SudMed Project

Modelling runoff in the Rheraya Catchment (High Atlas, Morocco) using the simple daily model GR4J. Trends over the last decades.

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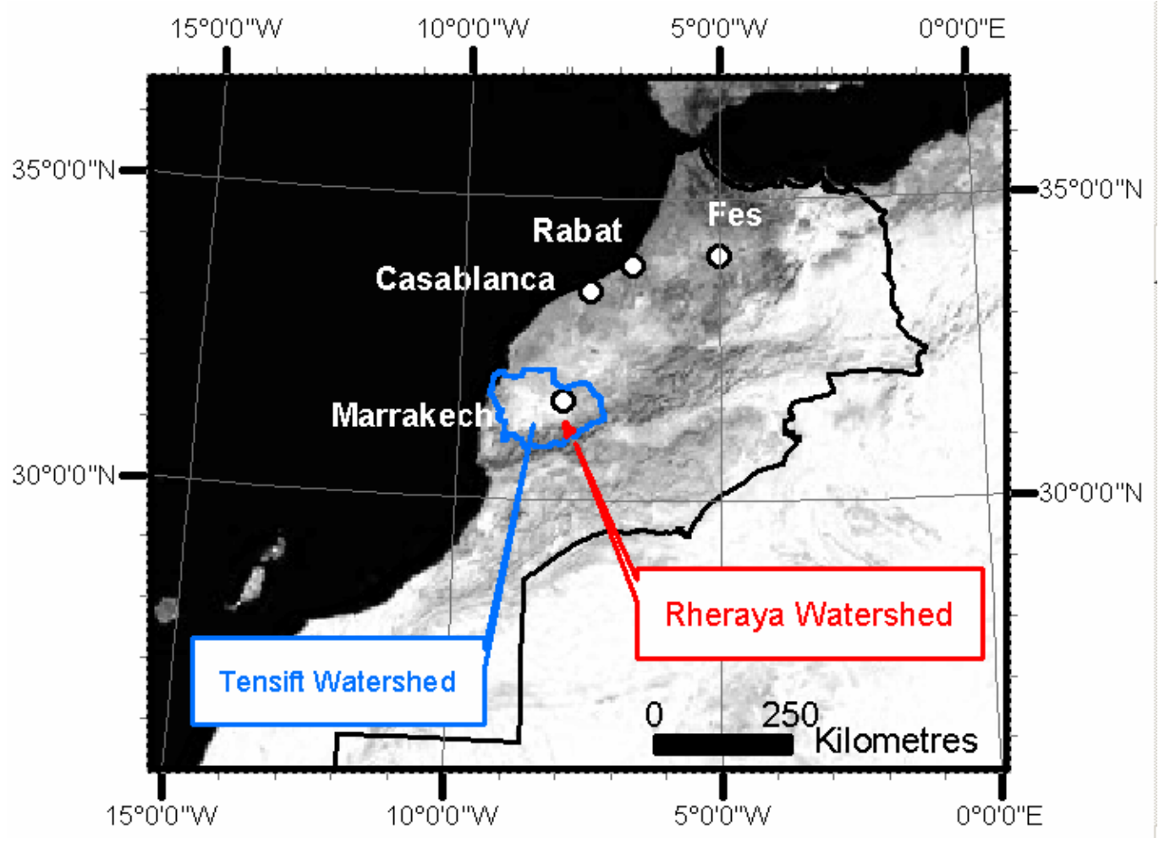
Scientific context

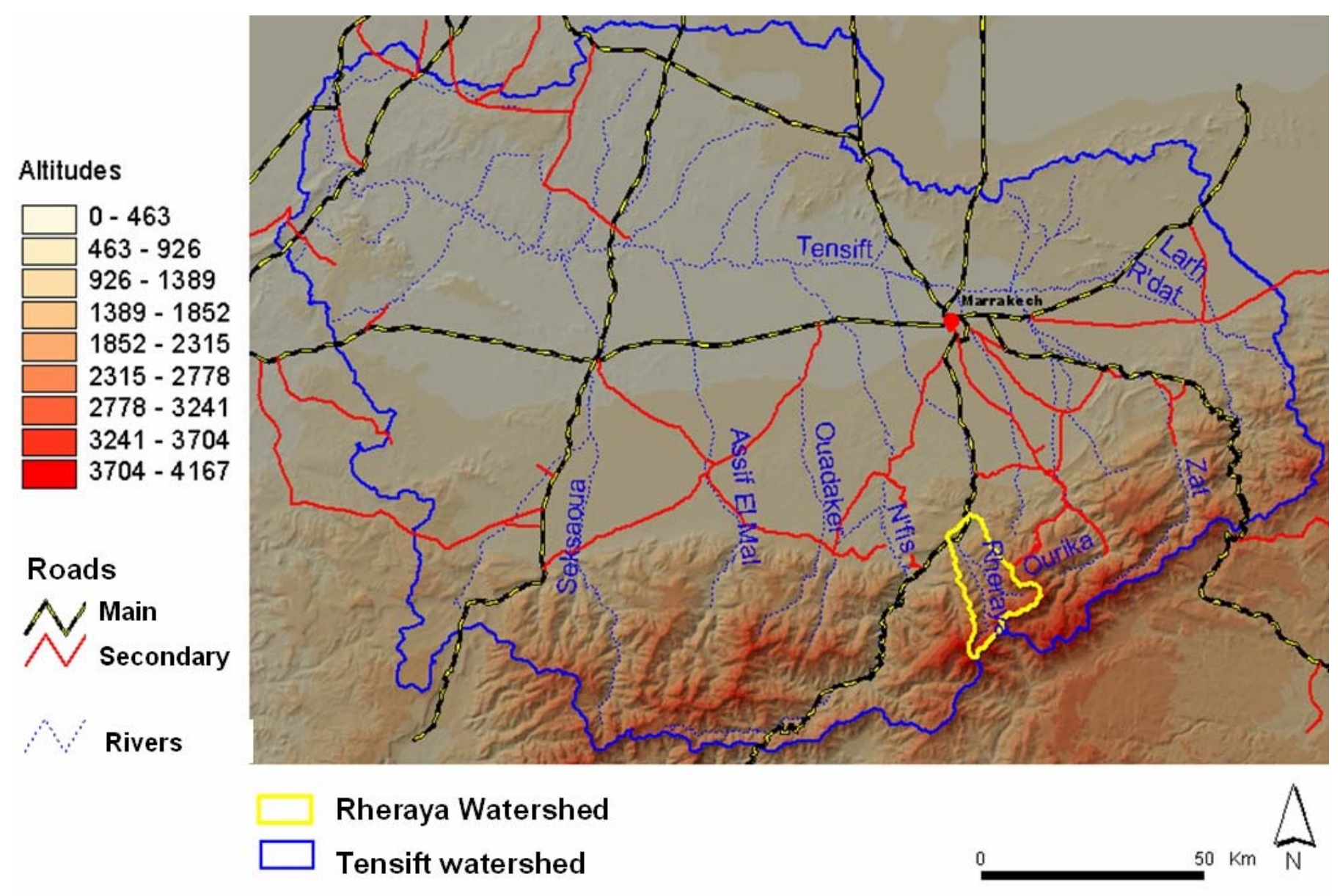
The Tensift watershed (20500 km2), located around Marrakech (Morocco) is experiencing water resource shortage resulting from the strong increase of water consumption due to both urban and agricultural development. The High Atlas mountains are the major source of water of the Tensift.

