Changing flood magnitude and frequency in snow-melt dominated catchments: the case of the Bucegi Mountains, in the Romanian Carpathian region

Elena Ruth Perju (1,2), Daniela Balin (1), Stuart Lane (1), and Liliana Zaharia (2)

(1) IGD-Alpine Environments, University of Lausanne, Lausanne, Switzerland (elena-ruth.perju@unil.ch),

(2) Faculty of Geography, University of Bucharest, Romania

I. Context & Aim

Flooding in mountain environments is an issue of particular concern, especially where those environments are occupied and/or used for activities like tourism. In this respect, Bucegi Mountains (in Romanian Carpathians) are little studied form the point of view of flood risk, although it is a region of national importance in terms of tourism, transport and communication.

The aim of this study is to identify trends in the magnitude and frequency of floods due to the variability of the main climatic parameters, in order to understand the possible changes in the dimension of flood risk.

II. Study region

Bucegi Mountains: Valea Cerbului Catchment Area

- ***Location:*** 25°30'E, 45°26'N, on the eastern slope of Bucegi Mountains
- ***Area:*** approx. 26 km²
- ***Altitudes: mean -*** 1536 m a.s.l.; max. – 2505 m a.s.l. (Omu Peak); min. – 860 m a.s.l.
- **Valea Cerbului River length**: 12 km (only on its last 7 km with a permanent character). Its confluence with Prahova River is situated in Buşteni city, a very important mountain resort (approx. 10,000 inhabitants).
- Prahova Valley (and Buşteni City) is crossed by one of the most important European Routes – E60 and by the main national railway 200 (figure 1 and photo 1).

Photo 1: Valea Cerbului River crossed by the European Route (E60) at Buşteni.

