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Impact of anthropic and climatic factors on hydrological extremes in the Italian Alps

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Introduction

- Changes in mean annual and maximum annual daily discharge progressively arise as strongly site-dependent phenomena;
- Both climatic and anthropic factors must be considered in interpreting such changes;
- Decrease trends in annual mean values can have a dramatic impact on freshwater demand sustainability and flood and precipitation extremes raise the concern of the public, media and experts;
- The climatic signal at annual and monthly scale is generally weak, so that series’ length and quality are crucial in order to obtain reliable results.
- As anthropic drivers *effects of reservoirs* and *land use changes* have been considered for large space and time scales

Impact of Global Warming on the water cycle (1): Flood timing

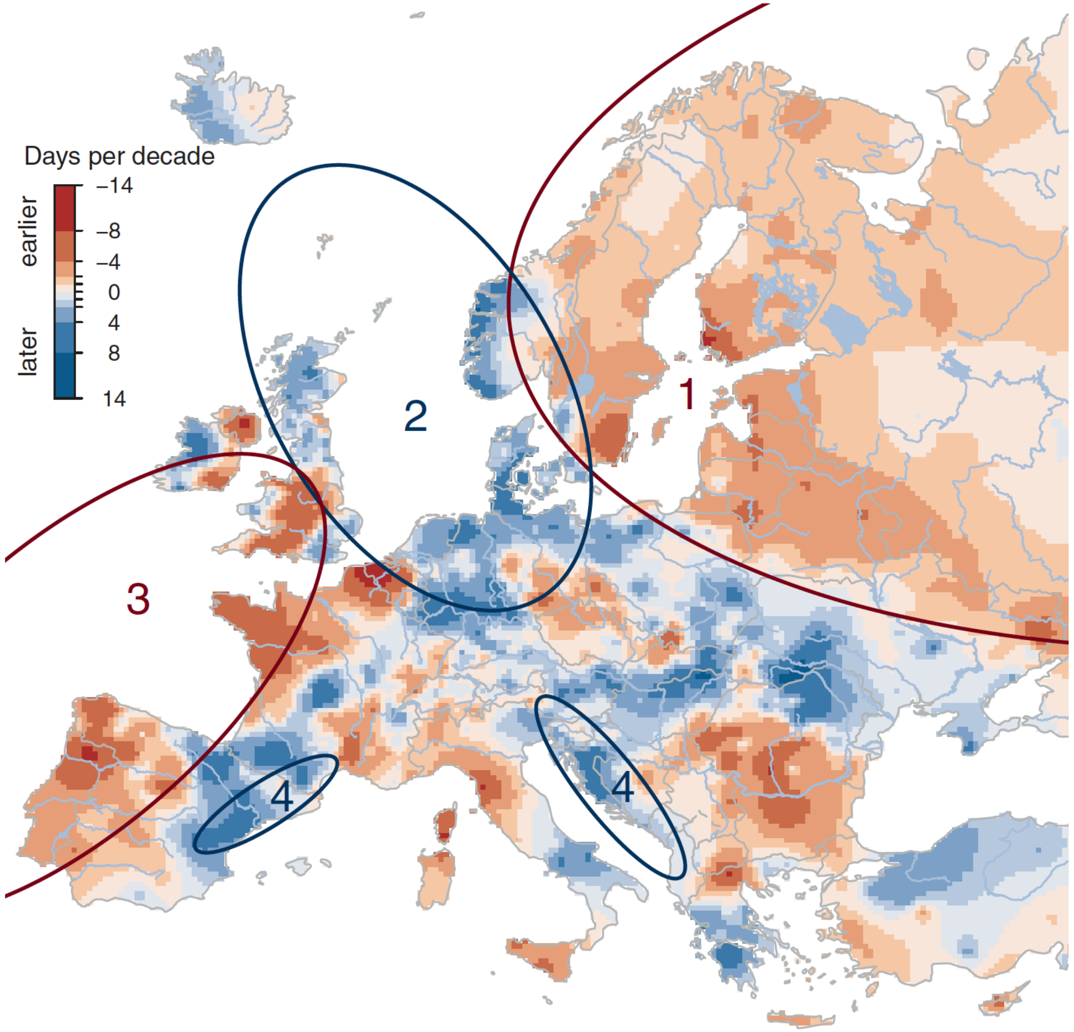


Fig. 1. Observed trends of river flood timing in Europe, 1960–2010. The color scale indicates earlier or later floods (days per decade). Regions with distinct drivers: Region 1, northeastern Europe (earlier snowmelt); region 2, North Sea (later winter storms); region 3, western Europe along the Atlantic coast (earlier soil moisture maximum); region 4, parts of the Mediterranean coast (stronger Atlantic influence in winter).

Bloeschl et al., Science, DOI: 10.1126/science.aan2506, 2017

Impact of Global Warming on the water cycle (2):
Flood intensity

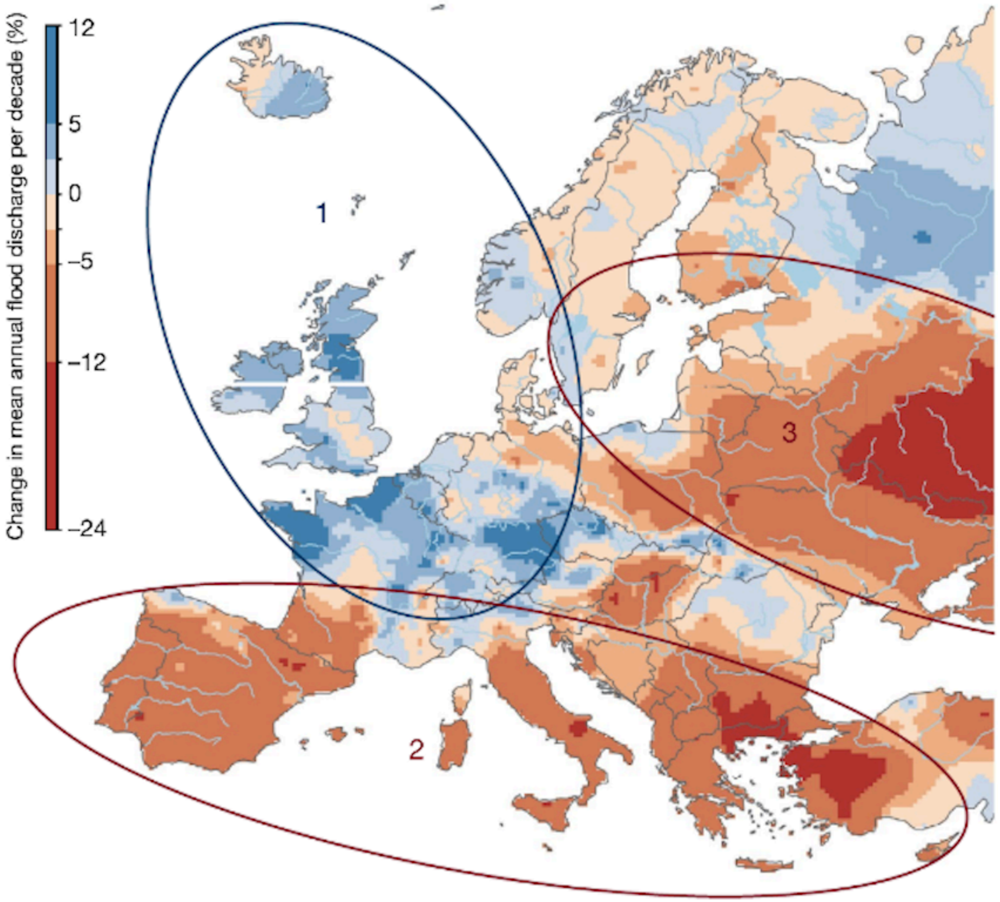


Fig. 1 | Observed regional trends of river flood discharges in Europe (1960–2010). Blue indicates increasing flood discharges and red denotes decreasing flood discharges (in per cent change of the mean annual flood discharge per decade). Numbers 1–3 indicate regions with distinct drivers. 1, Northwestern Europe: increasing rainfall and soil moisture. 2, Southern Europe: decreasing rainfall and increasing evaporation. 3, Eastern Europe: decreasing and earlier snowmelt. The trends are based on data from $n = 2{,}370$ hydrometric stations. For uncertainties see Extended Data Fig. 2b.

