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Hydrological response to an abrupt shift in surface air temperature over France in 1987/88

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SUMMARY

During the last few decades, Europe has seen a faster increase of observed temperature than that simulated by models. The air temperature over Western Europe showed an abrupt shift at the end of the 1980s, still insufficiently documented. The aim of this study is to assess the characteristics of this shift and its potential impacts on the hydrological cycle over France. Such an assessment is essential for a better understanding of past and future climatic changes and their impact on water resources.

A subset of 119 temperature, 122 rainfall, and 30 hydrometric stations was studied, over the entire French metropolitan territory. Several change-point detection tests were applied to temperature, rainfall and runoff time series.

A shift in annual mean air temperature was detected in 1987/88, for more than 75% of the stations, and for both minimum and maximum temperatures. An abrupt increase of about 1 °C in minimum and maximum temperature provides evidence of this shift, which shows strong seasonality, with significant increases for DJF, MAM and JJA. Its detection is not affected by the length of the time series or any potential artefacts associated to the conditions of measurement.

Cluster analysis of the rainfall stations was used to take account of regional variability in rainfall evolution. Two climate areas were obtained from this analysis: Mediterranean and temperate. No shift was detected in rainfall for either area. However, at annual and quarterly scales, several changes in runoff were observed between the periods 1969–87 and 1988–09. The significant changes occurred from January to July, in agreement with maximum increases in temperature. Evapotranspiration could well play a key role in these changes in the hydrological cycle, as a response to temperature increases in the watersheds studied.

1. Introduction

One of the major concerns about climate change is the availability of water resources for human activities (Huntington, 2006; Milly et al., 2008; Jiménez Cisneros et al., 2014). Fluctuations in global continental runoffs have been studied (Probst and Tardy, 1987; Pekárová et al., 2003; Labat et al., 2004), as well as their correlation with global warming (Gedney et al., 2006; Gerten et al., 2008). The link between global warming and the intensification of the hydrological cycle is robust across models (Held and Soden, 2006). Based on observations, Labat et al. (2004) show an increase of 4% in global runoff for a 1 °C global rise in air temperature. This relationship could mean that more intense evaporation has led to increased continental precipitation, resulting in global increases in runoff. Nevertheless, the existence of global-scale enhanced precipitation and runoff remains controversial (Allen and Ingram, 2002; Legates et al., 2005), and regional or local-scale relationships between changes in temperature, precipitation and runoff must still be assessed. Multiple factors influence the hydrological cycle at various space and time scales: decadal (Shorthouse and Arnell, 1997; Pociask-Karteczka, 2006), and multi-decadal climate variability (Giuntoli et al., 2013; Boé and Habets, 2014), climate change (Milly et al., 2005), evolution of land cover (Twine et al., 2004; Zhang and Schilling, 2006; Schilling et al.,

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2010), and water resource management (Graf, 2006; Döll et al., 2009). Consequently, observed changes in runoff are difficult to attribute conclusively to climate change (Harding et al., 2011). To better understand the impact of climate change on runoff, it is necessary to assess the contribution of each of the above-mentioned factors to the hydrological cycle. During the second half of the 20th century, several regions showed decreasing trends in runoff (most of Africa, Australia, Southern Europe, Central America, South and East Asia), partly explained by a decrease in precipitation (Dai, 2011). Although precipitation remains the main driver of runoff, an increase in the influence of other drivers (e.g. temperature, CO_2, land use and irrigation) has been highlighted for recent decades (Gerten and Gedney, 2008). Over Europe, a widespread decreasing trend in runoff has been found during spring and summer months (Stahl et al., 2010). Furthermore, some of the negative streamflow trends observed by Stahl et al. (2010) in France and Germany appear to be related to positive precipitation trends in June and July.

In France, increases in both minimum (Tmin) and maximum (Tmax) air temperatures have been observed for the 20th century (Moisselin et al., 2002). Few studies have explored the impact of increased air temperature on hydrology. Lang and Renard (2007) detected changes in several extreme hydrological indicators for southern watersheds, but observed no widespread change. Giuntoli et al. (2013) observed negative trends (mainly in southern France) in the 1968–2008 annual runoff, for around 26% of the watersheds studied, and positive trends in the volume deficit of drought flows, for 18% of the watersheds studied. They also detected changes in the seasonality of these drought flows, with earlier dates for the beginning, middle and end of drought flow periods, for 30%, 26% and 16% of stations respectively. In the Languedoc-Roussillon region, again in southern France, although annual precipitation did not show clear trends, a decrease of 20% was observed in runoff, for one-third of the watersheds studied by Lespinas et al. (2010). This decrease has mainly been attributed to an increase in air surface temperature of about 1.5 °C over the last forty years. For one of the rivers in Languedoc-Roussillon, the Têt, Ludwig et al., (2004) show an intensification of flood frequencies, during a period (1980–2000) when temperature rose dramatically.

