The AdaptAlp Dataset: Description, guidance and analyses

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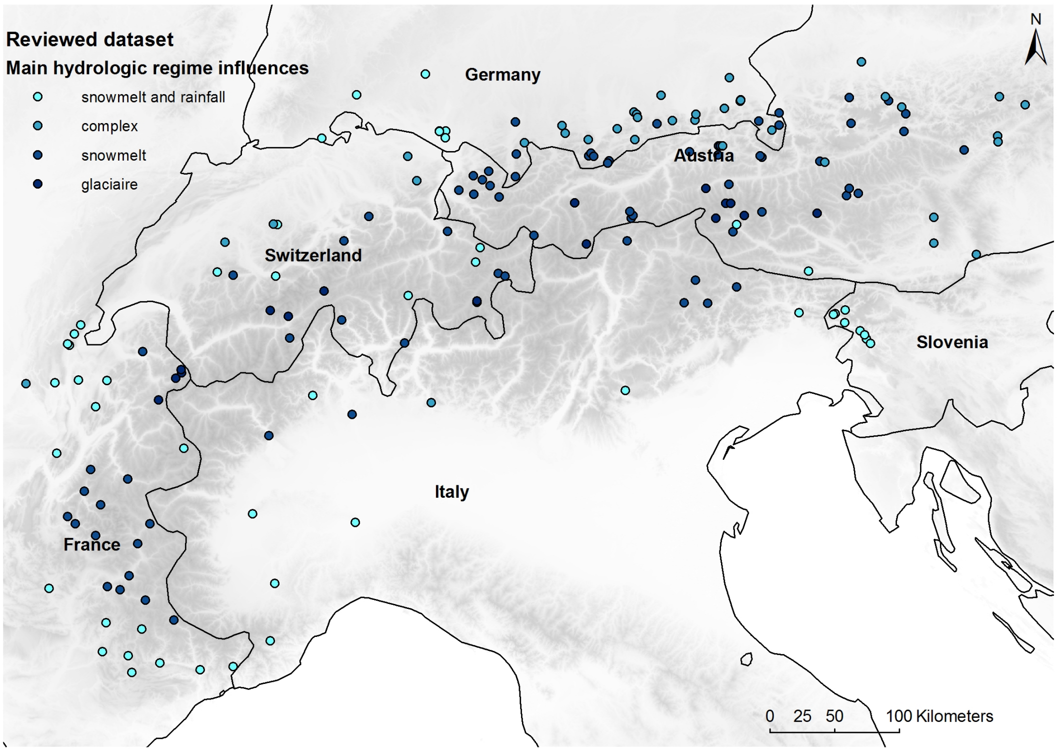

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Contents

I. Abstract

Detecting climate-related trends in hydrological series is a notoriously challenging task, in particular due to (i) the strong natural variability of hydrologic regimes; (ii) the existence of non-climatic factors that may induce trends in hydrologic series (e.g., water withdrawal, land use); (iii) the existence of non-homogeneities in the runoff records due to measurement issues. Reliable and powerful statistical methods for trend detection are required to address point (i), while points (ii) and (iii) suggest that trend detection should be based on a reliable dataset of homogeneous hydrologic series representing undisturbed catchments.

The study described in this report aims at detecting trends in the hydrologic regime of Alpine catchments. It is based on a dataset of 177 runoff time series collected over the Alpine space. These series cover at least forty years of daily record, are related to undisturbed catchments and have been quality-checked as thoroughly as possible by the partners of the project. The dataset covers the whole spectrum of hydrological regimes existing in the Alps (from glacier- to mixed rainfall/snowmelt regimes).

In a second step, a set of hydrologic indices is defined to characterize the hydrologic regime in terms of low, medium and high flow. In particular, these indices describe the drought severity and seasonality, and the intensity and timing of snowmelt flows.

At-site and regional statistical tests are applied for each hydrologic indice, and regional field significance is tested. Winter droughts tend to be less severe (in terms of volume and duration), while consistent trends affecting the timing of snowmelt flows are found. In particular, spring high flows due to snowmelt appear to start earlier in the season, and the duration of the snowmelt season is increasing.

II. Introduction

Mountain regions are important water towers for a significant part of the world's population. In the Alpine region, the Rhine, the Pô and the Rhône rivers flow from the Alps, which represent from 15% to 35% of their catchment areas, but contribute to about 30% to 50% of their total annual discharge [*Viviroli and Weingartner*, 2004]. Climate change is expected to have significant impact in mountain regions, both due to increasing temperatures and changing precipitation patterns [*IPCC*, 2007]. However, the evolutions observed so far in hydrologic series defy any global description, as highlighted by the studies of *Kundzewicz et al.* [2005] and *Svensson et al.* [2005] based on hydrologic stations worldwide. This lack of consistent result at a global scale led *Svensson et al.* [2006] to ask the following question : "*why is there no clear signal in observations*?".

Detecting climate-related trends in hydrological series is challenging for many reasons, amongst which the most important might be the following:

(i) River flow is the integrated response of many driving processes, including meteorological inputs (temperatures, precipitation), morphologic properties of the catchment (slopes, elevation), geological characteristics (groundwater in aquifers), etc. Consequently, hydrologic regimes present by nature a large inter-annual variability, which makes trend detection challenging from a statistical point a view, especially with short series.

(ii) In addition to the driving processes outlined above, many catchments are impacted by anthropogenic activities, including water withdrawal for irrigation or drinking water, dams for flood mitigation of hydro-electricity production, land use changes, etc. Unfortunately, it is rarely feasible to quantify the impact of these factors with precision, making such highly-anthropized catchments poorly suited to the detection of climate-related trends.

(iii) Measuring river discharge remains a difficult operation. In particular, ensuring the homogeneity of the measurement process over a long period is challenging, due to changes in measuring devices, changes in the rating curves, changes in the geometry of the measuring section, station relocations, etc. All these factors may create spurious trends in the hydrologic record.

The points above highlight the necessity to perform trend analyses using a thoroughly scrutinized and trustable dataset of long runoff time series, with good measurement quality and representing undisturbed catchments. The AdaptAlp dataset has been collected to fulfill these requirements.

This report describes the collection and utilization of the AdaptAlp dataset, which gathers daily runoff series from the six countries in the Alpine region: Austria, France, Germany, Italy, Slovenia and Switzerland. The report is organized as follows. Section III explains the strategy used to collect data, and describes the properties of the hydrologic stations forming the final dataset. Section IV describes the methods used to analyze the evolution of hydrologic regimes in the Alpine region. The results of this work are presented in Section V, and Section VI summarizes the main findings and discusses perspectives.

III. The AdaptAlp Dataset

III.1. Data collection and selection

The AdaptAlp dataset contains daily runoff series whose selection aimed at fulfilling the following requirements: (a) The catchment is geographically located in the Alps, and its regime is influenced (at least partly) by snowmelt; (b) the hydrologic station has been active over a period of at least 40 years, with a daily resolution; (c) the hydrologic station controls an "undisturbed" catchment where direct anthropogenic influences can be neglected; (d) the daily runoff series is free from any major non-homogeneity due to measurement issues.

