in 4.5 and 8.5 RCP
- Increase in PCP except in spring→ marked decrease
- PCP + sediments + increase T → magnitude events blooms



Water regulation and supply

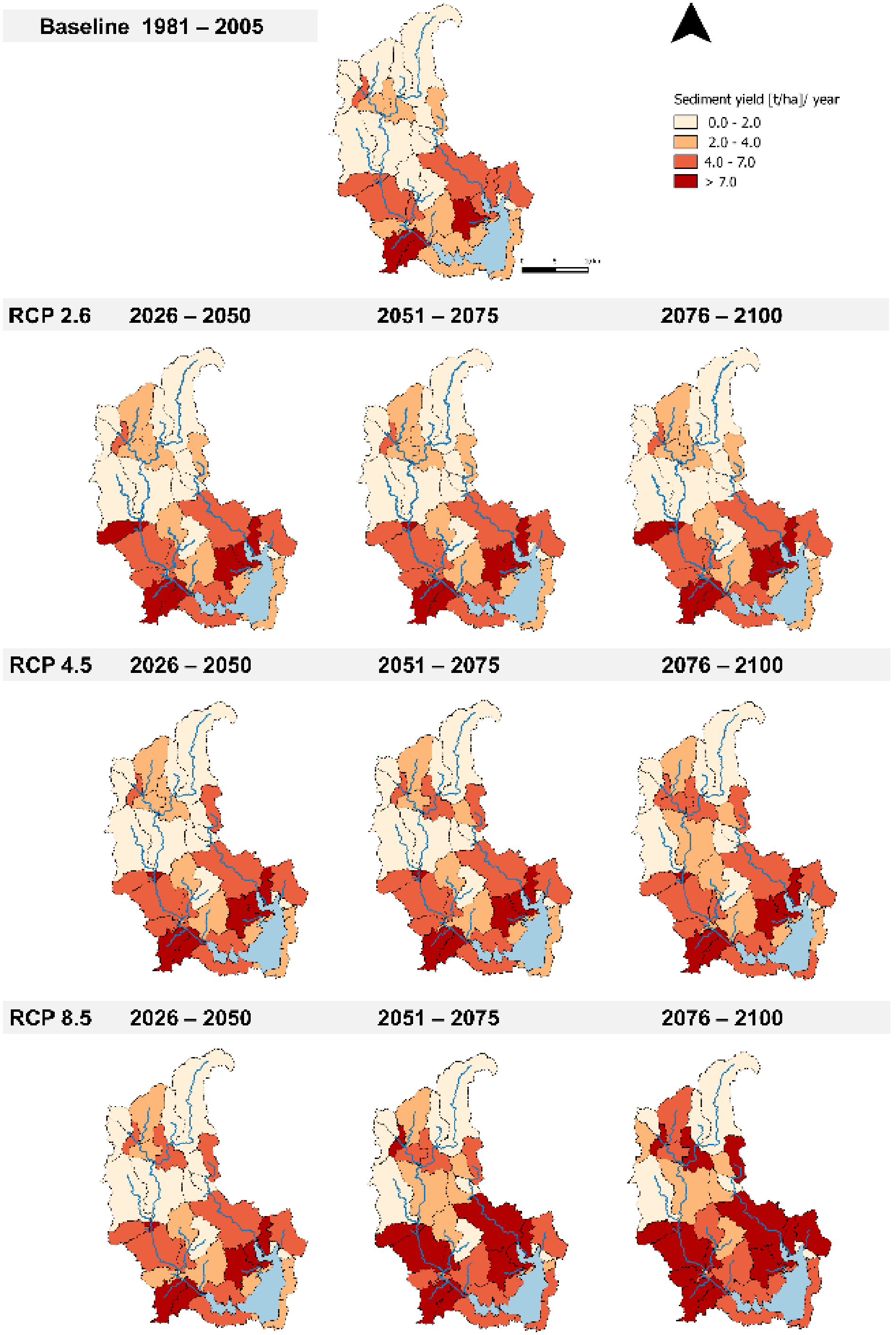
- + Precipitation and evaporation in a warming scenario
- + quantity of water (BW) and + transformation of PCP into ET (GWC) in the basin for the 2026–2100 scenario
- Warming trends can increase current ET, particularly in conjunction with precipitation
- Afforestation → + ET and - aquifer recharge → - water that reaches Laguna del Sauce catchment