Bloeschl et al., Nature, https://doi.org/10.1038/s41586-019-1495-6, 2019

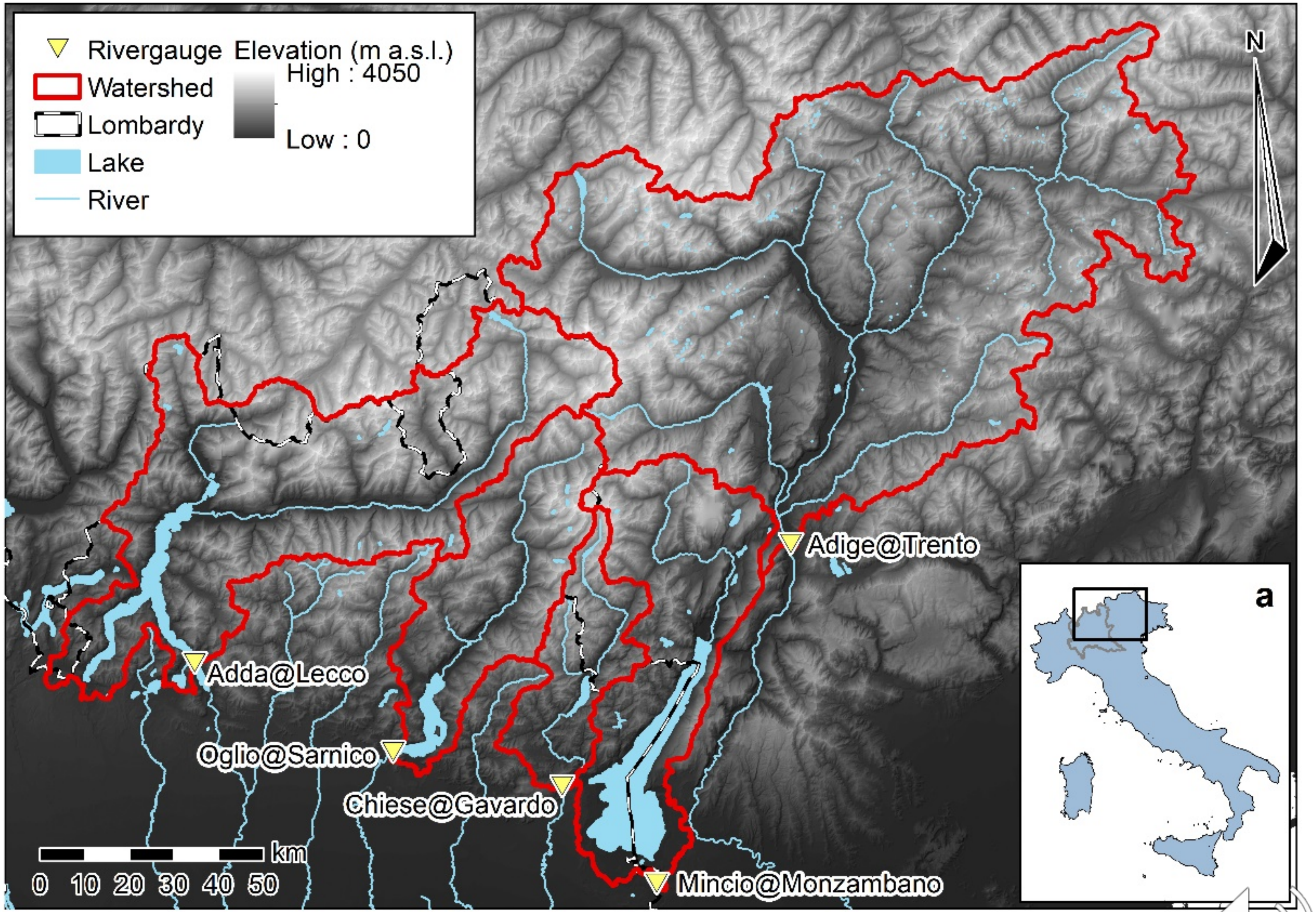
Study area: Central Alps

TOTAL INVESTIGATED AREA: 19,400 km^2

CONFLICTING EXPLOITATION OF FRESHWATER: irrigation, industrial, hydropower generation

SEASONAL REGULATION: total regulation volume in the area

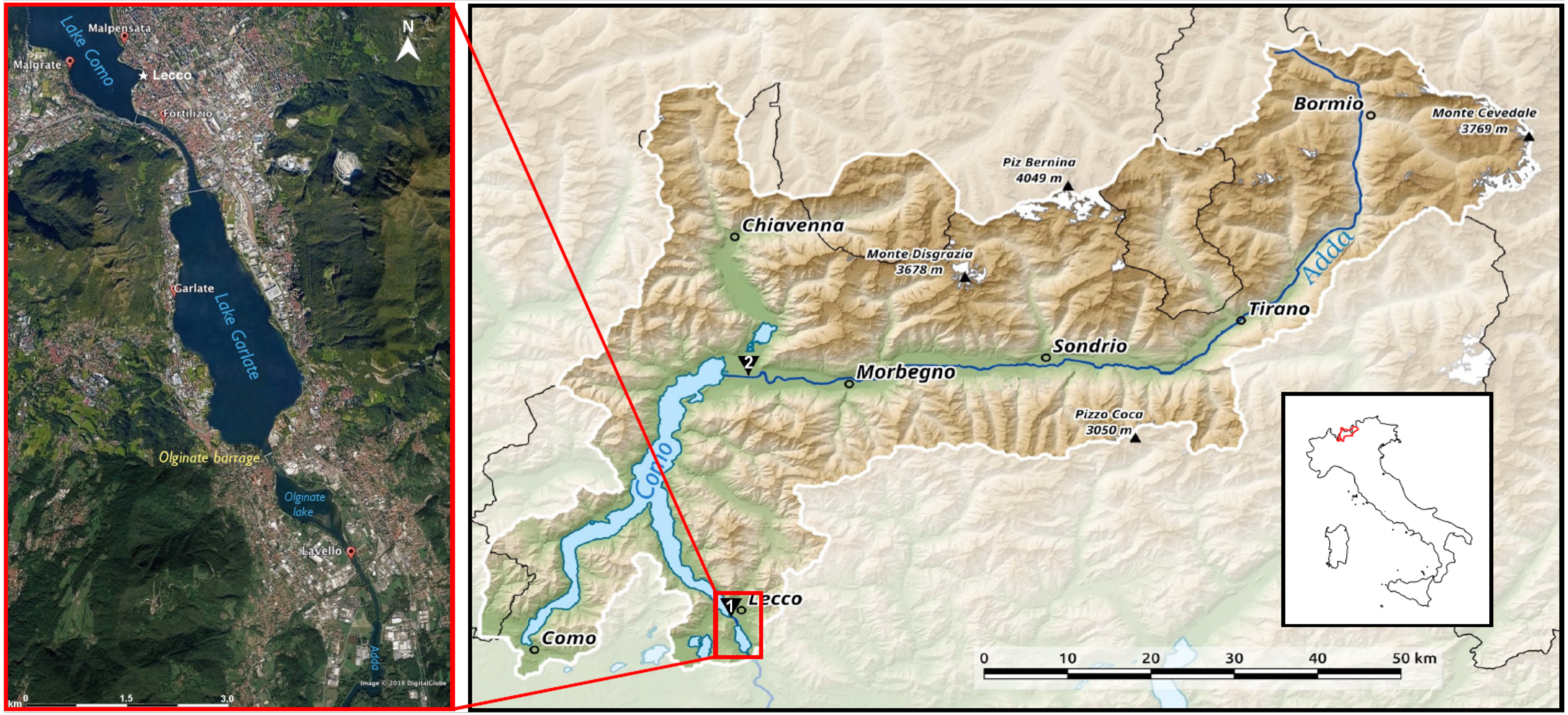
~ 2.3 10^9 m^3



River-flow data availability: annual and daily data

Watershed	**Adige**	**Mincio**	**Chiese**	**Oglio**	***Adda***
Rivergauge station	Trento	Monzambano	Gavardo	Sarnico	*Lecco*
Area [km^2]	9763	2350	934	1840	*4508*
Maximum elevation [m a.s.l.]	3899	3556	3462	3554	*4050*
Average elevation [m a.s.l.]	1735	966	1230	1429	*1569*
Minimum elevation [m a.s.l.]	186	60	198	154	*197*
Observation period	1862-2011	1950-2011	1934-2018	1933-2011	*1845-2016*
Sample size	150	62	72	79	*172*
Mean annual volume [mm]	708	709	1091	979	*1151*

Adda River in Lecco (4508 km^2)



Quality control of river-flow data

Data inconsistency, heterogeneity, anthropogenic regulations were checked by intercomparing long term time series e.g. the 172 years of Adda river

Ranzi, Roberto; Michailidi, Eleni Maria; Tomirotti, Massimo; Crespi, Alice; Brunetti, Michele; Maugeri, Maurizio (2020): Multi-century (1800-2016) meteo-hydrological series for the Adda river basin (Central Alps). *PANGAEA*, https://doi.org/10.1594/PANGAEA.919890

Always quote citation above when using data! You can download the citation in several formats below.

