GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO.6, PAGES 755-758, MARCH 15, 1999

Twentieth century trends in droughts in southern Switzerland

Martine Rebetez

Swiss Federal Institute for Forest, Snow and Landscape Research, Lausanne, Switzerland

Abstract. An investigation is made of the change in frequency of drought episodes in southern Switzerland. Episodes of drought are shown to have increased in frequency and persistence during the 20th century. They have been particularly frequent and long during the 1940s as well as since 1981. As these two periods have also been particularly warm, the results are discussed in relation to the increase in global atmospheric temperatures observed this century.

Introduction

In the context of global change, particular concern has been expressed about a possible increase in meteorological conditions favorable for forest fires. Wotton and Flannigan (1993) have simulated a double CO_2 situation with the Canadian Climate Centre's General Circulation Model (GCM) and shown a lengthening of the fire season. With the results of four GCMs, Stocks et al. (1998) have shown that under a 2 x CO_2 climate scenario, large increases are likely to take place in the areal extent of extreme forest fire danger in Canada and in Russia. In Spain, Pinol et al. (1998) have highlighted an increase in fire hazard indices measured over the period 1941 and 1994. Swetnam (1993), in an analysis of fire occurrence during the past 2000 years in giant sequoia stands, has shown that fire occurrence was related to yearly fluctuations in precipitation and to decadal-to-centennial variations in temperature.

As shown in previous publications. (e.g. Beniston et al., 1994; Rebetez and Beniston, 1998a; 1998b; Heino et al., 1998), the Alpine region has been observed to exhibit a particularly strong trend in atmospheric warming during the 20th century. Figure 1 illustrates the increase in daily mean temperature which has taken place in Switzerland this century compared to global average warming. During this period of 97 years the warming trend in Switzerland is more than twice that of the global average value. The alpine region is therefore a particularly interesting study-region for the analysis of 20th century climatological trends.

Drought, defined as a long period of time with little or no precipitation, is the precursor cause for forest fires in Ticino (Marcozzi et al., 1994). In a drought situation, fires are triggered by a number of factors among which the most common ones are linked to human behavior (Marcozzi et al., 1994; Tinner et al., 1998; Conedera et al., 1996).

Beniston et al. (1994) have shown that mean precipitation values do not exhibit any trends at the annual level. Other studies have shown that in Switzerland strong precipitation events have become more frequent in autumn durng this century (Rebetez et al., 1997). On the European level, a

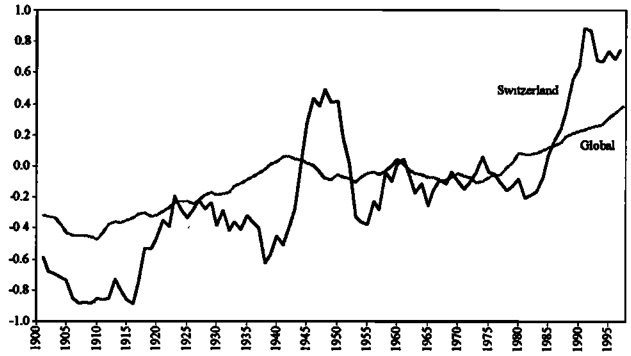

Figure 1: Trends in average temperature values from 1901-97. Switzerland: averaged from the values of the stations of Basel, Davos, Neuchatel and Saentis. Global: values from Jones and Wigley, 1992 and from a personal communication by P. Jones for the most recent part of the record.