The data collection was performed in two steps: a preliminary selection was first defined be selecting stations fulfilling requirements (a)-(d) above according to the meta-data information. In practice, one AdaptAlp partner per country made this selection in coordination with national data owners. This preliminary dataset contained series from 342 hydrologic stations from the following data owners:

- **Austria**: Bundesministerium für Land und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW), Hydrographisches Zentralbüro.
- **France**: Banque HYDRO (Ministry of ecology and sustainable development) + Electricité de France (EDF) + Compagnie Nationale du Rhône (CNR).
- **Germany**: Bayerisches Landesamt für Umwelt (LfU) and Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW).

- **Italy**: Agenzia Regionale per la Protezione Ambientale (ARPA) Piemonte + ARPA Lombardia + ARPA Veneto + ARPA Friuli Venezia Giulia + ARPA Valle d'Aosta + Ufficio Idrografico della Provincia Autonoma di Bolzano-Alto Adige.
- **Slovenia**: Environmental Agency of the Republic of Slovenia
- **Switzerland**: Federal Office for the Environment, Hydrology Division

The second step of the data selection strategy was to subject this preliminary dataset to a thorough scrutiny, in order to exclude stations violating any of the requirements (a)-(d) above. This was achieved as follows:

- Statistical tests for trends and step-changes were applied to several hydrologic indices for each station. The results were regrouped for each station into a "station summary sheet" (see example in Figure 1).
- Each summary sheet was inspected visually to identify stations presenting suspicious changes.
- A careful examination of the history of suspicious stations was undertaken in collaboration with the data owners in order to link these suspicious changes with particular events (e.g. station relocation, rating curve change, construction of a dam or other civil engineering structure, etc.).
- Stations where the change could be linked with a particular event were excluded from the dataset (e.g. changes appearing in Figure 1 were subsequently related to measurement problems and the station was hence excluded).

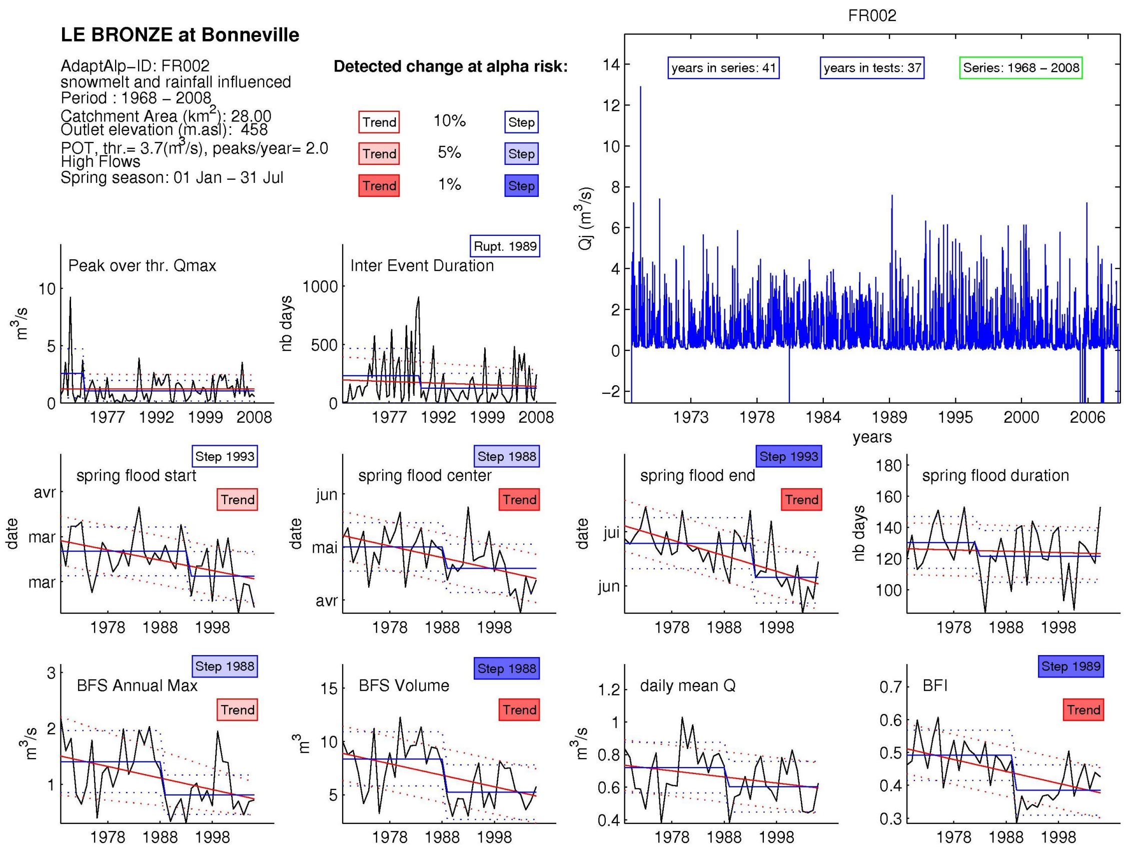


Figure 1. Example of a "station summary sheet" used to scrutinize data quality.

After this second selection step, the final dataset comprises 177 daily runoff series from stations located over the Alpine region as shown in Figure 2.

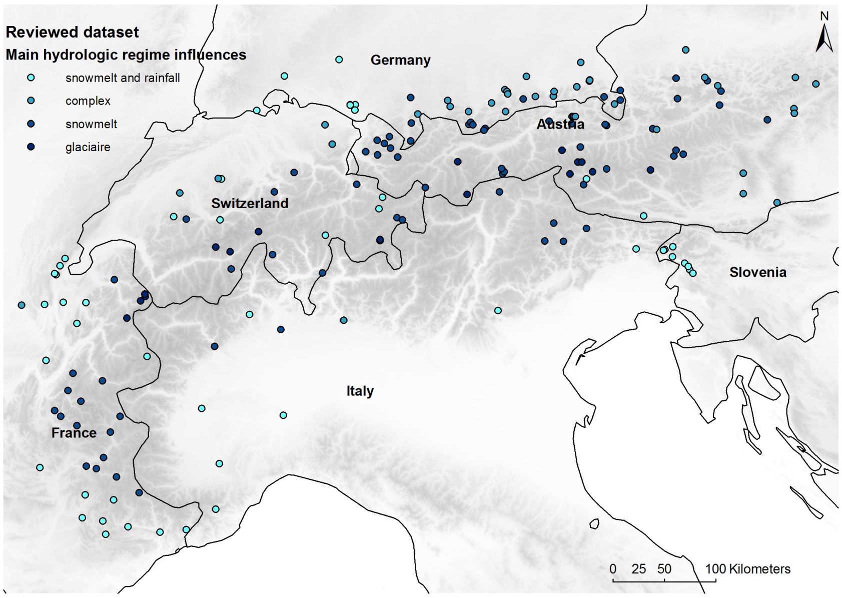


Figure 2. The AdaptAlp dataset (177 stations)

III.2. Description of gauging stations and catchments

In most European countries, gauging networks were developed in the 1950s and the 1960s. Consequently most of the records are available for the period 1961 – 2005. Figure 3 shows the contribution of each country of the Alpine space to the dataset.