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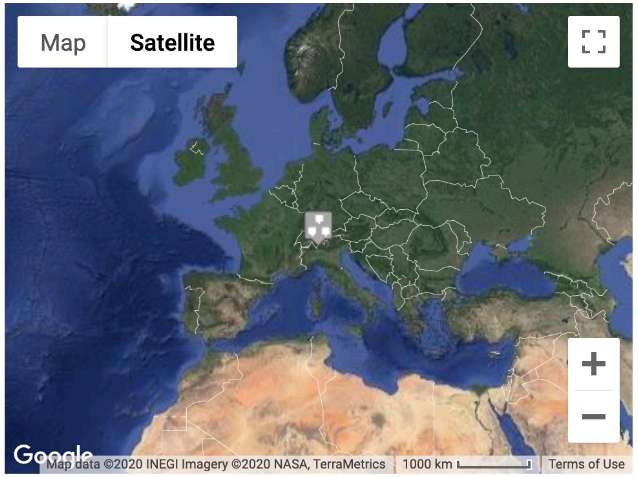
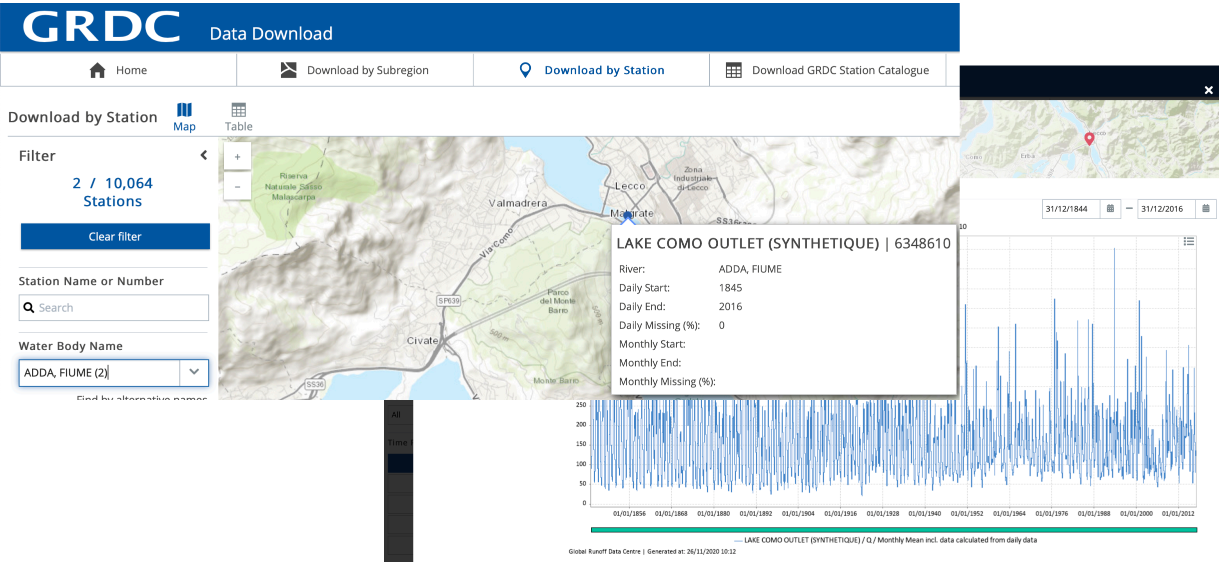




LAKE COMO OUTLET (SYNTHETIQUE) | 6348610

River: ADDA, FIUME
Daily Start: 1845
Daily End: 2016
Daily Missing (%): 0
Monthly Start:
Monthly End:
Monthly Missing (%):

Ranzi et al., J of Climatology, 2021
Global Runoff Data Center
portal.grdc.bafg.de

Analysis methodology

Individual series analysis: *k*=1, …, *N*

$$x_k = m_k\, t + \ q_k$$

$$m_k = median\left(s_{kij} = \frac{x_{kj} - x_{ik}}{t_j - t_i}; 1 \leq i < j \leq n_k \right)$$

$$q_k = median(x_{ki} - m_k\, t_i; 1 \leq i \leq n_k)$$

Advantages:

- they are more robust when outliers are present;
- they are comparable to least squares estimators in terms of standard error according to hypotheses of normality and homoscedasticity of the dependent variable, but they are superior according to the hypothesis of normality (when used on its own);
- confidence boundaries for regression line slopes can straightforwardly be derived.

Analysis methodology

Pool analysis: *k*=1, …, *N* with $N \geq 2$

$$m_p = \frac{\sum_{k=1}^{N}\sum_{i=1}^{n_k}\left(t_i - \widehat{t_k}\right) x_{ki}}{\sum_{k=1}^{N}\sum_{i=1}^{n_k}\left(t_i - \widehat{t_k}\right)^2}, where\ \widehat{t_k} = \sum_{i=1}^{n_k}\frac{t_i}{n_k}$$

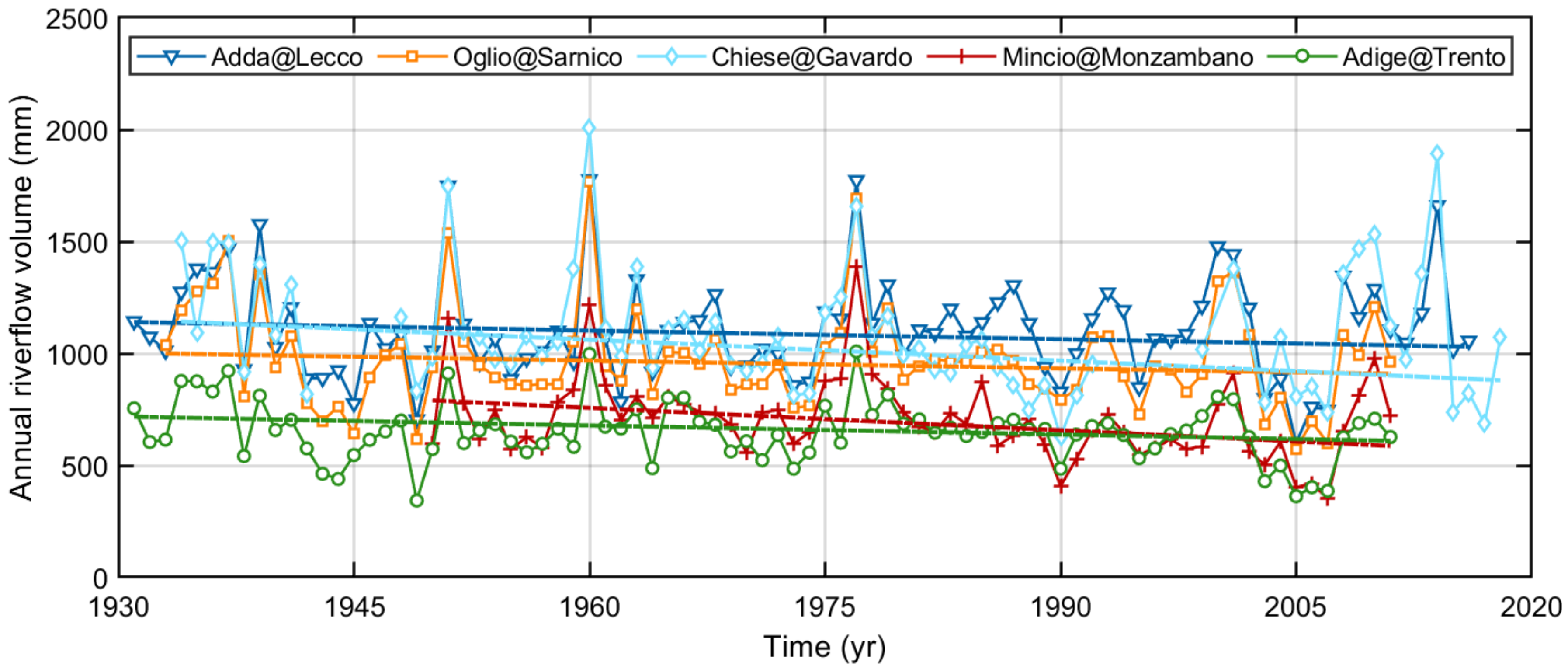
Sen-Adichie test for parallelism hypothesis $H_0\colon m_1 = \ldots = m_N = m_p$