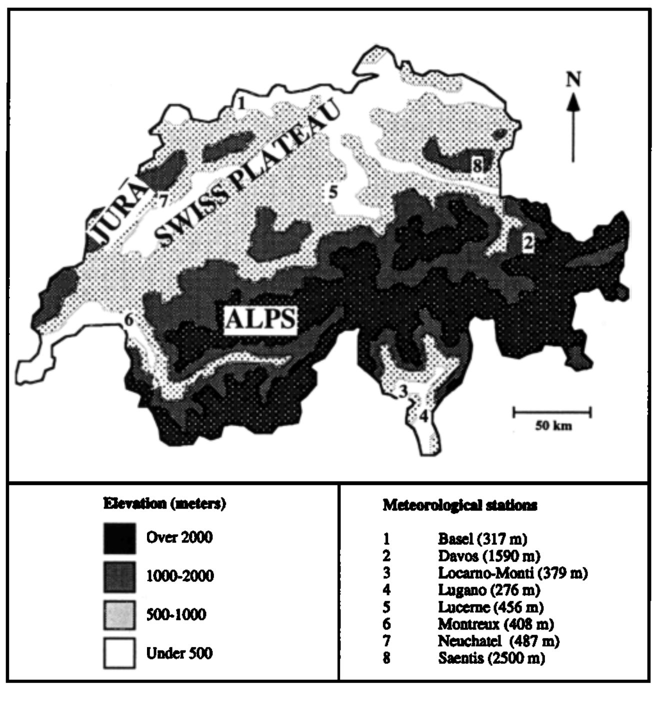

Figure 2: Map of Switzerland with location of the meteorological stations

numerical simulation carried out over Europe with a temperature increase of 2 K also indicates a substantial shift towards more frequent events of strong precipitation (Frei et al., 1998). On the global level, Tsonis (1996) has shown that although the global mean precipitation has not changed during the last century, the fluctuations about the mean have increased significantly, an overall positive trend in precipitation variability has occured and extremes have

Paper number 1999GL900075.
0094-8276/99/1999GL900075$05.00

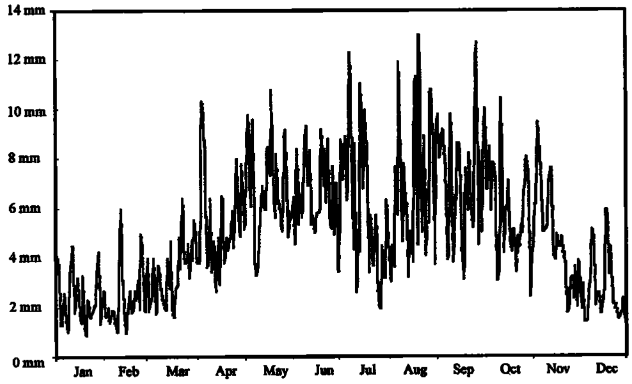

Figure 3: Average daily precipitation 1901-1997 in Locarno

become more frequent.

Although the effective occurrence of forest fires on a given day depends mainly on human factors, it is important to know whether the frequency of general climatic conditions favorable for forest fires are changing under the influence of global change. As it has been shown that among the usual meteorological variables, precipitation is a determinant parameter, particularly in Ticino (Conedera et al., 1996; Mandallaz and Ye, 1997), but also more generally (Swetnam, 1993). The purpose of this paper is 1) to analyse long term precipitation in order to highlight the trends in drought situations which are likely to lead to forest fires in Ticino and 2) to analyse drought, considered as an extreme value of precipitation, and compared to total amounts of precipitation.

Data

Two meteorological stations exhibit daily precipitation data from October 1900 until December 1997 in Ticino, namely Locarno and Lugano (figure 2). Some changes have occured in the equipment and location of these stations which may in some cases affect the precipitation amounts during episodes of heavy rain, particularly with strong westerly winds (MeteoSwiss documentation, unpublished; Groisman and Legates, 1995). These problems should not affect the conclusions of this research however, as they concern mainly the measurement of days with little or no rain. For comparison purposes, data from Basel, Davos, Lucerne, Montreux, Neuchatel and Saentis have also been used. Unless otherwise mentioned, precipitation refers to rain or the water equivalent of solid precipitation; tranformation of solid precipitation into its water equivalent is made on the spot by MeteoSwiss.

Results

Figure 3 shows that Ticino experiences a dry season in winter, on average from mid-November to mid-March. The driest period occurs from the end of December and throughout the month of January. Although these values have been averaged for nearly a whole century of data, differences between one day and the next illustrate the very high variability of precipitation in Ticino.