The general objective of the SudMed project is to understand the hydrologic processes of the mountain basins and their relation with the Haouz aquifer in the plain
The specific objective of this study is to model the hydrologic functioning of the Rheraya catchment and to understand the evolutions observed since last decades

The conceptual models **GR4J** (Perrin, 2003) is used, because it is well suited when data is lacking to run complex models.

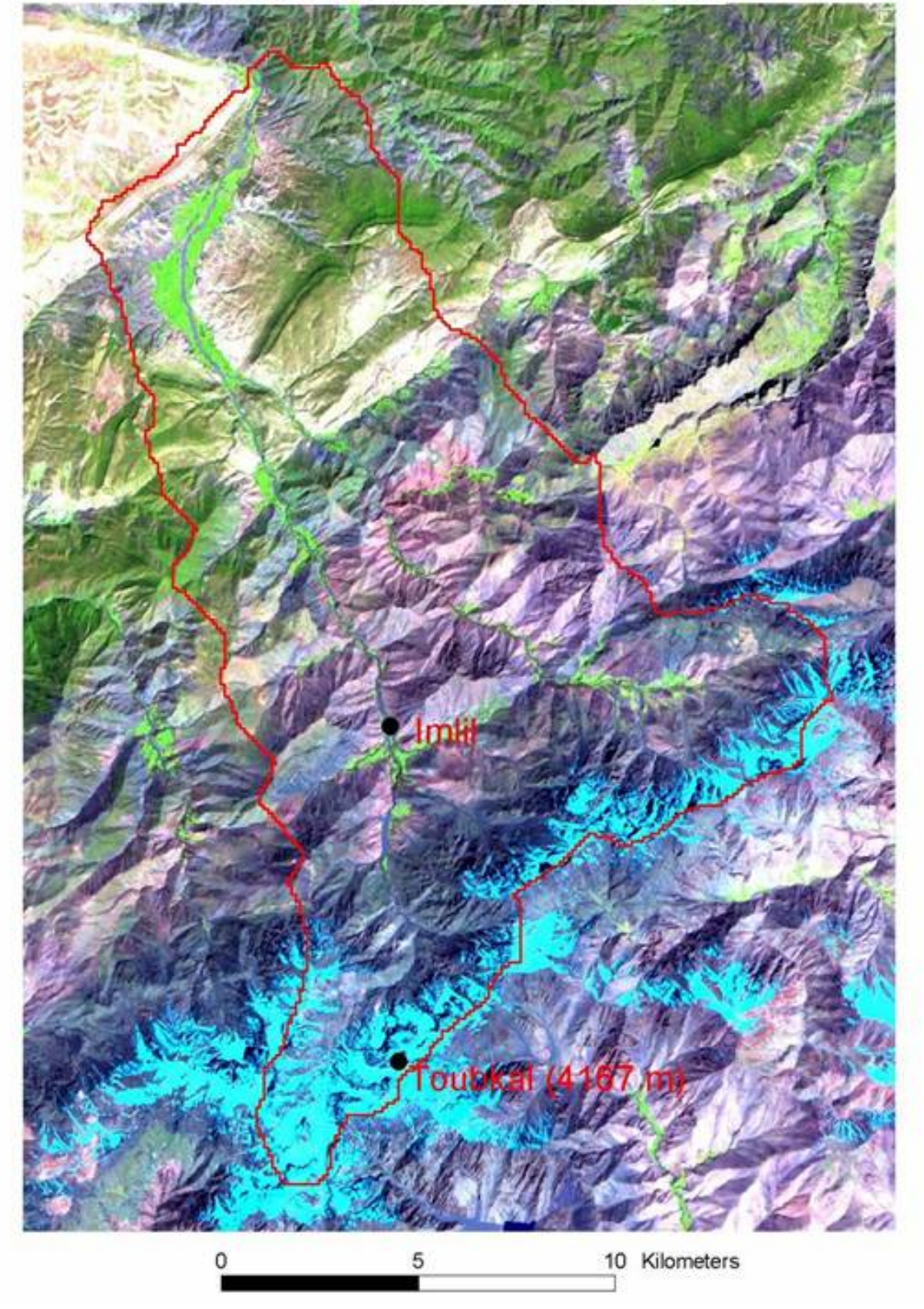
The study area





The hillslopes are covered by degraded rangelands with little vegetation and a stone cover usually over 50%, whereas a thin strip of irrigated crops are found in the valley on either side of the river.