Advantages:

- more robust estimate relying on a large sample size;
- if the parallelism hypothesis cannot be rejected, pool slope m_p, can be interpreted as a regional trend estimate.

Results: river-flows

Watershed	**m_k**	**m_{kl}**	**m_{ku}**	**α_{0k}**	**τ_k**	**α_{tk}**	**ρ_k**	**α_{rk}**	**m_p**	**α_p**	**α_{pk}**
	(mm/yr)	(mm/yr)	(mm/yr)	(%)	-	(%)	-	(%)	(mm/yr)	(%)	(%)
Adige	**-1.34**	**-1.75**	**-0.98**	**<0.1**	**-0.30**	**<0.1**	**-0.46**	**<0.1**	-1.45	54.8	66.2
Mincio	**-3.33**	**-5.00**	**-1.28**	**0.5**	**-0.24**	**0.6**	**-0.32**	**1.0**			15.8
Chiese	**-3.12**	**-5.02**	**-1.10**	**0.8**	**-0.21**	**0.8**	**-0.28**	**1.6**			16.2
Oglio	-1.16	-2.91	0.56	32.2	-0.08	32.4	-0.11	32.8			71.3
Adda	**-1.29**	**-1.85**	**-0.70**	**<0.1**	**-0.19**	**<0.1**	**-0.27**	**<0.1**			62.2



α_{0k} Theil test for null slope

$\alpha_{\tau k}$ Mann-Kendall test

$\alpha_{\rho k}$ Spearman test

α_p Sen-Adichie test

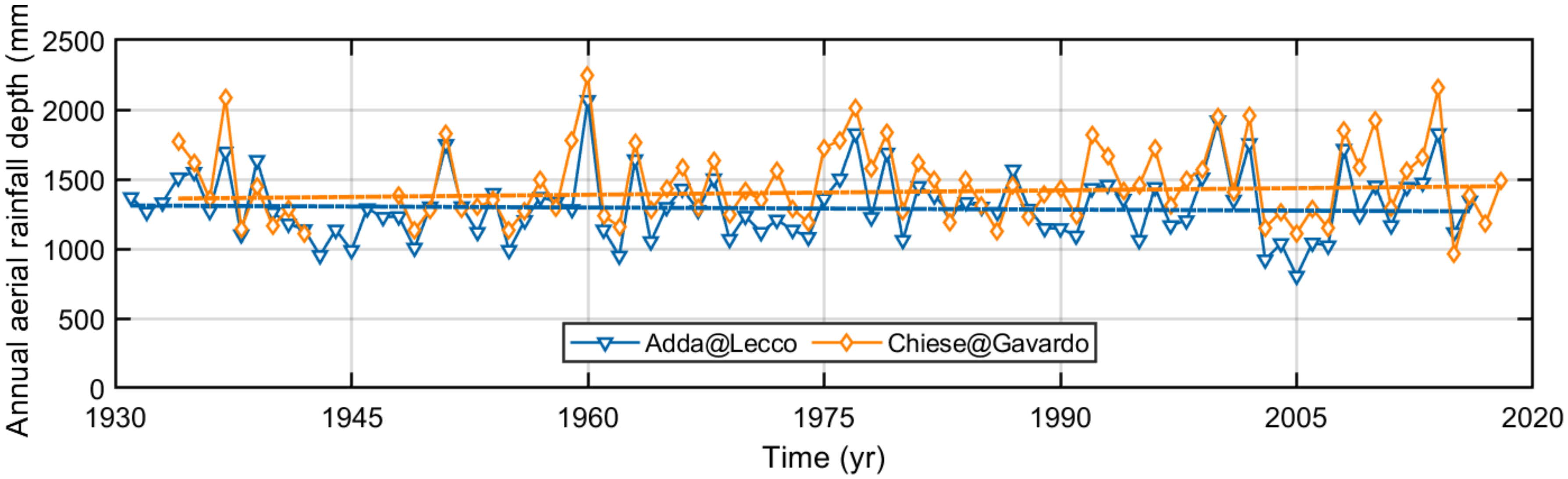
α_p Theil test for m_p slope

lower-upper limits symmetric 5-95% percentiles

Discussion (1-effect of climate)

Potential reasons for a regional statistically significant river-flow decline:

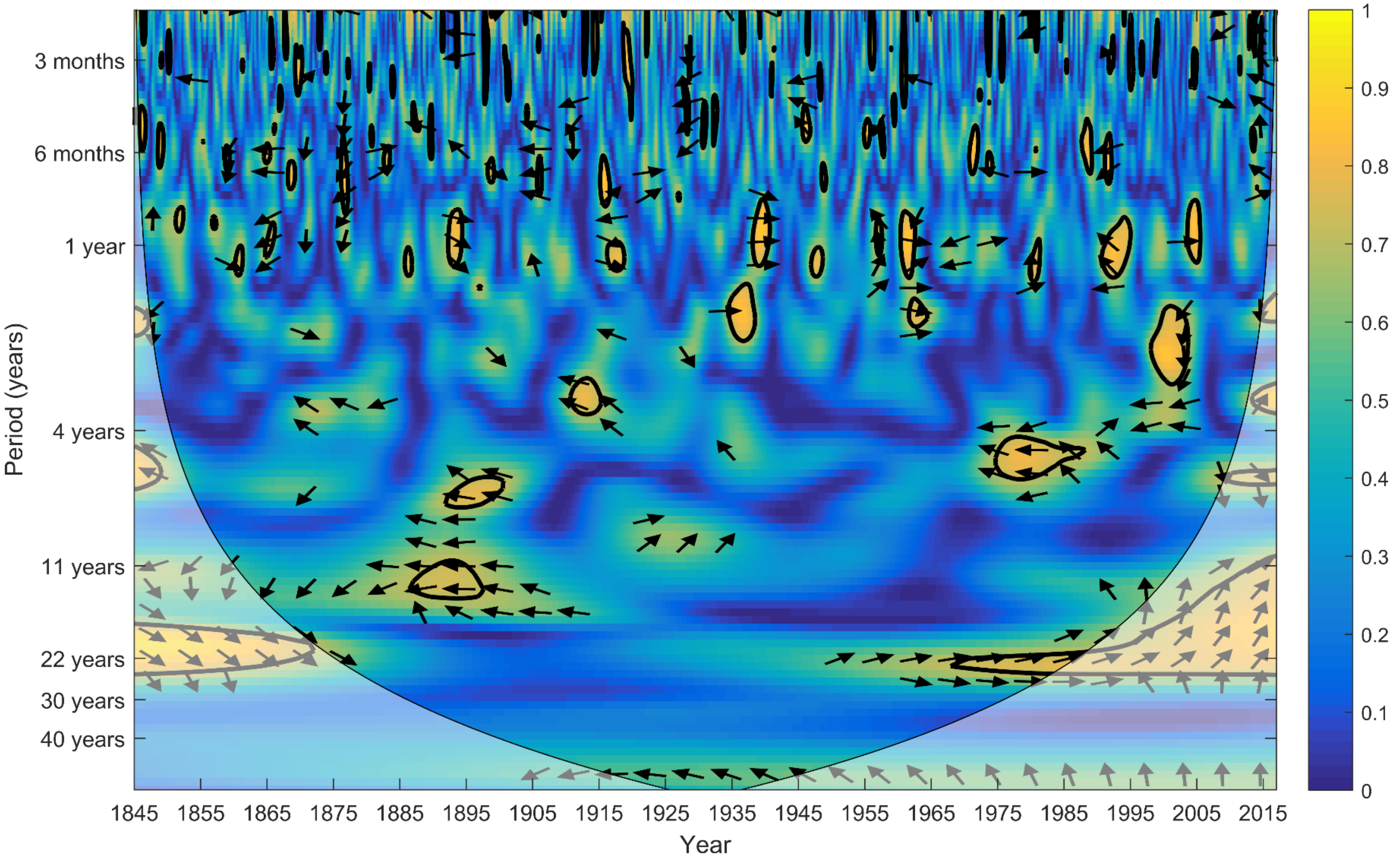
- Storage in glaciers
- Decrease in mean-aerial annual rainfall depths
- Increase in hydrologic losses (evapotranspiration)