Figure 4 shows that the driest month, January, exhibits 77% of dry days and 82% of days with less than 1 mm of precipitation in Lugano. But even the wettest month, May, exhibits a majority of dry days, i.e. 51%. On the Northern side of the Alps, in Lucerne for instance, January, with 67% of dry days, is not drier than the autumn months, which exhibit 66 % of dry days in September and 68% in October. As in Ticino, spring is the wettest period of the year, as far as the frequency of precipitation is concerned; it is also wetter than Ticino, with 42 % of dry days in June. The lack of precipitation from December to February is one the main characteristics of the precipitation regime in Ticino compared to the rest of the country (Baeriswyl and Rebetez, 1997) and indeed to the rest of the European alpine domain (Frei and Schaer, 1998). Another main characteristic is the high number of dry days, not only in winter but throughout the year, in spite of a high yearly precipitation sum: 1.8 m in Locarno and 1.7 m in Lugano, compared to 1.2 m in Lucerne or 1.3 m in Montreux. Concerning mean annual precipitation, Ticino records among the highest sums not only in Switzerland but in the European Alps (Frey and Schaer, 1998). In Ticino most of the precipitation falls between April and October, mainly as heavy convective downpours on a limited number of days. At all seasons except winter, Ticino is located within the wettest region in the Alps (Frei and Schaer, 1998) as far as precipitation sums are concerned but not as far as the frequency of precipitation is concerned. When the number of rainy days is taken into consideration, even on a yearly basis, Ticino comes out remarkably dry compared to the rest of the Alps, particularly the Northern side (Frei and Schaer, 1998).

Figure 5 shows that there is a high interannual variability with no significant trends in annual precipitation sums. Concerning the dry season sums, from November to March (figure 6), there is no significant trend either, but a rather dry period can be noticed since the beginning of the 1980s as well as during the 1940s.

When assessing the effects of these particular climatic conditions to forest ecosystems, a drought is not necessarily a period with no precipitation at all but rather a period with little precipitation, i.e., an amount which is not sufficient to significantly change the moisture content of the fuel. It has been arbitrarily decided here to conduct an analysis of the length of periods with a maximum total amount of 10 mm of