Table 5. Water regulation indicators: Water Yield (variation and mean values ex-pressed in percentage), Blue Water (BW), Green Water Flow (GWF), Green Water Storage (GWS) and Green Water Coefficient (GWC) in comparison to the three different projected periods for all RCPs and both models used.

Pathway	Scenario	Period	Water Yield (mm)	Δ Water Yield (%)	BW (mm)	GWF (mm)	GWS (mm)	GWC
Baseline	-	1981–2005	275.75	-	283.5	753.29	86.49	0.72
RCP 2.6	NF	2026–2050	306.53	11.2%	315.13	750.7	88.78	0.70
	MF	2051–2075	261.93	−5.0%	269.1	754.8	99.985	0.73
	FF	2076–2100	270.50	−1.9%	277.89	762.1	89.085	0.73
RCP 4.5	NF	2026–2050	301.35	9.28%	309.62	759.68	94.37	0.70
	MF	2051–2075	316.12	14.64%	324.91	758.05	87.91	0.69
	FF	2076–2100	297.14	7.76%	305.33	753.08	87.95	0.71
RCP 8.5	NF	2026–2050	292.54	6.09%	300.57	749.22	85.01	0.72
	MF	2051–2075	330.78	19.96%	339.79	765.37	95.42	0.68
	FF	2076–2100	342.98	30.92%	352.55	785.75	85.97	0.69

Soil erosion control

- Greater contribution of sediments and nutrients to the lake → forest plantations + agricultural and urban uses
- Sub-basins of the main tributaries of Laguna del Sauce → increased sediment yield, which can negatively affect water quality
- Areas with greater future variation have an estimate of erosion ≥ 7 t ha−1, which is > the tolerable loss defined for Uruguay → "hot spots" to the sediment balance.
- Areas with erosion ≥7 t ha−1 will increase over time → + sediments towards water bodies (eutrophication and turbidity) → Intensification of extreme events
- Preserving native vegetation and grasslands is crucial for erosion control, but trade-offs related to livestock grazing should be considered