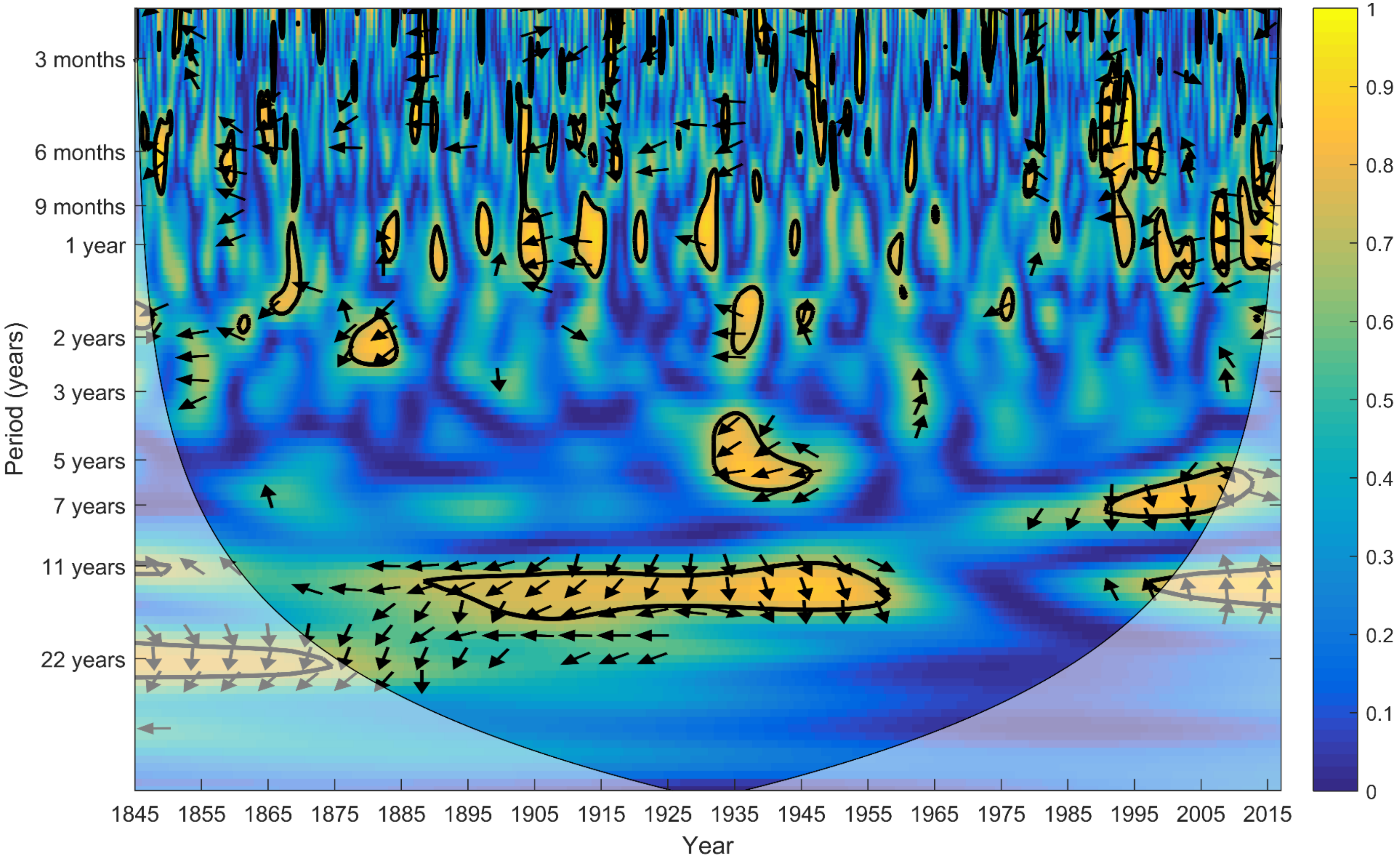
No evidence of a statistically significant decrease in annual rainfall

The climatic signal at annual and monthly scale is generally weak: teleconnections with wavelet transform

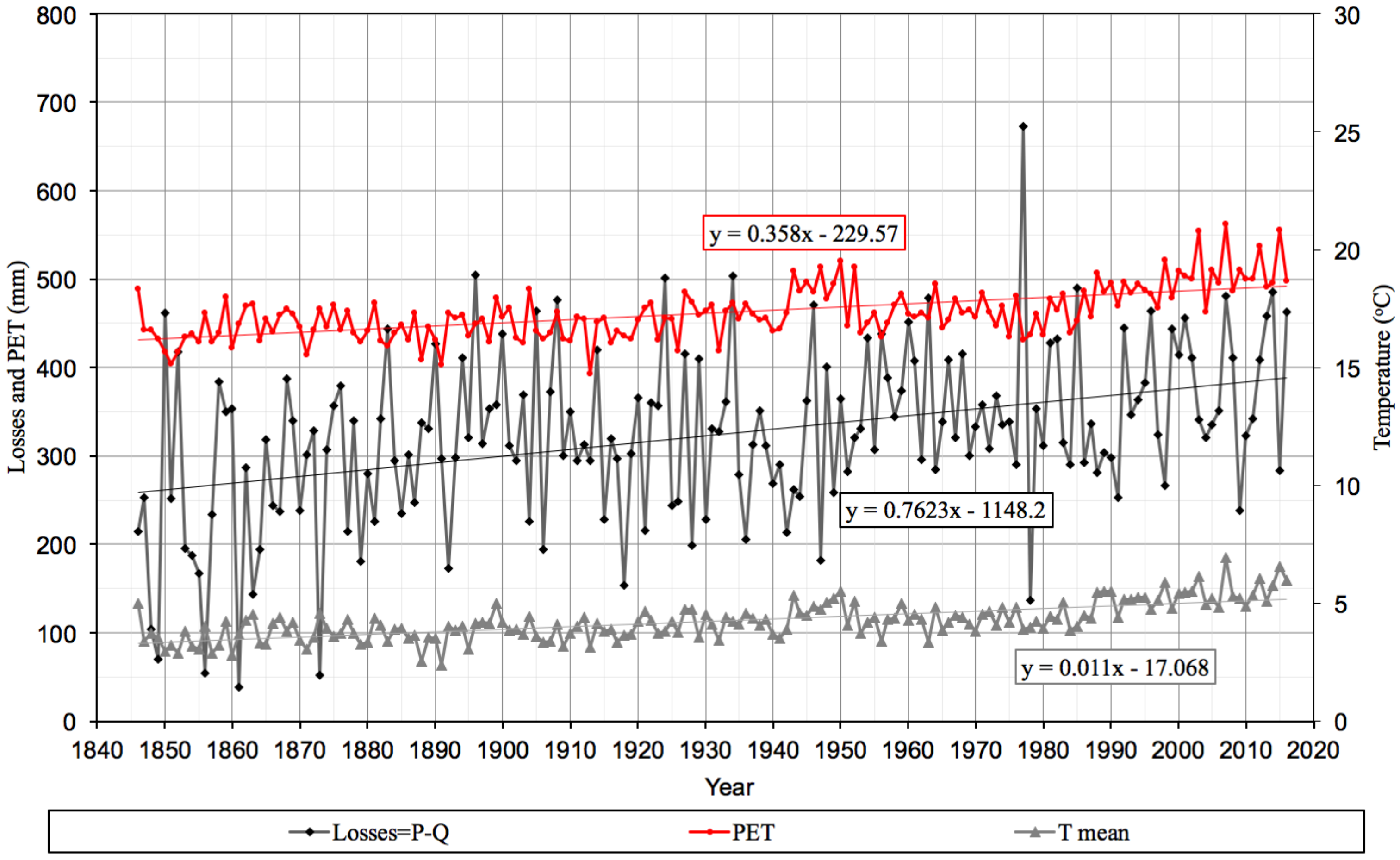
Wavelet cross coherence between sunsposts (Zanchetti et al., 2008 for the Po river) and precipitation does not indicate significant coherence



