Are there evidences of the impacts of global warming on runoff regimes in the southern Alps?

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1 INTRODUCTION

There is a wide consensus (Oreskes, 2004; Lovell, 2006), with some exceptions (Gerhard, 2004, 2006) on the fact that the Earth is experiencing a fast climate warming which will affect natural and human systems. In terms of impact on the hydrological cycle, on the basis of experimental evidences, the IPCC 4th Assessment report (IPCC, 2007) and the report by Bates et al. (2008) depict, in summary, a situation characterized by snow cover reduction in the northern Hemisphere and glacier retreat almost worldwide. However, no clear signals of runoff changes are documented by the IPCC at the global scale (Bates et al., 2008), although several studies at the regional scale report about significant variations on a statistical basis in the 20th century. This evidence could have relevant feedbacks, in the near future, on the water management policies (Parry *et al.*, 2001) and engineering design, particularly in those regions which are deeply exploited for hydropower production, as the southern Alps (Ranzi *et al.*, 2009), and where irrigation and domestic water demand are in conflict with industrial uses.

As an impact on the hydrological cycle and runoff, the temperature rise is expected to increase convection and, on a global scale, precipitation: the fraction of precipitation in the form of snow vs. rain will decrease, instead. An increase of winter runoff, with respect to the total annual amount, is therefore expected. It is considered a "very robust finding" (Bates et al., 2008) that, in a warming scenario, changes in the runoff regime will be observed particularly in those regions where the ice- and snow-cover are important for the runoff production. Many Authors recently pointed out this aspect for various basins characterized by more or less strong glacial- and nival-influence on the runoff regime (e.g. Seidel *et al.*, 1998; Pfister *et al.*, 2004; Krysanova *et al.*, 2005; Schaefli *et al.*, 2007).

The total amount of runoff is also deeply influenced by the evapotranspiration losses, which locally depend on a number of factors such as the total precipitation and its regime, the air temperature and energy exchanges, the climatic feedback on the self-vegetation and the anthropogenic effects on the forest cover. The vegetation species can in fact put into action a wide number of different mechanisms (e.g. genetic adaptation, biological invasion, species extinction) in order to react to a climate change (e.g. Walther *et al.*, 2002, for a review). It is otherwise a common feeling that slight climate warming is often accompanied by a rise of the tree-line at the expense of pasture and grass at the highest altitudes. In the southern Alps, this process can be accelerated by reforestation due to the decline of the wood use for fuel and to the abandonment of the high-altitude pastures (FAO, 2007) as we verified in a medium-altitude range basin (Ranzi et al., 2002). While evaporation from water surfaces and dry areas will increase in a global warming, there is a lack of scientific consensus about the transpiration losses. They might increase because of the higher energy available or also decrease as a negative feedback due to the enhanced stomatal resistance with the rising atmospheric carbon dioxide concentration. As it was pointed out by Bates et al. (2008), only a few experimental studies are currently available in order to formulate a robust hypothesis on the effect of a climate change scenario on the evapotranspiration losses in the water balance.

As a significant example on how warming temperature, precipitation changes and hydrological feedback had impact on runoff regime, climatological series of runoff for four major basins in the southern Alps are presented and discussed. They are compared with temperature and precipitation trends analysed at the local scale for one of the catchments, that of the Adige river, and with trends identified in recent extensive climatological studies for the Greater Alpine Region. Differences between the runoff series highlight the complexity of natural feedbacks and of anthropogenic factors affecting runoff changes as a response to climatic variability.

2 TEMPERATURE

Temperature trends in the Alpine region and over a long time window starting in the second half of the 18th century are provided by a 242 meteorological series collected in the HISTALP database (Auer *et al.*, 2007). As it has been pointed out by the Authors, the whole Alpine region is characterized by uniform trends of temperature.

