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Better understand mountain hydrology to enhance climate change impact assessment

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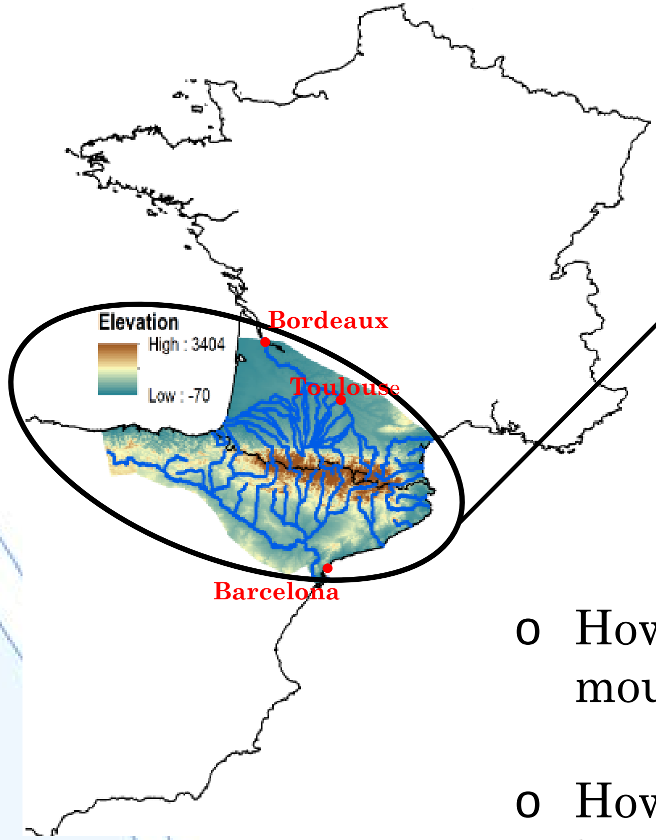
Mountains are the water tower of the world

"[..] the most important water towers are also among the most vulnerable, and climatic and socio-economic changes will affect them profoundly. This could negatively impact 1.9 billion people living in (0.3 billion) or directly downstream of (1.6 billion) mountainous areas. Immediate action is required to safeguard the future of the world's most important and vulnerable water tower"

After : "Importance and vulnerability of the world's water towers" 2020 , Immerzeel et al. ***Nature 577***