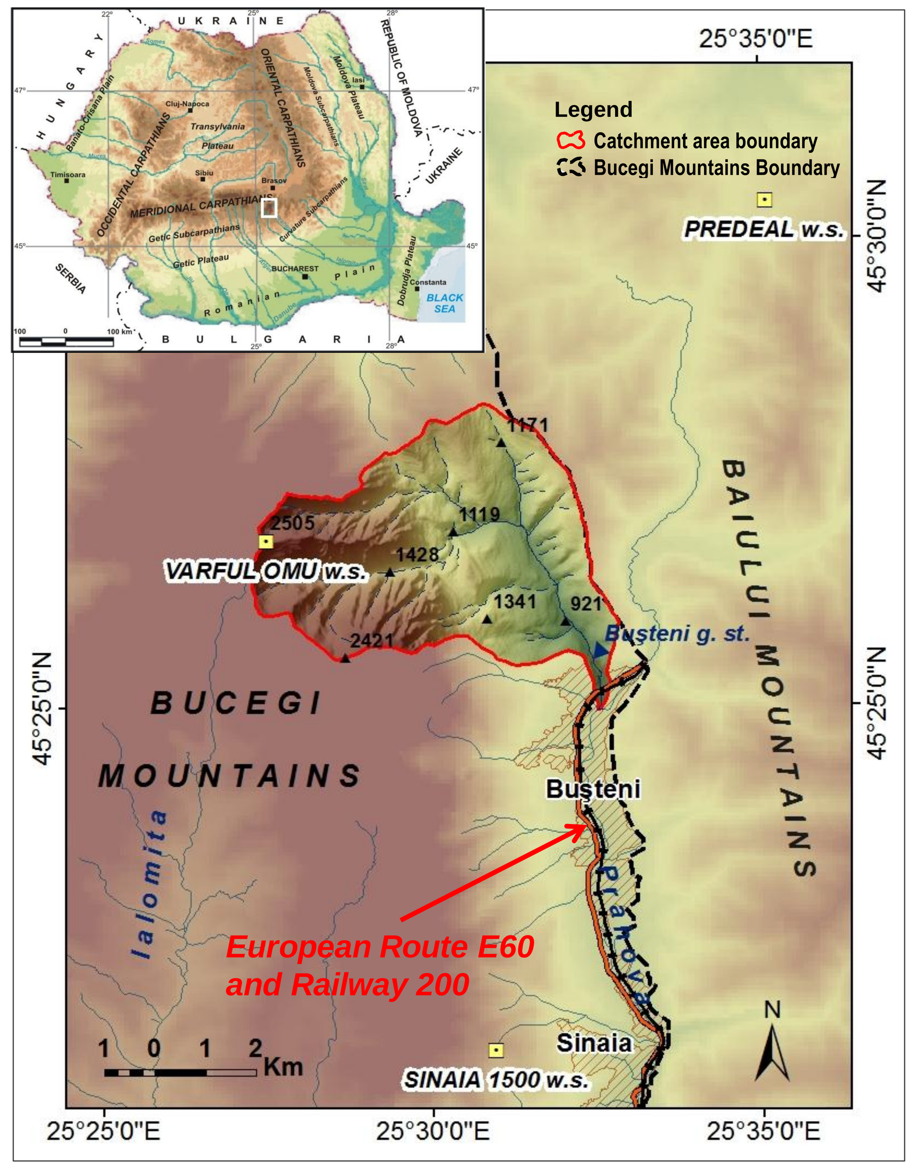

***Figure 1:** Geographical location of Bucegi Mountains, of Valea Cerbului Catchment, of gauging (g.st.) and weather stations (w.s.) considered and the main issues in terms of flood risk*

III. Data and Methods

3.1. Data

- **Hydrological data**: Daily discharge
  Annual maximum discharge } 1961-2010
  Hourly discharge during analyzed floods

  Gauging station: Buşteni, on Valea Cerbului River, situated approx. one kilometer upstream the confluence with Prahova River, at 890 m a.s.l. (figure 1)

  Data source: "Romanian Waters" National Administration
- **Climatic data:** Daily data on the main climatic parameters: precipitation, temperature
  sunshine duration, air humidity, wind speed

  Weather stations: Vârful Omu (2505 m a.s.l.) – 1961-2010, for precipitation and temperature
  – 1991-2010, for sunshine duration, air humidity, wind speed

  Sinaia 1500 (1510 m a.s.l.)
  Predeal (1090 m a.s.l.) } For precipitation, 1971-2004

  Data source: ECA&D (http://eca.knmi.nl/), accessed on 01/20/2012, National Meteorological Administration
- **Cartographic data:** Digital Elevation Model of the catchment area, resolution: 50X50 m², realised in GIS environment (ArcGIS 10.1)

2. Methods

- Statiscal analyses: frequency analysis; statistical significance of trends (using Mann-Kendall test); analysis of 42 flood hydrographs (from 1986 to 2010) to determine their main wave flood characteristics.
- Physically-based hydrological model: **Wa**ter Flow and **B**alance **Si**mulation **M**odel (WaSiM-ETH) used for, (i) interpolation of temperature and precipitation, coupled with the morphology of the relief, (ii) generation of distinct data series for rainfall and snowfall, (iii) simulation of the snow stock.

IV. Results

4.1. Flood magnitude

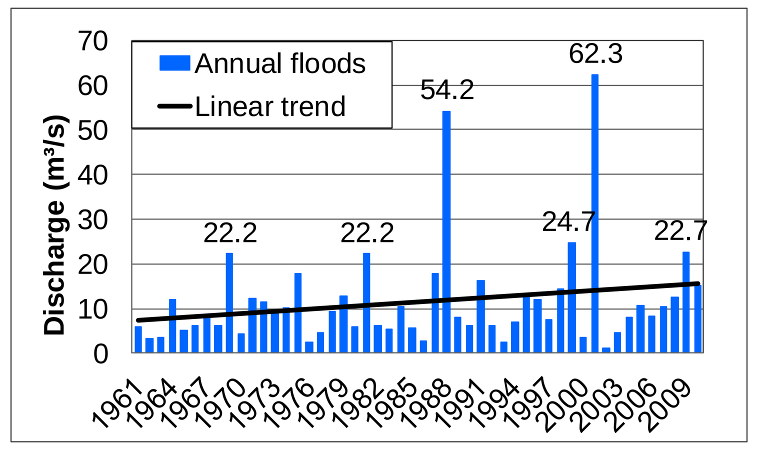

***Figure 2:** Maximum discharge of the annual floods between 1961-2010, at Buşteni gauging station, on Valea Cerbului River and their linear trend*