Instead some coherence with North Atlantic Oscillation at 11-15 years scale is observed



Discussion 2 -ncrease in hydrologic losses (evapotranspiration) due to afforestation

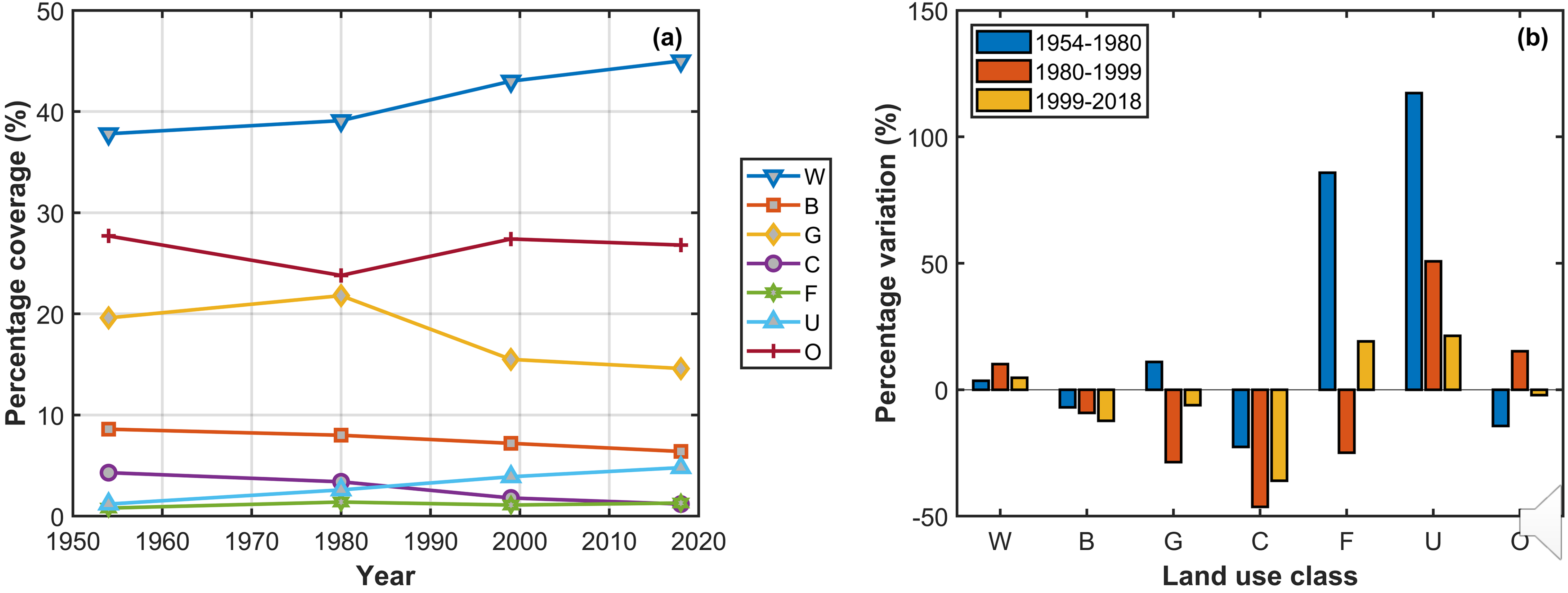


Already shown for the Adda riverbasin (Ranzi et al., JOC, 2021) where PET is however less than observed Losses=P-Q

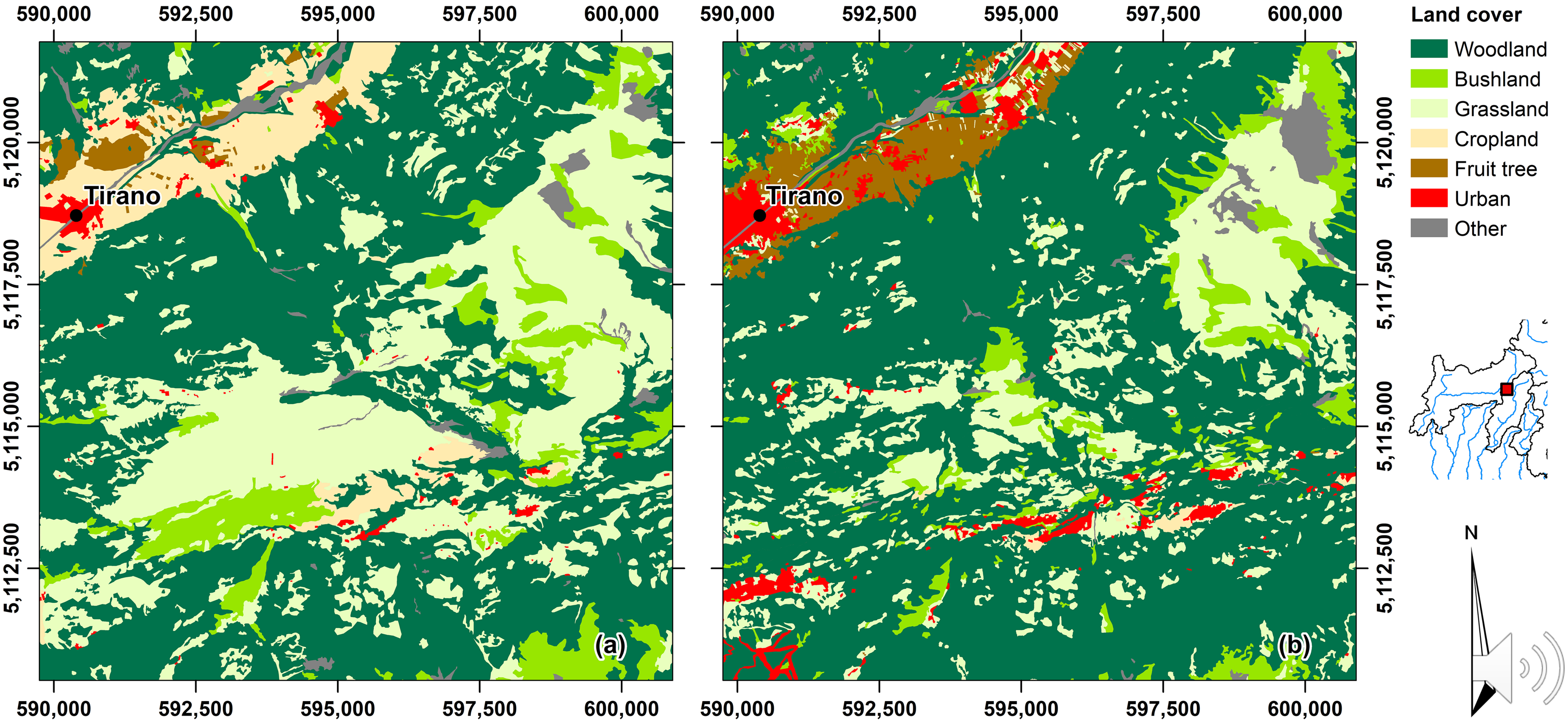
Afforestation as a concomitant cause

Land cover analysis 1954, 1980, 1999 and 2018 (Lombardy Region).

