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Variability in snow depth time series in the Adige catchment

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ABSTRACT

Study region: The Upper and Middle Adige catchment, Trentino-South Tyrol, Italy.
Study focus: We provide evidence of changes in mean seasonal snow depth and snow cover duration in the region occurred in the period from 1980 to 2009.
New hydrological insights for the region: Stations located above and below 1650 m a.s.l. show different dynamics, with the latter experiencing in the last decades a larger reduction of average snow depth and snow cover duration, than the former. Wavelet analyses show that snow dynamics change with elevation and correlate differently with climatic indices at multiple temporal scales. We also observe that starting from the late 1980s snow cover duration and mean seasonal snow depth are below the average in the study area. We also identify an elevation dependent correlation with the temperature. Moreover, correlation with the Mediterranean Oscillation Index and with the North Atlantic Oscillation Index is identified.

1. Introduction

Seasonal snow cover duration and mean seasonal snow depth have received significant attention in studies dealing with climate change (Gobiet et al., 2014; Beniston and Stoffel, 2014), hydrology (Barnett et al., 2005; Berghuijs et al., 2014; Schneeberger et al., 2015), nitrogen and carbon cycle (Williams et al., 1998; Euskirchen et al., 2006), ecosystem functioning (Keller et al., 2005), soil processes (Groffman et al., 2001) and economy (Steiger and Stötter, 2013; Beniston, 2012a). Most of the existing studies focus on the Swiss and Austrian Alps (e.g. Beniston, 1997; Hantel et al., 2000; Schöner et al., 2009; Marty, 2008; Laternser and Schneebeli, 2003; Beniston et al., 2003). Much less attention has been devoted to the Southeastern Alps, in the Italian territory (Bocchiola and Rosso, 2007; Valt and Cianfarra, 2010; Terzago et al., 2010; Pistocchi, 2016), despite the importance of snow dynamics in timing water resources availability (Chiogna et al., 2016; Callegari et al., 2015), streamflow generation (Penna et al., 2013, 2017; Chiogna et al., 2014; Engel et al., 2016) and ecosystem functioning (Lencioni et al., 2011; Esposito et al., 2016).

In this paper, we analyze the dataset available covering the Adige catchment and five surrounding stations highly correlated with those within this river basin. We focus on the period of 1980–2009, which is the richest of data for the area investigated. Furthermore, the analysis of snow dynamics in this time frame is of particular interest, since the 1990s have been an unusually warm and dry period for this region (Brunetti et al., 2009). Deepening the knowledge of snow dynamics South of the main Alpine ridge is relevant because it is influenced by a meteorological circulation pattern that differs from the territories in the northern side of the mountain chain (Xoplaki et al., 2004; Buzzi and Tibaldi, 1978). Owing to the different circulation patterns, different snow dynamics may be observed in the two regions, and the validity of the outcomes obtained for the Swiss and Austrian Alps does not necessarily apply also to the Italian Alps. Moreover, the Adige catchment can be assumed as representative of the Southern Alpine ridge.

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First, we study the difference of the behavior of stations above and below 1650 m a.s.l. and the changes in mean seasonal snow depth and snow cover duration occurred after 1987, showing that temperature changes may explain the observed snow dynamics, in particular for low elevation sites. Then, we perform a wavelet analysis (Torrence and Compo, 1998) of the mean seasonal snow depth and of the snow cover duration at four elevation classes (below 1350 m a.s.l., between 1350 m a.s.l. and 1650 m a.s.l., between 1650 m a.s.l. and 2000 m a.s.l. and above 2000 m a.s.l.). This allows us to identify changes occurring in the snow depth and snow cover duration signals at various temporal scales. Finally, we apply the wavelet coherence analysis (Grinsted et al., 2004) in order to investigate the relationship between the variations of the mean seasonal snow depth and that of climate indices such as the North Atlantic Oscillation Index (Hurrell, 1995) and the Mediterranean Oscillation Index (Palutikof, 2003). Several studies tried to link the North Atlantic Oscillation Index (NAOI) to the snow variability in order to explain it, however these results are not univocal (Scherrer and Appenzeller, 2006; Schöner et al., 2009; Scherrer et al., 2004; Durand et al., 2009; Beniston, 1997).

Section 2 describes the study area and the dataset available for this study, Section 3 is devoted to the description of the results, which are then discussed in Section 4, and finally Section 5 summarizes the conclusions.