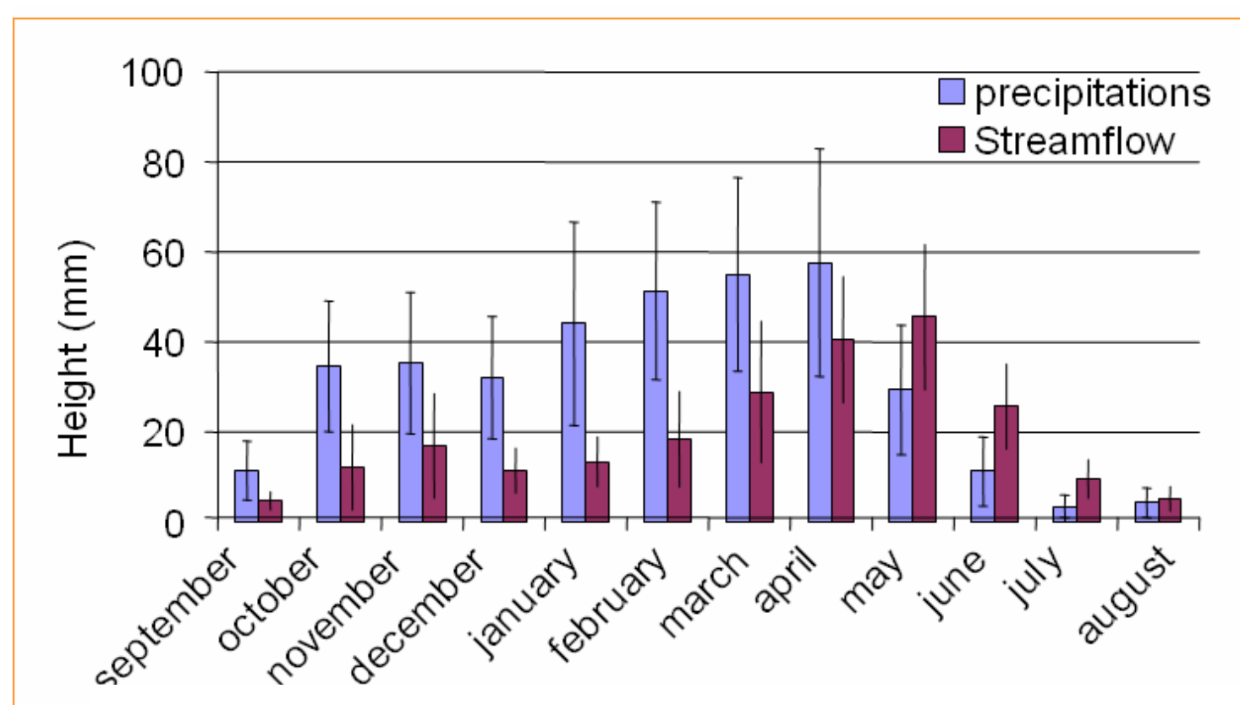
Rheraya Watershed
Landsat color composition 7,4,3



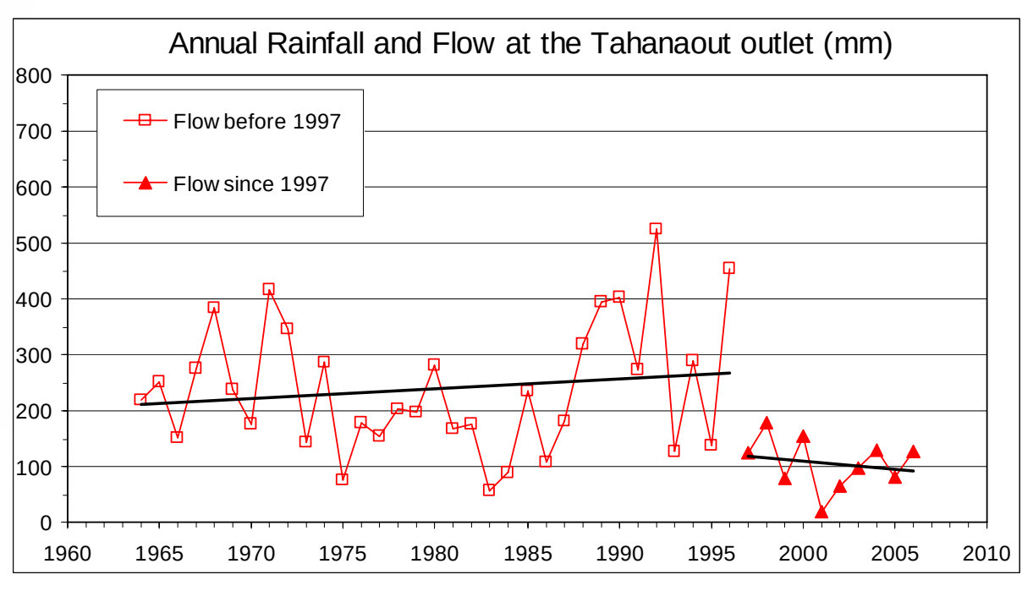
The Rheraya (224 km2) is one of the main catchments of the Tensift High Atlas, with altitudes ranging from 1084 to 4167 m (fig.1). The precipitation are very variable in time, with an average value of 500mm estimated in this study, partly falling as snow at high altitudes. The reference evapotranspiration is about 1073 mm at the altitude of 1900 m. The average streamflow at Tahanaout over the period study (1989-2006) is 1.44 m3/s (202 mm).