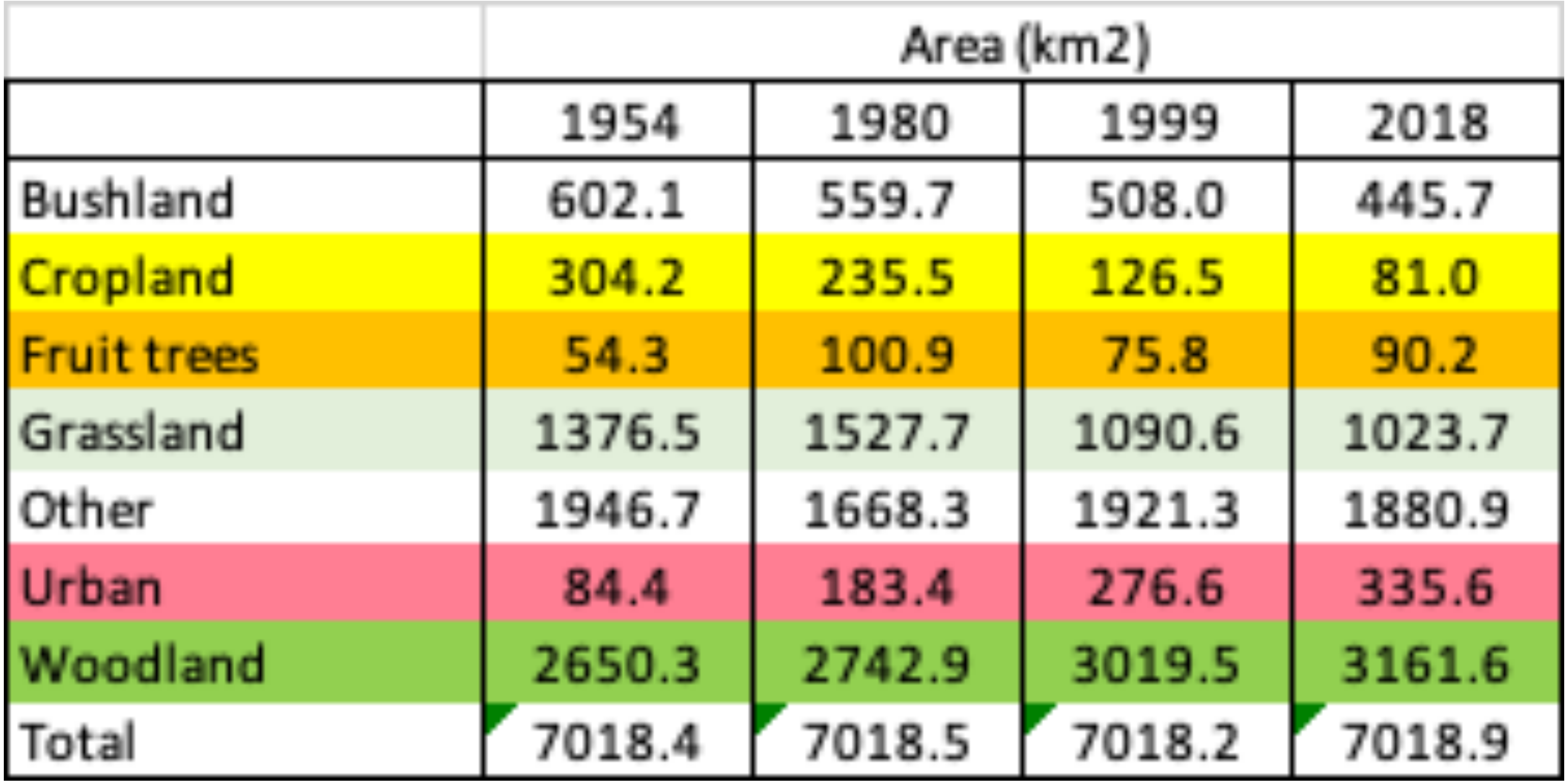
Woodland (W), Bushland (B), Grassland (G), Cropland (C), Fruit trees (F), Urban (U), Other (O).



Afforestation example (1954 vs 2018)



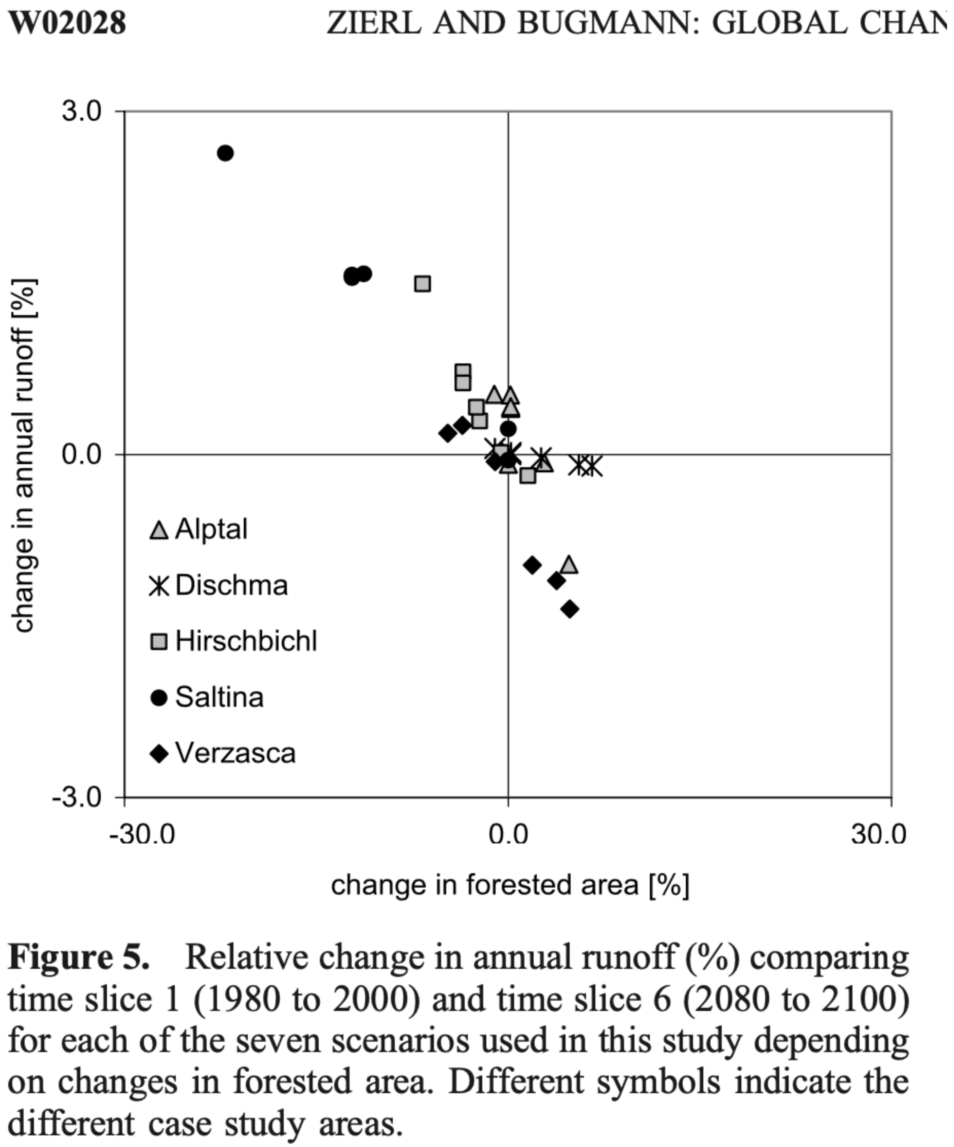
Land use changes likely cause of increased ET=P-Q losses



	Area (km2)			
	1954	1980	1999	2018
Bushland	602.1	559.7	508.0	445.7
Cropland	304.2	235.5	126.5	81.0
Fruit trees	54.3	100.9	75.8	90.2
Grassland	1376.5	1527.7	1090.6	1023.7
Other	1946.7	1668.3	1921.3	1880.9
Urban	84.4	183.4	276.6	335.6
Woodland	2650.3	2742.9	3019.5	3161.6
Total	7018.4	7018.5	7018.2	7018.9

Afforestation

Zierl and Bugmann (WRR, 2005) showed after simulations and Gurtz et al. (HP, 1999) also with data on the Swiss Alps how forested areas decrease annual runoff



W02028 ZIERL AND BUGMANN: GLOBAL CHAN

Figure 5. Relative change in annual runoff (%) comparing time slice 1 (1980 to 2000) and time slice 6 (2080 to 2100) for each of the seven scenarios used in this study depending on changes in forested area. Different symbols indicate the different case study areas.