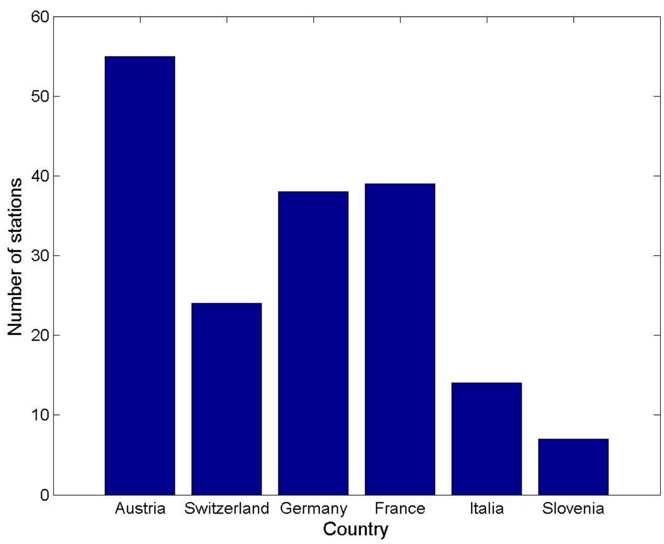


Figure 3. Origin of the 177 stations of the AdaptAlp dataset.

The relatively low contribution of Italian data might appear surprising at first sight. It can be explained by a reorganization of hydrological services in the country (moving from a national to a regional organization), resulting in a lack of homogeneity of long series and important periods of missing data, especially in the 1980s. However, discussions with Italian data owners revealed that many long series exist in the country, but in a paper format. Consequently, a digitalization campaign was undertaken, resulting in the digitalization of 10 long series using a optical character recognition (OCR) software. This digitalization is time-consuming (OCR-derived series need to be verified) and could not be extended beyond the 10 retrieved series. However, there is scope to improve the Italian contribution to the dataset given that many other long series exist in the hydrologic annals.

10 - PO a MONCALIERI (Meirano) (Mr) (1) *Anno 1979*

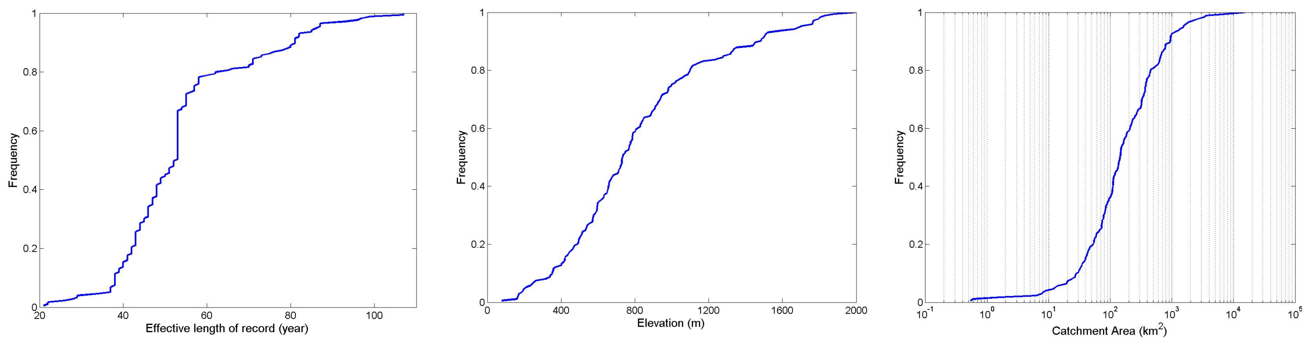
CARATTERISTICHE DELLA STAZIONE: Bacino di dominio km² 4885 (permeabile per circa il 46%), di cui km² 0.81 di aree glaciali. Serbatoi artificiali m³ 13.000.000. Altitudini: max 3841 m.s.m. (Monviso); media 950 m.s.m.. Distanza dalla foce in mare km 592. Idrometro di Meirano inizio osservazioni: giu.1931; inizio misure: gen.1927. Quota zero idrometrico 214.22 m.s.m..Altezze idrometriche: max m 6.63 (4 mag.1949); minima m -1.29 (25 ago.1962). Idrometrografo di Moncalieri:inizio osservazioni: lug. 1963. Quota zero idrometrico 212.49 m.s.m.. Altezze idrometriche: max m 7.50 (20 mag.1977); minima m 0.68 (12 set.1964). Portate: max m³/s 2230 (4 mag.1949); minima m³/s 9.0 (8-9 ago.1929); media m³/s 82.7 (1927 ÷ 1979).