In Europe, observed temperature shows a faster increase than that simulated by models (van Oldenborgh et al., 2009). Two changes have been observed for the North Atlantic Ocean: in the 1970s, and at the end of the 1980s (Werner et al., 2000). The second change resulted in a substantial warming of the North Atlantic Ocean during the early 1990s (Sutton and Dong, 2012), which followed a surge of persistent positive North Atlantic Oscillation (NAO) winter phases (Robson et al., 2012). Although these changes coincided, the shift in surface temperature (+1 °C) observed around 1987/88, at the European scale, cannot be explained by the NAO alone (Keevallik, 2003). De Laat and Crok (2013) show that this shift over Western Europe has been detected in the upper-air temperature from reanalysis data and in ocean heat content. They suggest that it was induced by an increase in Surface Solar Radiation (SSR), or brightening, over Europe, combined with a succession of cold and warm years (associated to a persistent positive phase of the NAO during the early 1990s). This hypothesis is consistent with the global rise in SSR, highlighted by several authors, at the end of the 20th century (Wild, 2009). Since 1987/88, a warmer climate over Western Europe has impacted various compartments of our environment, such as: the number of snow days in Switzerland (Marty, 2008), groundwater and surface water temperature in Switzerland (Figura et al., 2011), marine ecosystems in the North Sea (Schlueter et al., 2008, 2010) and in the Bristol Channel, England (Henderson, 2007), and the temperature of the Adriatic Sea (Matic et al., 2011). Clearly, over the past fifty years, the climate of Western Europe seems to have experienced two temperature regimes. However, the characteristics (amplitude and seasonality) of this shift and its impact on runoff remain insufficiently documented. We focus on the following questions:

- Did this shift occur throughout French metropolitan territory?
- What were its seasonal characteristics and its amplitude?
- Did other similar shifts occur during the 20th century?
- Was this shift associated with a change in rainfall?
- Did this shift impact the runoff of French rivers, and if so, how?

Section 2 presents the climate and hydrometric data-sets and statistical procedures used. Section 3 presents the characteristics of the shift and the need to take into account regional rainfall specificities before assessing the annual and seasonal hydro-climatic responses of rivers. Section 4 summarizes our findings and their implications for the water cycle at regional scale in the context of global warming.

2. Material and methods

2.1. Climate data-sets

Data were produced by Météo-France. Time series from the Météo-France Station Network (MFSN) were provided at a daily scale, for the period 1961–2013. Homogenized time series (Caussinus and Mestre, 2004) were provided at a monthly scale, for the period 1890–2002. The climate data-set was therefore composed of 119 temperature and 122 rainfall MFSN series, and 43 minimum temperature (Tmin), 48 maximum temperature (Tmax) and 52 rainfall homogenized series.

The MFSN series were used for climate shift detection. The homogenized series, covering a much longer period, were used to eliminate non-climatic shifts caused by "noisy" data records (location change, automation, sensor drift, etc.). The use of data from as far back as 1890 potentially allowed changes to be detected throughout the whole of the 20th century. The MFSN is evenly distributed all over France (Fig. 1), but homogenized series, which represent several observation stations, cannot be represented on the map.

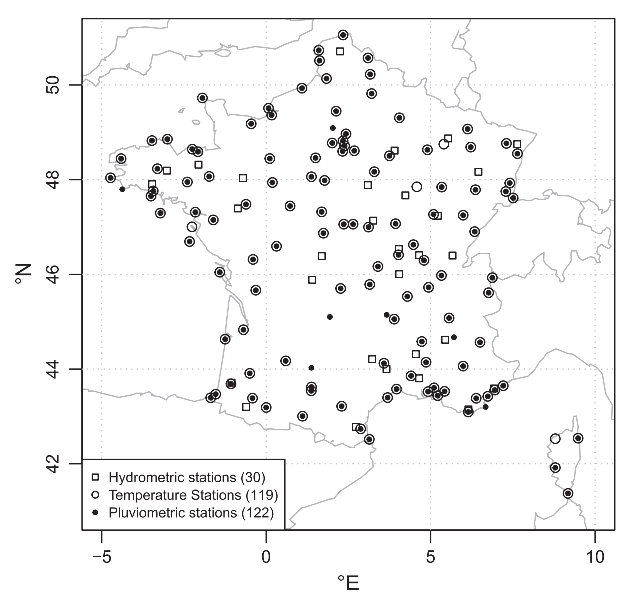

Fig. 1. Map of temperature, rainfall and hydrometric stations used.