Hydroclimatic data recorded and changes observed

Streamflow



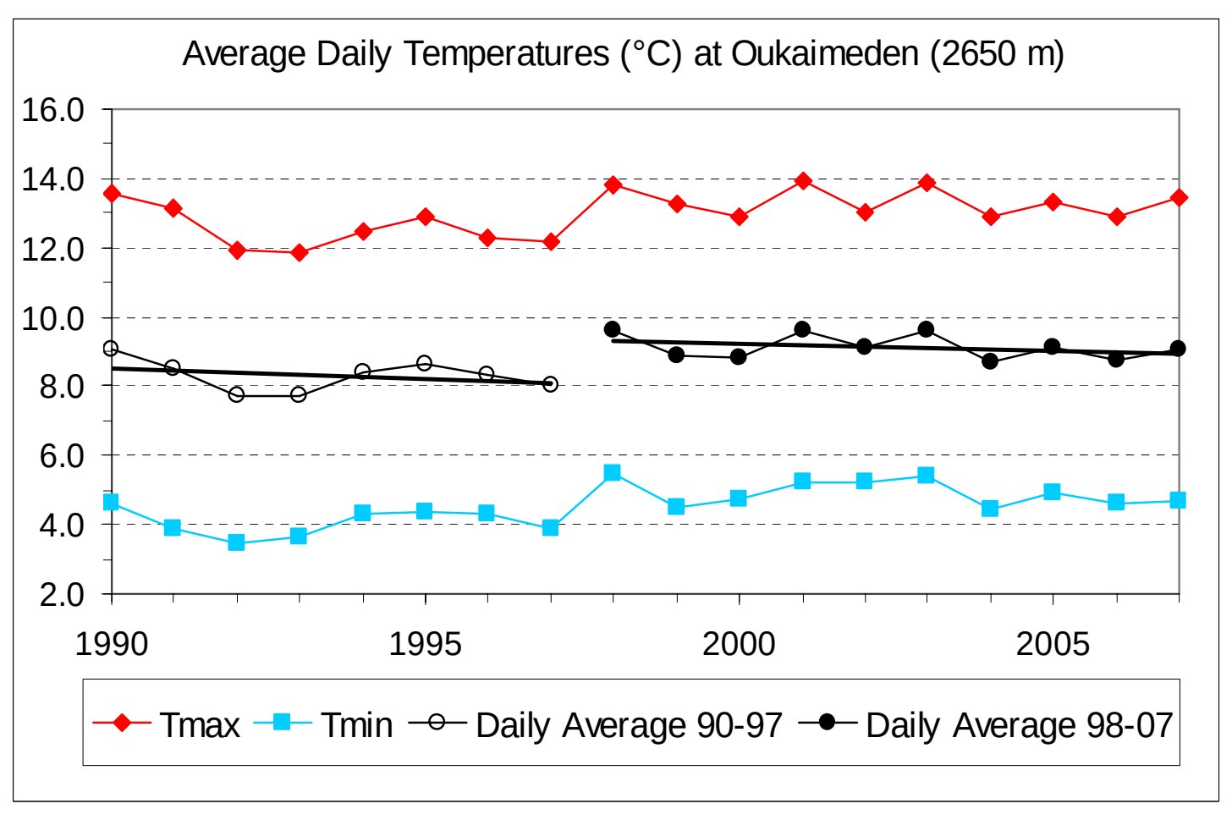
Recordings done at Tahanaout show the very high variabilty of Rainfall and Stream flow.



Tahanaout	1925-1970	1970-1997	1997-2006
P (mm)	440	380	336
Q (mm)	360	223	105
Q/P ratio	0.82	0.59	0.31