PORTATE MEDIE GIORNALIERE IN m^3/s

Giorno	Gennaio	Febbraio	Marzo	Aprile	Maggio	Giugno	Luglio	Agosto	Settembre	Ottobre	Novembre	Dicembre
1	63.4	60.6	70.8	74.6	69.8	80.7	56.1	38.0	49.5	49.5	112.0	63.4
2	61.5	57.9	68.9	72.7	68.0	101.0	80.0	37.4	46.5	49.5	101.0	61.5
3	59.6	57.9	66.2	72.7	69.8	117.0	144.0	37.4	46.5	49.5	98.9	61.5
4	59.6	56.1	65.3	72.7	70.8	109.0	109.0	36.8	46.5	49.5	91.7	61.5
5	57.9	56.1	65.3	74.6	68.9	112.0	94.1	36.8	45.1	57.9	87.2	61.5
6	56.1	57.9	65.3	70.8	63.4	117.0	87.2	37.4	43.7	59.6	87.2	61.5
7	54.4	57.0	65.3	68.9	63.4	114.0	76.6	36.3	43.7	56.1	85.0	61.5
8	56.1	56.1	65.3	67.1	67.1	104.0	66.2	45.1	41.0	52.7	82.8	61.5
9	56.1	56.1	64.3	65.3	63.4	96.5	59.6	39.8	41.0	51.9	78.6	60.6
10	57.9	56.1	64.3	67.1	61.5	89.5	54.4	37.4	41.0	51.1	78.6	57.9
11	57.9	61.5	63.4	70.8	59.6	87.2	49.5	36.3	43.7	57.9	74.6	59.6
12	57.0	120.0	65.3	74.6	57.9	78.6	46.5	36.3	49.5	85.0	70.8	59.6
13	56.1	80.7	72.7	69.8	59.6	76.6	45.1	37.4	49.5	91.7	72.7	57.9
14	57.0	70.8	78.6	67.1	65.3	78.6	45.1	37.4	48.8	133.0	72.7	57.9
15	51.9	66.2	130.0	64.3	70.8	74.6	43.7	36.3	48.0	214.0	85.0	57.9
16	51.1	120.0	282.0	65.3	70.8	67.1	41.7	36.8	46.5	204.0	90.6	57.9
17	51.1	325.0	128.0	69.8	68.9	63.4	42.3	35.2	48.0	221.0	78.6	56.1
18	51.1	296.0	100.0	78.6	65.3	61.5	41.0	39.8	48.0	177.0	74.6	56.1
19	51.1	151.0	85.0	72.7	63.4	56.1	39.8	86.4	48.0	134.0	74.6	57.9
20	51.1	122.0	171.0	70.8	64.3	56.1	39.8	78.6	46.5	114.0	76.6	56.1
21	51.1	112.0	128.0	68.9	102.0	54.4	38.6	61.5	49.5	101.0	74.6	56.1
22	52.7	91.7	98.9	68.9	91.7	51.1	38.6	54.4	52.7	96.5	70.8	65.3
23	52.7	85.0	89.5	68.9	80.7	49.5	39.8	56.1	57.9	96.5	70.8	101.0
24	56.1	82.8	85.0	74.6	82.8	48.0	39.8	54.4	52.7	104.0	68.0	72.7
25	57.0	74.6	82.8	74.6	78.6	48.0	38.6	52.7	54.4	96.5	67.1	70.8
26	57.9	72.7	87.2	74.6	72.7	46.5	38.6	51.1	52.7	87.2	65.3	68.9
27	56.1	72.7	94.1	79.7	65.3	46.5	38.0	51.1	51.1	111.0	65.3	72.7
28	59.6	70.8	90.6	72.7	68.9	54.4	37.4	52.7	51.1	184.0	65.3	69.8
29	64.3		87.2	70.8	70.8	61.5	37.4	52.7	50.3	161.0	64.3	66.2
30	67.1		82.8	68.9	74.6	59.6	38.6	51.1	49.5	134.0	63.4	63.4
31	63.4		76.6		76.6		37.4	51.1		122.0		63.4

Figure 4. Example of digitalization of data in hydrologic annals for Italian stations.

Figure 5 shows the effective length of record (i.e. after removal of missing values) of the 177 series. The majority of the stations provide between 40 and 50 years of daily data, with a few series effectively shorter than 40 years (due to missing data) and a few very long series, with more than 80 years of data. The gauging station elevations are mostly comprised between 400 and 1200 m. Catchments of varied size are represented in the dataset, with the majority of catchments having an area comprised between 100 and 1000 km².



(a) *(b)* *(c)*

Figure 5. Properties of the AdaptAlp dataset: distribution of effective record length (a), station elevation (b) and catchment area (c).

III.3. Hydro-climatic regions

The diversity of catchments in the dataset leads to a mixture of hydrological regimes. The whole spectrum of Alpine regimes is indeed represented in the dataset, from pure glacier and snowmelt regimes to mixed rainfall-snowmelt regimes. In order to allow regime-specific trend analyses, a classification of catchments is carried out. It is performed by computing the inter-annual monthly streamflow for each station, and clustering stations with similar monthly streamflow patterns into homogeneous classes. The Kohonen clustering method [*Wehrens and Buydens*, 2007] is used for this purpose, and leads to nine clusters represented in Figure 6.

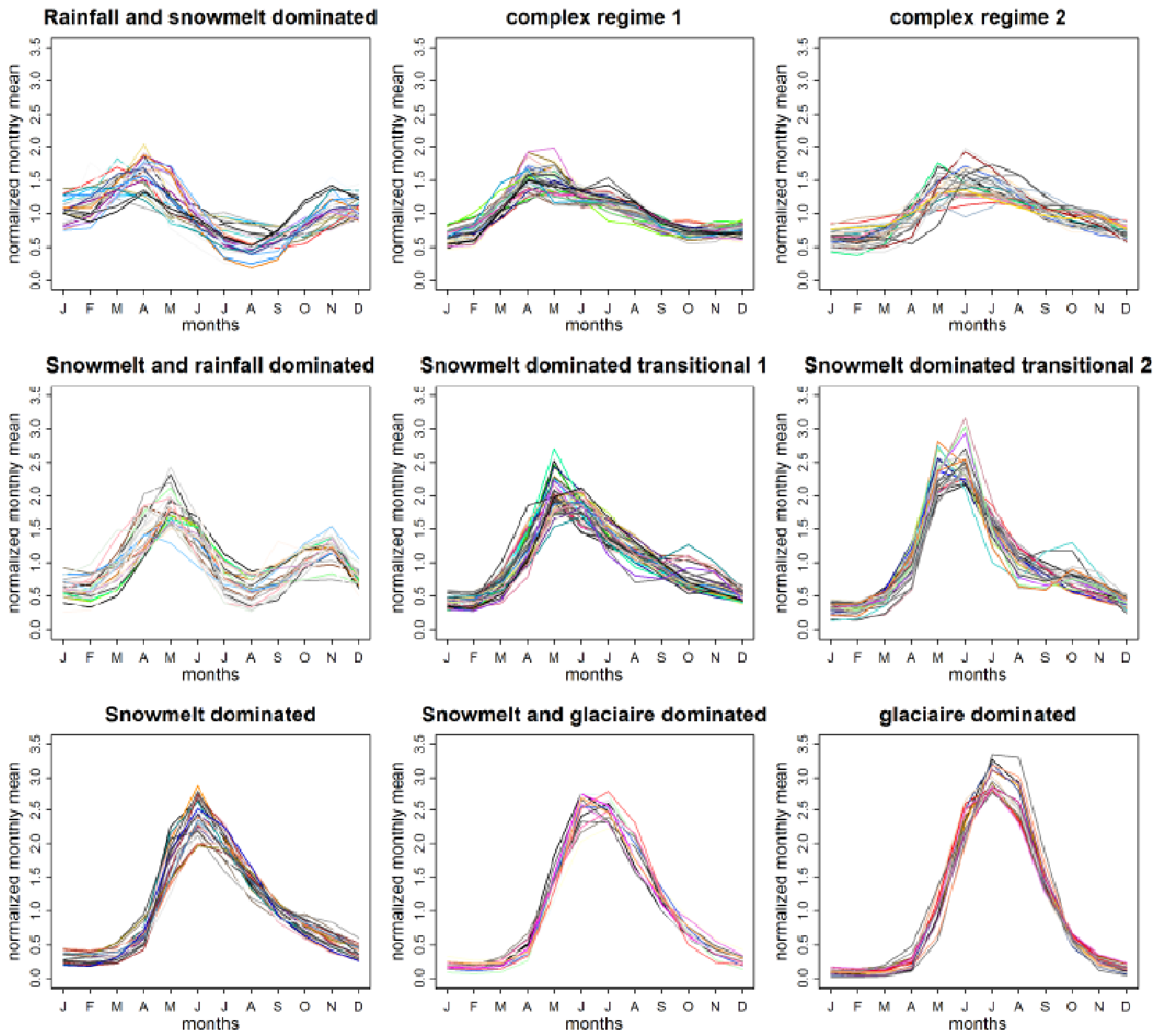


Figure 6. Illustration of the nine hydrologic regimes identified in the AdaptAlp dataset. Each line represents the inter-annual monthly streamflow of one particular station (after standardization by the inter-annual mean).