IHARIS – regulation of extreme events

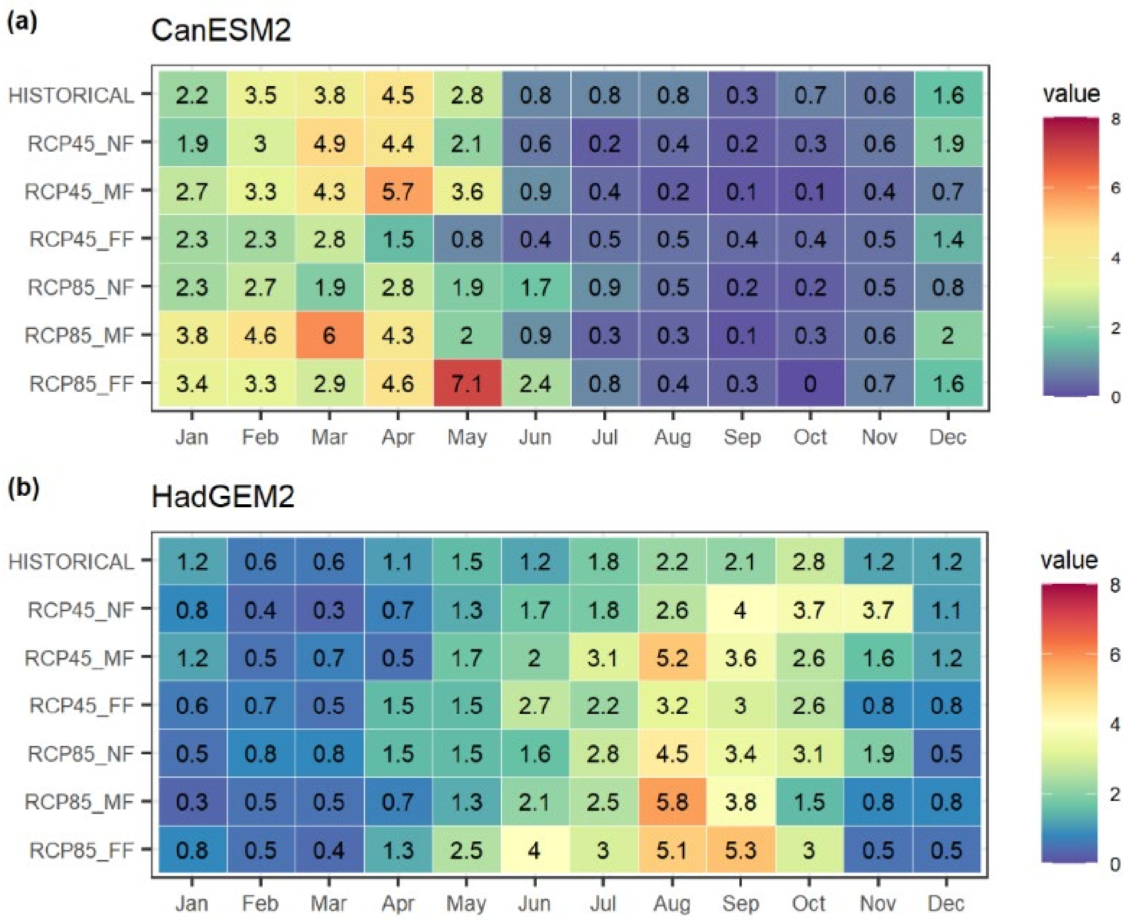
- Floods seasonality: both climate models predict changes in magnitude, frequency and duration (especially RCP 8.5) → yet, not a clear trend!

- Increased duration of floods, especially in FF: more consecutive days in a year with a percentile above 5% → loss of stream rapids

- Disrupt natural cycles of species →potential impacts on their survival and allowing the intrusion of non-native species with fewer environmental restrictions