The streamflow at Tahanaout dramatically dropped since 1925

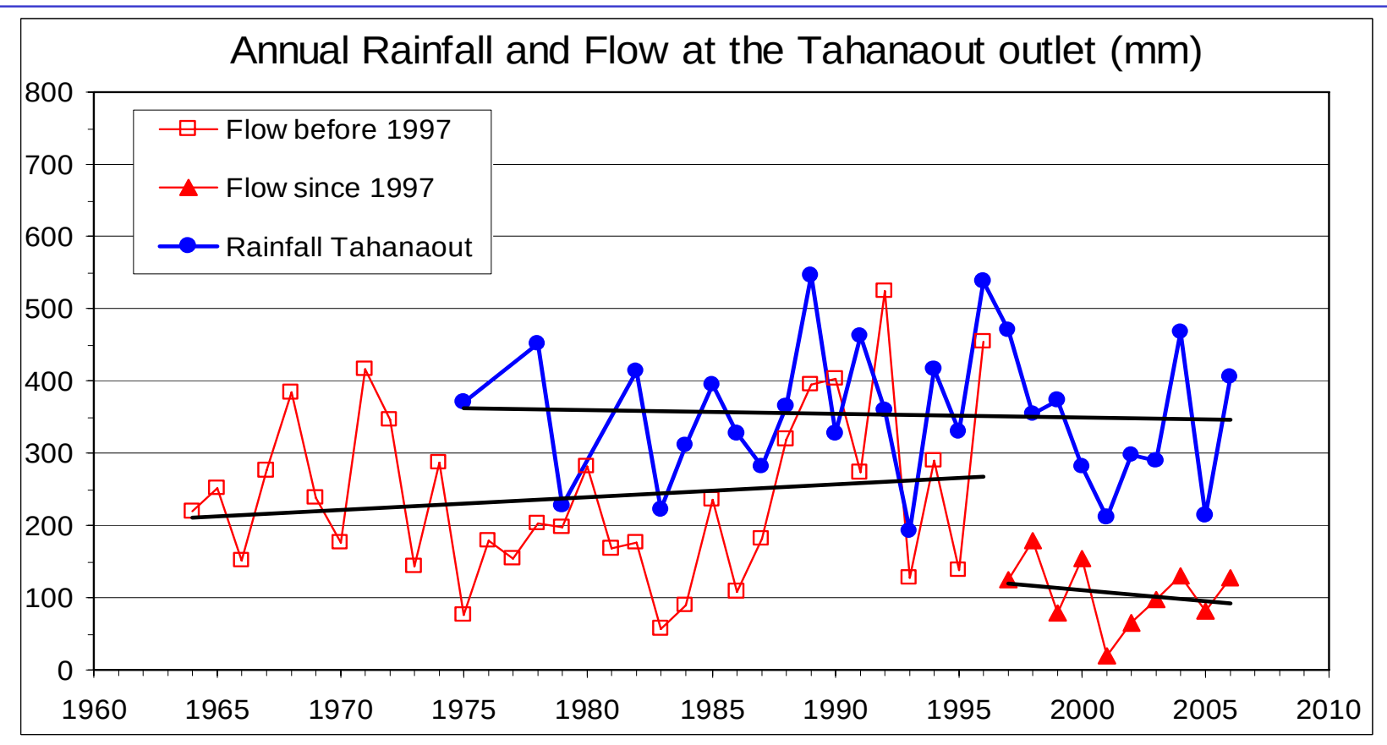
Temperatures



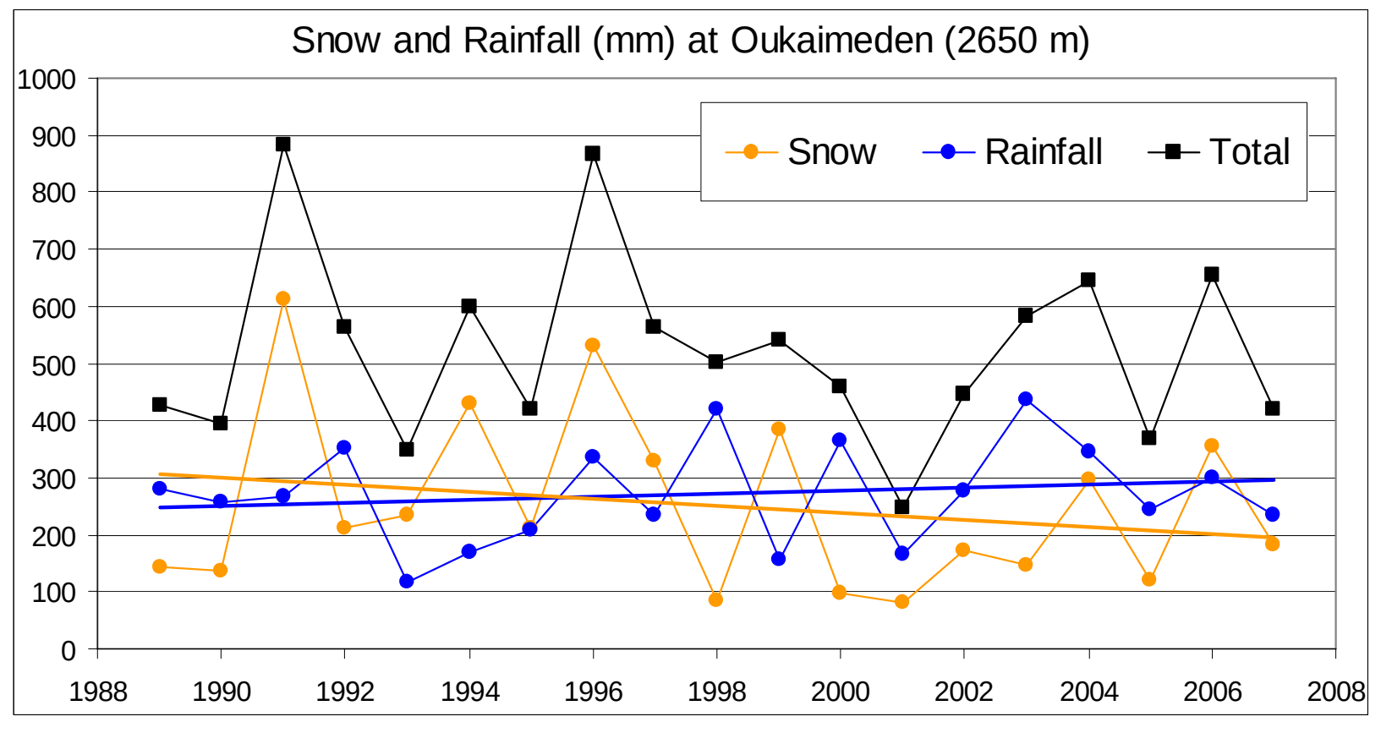
	Average of daily values		
	T min	T daily average	T max
1989-1996	4.1	8.3	12.5
1996-2007	4.9	9.1	13.3

The temperature at Oukaimeden exhibit a slight but significant increase since 1997.

Precipitations



Unlike the Streamflow, the rainfall recorded at Tahanaout and at Oukaimeden show no clear decrease since 20 years.



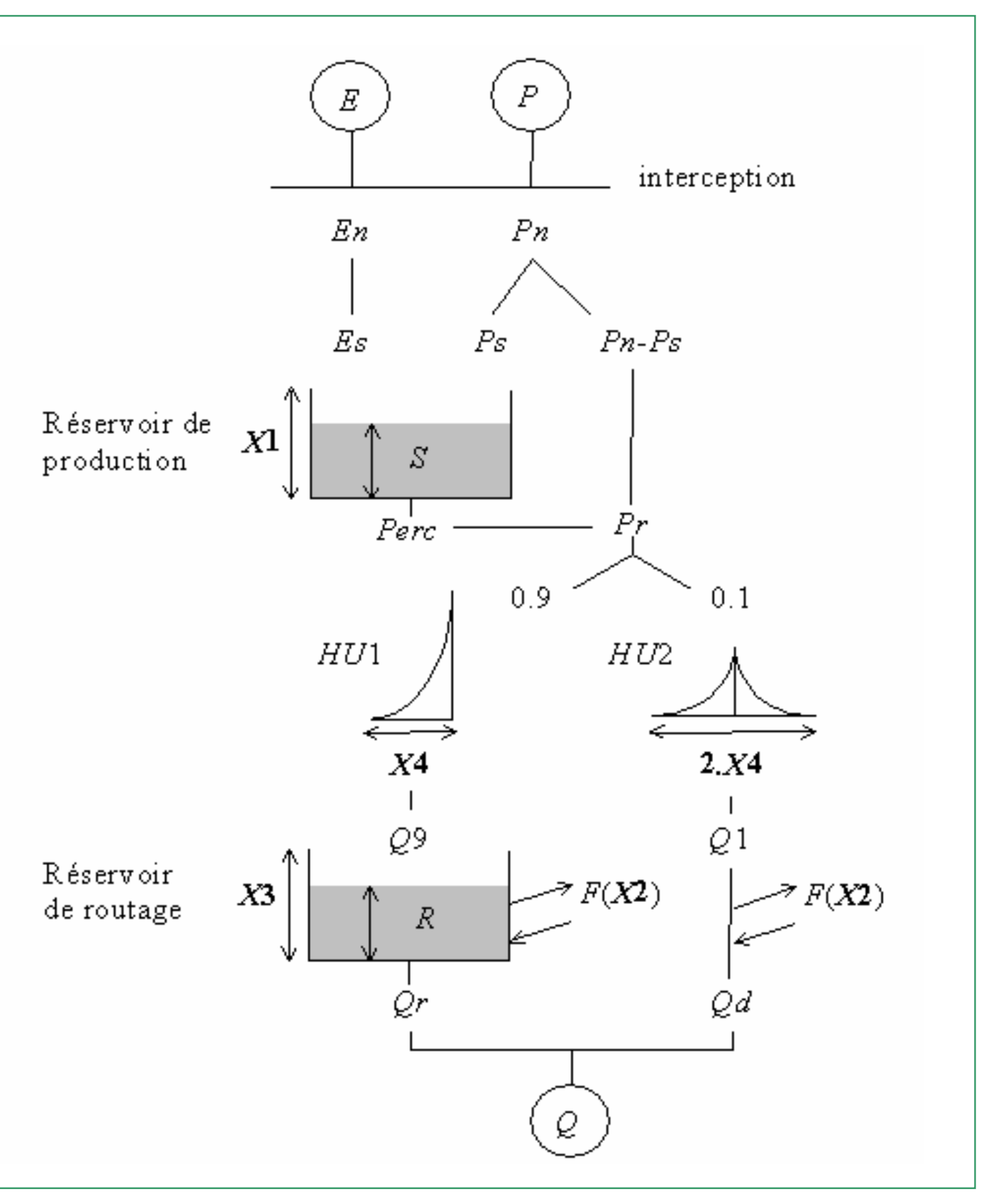
The Oukaimeden recordings show a decrease in the proportion of snow in the precipitation, snow was merely higher than rain until 1997, and becomes lower from 1998. This tendancy can be linked to the raise of temperatures from about 1998.