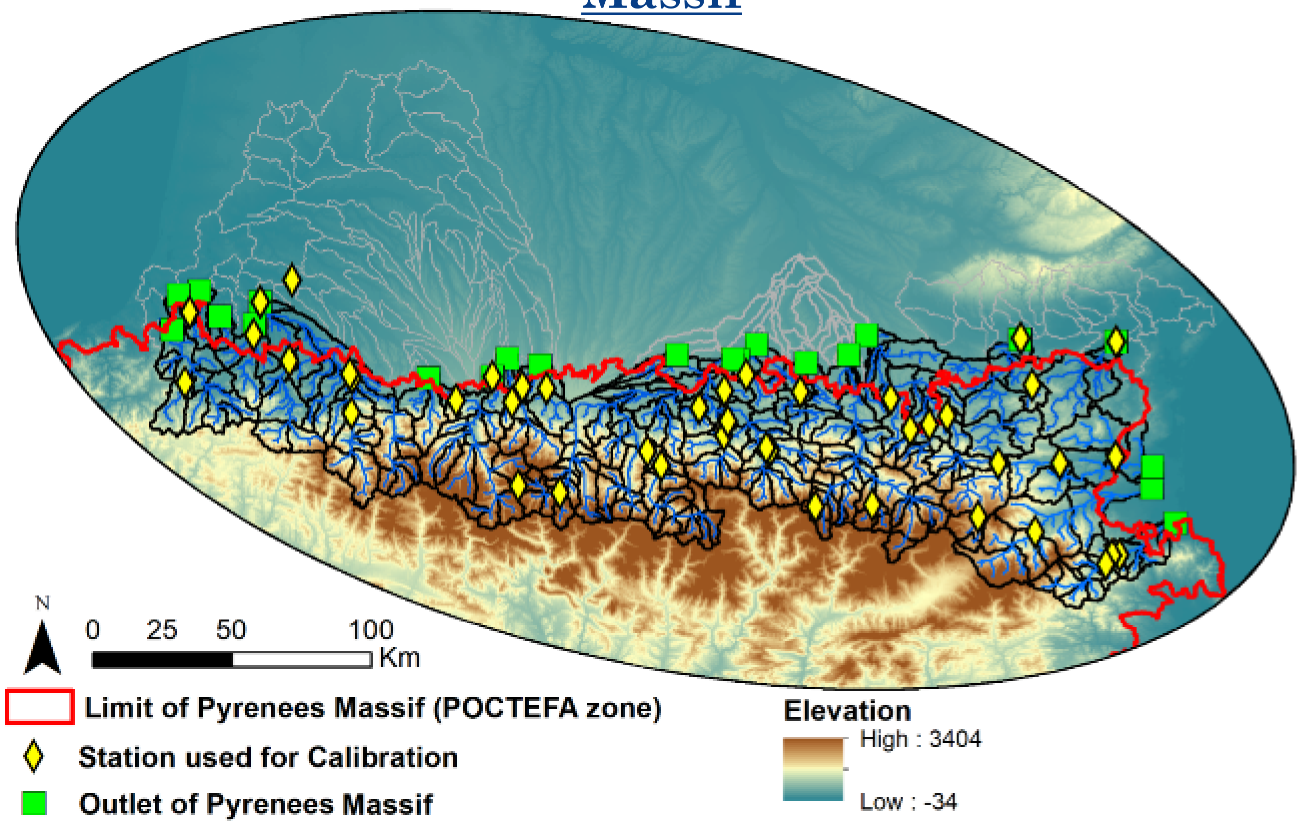
The Pyrenean Massif is a key regulator into the water supply mechanisms for a large region in France and Spain which include some major cities such as Toulouse, Bordeaux or Barcelona

PIRAGUA Project:
characterization of the water resources of the Pyrenees

- How climate change will impact the water yield delivered by the mountainous area to the plain downstream?

- How climate change will impact the repartition - spatial and temporal - between the different fluxes and stocks within the water cycle?

The Soil and Water Assessment tool over the Pyrenean Massif



Data Type	Source	Resolution	
		Space	Time
DEM	Shuttle Radar Topography Mission (Jarvis et al. 2008)	~90 m	2009
	European Digital Elevation Model version 1.1 (https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=mapview)	~25 m	2011
Land Uses	Corine Land Cover 2012 (France-Spain) (Büttner et al. 2014)	100 m	2012
	Mapa de Cobertes del Sòl d'Andorra (www.iea.ad/mapa-de-cobertes-del-sol-d-andorra-2012)	250 m	2012
Soils	Harmonized world soil database (Nachtergaele et al.2008; Wiederet al. 2014)	~1 km	2012
Weather	SAFRAN/PIR1 (Quintana-Seguí et al. 2017, 2016)	~2.5 km	Diario (1979-2014)
Discharge	Banque Hydro (www.hydro.eaufrance.fr/)	Vectorial	diario

Calibration and validation:
5 SWAT project for each watershed
43 stations into the mountainous area.