- Mortality of the most sensitive plant species due to anoxic stress

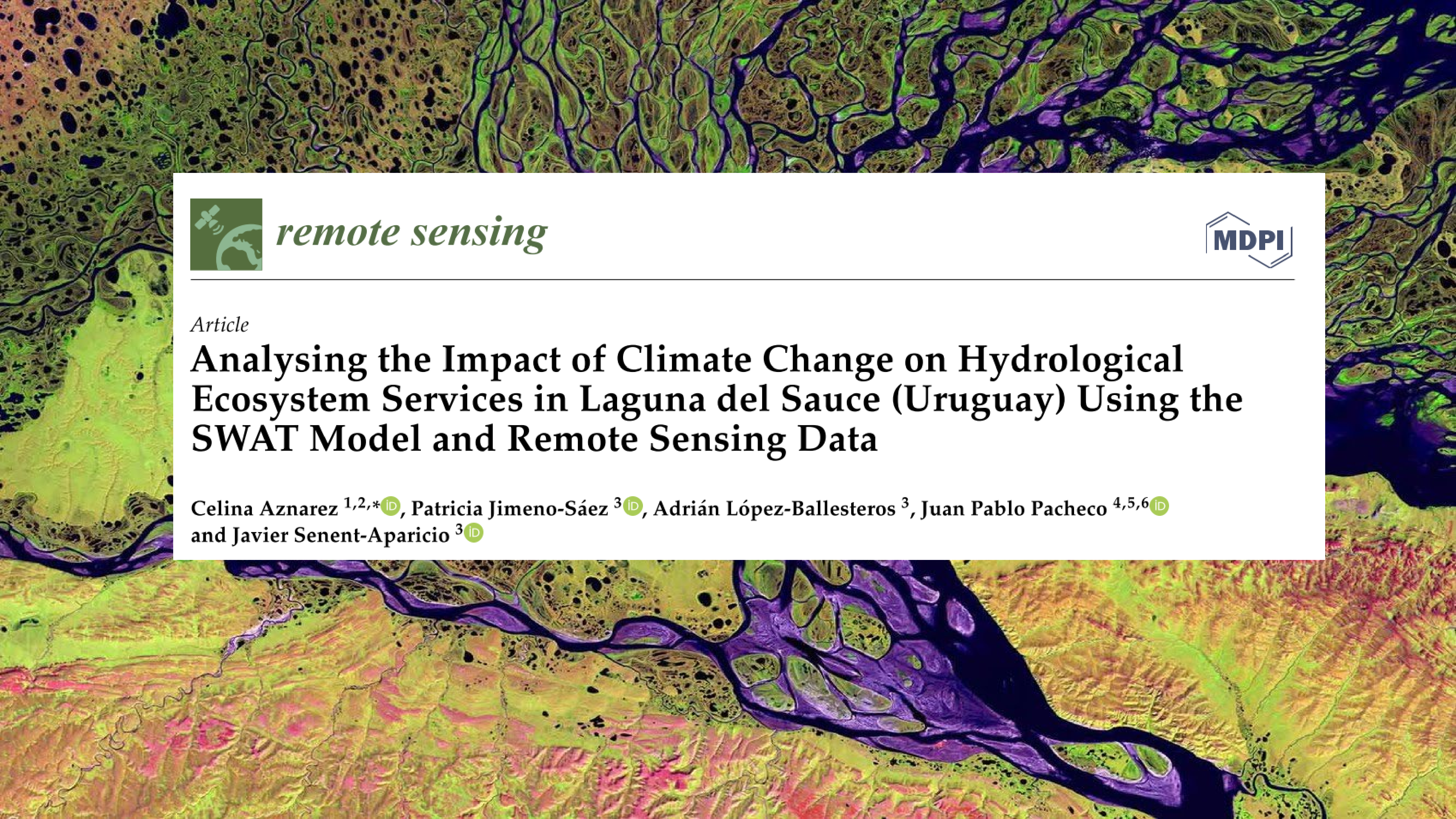
- Synergies with + erosion and transport of sediments and nutrients towards the Laguna del Sauce



Impact of climate change on flood seasonality. Y-axis represents the RCP pathway for the different time scenarios (NF, MF, FF) for each month. Colour gradient represents the average number of days in the month when flow is equalled or surpassed the flow associated with the 5% exceedance percentile

Conclusions

- SWAT model proved to be effective to forecast the impacts of climate change on multiple HES indicators in Laguna del Sauce catchment
- Efficient **ET satellite-based calibration** (SSEBOP) to our case study → useful technique for scaling satellite-derived data. This was also the case using CHIRPS (PCP) data
- In all scenarios, the catchment may experience a change in **seasonality and an increase in extreme precipitation events**, particularly in **frequency** and **magnitude**. These changes are a threat to the stability of freshwater and HES supply
- Identifying where HES are likely to be affected is key to prioritizing areas and focusing **monitoring and management** efforts
- **Strengthening on-site monitoring capabilities** would allow for more accurate model identification and reduced model uncertainty → increased complexity



remote sensing

MDPI

Article

Analysing the Impact of Climate Change on Hydrological Ecosystem Services in Laguna del Sauce (Uruguay) Using the SWAT Model and Remote Sensing Data

Celina Aznarez [1,2,*], Patricia Jimeno-Sáez [3], Adrián López-Ballesteros [3], Juan Pablo Pacheco [4,5,6] and Javier Senent-Aparicio [3]

Thank you!

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Contact:
Celina.Aznarez@bc3research.org
@celiaznarez