Model description and data preparation

GR4J is a conceptual daily model (Perrin, 2003) based on the 4 variables characterizing :
X1 = production store (surface store)
X2 = exchanges between catchment and outside (deep percolation)
X3 = Routing store (deep store)
X4 = Unit hydrogram defining the routing time pattern of water

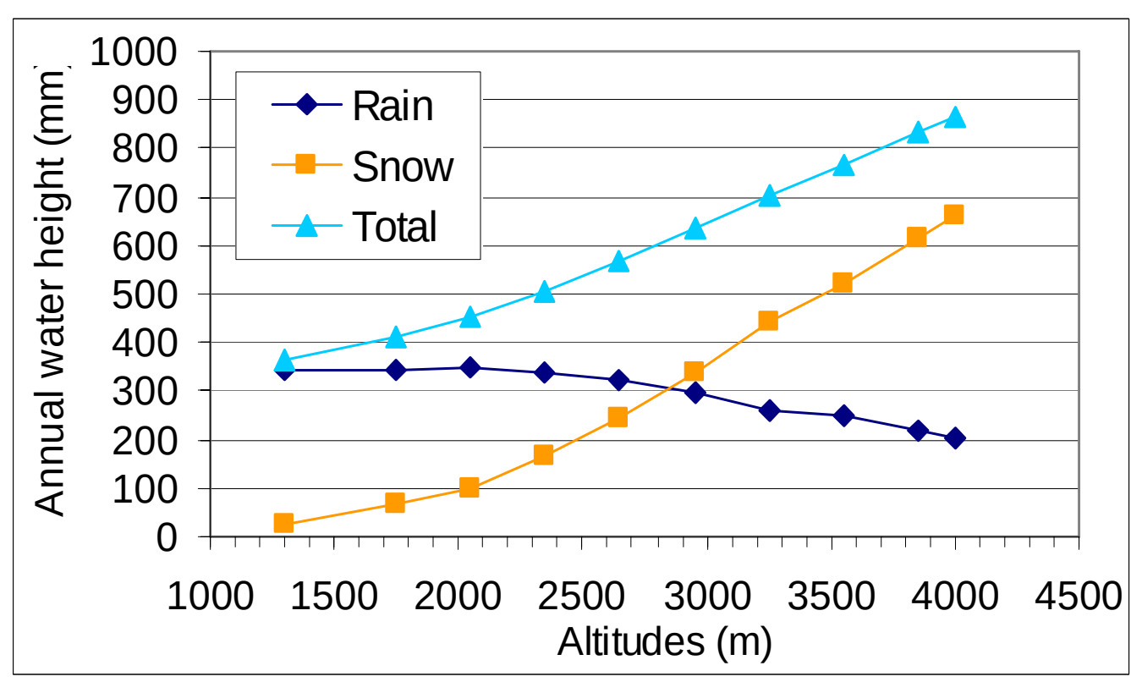
To account for the important snow precipitations in this watershed, the Makhlouf (1994) module was modified. We separated the generation of precipitation based on stations recording and gradient, (2) the generation of snow based on temperature, (3) the melt of snow based on temperature. This segmentation allows for better control of the input (precipitations) and internal variables (snowmelt) and limit the equifinality problems.

The maximum daily evapotranspiration input in GR4J was evaluated to 0.25*ET0, to account for the land cover : mainly bare soils with a lot of stones. ET0 was computed with the Hartgreaves formula.