Calibration at monthly time step conducted with SWAT-Cup with KGE as objective function over the period 1986-2005 (+5yrs of warmup)

Validation over the period 2006-2013

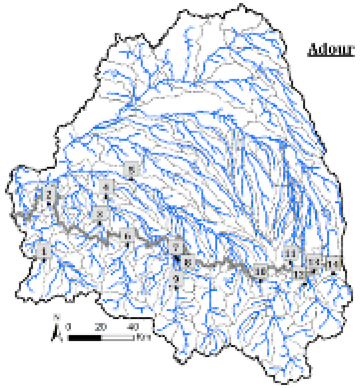
Analyzed output:
1) Discharge at 19 outlets of the Pyrenean Massif to get an integrative view of water resources "produced".
2) Distribution of the water with the mountainous area between SnowPack/Snow Melt/ Evapotranspiration/WaterYield

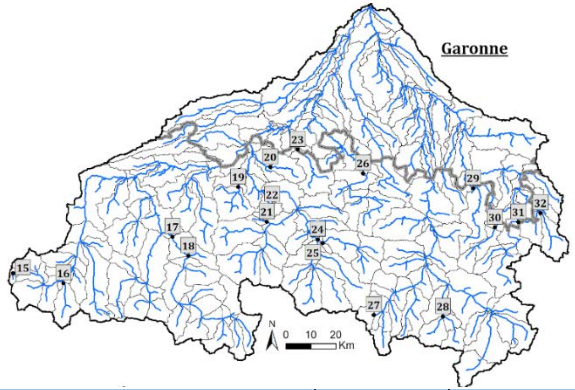
The Soil and Water Assessment tool over the Pyrenean Massif: Performances

Calibration: all stations have a KGE (scaled inspired by Gupta et al. 2009) good (blue) or very good (green). Lower score for 5 stations with only acceptable performances (Orange). NSE (scale from Moriasi et al. 2007) show also very good to acceptable results, but 3 stations have unsatisfactory performance (Red) unless their KGE scores are ranked as good.

Validation: The overall performance of the model is little degraded over the calibration period. Only one station return a KGE and NSE unsatisfactory. Two of the station with unsatisfactory. NSE in calibration shows good performance in validation and 2 stations pass from satisfactory to unsatisfactory result. This show the relative robustness of the model over the massif.

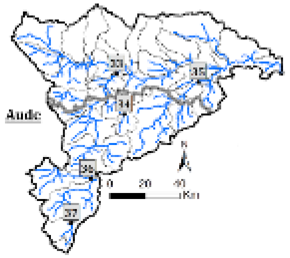
Watershed	Station	Id. Station	Calibration 1986-2005		Validation 2006-2013	
			KGE	NSE	KGE	NSE
Adour	1	Q9164610	0.81	0.82	0.90	0.8
	2	Q8345910	0.57	0.50	0.72	0.71
	3	Q8032510	0.78	0.86	0.77	0.82
	4	Q7412910	0.76	0.78	0.80	0.77
	5	Q5501010	0.71	0.59	0.85	0.78
	6	Q7322510	0.64	0.63	0.84	0.73
	7	Q7002910	0.81	0.68	0.80	0.68
	8	Q6142910	0.69	0.43	0.64	0.49
	9	Q6332510	0.72	0.58	0.65	0.52
	10	Q4801010	0.70	0.40	0.71	0.65
	11	Q0214010	0.60	0.57	0.74	0.73
	12	Q0115710	0.80	0.59	0.50	0.27
	13	Q0554010	0.53	0.58	0.74	0.76
	14	Q0522520	0.89	0.84	0.88	0.81
	Average		**0.72**	**0.63**	**0.75**	**0.68**