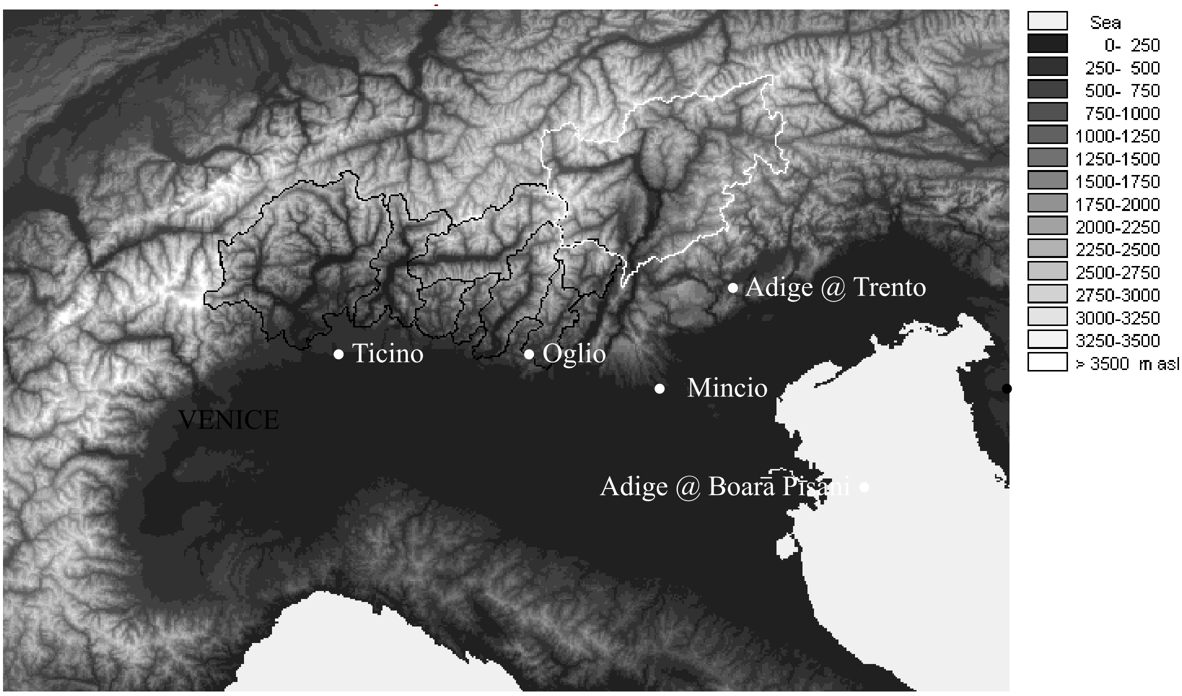

Figure 1. The outlet of the investigated basins, in northern Italy: for the Adige at Trento (9763 km^2) data about temperature, precipitation and runoff regime are presented .