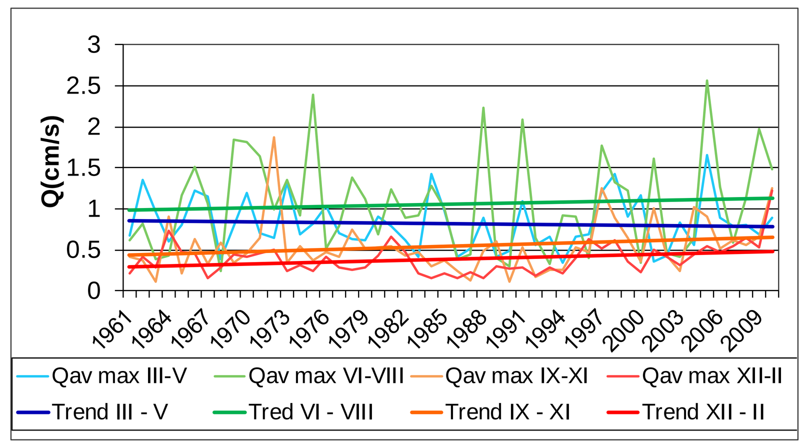

***Figure 3:** Seasonal variability of the mean maximum discharge and their linear trends for 1961-2010*

- The magnitude of the annual floods shows an upward trend, statistically significant, with α = 0.1 (level of significance) (Mann-Kendall trend test) (figure 2).
- Upward trends in Autumn and Winter (α = 0.1 level of significance) and downward trends in Spring (statistically insignificant) (figure 3, table 1).

Season	Statistical test *Z*	Level of significance (α)	Sen's slope
Spring (III - V)	-0.49	—	-0.002
Summer (VI – VIII)	0.20	—	0.0010667
Autumn (IX – XI)	1.79	**0.1**	0.0044210
Winter (XII – II)	1.81	**0.1**	0.0027058

***Table 1:** Statistical significance of trends in seasonal variability of the mean maximum discharge of the Valea Cerbului River at Buşteni (1961-2010)*

4.2. Flood frequency

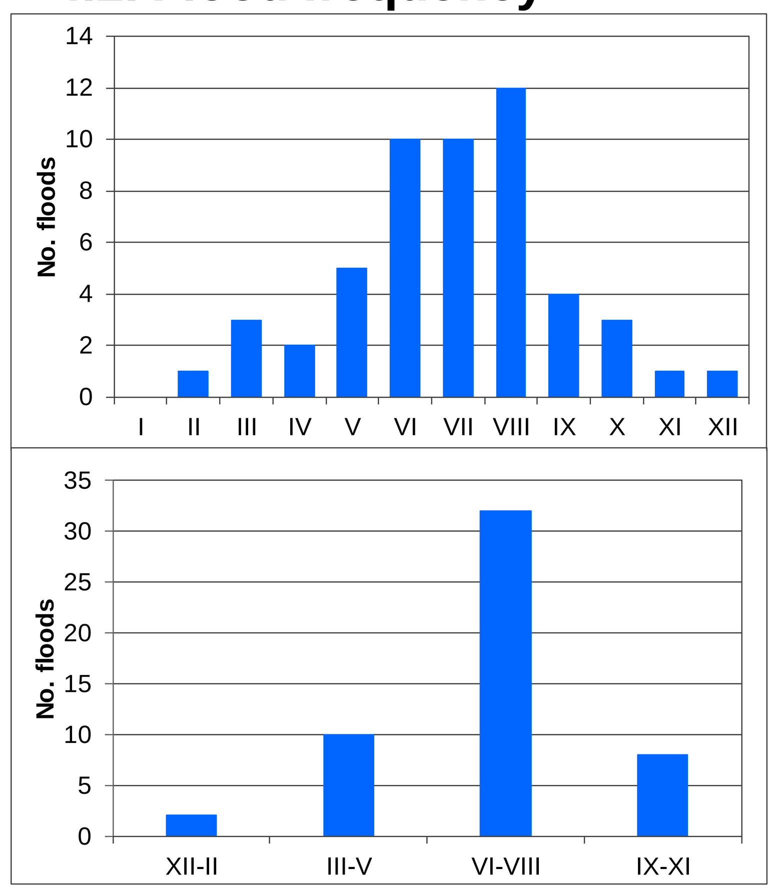

***Figure 4:** Annual floods: monthly (up) and seasonal (down) frequency, at Buşteni gauging station, for the period 1961-2010*