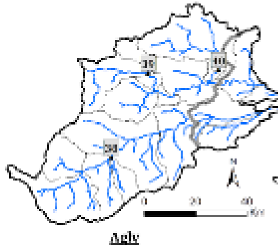




Watershed	Station	Id. Station	Calibration 1986-2005		Validation 2006-2013	
			KGE	NSE	KGE	NSE
Garonne	15	O0105110	0.73	0.78	0.47	0.62
	16	O0126210	0.73	0.58	0.71	0.64
	17	O0010040	0.75	0.57	0.74	0.65
	18	O0015310	0.60	0.56	0.66	0.62
	19	O0554010	0.80	0.74	0.85	0.75
	20	O0584310	0.89	0.86	*No Data*	
	21	O0485110	0.47	0.51	0.19	0.24
	22	O1432930	0.47	0.52	0.48	0.56
	23	O0624010	0.91	0.89	0.93	0.87
	24	O0362510	0.67	0.53	0.66	0.60
	25	O0384010	0.67	0.65	0.77	0.70
	26	O0744030	0.77	0.76	0.78	0.79
	27	O1115010	0.89	0.86	0.81	0.80
	28	O1076010	0.84	0.82	0.83	0.83
	29	O1584610	0.84	0.84	0.82	0.85
	30	O1484310	0.63	0.61	0.58	0.56
	31	O1442910	0.88	0.76	0.81	0.69
	32	O1464010	0.77	0.85	0.43	0.61
	Average		**0.74**	**0.71**	**0.68**	**0.67**

Watershed	Station	Id. Station	Calibration 1986-2005		Validation 2006-2013	
			KGE	NSE	KGE	NSE
Aude	33	Y1232010	0.85	0.80	0.88	0.81
	34	Y1225010	0.64	0.63	0.47	0.46
	35	Y1564010	0.91	0.82	0.82	0.82
	36	Y1105010	0.82	0.66	0.52	0.52
	37	Y1012010	0.81	0.76	0.68	0.71
	Average		**0.81**	**0.73**	**0.67**	**0.66**
Agly	38	Y0436420	0.78	0.60	*No data*	
	39	Y0624020	0.65	0.41	0.80	0.72
	40	Y0655010	0.56	0.58	0.81	0.66
	Average		**0.66**	**0.53**	**0.81**	**0.69**
Tech	41	Y0254050	0.83	0.80	*No data*	
	42	Y0255020	0.75	0.69	0.38	0.60
	43	Y0245210	0.79	0.70	0.56	0.73
	Average		**0.79**	**0.73**	**0.47**	**0.67**