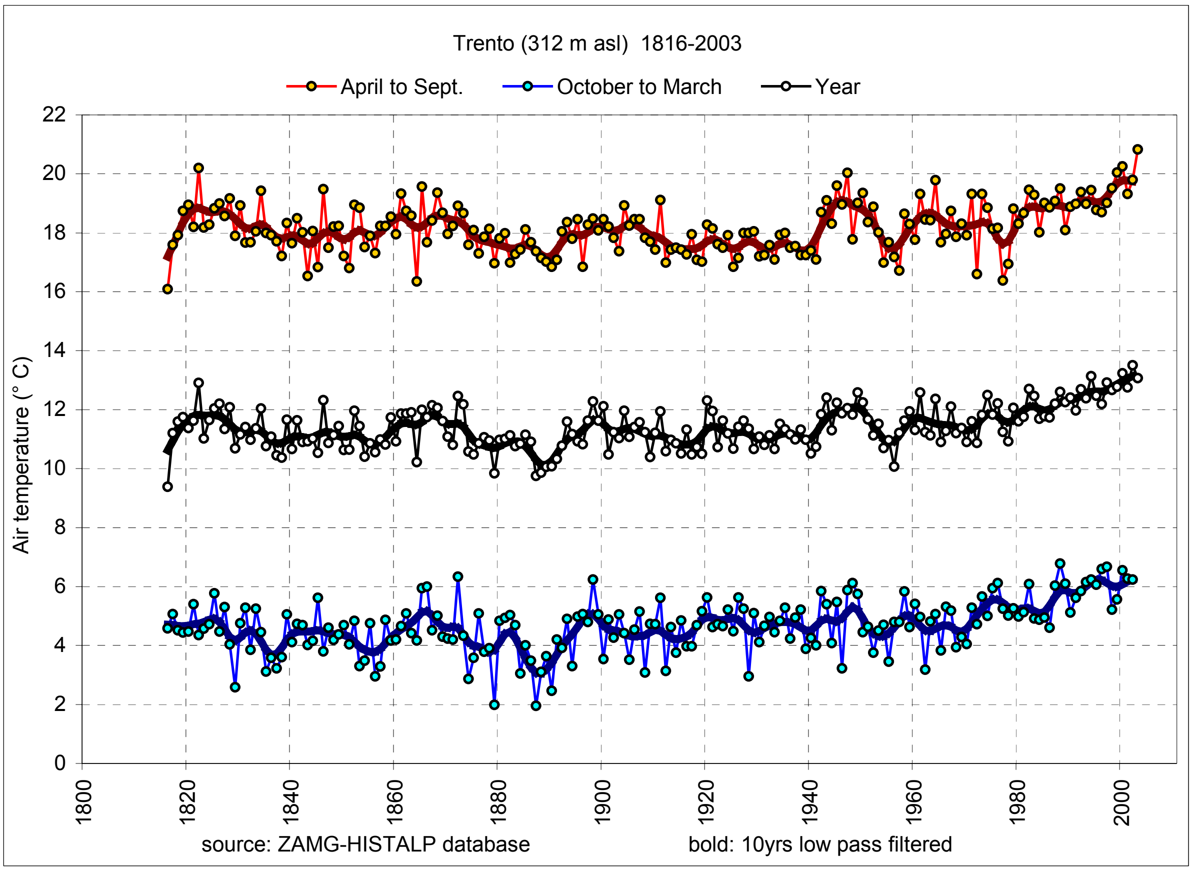

Figure 2. Mean air temperature at the Trento-Laste station (312 m asl). In bold the 10 years low pass filter trendline. Source: www.zamg.ac.at/ALP-IMP (courtesy of R. Böhm).

Thus, when a warming or cooling trend occurred, analogous pattern were recognized both in all the Alpine subregions (NE, NW, SW, SE) and at different altitudes. Looking at a long time window, the 20th century is characterized by rising temperatures and the maximum observed since 1990s with regard to the reference 1901 – 2000 control period, is the principal one of the whole time window covered by the record. In this paper we focuse our analysis on the SW part of the Alps, as shown in Fig. 1. Over the 1886-2005 time period, confirming the global trend to a fastening warming, in this area the rate of increase of mean annual temperature was 1.4 ± 0.1°C/century (Brunetti *et al.*, 2009) with significance higher than 99% with Mann-Kendall test. In the second half of the century trends are higher than of those observed in the same regions in the first half of the 20th century. Local values of the trends are however affected by the regional atmospheric circulation. For instance for the Trento-Laste meteorological station, located at 312 m a.s.l. altitude close to one of the streamgauges of the Adige river, the mean trend over the 1886-2003 time window was 1.5 °C/century (Fig. 2), with slightly higher values in winter (1.54 °C/century from October to March) than in summer (1.40 °C/century from April to September). In the 1923-1996 period, we selected for the hydrological analysis of precipitation and runoff (Fig. 3), mean annual temperature increased 1.6 °C/century, with a further confirmation of a faster warming in the last decades.

3 PRECIPITATION

Precipitation is expected to increase at the global scale as a result of enhanced evaporation and convection. However regional patterns can change dramatically. This uncertainty on the response of precipitation to a climate warming is confirmed by recent climatological analyses in the Alps. A tendency of an increase in the NW part of the Alps and of a decrease in the SE part is observed but only the former trend was considered as statistically significant by Brunetti *et al.* (2009), with an 11% increase over the 1901-2000 period. In the Adige river gauged at the Trento station mean annual precipitation, estimated as 832 mm in the 1923-1996 period using a network of 14 stations, showed a decrease of 105 mm/century, a tendency which is consistent with the precipitation decrease in the south-eastern Alps. Such a trend is confirmed also The impact on runoff of the combined effect of increased temperature and enhanced precipitation is not trivial as Fig. 3 shows.