- The maximum frequency of annual floods is clustered in Summer, from June to August: 19,2% of cases in June, 19,2% of cases in July, 23,1% in August (figure 4)
- The linear trend in annual number of floods shows a slow ascending, but not statistically significant (floods are defined as every daily discharge three times greater than the mean annual discharge (consecutive large values were considered as a single flood) (figure 5).

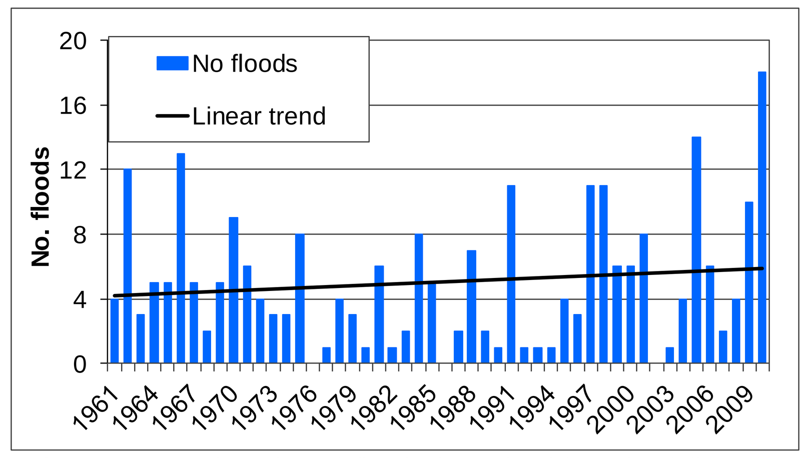

***Figure 5:** Annual number of floods determined from the daily discharge recorded at Buşteni g. st., between 1961-2010*

3. Flood features

	Q max (mc/s	Tc (hours)	Ts (hours)	Tt (hours)	W (mil. m³)	H (cm)	q (l/s*km²)	k
Mean values	11.45	14.2	24.9	39.2	0.467	11.5	364.8	0.46
Max. values	62.3	52	84	120	1.888	51.1	2396.2	0.72
Min. values	1.58	1	0,83	2.5	0.031	1	60.8	0.18

Table 2: Mean, minimum and maximum values of the main characteristics of floods recorded at Buşteni g. st., on Valea Cerbului River (1986– 2010): Q max - maximum discharge, Tc - increasing time, Ts - decreasing time, Tt - total duration, W - total water volume , H - water layer, q - specific discharge, k-shape coefficient.

- The morphology of the catchment area favors the occurrence of flash floods, therefore the minimum duration of a flood is of only one and a half hours and a minimum level increasing time of one hour.

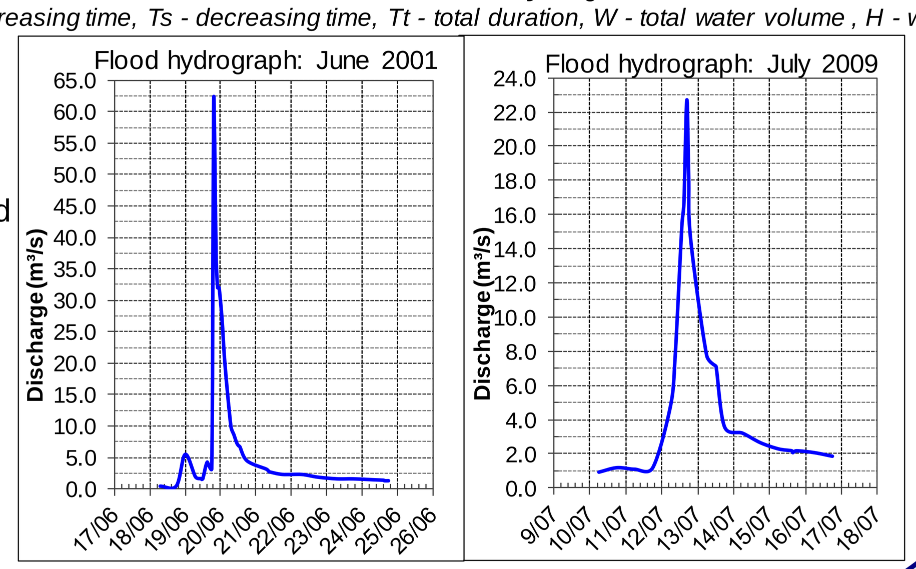

Figure 6: The hydrographs of two important floods: the historical flood of June 2001 (left) and the flash flood of July 2009 (right)