Data Pre-processing

Precipitations generation

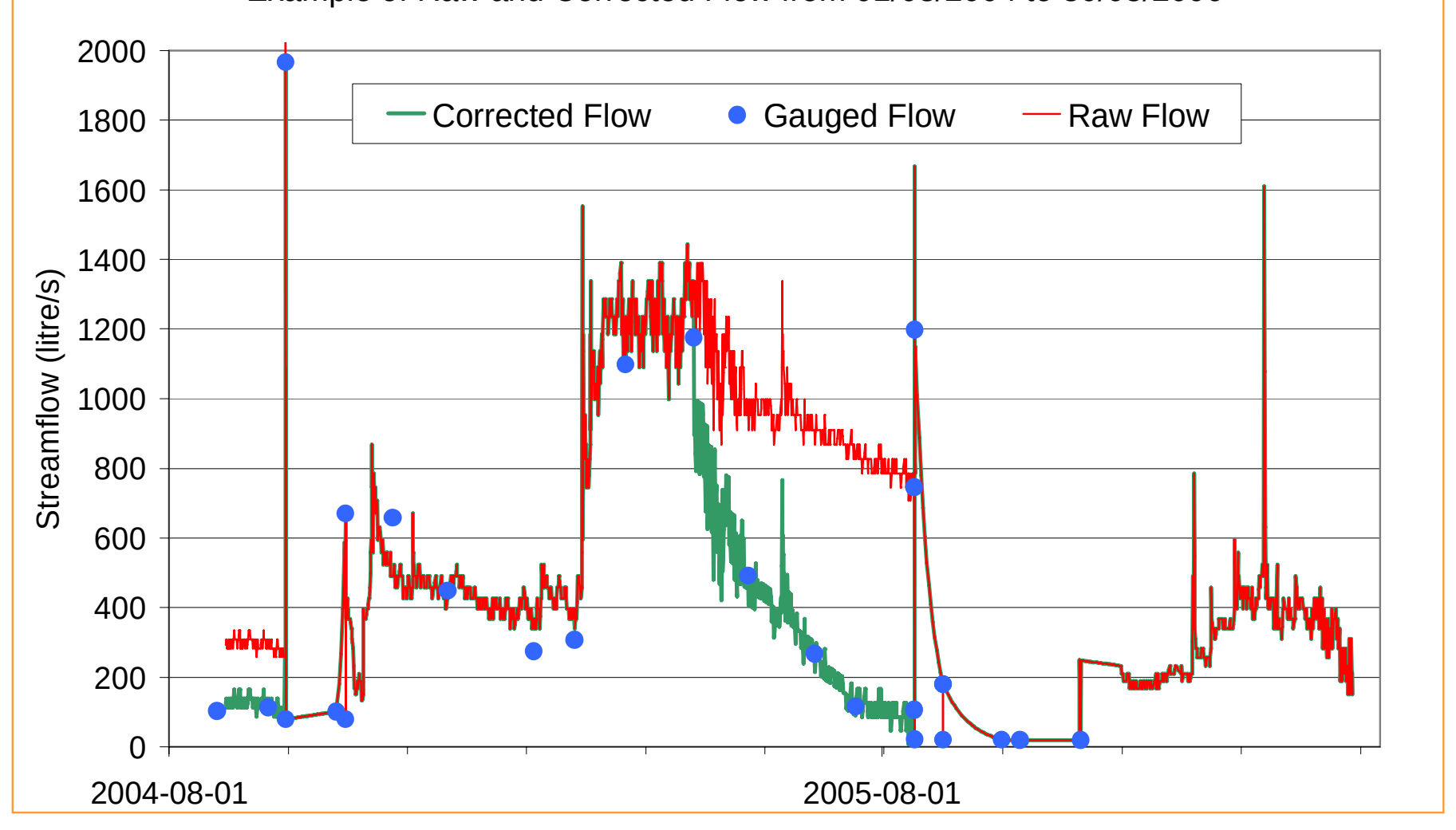


The snowfall account for 34% of the total amount of precipitations (167mm vs 494mm for 1989-2006)

Streamflow correction

The Tahanaout Rheraya outlet has an unstable rocky bed
=> errors in streamflow.
=> correction by a linear correction, forcing the streamflow curve to pass by gauging values, excluding gauging done during quick events.

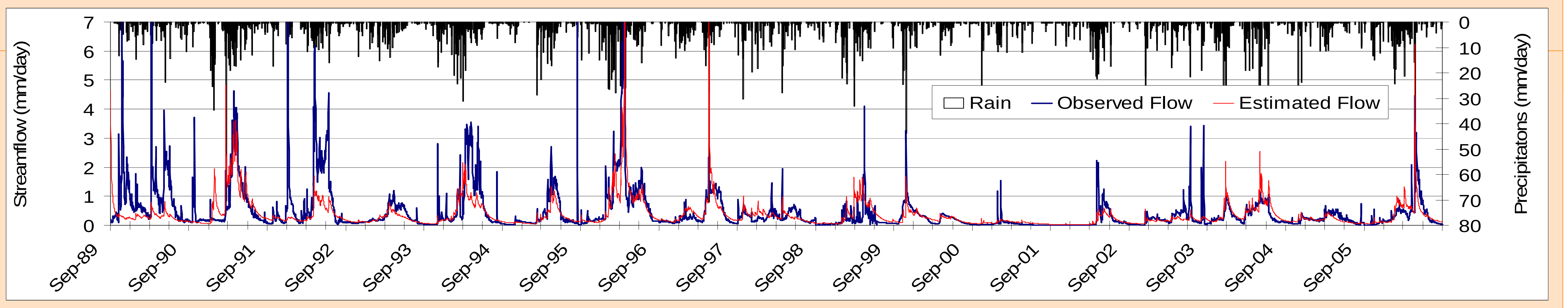
Example of Raw and Corrected Flow from 01/08/2004 to 30/03/2006