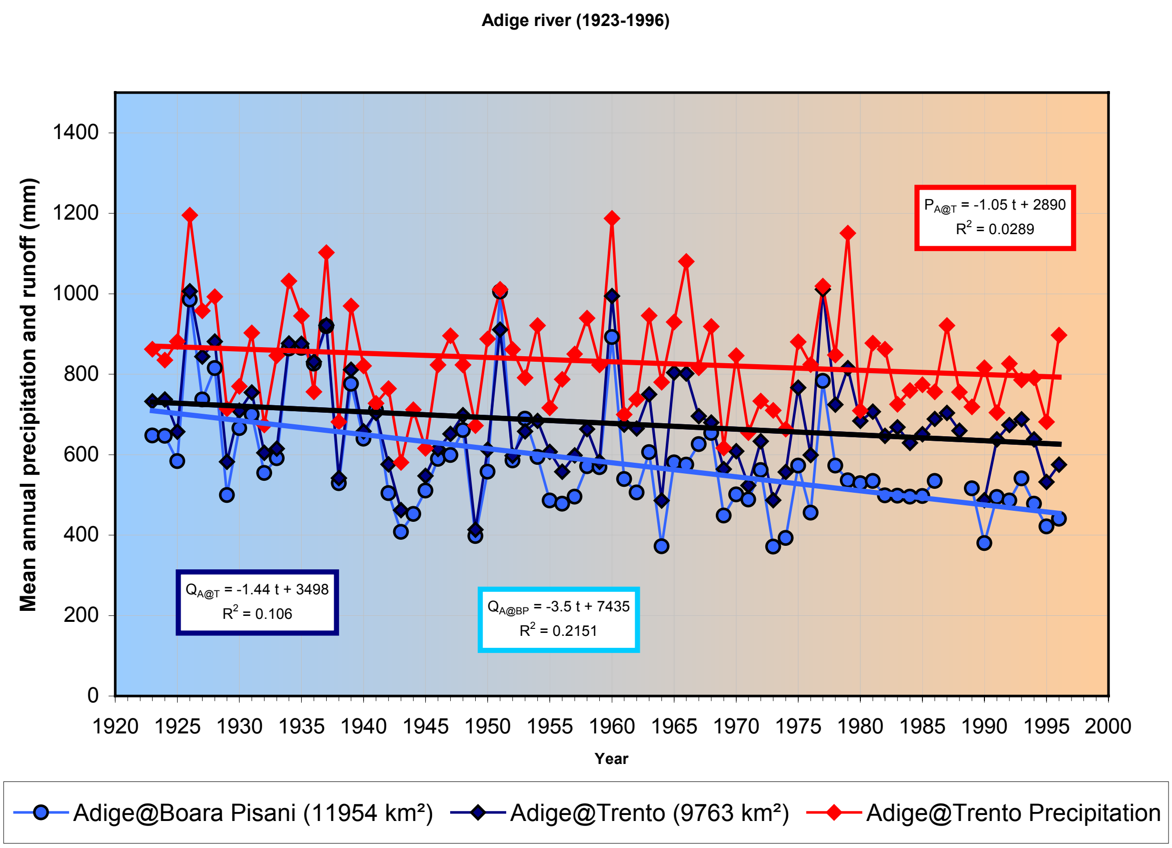

Figure 3. Annual precipitation and runoff for the Adige basin.

The precipitation decrease was more marked in the winter season and as combined effect with the temperature increase, a rapid retreat of glaciers is observed in the region.

Also a decreasing trend of snow water equivalent accumulation is observed with systematic measurements conducted over a dense network of monitoring sites which is being operated from 1966 to date in the Central Italian Alps. A 50% decrease of mean snow water equivalent accumulation in April was observed over the 1966-2006 period, on average, in the 1500-2500 m a.s.l. altitude range. The decrease of mean areal snow water equivalent in the last decade, compared to that of the 1966-1975 decade, is statistically significant on the basis of a Student-t test with significance level α=0.05. Also on the basis of a Mann-Kendall test the hypothesis of the absence of a decreasing trend of snow water equivalent is rejected.

4 RUNOFF

Because of the lower precipitation and of an increase of evapotranspiration losses which are likely to occur also as a consequence of the observed increase of the forested areas due to afforestation (Ranzi *et al.*, 2002), in the Adige basin runoff decreased more rapidly than precipitation already in the 20th century. With a mean of 681 mm for the Adige at Trento over the 1923-1996 period, a 144 mm/century decrease of runoff was observed and an even higher decrease was observed at the basin outlet into the Adriatic sea, close to the Boara Pisani station which gauges a basin area of 11 964 km^2. Worth noticing the fact that runoff measured in the mountain part of the catchment gauged at Trento was very close to that measured at the outlet of Boara Pisani until the mid of the century. Then runoff at Boara Pisani was much lower that that measured at Trento. A possible explanation is the increase of water pumped from the river and the surrounding groundwater for irrigation purposes in the downstream agricultural areas, and increase evapotranspiration losses. Because the exploitation of water resources increased significantly in the second half of the century this anthropogenic factor is a likely reason of the runoff decrease in the downstream areas. Another factor of minor importance is the diversion of a maximum discharge of 500 m^3/s from the Adige river to the Lake Garda and the Mincio river which occurred during about ten flood events starting with the year 1960 when a by-pass gallery was constructed.