In addition to the classification into hydrological regimes, the Alps are divided in four climatic regions (Figure 7), as defined in the HISTALP project using an historical climatic database [*Auer et al.*, 2007]. This classification is derived by considering several climatic variables, including normalized air pressure, air temperature, precipitation, cloudiness, and sunshine duration. The climatic and hydrologic classifications are complementary because the former creates homogenous regions for the main climatic forcings of river streamflow, while the latter ensures the homogeneity of the hydrologic regimes at the catchment scale. Consequently, both classifications will be combined to create homogeneous hydro-climatic regions, regrouping catchment with similar hydrologic behavior and forced by similar climatic drivers.

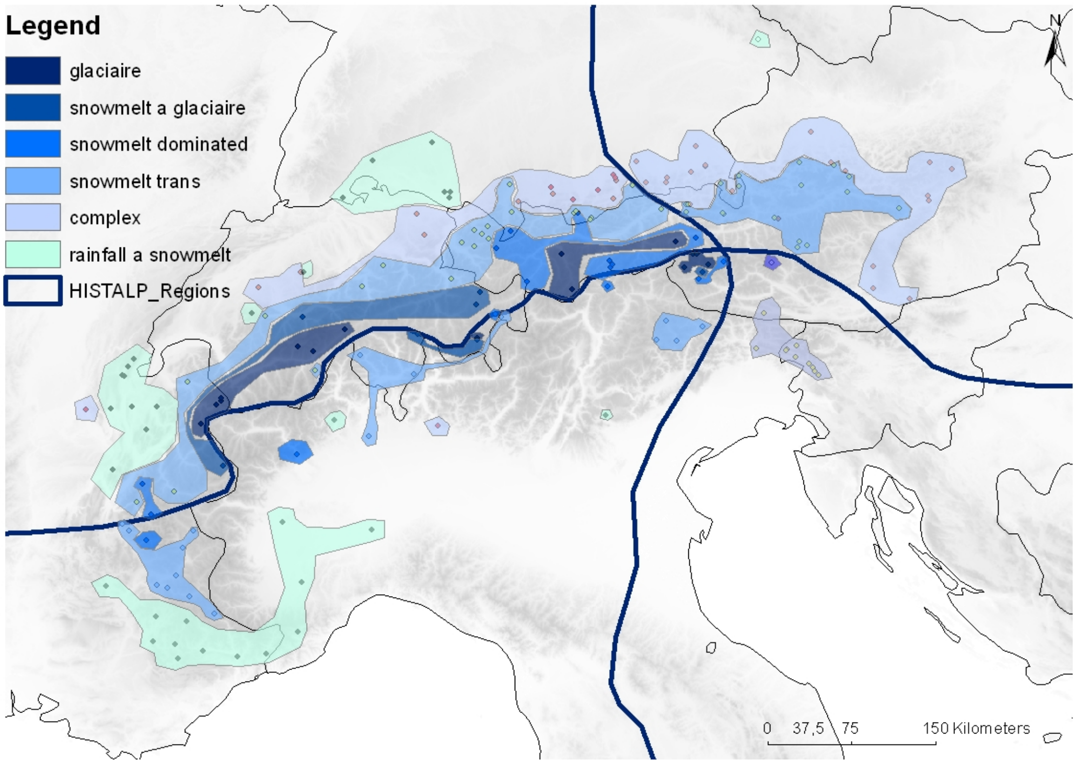


Figure 7. The four HISTALP climatic regions as defined by *Auer et al.* [2007]: North-West (NW), South-West (SW), South-East (SE) and North-East (NE), and the classification of the stations in the AdaptAlp Dataset into hydrological regimes .

IV. Methods

IV.1. Hydrologic indices

The trend analysis carried out on the AdaptAlp dataset focuses on winter low flows and spring snowmelt-related high flows. Both phenomena are described by hydrological indices describing the magnitude and seasonality of high and low flows. Medium flows are also analyzed through two additional indices.

"Hydrological years" are defined and will be subsequently used to compute the indices:

- For glacier and snowmelt-dominated regimes, the "high flow year" starts in February and the "low flow year" starts in June.
- For mixed regimes (with both snowmelt and rainfall influences), the "high flow year" starts in January and the "low flow year" starts in May.

IV.1.1 Low flow indices

Droughts are defined using a low-threshold approach [e.g. *Fleig et al.*, 2006]: a low-flow threshold equal to the 15%-quantile of the flow duration curve is first defined for each station. Three indices describing the drought severity are then defined as illustrated in Figure 8: the annual volume deficit, the annual drought duration and the annual minimum streamflow. In addition, three timing indices describing the drought seasonality are calculated: the "drought start" is defined as the date at which the volume deficit reaches 10% of the annual volume deficit. Similarly, the "drought center" and the "drought end" correspond to 50% and 90% of the total volume deficit.

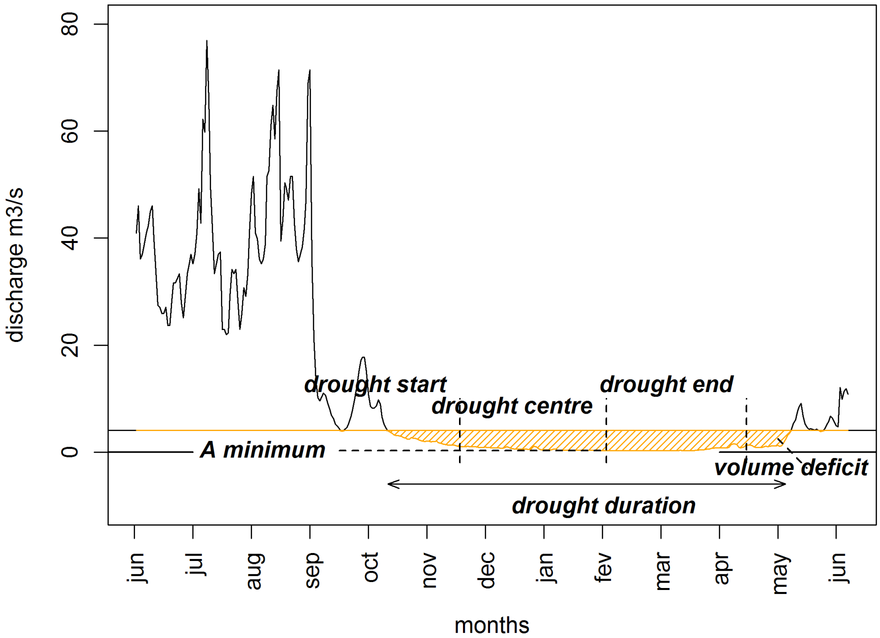


Figure 8. Definition of low flow variables.