V. Discussions

Since the climatic conditions are the most important factor for the surface flow regime, the annual and monthly variability of the main climatic parameters could explain the causes for the maximum flows variability in the studied catchment. Therefore, we analyzed the data series resulted from WaSiM-ETH (temperature, liquid and solid precipitation) as they represent an average for the entire catchment area.

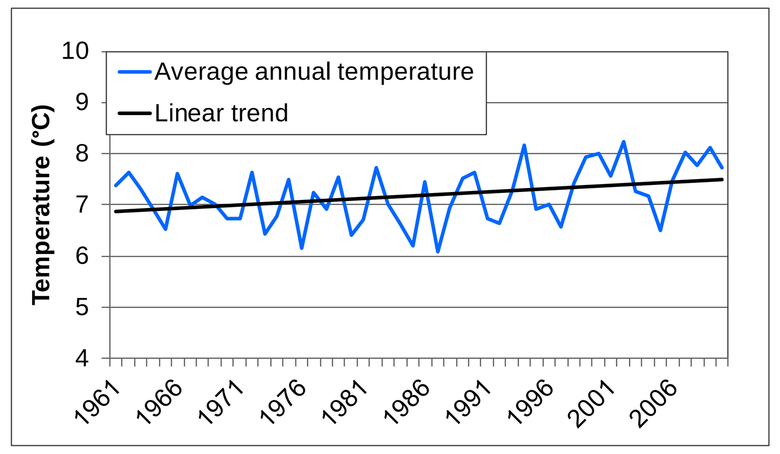

***Figure 7:** Average annual temperatures for 1961-2010, interpolated with WaSiM-ETH, based on measured temperature data series, and their linear trend, in Valea Cerbului Catchment*

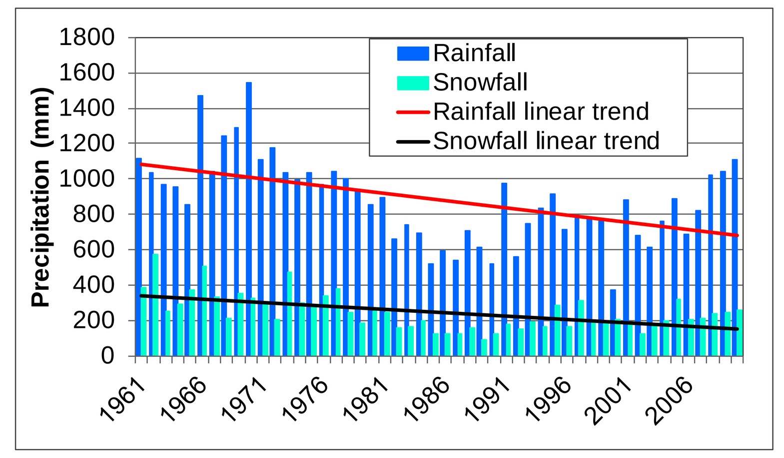

***Figure 8:** Annual amounts of rainfall and snowfall for 1961- 2010, resulted from the interpolation of measured precipitation data series, with WaSiM-ETH simulation and their linear trends*