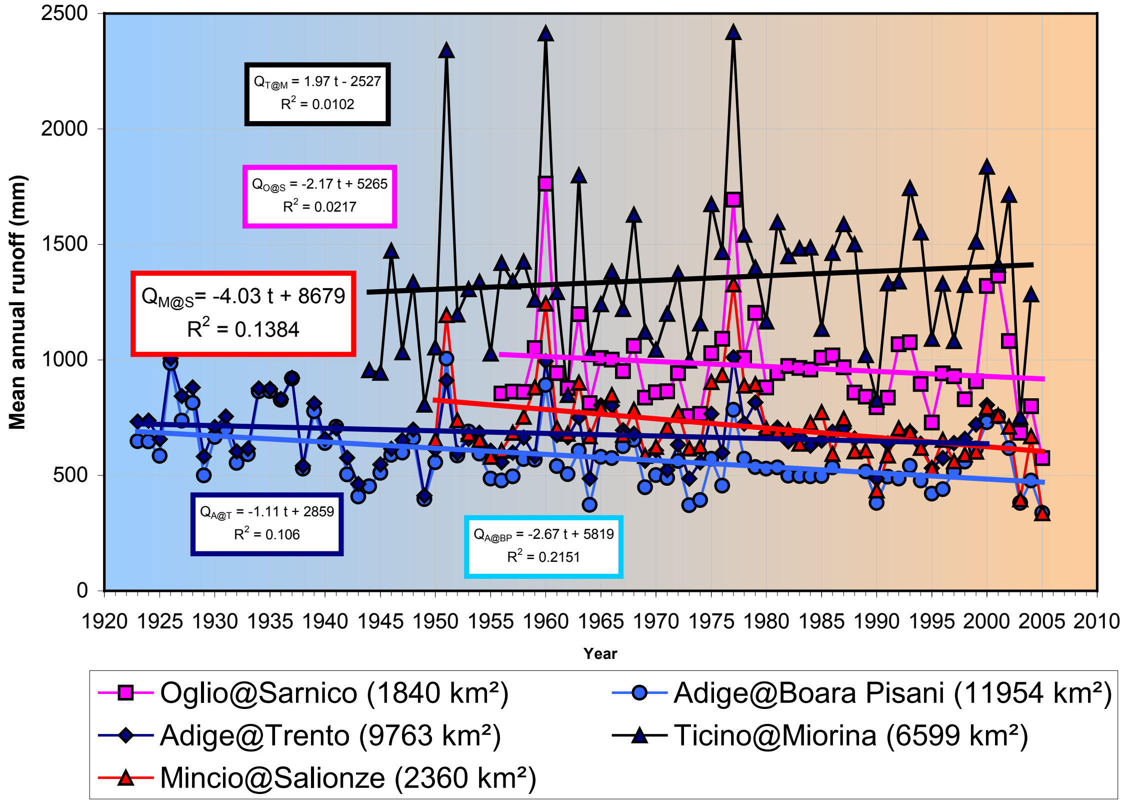

Figure 4. Annual runoff and trendlines in five basins of the southern Alps

A marked decrease of mean annual runoff is observed also for the Mincio at Salionze river, at the outlet of the Garda Lake and for the Oglio at Sarnico (see Fig. 1), in the Central Italian Alps.

For the Ticino at Miorina river, instead, an increase of runoff is observed. Compared to mean annual runoff of 1345 mm measured over the 1944-2004 period an increasing trend of 197 mm/century is estimated. It can be the result of some factors: first of all trendlines are very sensitive to anomalies in the time-series. The initial two dry years influence heavily the slope of the trendline. Then the Ticino river is located in the western side of the Alps where precipitation tend to increase. A third factor can be related to the glacier's retreat, although glaciers cover only a small fraction of the Ticino riverbasin.

5 CONCLUSIONS

In order to assess the impact of a potential global warming on runoff regime in the Alps temperature, precipitation and runoff data for four basins in the southern Alps were analysed, together with a review of climatological literature. Our data confirm a temperature increase of about 1.5 °C/century over the last two centuries for that region, with an acceleration in the last decade of the 20th century.

Precipitation tends to decrease in that area, instead. As a balance between precipitation increase and evapotranspiration changes for the current century Labat et al. (2004) estimate an increase of 4% in the global amount of runoff each 1 °C of temperature increase. This result seem not to be consistent with the observation in the investigated area as a decrease of more than one hundred of millimeters per century is observed for four out of five gauging stations. In one station, Adige at Boara Pisani, a faster decrease over the last period occurred likely due to anthropogenic factors as the exploitation of river runoff and groundwater resources for agricultural and other consumptive uses. For another station, Ticino at Miorina, a runoff increase is observed, likely due to precipitation increase in that region and glacial runoff.

Patterns and trends of runoff changes are highly variable in the investigated area and this can be true worldwide. The impact of global warming on hydrology seems to be one of the most uncertain aspect of climate change. Also for this reason IAHR launched the CCHE-Climate Change impact on the Hydrological cycle, water management and Engineering project (Ranzi *et al.*, 2010) and this study was a small contribution to it.

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