IV.1.2 Snowmelt flow indices

For high flows, this study focuses on snowmelt-related streamflow occurring in spring and summer. For this purpose time series are first filtered in order to minimize the influence of isolated rainfall-induced peaks overlaid on top of the snowmelt-induced runoff. The base flow separation (BFS) method proposed by *Tallaksen and Van Lanen* [2004] is used for this purpose. Two indices characterizing the snowmelt streamflow intensity are defined: the annual maximum value of the baseflow and the annual baseflow volume. Three seasonality indices are defined similarly as section IV.1.1: the high flow start, centre and end correspond to the dates at which 10%, 50% and 90% of the annual baseflow volume is reached, respectively. Lastly, the spring flood duration is calculated as the time between the start and the end of the high flow period.

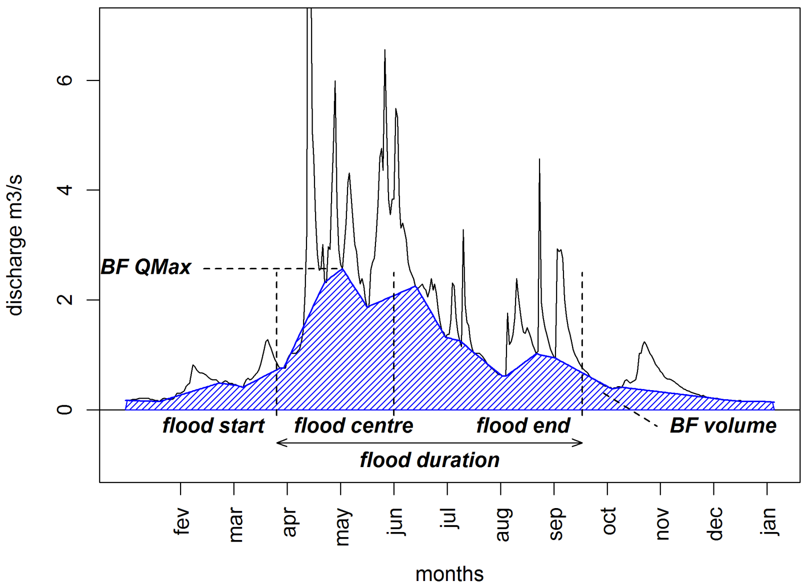


Figure 9. Definition of high flow variables.

IV.1.3 Other indices

Two additional indices are considered to characterize medium flows: the annual mean flow (AMF) and the base flow index, defined as the ratio between the annual baseflow volume and the annual total volume.

IV.2. Statistical tests

The trend detection analysis is performed by applying statistical tests to the time series of hydrologic indices defined in previous section IV.1.

IV.2.1 At-site test

The Mann-Kendall trend test [*Mann*, 1945; *Kendall*, 1975] is used for at-site trend detection. This test was selected because it is distribution-free, i.e. it does not require making any distributional assumption. However, this test does assume independent data, which may not be the case for some of the studied indices (especially low-flow indices). Consequently, the “modified” Mann-Kendall test proposed by *Hamed and Rao* [1998] is implemented.

IV.2.2 Field Significance

When applying a statistical test to a large number of series with a 10% error level, it is expected to detect about 10% of significant trends, even in the absence of any change in the series. Consequently, at-site testing is complemented with an evaluation of the field significance of the results, which allows answering the following question: what is the minimum number of significant at-site trends to consider that they cannot all be due to chance? The Bootstrap procedure proposed by *Douglas et al.* [2000] is used for this purpose.

IV.2.3 Regional test

Although an assessment of field significance is necessary to qualify detected trends at a regional level, it does not allow evaluating the consistency of changes within a homogenous hydro-climatic region. As an illustration, if a region is affected by numerous trends in both upward and downward directions, it will be declared “field significant” despite a lack of consistency in detected trends. However, in the context of detecting climate-related trends, one would expect that catchment with similar behavior, and located in the same climatic region, should respond in a similar way to an evolution of climate forcings. Consequently, the regional consistency of trends is studied by applying a specific test proposed by *Renard et al.* [2008]. In a nutshell, this test attempts to detect a common trend for a set of stations located in the same hydro-climatic region, but will not detect trends that are not consistent across the region.

V. Results

All tests described in previous section IV.2 are applied with an error level equal to 10%. At-site tests are applied on series restricted to the common period 1961 – 2005, leading to the analysis of 126 to 140 stations (depending of the stations quality for low, medium, or high flows). The period of study for the regional test is region-specific in order to optimize the number of stations available for each hydro-climatic region. However, these periods broadly cover the same period 1961-2005. The acceptable annual missing value rate is set to 0.5%, with years not fulfilling this requirement being considered as missing values.

V.1. Low flows

Winter drought severity appears to decrease overall (Figure 10): volume deficit (a) and drought duration (c) are indeed decreasing for 25% and 26% of stations, respectively, while annual minimum (c) is increasing for 25% of stations. By contrast, seasonality indices show fewer changes, with the exception of the drought end (f) which tends to occur earlier for 21% of stations. Note that there are nearly no Italian stations in Figure 10: this is due to extended periods of missing values in the 1980s as mentioned previously, corresponding to the reorganization of hydrologic services. By restricting the analysis to a common period 1961-2005, those stations could not be considered in the analysis. However, Italian stations are included in the regional analysis (Figure 11, mostly in climatic region SW), since using region-specific periods allows more flexibility in the selection of stations.

Figure 11 allows considering these results at the scale of hydro-climatic regions: glacier- and snowmelt-dominated regimes present several regionally significant trends towards less severe droughts. Conversely, stations with regime “rainfall-snowmelt 2” in the SE climatic region present the opposite trend, towards more severe droughts. In terms of seasonality, regionally consistent downward trends are detected for regimes “snowmelt 2, snowmelt 3 and composite 2”, while opposite trends are detected for snowmelt-rainfall regimes in the SE region.