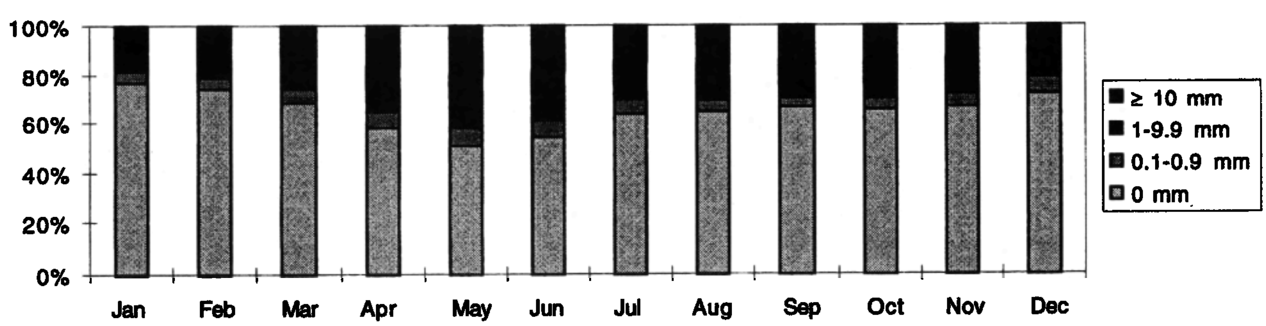

Figure 4: Average monthly distribution of precipitation frequencies 1901-1997

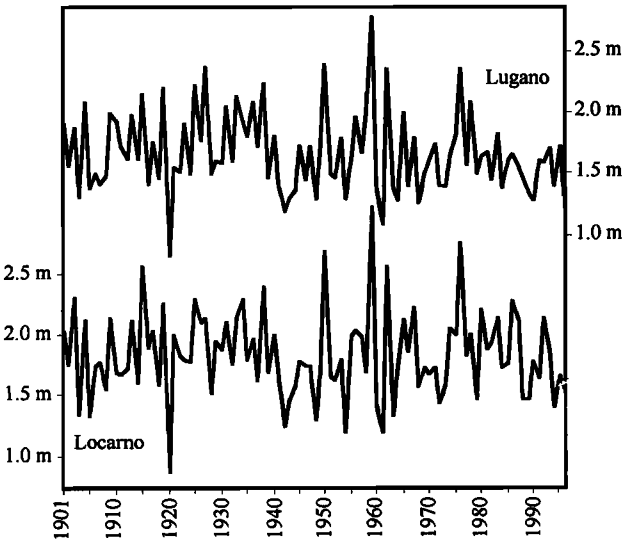

Figure 5: Annual sums of precipitation (1901-1997)

rain, and not to limit the analysis to absolutly dry days, in order not to run the risk of eliminating drought periods because they were interrupted by events where minor precipitation amounts were recorded. Looking for drought as an extreme value of precipitation, we defined a threshold for the minimum lengh of the drought period which would allow the analysis of 10 to 15% of the years. This threshold came out to lie at approximately 60 days, this length corresponds to 12 events in Lugano and 15 in Locarno.

The results for this analysis are presented in figure 7. A regression analysis has been performed on these results, not taking into account the years with zero event. At both locations, it shows an increasing trend in the length of the drought episodes. The results of a Student's t-test on these regressions show that they are significant at 98% at both locations. As regression analyses are sensitive to data at the end of the time series and because 1997 happens to have a

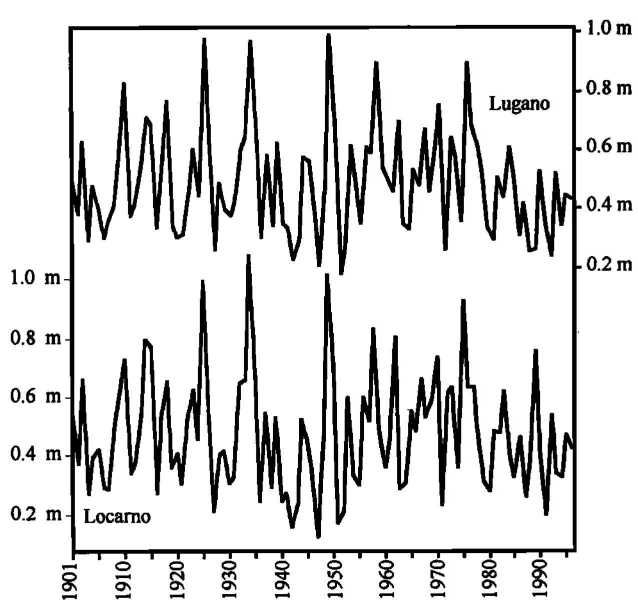

Figure 6: Dry season sums of precipitation (November-March, 1901-1997)

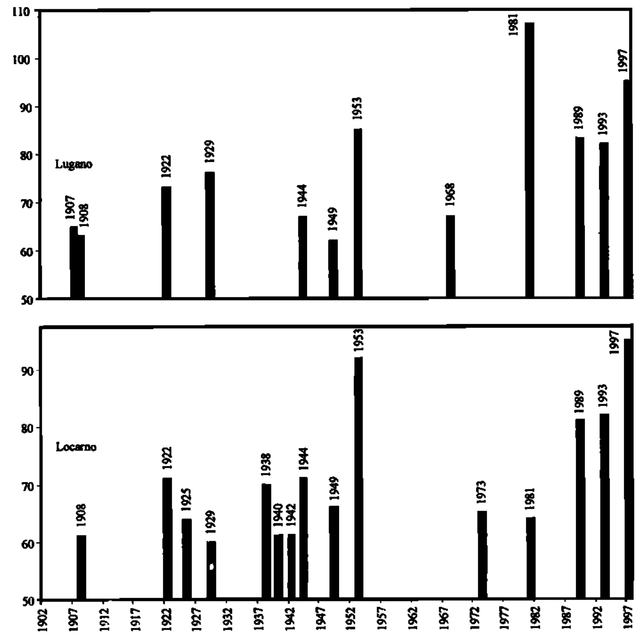

Figure 7: Episodes with at least 60 days of total precipitation less than 10 mm

large value (the largest for Locarno), we performed a regression analysis without the 1997 data. The results were still significant, although naturally a little less so, at the 95% level in Lugano and 92% in Locarno. In order to know how sensitive these results are to the threshold of 60 days, we have done the same analysis with lower thresholds at 50 and 55 days, respectively. The results are still significant at the 55-day threshold (95% in Lugano, with 15 observations, 99% in Locarno, with 20 observations), but barely at the 50-day threshold: 92% in Locarno, not significant in Lugano.