2. Material and methods

2.1. Study area

The Adige catchment is one of the most important river basins in Italy, mainly for its large catchment area (12,100 km^2) and length (409 km) and for its hydropower generation. A recent review of Chiogna et al. (2016), described the hydrological conditions in the catchment and its chemical and ecological status in details. The most important tributaries of the Adige catchment are located in the Alpine part of the basin, and hence they are strongly influenced by snow dynamics (Mei et al., 2014; Tuo et al., 2016). An increasing concern is rising due to the effects of climate change in this area, since this has already shown important implications for water resources management, and above all, for hydropower production and for winter tourism (Majone et al., 2016). In terms of atmospheric circulation, the Adige catchment is mainly affected by southwest weather patterns and lee cyclones (Xoplaki et al., 2004; Buzzi and Tibaldi, 1978). Brunetti et al. (2006a, 2009) observed a slight negative trend in precipitation for the South Western area of the Greater Alpine Region. The Adige river basin belongs to this area, however, more recent studies, specifically addressing precipitation trends in the river catchment (Lutz et al., 2016; Adler et al., 2015) did not identify significant trends. Moreover, Adler et al. (2015) indicates two additional drawbacks of the precipitation dataset available for the study area. The first is that very few stations are available for elevations above 2000 m a.s.l. The second is the significant underestimation of winter precipitation due to undercatch of the rain gauges during snowstorms. Therefore, in this study we will not investigate the correlation between snow and the available precipitation dataset. Brunetti et al. (2006a,2009 observed a positive and statistically significant temperature trend in the river basin. Moreover, the quality of the available time series was verified (see e.g. Adler et al., 2015). Therefore, we focus our analysis on the correlation between temperature and snow.

2.2. Description of the dataset

Snow depth time series of meteorological stations located in the Adige catchment are a relevant source of information to study snow dynamics in the Alpine region (Fig. 1) because of their spatial distribution over a wide elevation range and time spanning. In order to extend the dataset as much as possible we included five additional stations (Malga Bissina, Caoria, Brocon – Marande, San Martino di Castrozza and Sexten), which are outside the catchment, but very close to its boundaries. This choice was justified by the high correlation ($r > 0.9$) of the time series at similar elevations in this region. The dataset is therefore composed by 37 stations. The stations have been grouped into four elevation classes, as shown in Table S1: below 1350 m a.s.l. (14 sites), between 1350 m and 1650 m a.s.l. (12 sites), between 1650 m and 2000 m a.s.l. (7 sites) and above 2000 m a.s.l. (4 sites).

The dataset consists of daily data for the period 1st November–30th April between two successive years of the time series. Conventionally, we attributed this period to the starting year, e.g. the season 1990 is intended to be comprised between 1st November 1990 and 30th April 1991. The time series may be formed by merging data obtained at stations which may have been relocated during the period from 1980 to 2009. Moreover, the time series are formed merging data from three different sources, according to quality indices criteria (Marcolini et al., 2017). Before the merging operation, we have checked the quality of the data. The highest quality index was assigned to manual data (measured from operators directly in the field), the second highest to automatic data (measured from automatic instruments), while historical data (collected from different sources, such as the Zentralanstalt für Meteorologie und Geodynamik (ZAMG) of Vienna and the Hydrographic office of the Province of Trento) are considered the least reliable, because measuring procedures and station locations are not always well documented. The merging of the data was performed to obtain single and longer time series for each site. Short gaps in the time series (i.e., shorter than 14 days), were filled by support vector machine regression (Smola and Schölkopf, 2004) performed by applying the Matlab toolbox Spider (http://www.kyb.tuebingen.mpg.de/bs/people/spider/), which uses the snow depth of the two best correlated stations and, if available, snowfall, temperature and precipitation data of the examined stations, as input variables for the regression.

Verifying the homogeneity of the time series is an important prerequisite for detecting trends and investigate climatic changes. Therefore, breakpoints in the time series (Auer et al., 2007; Brunetti et al., 2006a) caused by station relocation or merging of different sources should be detected before carrying on further analyses. In this article, we only consider homogenous time series in the period from 1980 to 2009. To check for homogeneity of available snow depth time series, we applied the Standard Normal Homogeneity Test (SNHT) (Alexandersson and Moberg, 1997; Alexandersson, 1986; Marcolini et al., 2017).