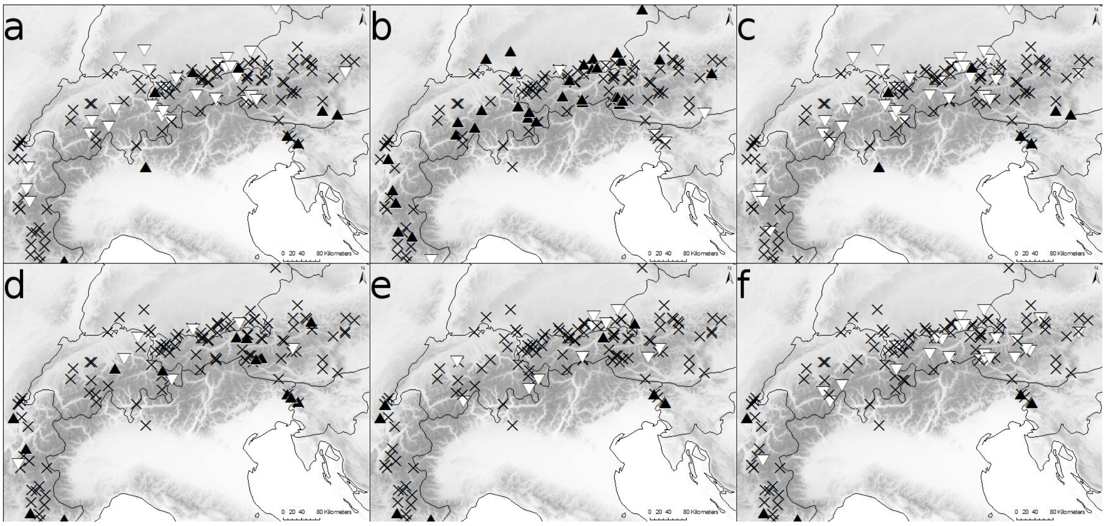


Figure 10. Results of at-site trend tests results (∇ = downward, ▲= upward, x = not significant) for low flow : (a) volume deficit, (b) annual minimum, (c) drought duration, (d) drought start, (e) drought center, (f) drought end.

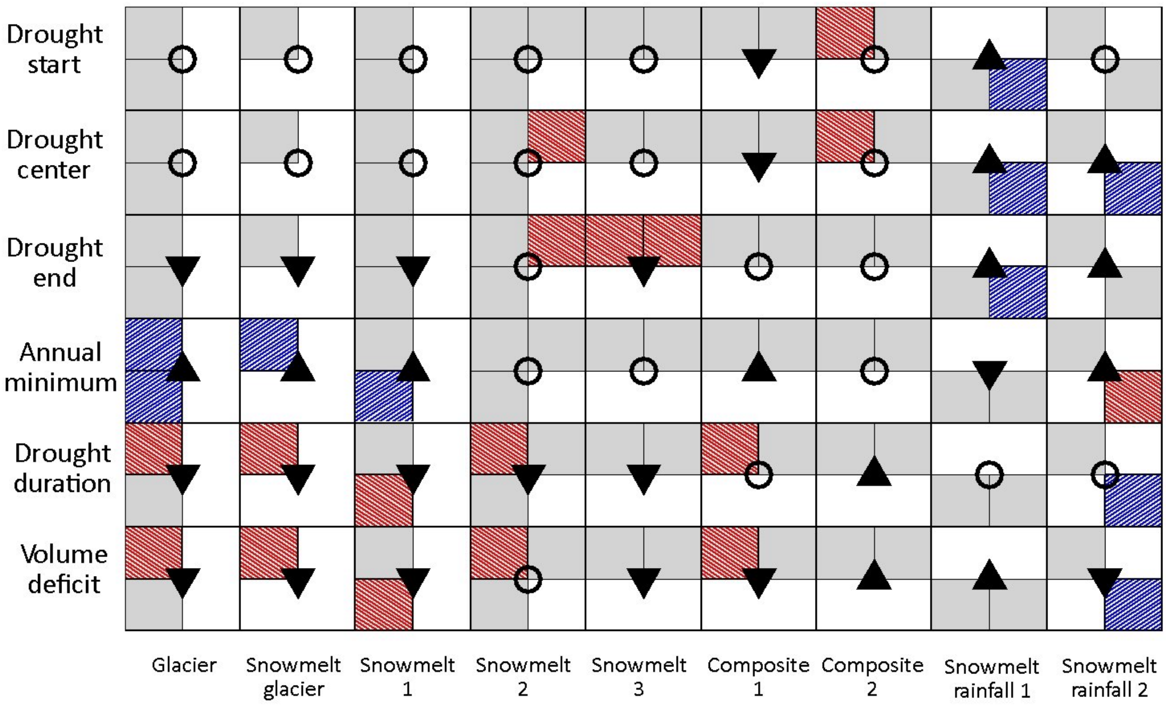


Figure 11. Results of the regional test for low flow. Rows represent hydrologic indices, columns represent hydrologic regimes. Each regime is divided into four squares representing the four HISTALP climatic regions (NW, SW, SE and NE), thereby representing hydro-climatic regions. Grey square = non-significant regional trend, red square = significant downward regional trend, blue square = significant upward regional trend, white square = no station for this climate/regime combination. ▲= at-site upward trends are field significant, ▼ = at-site downward trends are field significant, O = at-site trends are not field significant.

V.2. Snowmelt flows

At-site results do not reveal any generalized change for snowmelt-related flows intensity (Figure 12 a-b). However, a focus on glacier-influenced regimes highlights significant trends: high flow volume is increasing (a, 93% of glacier-influenced stations), as well as annual maximum of snowmelt flows (b, 47% of glacier-influenced stations). Regional results (Figure 13) confirm these observations, with regionally consistent upward trends detected on these variables for glacier-influenced regimes.

The duration of the snowmelt season shows an overall increase over the Alps (Figure 12c, 49% of stations), partly explained by an earlier start (Figure 12d, 49% of stations). At the scale of hydro-climatic regions (Figure 13), snowmelt-influenced regimes are the most impacted by the increased in duration and precocity of the snowmelt season, with several regionally significant trends detected on those indices.

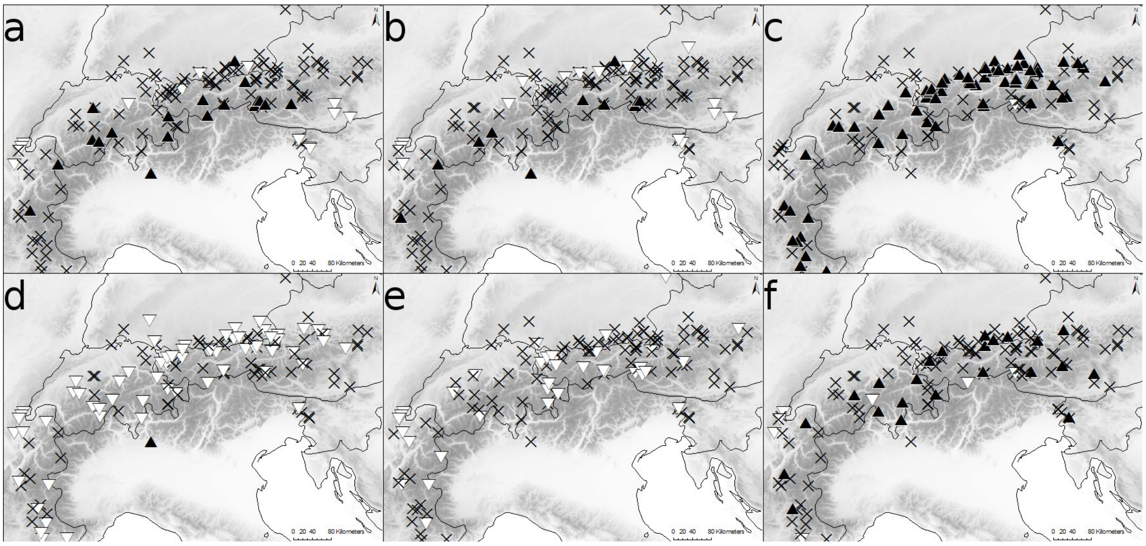


Figure 12. Results of at-site trend tests results (∇ = downward, ▲= upward, x = not significant) for high flow : (a) snowmelt volume, (b) snowmelt annual maximum, (c) snowmelt duration, (d) high flow start, (e) high flow center, (f) high flow end.