Calibration and results

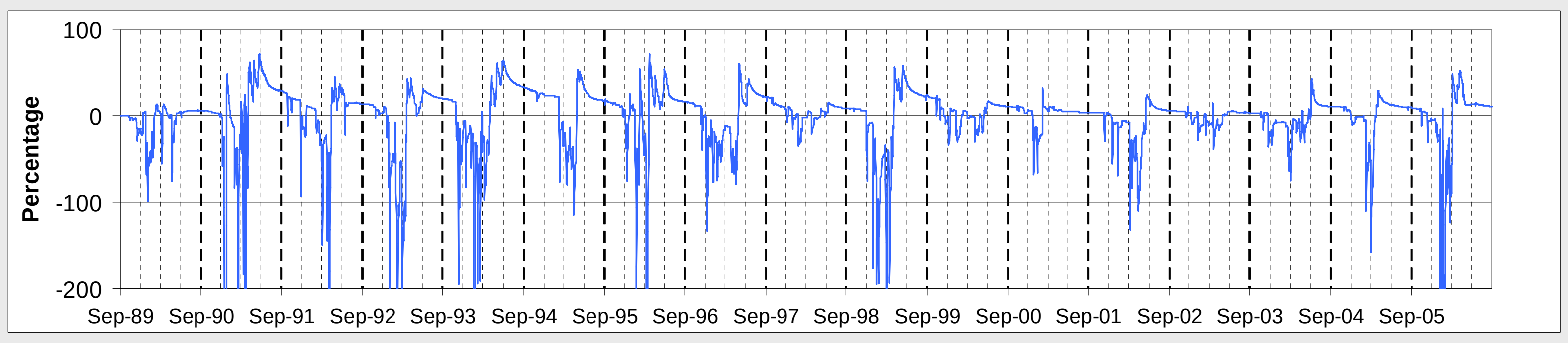
GR4J Calibration

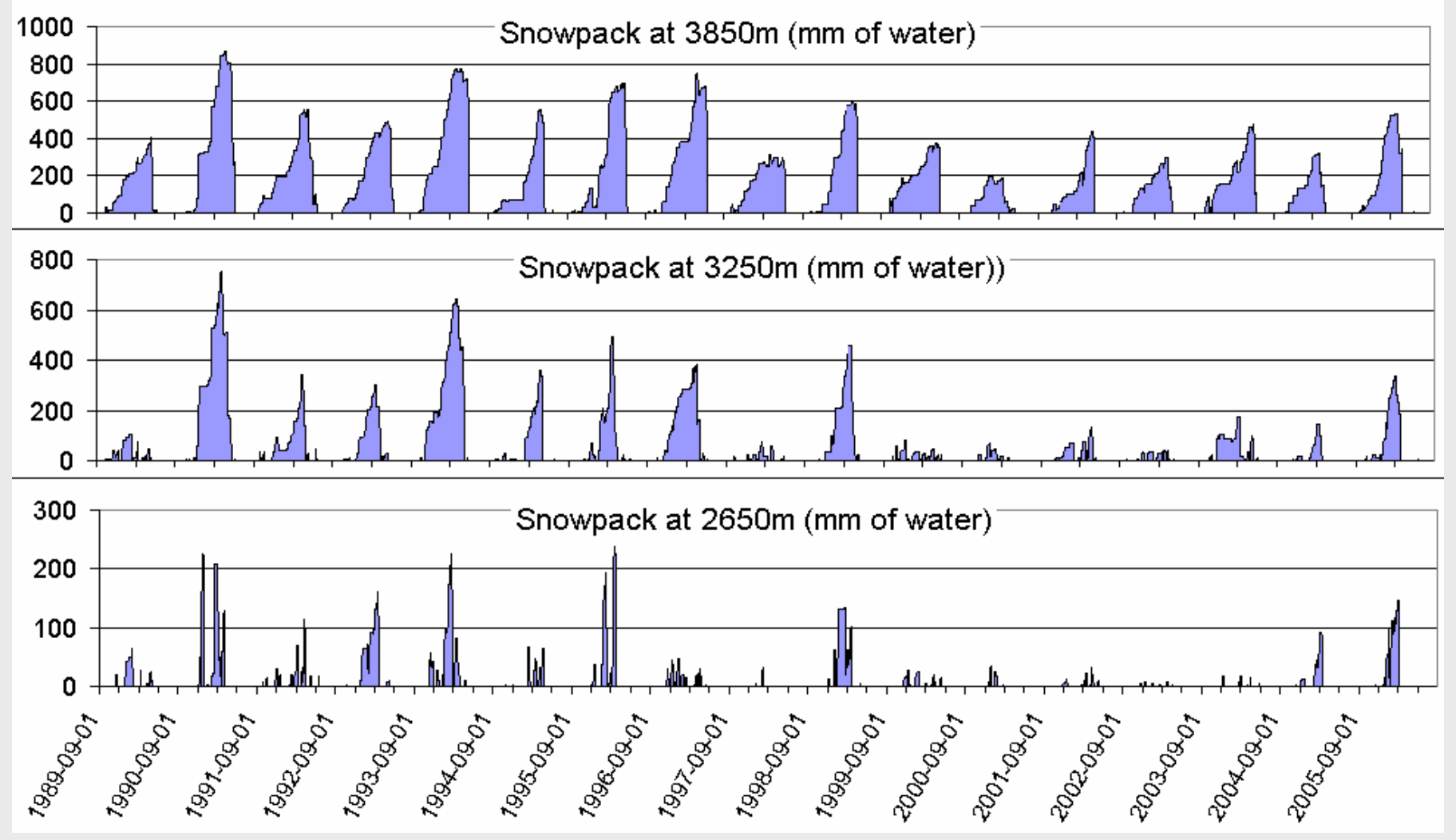
To discard the higher errors related to high streamflows during flood events, and to focus on base streamflows, the Nash was calculated on the square root of streamflow (Nash(VQ). The ultimate Nash(VQ) computed obtained was 0.568 which is low compared with well gauged basins but is rather satisfactory in our is largely due to the quality of rainfall / flow time series.
For the 90/91hydrological year, considered as one of the best recorded, the Nash(Q) obtained with GR4J (0.85) is as good as the one obtained with SWAT (0.83).



Snow dynamic

Snow shows a very high sensitivity to temperatures, especially at lower altitudes. Removing the snow without modifying the calibration makes Nash(VQ) decrease from 0.568 to 0.426. The snow contribution appears to smooth flows in winter, and to contribute to +50 to +25% to the spring flows and to +25 to +5% in summer.





Increased Agricultural water takings ?

The ratio between streamflow computed by GR4J and observed stream flow is significantly different for the two periods highlighted, i.e. before and after 1997, with the values of 68% and 109% respectively => actual stream flows are much lower than the computed ones in the recent decade.

Hypothesis 1: changes in the basin hydrological processes not accounted for by GR4J due to its relative physical weakness…

Hypothesis 2: increased water use by agriculture, triggering an increased evapotranspiration. Indeed, a strong development of tree cultivation has occurred in this basin since 1990.

To corroborate hypothesis 2, we added an arbitrary term of 0.25 mm to the daily ETR from 1996 to 2006 => The Nash(VQ) increased to 0.58 after recalibration, and the new balance of fluxes in the basin matches more to the expected one, with deep percolation decreasing to 66% of the runoff.

Catchment budget Balance

To validate the GR4J calibration, the balance of average fluxes in and out the watershed is computed:

Precipitations (P) = Streamflow (Q) + Deep percolation (DP) + Evapotranspiration (ETR)

P and Q are well controlled variables, whereas ETR and DP suffer from potential mutual compensation. The ETR is here about half the precipitations which seems ok for such a catchment. Conversely, the deep drainage part remains overestimated, hydrogeologists estimating it here to only half the surface flow.

Precipitations *(mm/year)*	Stream flow *(mm/year)*	Deep percolation *(mm/year)*	Evapotranspiration *(mm/year)*
501	133 (actual 171)	132	236

Precipitations *(mm/year)*	Stream flow *(mm/year)*	Deep percolation *(mm/year)*	Evapotranspiration *(mm/year)*
494	139 (actual 171)	92	270

Conclusions

- **Big changes** have occurred since 1997 (temperature, snow, streamflow).
- **The snow dynamics** is very sensitive and greatly amplifies the climatic variations.
- **The decrease of the streamflow** appears to be much more rapid than the decrease in precipitations
- **Agriculture takings** seems to have increase a lot and modified the catchment functionning.
- Balance between **deep percolation and evaporation** has to be better estimated (ET field measurements)

- In spite of its simplicity, the use of GR4J in the Rheraya catchment gives **interesting insights about its functioning.**
- **GR4J is well adapted to poor quality data** if long enough time series are available
- The lack of physical soundness may hamper the use of such conceptual models for scenario testing. Nevertheless, the **very contrasted years** tested since 1989 looks like a test of climate change scenario, which was **successfully managed by GR4J**…

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