Time series	Test Z	Level of significance (α)	Sen's slope
Temperature			
Winter	**1.288188**		0.01587667
Spring	-0.10038		-0.0007527
Summer	4.567212	**0.001**	0.04233658
Autumn	-0.1673		-0.0019166
Annual	2.057755	0.05	0.01263976
Rainfall			
Winter	-3.04481	0.01	-1.3723158
Spring	-3.17865	0.01	-2.8112105
Summer	-1.95738	0.1	-2.0187273
Autumn	-0.75284		-0.4294571
Annual	-3.47978	0.001	-8.4991818
Snowfall			
Winter	-3.81438	**0.001**	-2.3095
Spring	-2.07448	**0.05**	-0.78975
Summer	-3.94821	0.001	-0.0500303
Autumn	-0.68592		-0.1524
Annual	-3.12846	0.01	-3.0557333
Snow stock			
Winter	-3.89802	**0.001**	-26.406987
Spring	-2.94443	**0.01**	-37.025088
Summer	-3.41286	0.001	-0.7746667
Autumn	-0.63573		-0.3824375
Annual	-3.44632	0.001	-2.5078241

***Table 3:** Statistical significance of trends in seasonal and annual climatic data series, interpolated (temperature, liquid/solid precipitation distinction) and simulated (snow stock) with WaSiM -ETH*

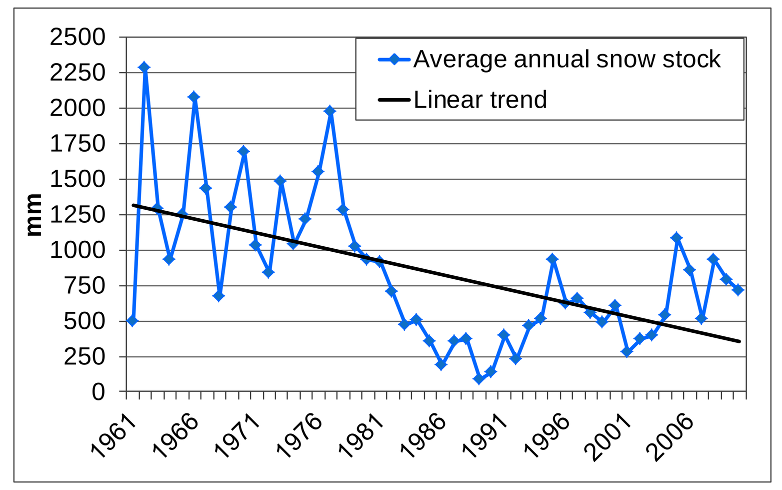

***Figure 9:** Average annual snow stocks for 1961-2010, simulated with WaSiM-ETH and their linear trend*

- Upward trend in annual temperatures (figure 7) (statistically insignificant for Winter months, but with a 0.001 level of significance in Summer) (table 3)
- Downward trend in Spring and Summer for rainfall (also for the annual amounts) (figure 8)
- Downward trend in solid precipitation during Winter and Spring (0.001 level of significance)
- Important decrease in snow cover depth at both annual and seasonal level (figure 9)
- Although at an annual scale the precipitation (liquid and solid) and the snow cover have an downward trend, the annual floods show an increase of peak discharge.
- Seasonally, the magnitude of floods shows a downward trend in Spring (but statistically not significant), in accordance with the snow stock and snowfall trends. In Winter, while the medium maximum discharge has an upward trend, the precipitation (both liquid and solid) and the snow cover tend to decrease.
- The discrepancy between the trend in flood magnitude and the trend in precipitation and snow cover at annual and seasonal scales, indicates possible changes in the magnitude and frequency of short duration and intense events (heavy rainfall, sudden snowmelt) that generate floods.

VI. Conclusions & outlook

- The earlier onset of spring snowmelt, consequently the decreasing of snow cover depth should determine a shift of floods towards early Spring, but the maximum frequency of floods occurs in Summer (with the highest frequency in August), an unusual behavior for a snowmelt dominated catchment: is it an atypical case or could the discharge data series recorded at Buşteni gauging station be uncertain/ unreliable?
- Regarding the outlooks of the present study, more detailed analysis of the frequency and intensity of short duration events, like heavy rainfall and Winter heat waves, should be conducted, in order to better explain the trends identified in flood's magnitude and frequency.

References:

Perju R., 2012, Characteristics of floods in Valea Cerbului Catchment, *Water resources and Wetlands*, Edit. Transversal, Tulcea, p. 248-253.

Salmi T., Määttä A., Anttila P, Ruoho-Airola T., Amnell T., 2002 : Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS, *Publications on Air Quality* No. 31.