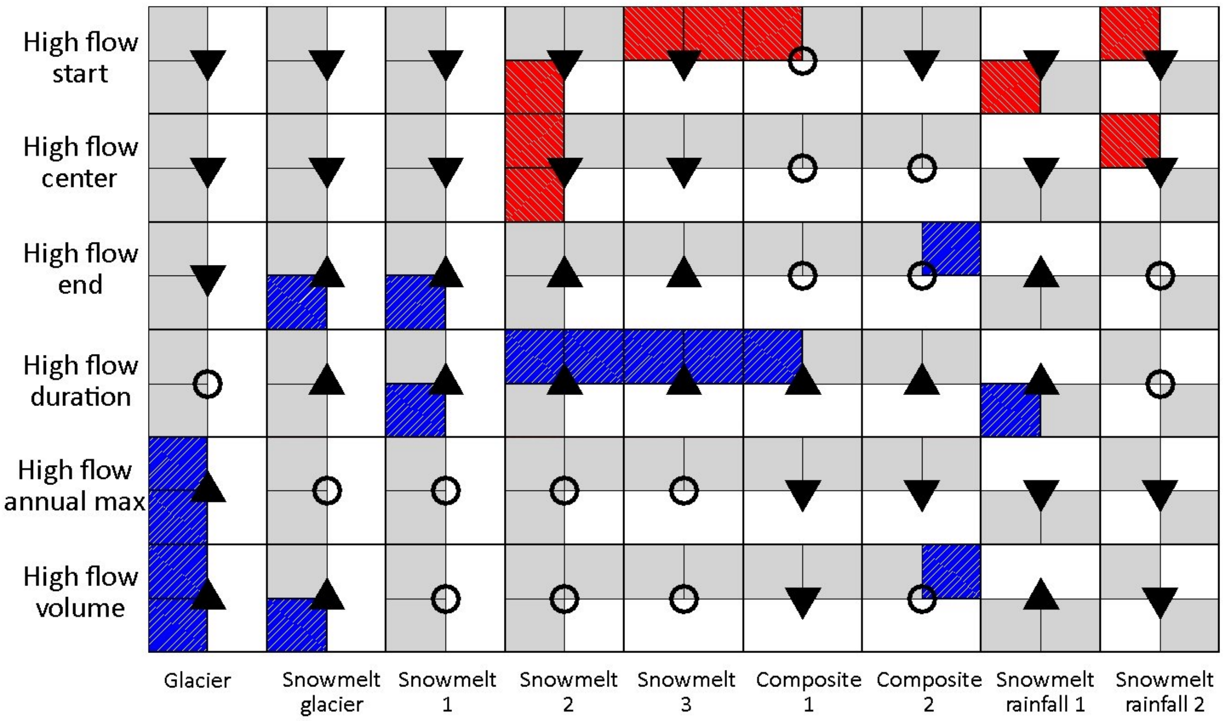


Figure 13. Same as Figure 11 for high flow.

V.3. Other indices

Results for medium flows show few significant results at the scale of the Alps (Figure 14). The only exception is the glacier regime, with significant trends toward increasing BFI and annual mean flow being detected for 62% and 77% of stations, respectively.

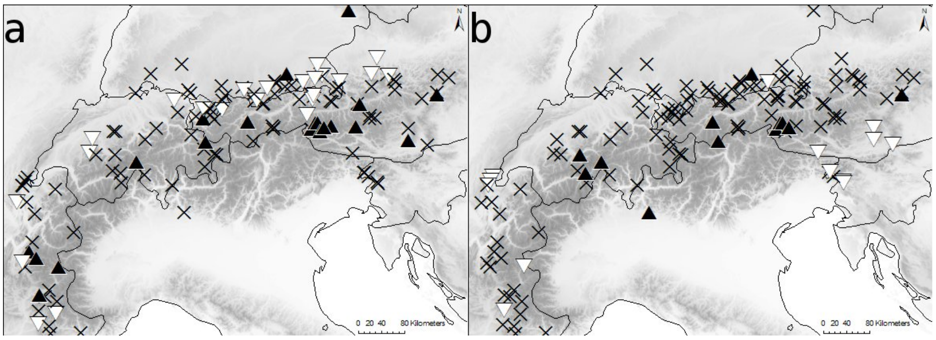


Figure 14. Results of at-site trend tests results (∇ = downward, ▲= upward, x = not significant) for medium flow : (a) BFI, (b) Annual mean flow.

VI. Conclusions

The work carried out by AdaptAlp partners led to the gathering of a hydrologic dataset well suited to the detection of climate-related trends in the hydrologic regime of Alpine catchment. The AdaptAlp dataset comprises 177 long series of daily runoff collected over the Alpine space. These series cover at least forty years of daily record, are related to undisturbed catchments and have been thoroughly quality-checked by the partners of the project. The dataset covers the whole spectrum of hydrological regimes existing in the Alps (from glacier- to mixed rainfall/snowmelt regimes). Part of this dataset will be made available in the next future through the Global Runoff Database Center (GRDC: http://www.bafg.de/GRDC/EN/Home/homepage__node.html).

Statistical tests were applied to the stations of this dataset at the local and regional scales. The main significant trends can be summarized as follows:

- **Winter droughts**:
  - Severity tends to decrease for glacier- and snowmelt-dominated regimes.
  - A slight shift (towards more precocity) is detected for snowmelt and composite regimes in Northern Alps.
  - Mixed snowmelt-rainfall regimes in South-Eastern Alps (mostly Slovenian stations) show the opposite evolution: severity tends to increase and seasonality seems shifted towards more lateness.
- **Spring snowmelt-related high flows**:
  - An increase in the volume and peak of snowmelt flows is detected for glacier regimes.
  - An increase in the duration of the snowmelt season is detected for snowmelt regimes, along with an increased precocity of the beginning of the snowmelt season.
- **Medium flows**:
  - Glacier regimes show increasing mean annual flow and increasing base flow index.

Note that the analyses carried out in this study do not establish a formal link between the detected trends and climate change: this would require an additional attribution study [see the distinction between *detection* and *attribution* made by *IPCC*, 2007]. However, the consistency of detected trends at least suggests that the changes are unlikely to be linked with measurement issues, and are more likely climate-related. Whether these evolutions are linked to climate change or to climate decadal variability remains an open question, which cannot be answered on the sole ground of the analyses described in this report. The AdaptAlp dataset offers an attractive opportunity to study in further depth the relationship between climate and catchment hydrology at the Alpine scale.

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