During the 97 winters analysed here, in Locarno, there have been 20 episodes of drought lasting at least 55 days, 15 episodes lasting at least 60 days and 7 episodes lasting at least 70 days. The 4 longest episodes (81 days or more) all took place during the 2nd half of the century, 3 of them since 1989. In Lugano, the 5 longest episodes took place during the 2nd half of the century, 4 of them since 1981. With an average value of 1 episode lasting 60 days or more per 8 years, 4 of them took place during the last 17 winters, and 3 during the last 9.

Discussion

Our results show that the frequency and duration of drought episodes have been increasing towards the end of the 20th century at both the meteorological observing sites investigated in Ticino. Even more than an increasing trend, it is particularly important to note that drought episodes have been remarkably long and frequent during the 1940s and after 1980, which correspond to the warmest decades in Switzerland (cf. Beniston et al., 1994 and figure 1 in this paper). The reverse occured during the cooler period which intervened between 1950 and 1980, during which very few drought episodes were recorded. This suggests that climate warming could be accompanied by an increase in the frequency and duration of extreme drought episodes.

It is particularly interesting to point out the fact that only extreme drought episodes are getting longer and more frequent but not average precipitation values. Our results show that there is no trend in precipitation sums, either for yearly, or for seasonal values. Similarly, another analysis of Swiss precipitation data related to heavy precipitation episodes in August and September has highlited the fact that very extreme precipitation episodes (capable of triggering debris flows in the Alps) have become more frequent towards the end of the 20th century, although no trend has been observed in precipitation sums (Rebetez et al., 1997). The numerical simulations conducted by Frei et al. (1998) also indicate a shift towards more frequent events of strong precipitation in Autumn. The results obtained in the present research suggest that climate warming could be accompanied by an increase not only in the frequency of strong precipitation events, but could also result in an increase in the frequency of extreme events at both extremes, one linked to droughts, the other to heavy precipitation. This would be in agreement with the global results obtained by Tsonis (1996) showing widespread increases in variability of precipitation.

Conclusions

An analysis of two long time series of precipitation in Ticino (1900-1997) has been conducted in order to highlight a possible trend in drought episodes. The results show that there are significant trends in extreme drought situations. These have become more frequent and tend to last longer in the latter part of the 20th century. Drought situations have been particularly long and frequent since 1981. The 1940s also saw a remarkably warm decade in Switzerland, which was accompanied by frequent drought episodes until 1953. It must be stressed that in parallel, there is no significant trend in precipitation sums, whether on a yearly or a seasonal basis. The relationship observed here between longer and more frequent drought episodes on the one hand, and warmer temperatures on the other, suggests that future climate warming could be accompanied by an increase in the frequency and length of extreme drought episodes. These results are in agreement with those obtained by different authors (Stocks et al., 1998; Wotton and Flannigan, 1993) working with General Circulation Models which simulate situations of doubled atmospheric CO2 concentrations.

Acknowledgements

The author is grateful to Marco Conedera (FNP Sottostazione Sud delle Alpi), Fosco Spinedi (MeteoSwiss, Locarno), Martin Beniston (University of Fribourg) and two anonymous reviewers for their useful information and suggestions, to MeteoSwiss for providing the climatological data and to Michèle Kaennel (WSL, Birmensdorf) for assistance with the literature survey for this article. This work has been supported in part by the Forest Investigation Programme, a joint project between the Swiss Federal Office of the Environment, Forests and Landscape (BUWAL, Bern) and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Birmensdorf).