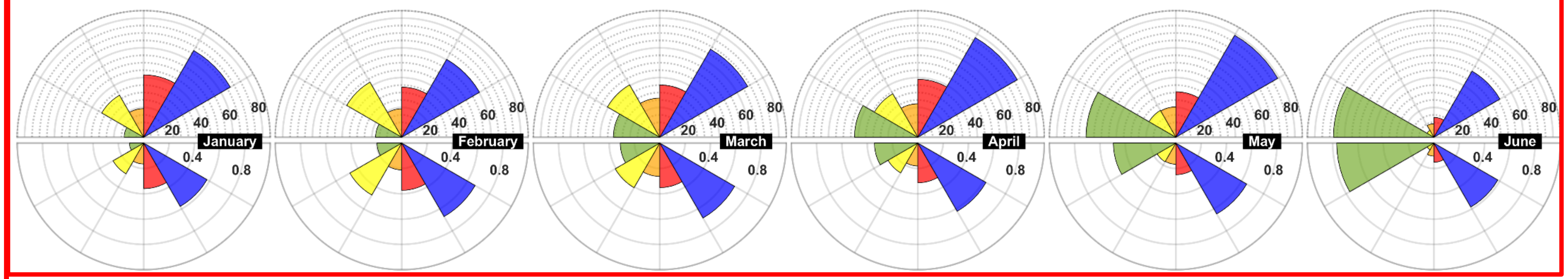


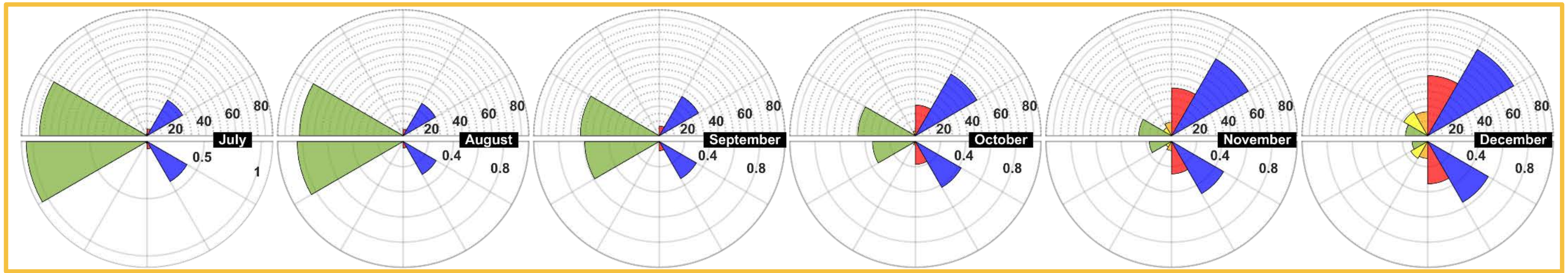
The Soil and Water Assessment tool over the Pyrenean Massif: Preliminary results

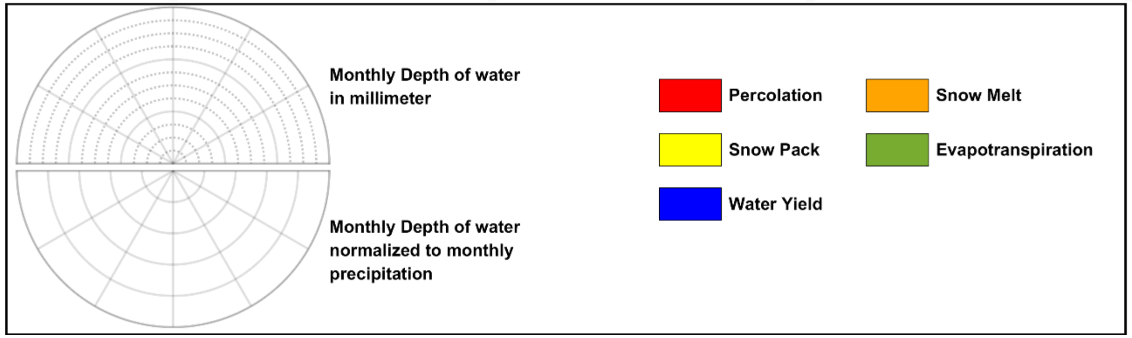
Monthly water distribution over the entire mountainous area for the period 1980-2010

During January-March, Snow pack represent 30 to 50% of the monthly precipitation and snow melt favor the infiltration-recharge-processes

The role of snowpack is to sustain the recharge and the water yield during the spring / first months of summer



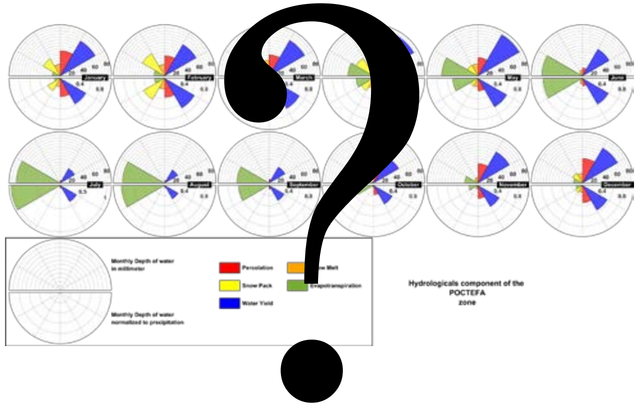




When during July-September, the role of « water tower » of the mountainous area drastically decrease and provide substantially less water to the low land

The Soil and Water Assessment tool over the Pyrenean Massif: The next step

Monthly water distribution over the entire mountains area in the future?



Next step of the Piragua project: Explore the change within the distribution of hydrological component over the next century

Use of projections specially developed for the Pyrenean region through the CLYM'PY project (https://www.opcc-ctp.org/fr/climpy)

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