Reference list

Baeriswyl P.-A. and Rebetez M., Regionalization of Precipitation in Switzerland by means of Principal Component Analysis, *Theor. and Appl. Clim., 58,* 31-51, 1997.

Beniston M., Rebetez M., Giorgi, F., and Marinucci, M. R., An analysis of regional climate change in Switzerland. *Theor. and Appl. Clim., 49,* 135 - 159, 1994.

Conedera, M., M. Marcozzi, B. Jud, D. Mandallaz, F. Chatelain, C. Frank, F. Kienast, P. Ambrosetti and G. Corti, *Incendi boschivi al Sud delle Alpi: passato, presente, e possibili sviluppi futuri.* 96 pp., Hochschulverlag ETH, Zürich, 1996

Frei C., Schär C., A precipitation climatology of the Alps from high-resolution rain-gauge observations. *International Journal of Climatology 18(8),* 873-900, 1998.

Frei C., C. Schaer, D. Luethi and H. C. Davies, Heavy precipitation processes in a warmer climate. *Geophys. Res. Letters, 25(9),* 1431-1434, 1998.

Groisman P.Y., Legates D.R., Documenting and detecting long-term precipitation trends: where we are and what should be done. *Climatic Change 31(2-4),* 601-622, 1995.

Heino, R., Brázdil, R., Førland, E., Tuomenvirta, H., Alexandersson, H., Beniston, M., Pfister, C., Rebetez, M., Rosenhagen, G., Rösner, S., and Wibig, J., Progress in the study of climatic extremes in Northern and Central Europe. *Climatic Change,* 1998, in press.

Jones P. D., Wigley, T. M. L., Global warming trends. *Scientific American 263,* 84-91, 1992.

Mandallaz D., Ye R., Prediction of forest fires with Poisson models. *Canadian Journal of Forest Research 27(10),* 1685-1694, 1997.

Marcozzi M., Bovio G. Mandallaz D., Influenza della meteorologia sull'indice di pericolo degli incendi boschivi nel Cantone Ticino. *Schweiz. Z. Forstwesen 145,* 183-199, 1994.

Pinol J., Terradas J., Lloret F., Climate warming, wildfire hazard and wildfire occurence in coastal eastern Spain. *Climatic Change 38,* 345-357, 1998.

Rebetez, M., Lugon, R., and Baeriswyl,. P.A., Climatic warming and debris flows in high mountain regions: The case study of the Ritigraben Torrent (Swiss Alps). *Climatic Change, 36,* 371 - 389, 1997.

Rebetez, M. and M. Beniston, Changes in temperature variability in relation to shifts in mean temperatures in the Alpine region this century, in *The impacts of Climate Variability on forests,* edited by M. Beniston and J. Innes, Springer-Verlag, Heidelberg/New York, 49-58, 1998a.

Rebetez, M. and M. Beniston, Changes in sunshine duration are correlated with changes in daily temperature range this century. An analysis of Swiss climatological data, *Geophysical Research Letters, 25 (19),* 3611-3613, 1998b.

Stocks B.J., Fosberg M.A., Lynham T.J., Mearns L., Wotton B.M., Yang Q., Jin J.Z., Lawrence K., Hartley G.R., Mason J.A., McKenney D.W., Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change 38(1),* 1-13, 1998.

Swetnam T. W., Fire History and Climate Change in Giant Sequoia Groves. *Science,* 262, 885-889, 1993.

Tinner W., Conedera M., Ammann B., Gäggeler H.W., Gedye S., Jones R., Sägesser B., Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since AD 1920. *The Holocene 8(1),* 31-42, 1998.

Tsonis A.A., Widespread increases in low-frequency variability of precipitation over the past century. *Nature 382,* 700-702, 1996.

Wotton B., Flannigan M., Length of the fire season in a changing climate. Forestry chronicle 69(2), 187-192, 1993.

M. Rebetez, FNP-AR, EPFL, CP 96, CH-1015 Lausanne, Switzerland. (e-mail: rebetez@wsl.ch)

(Received, September 25, 1998; revised, January 4, 1999; accepted, January 28, 1999.)