Discussion (3-effect of reservoirs upstream and Lake's management downstream)

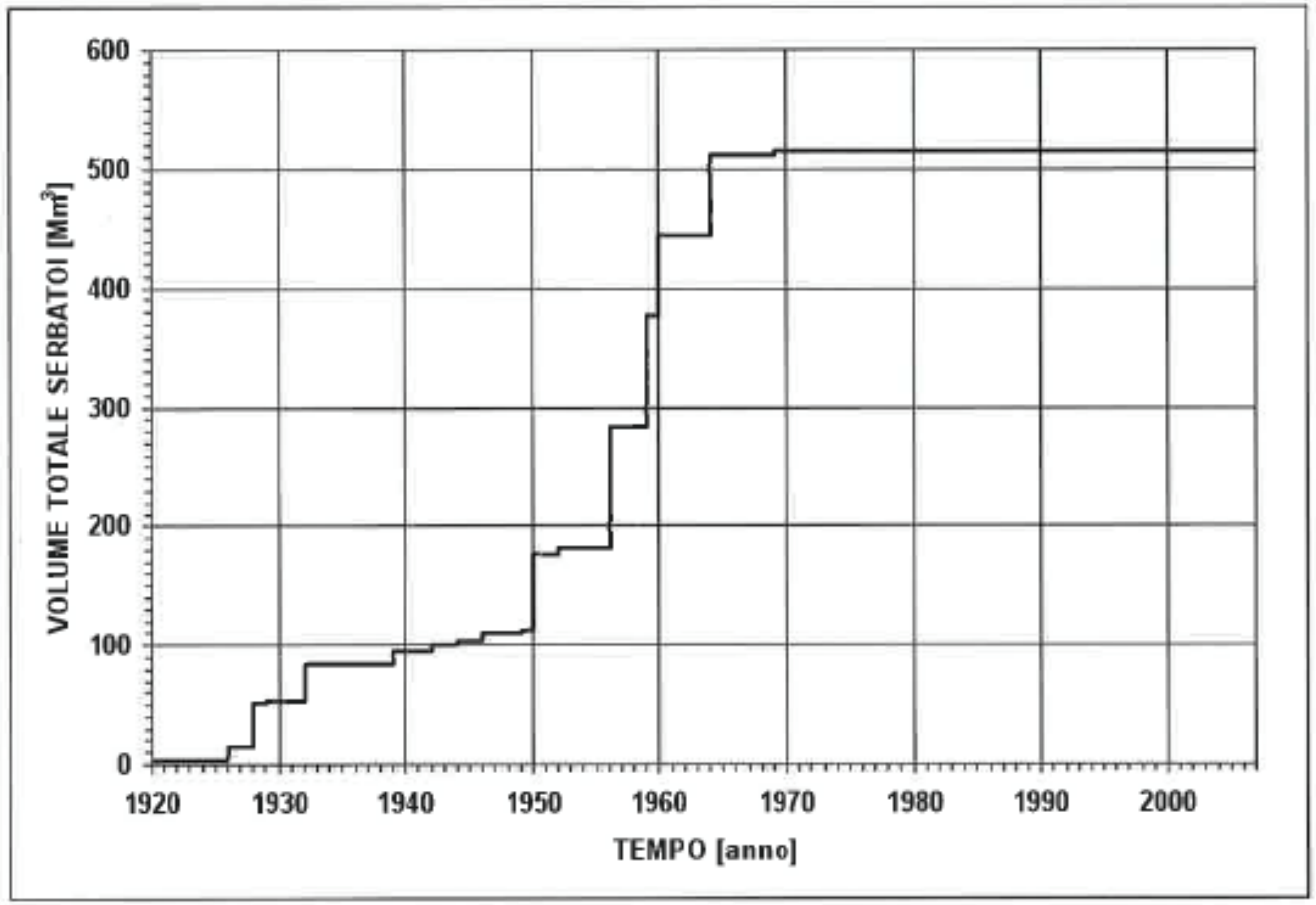
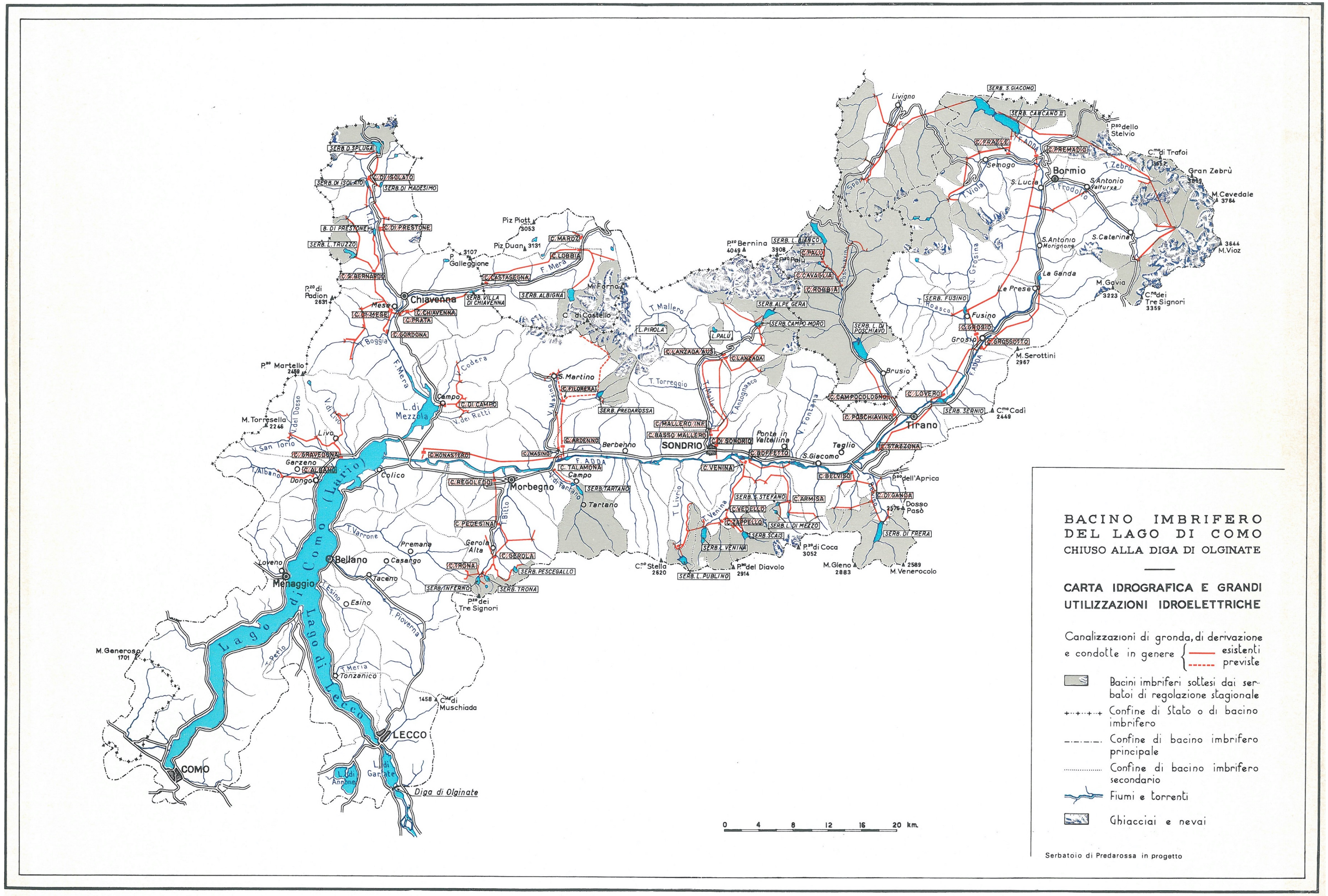
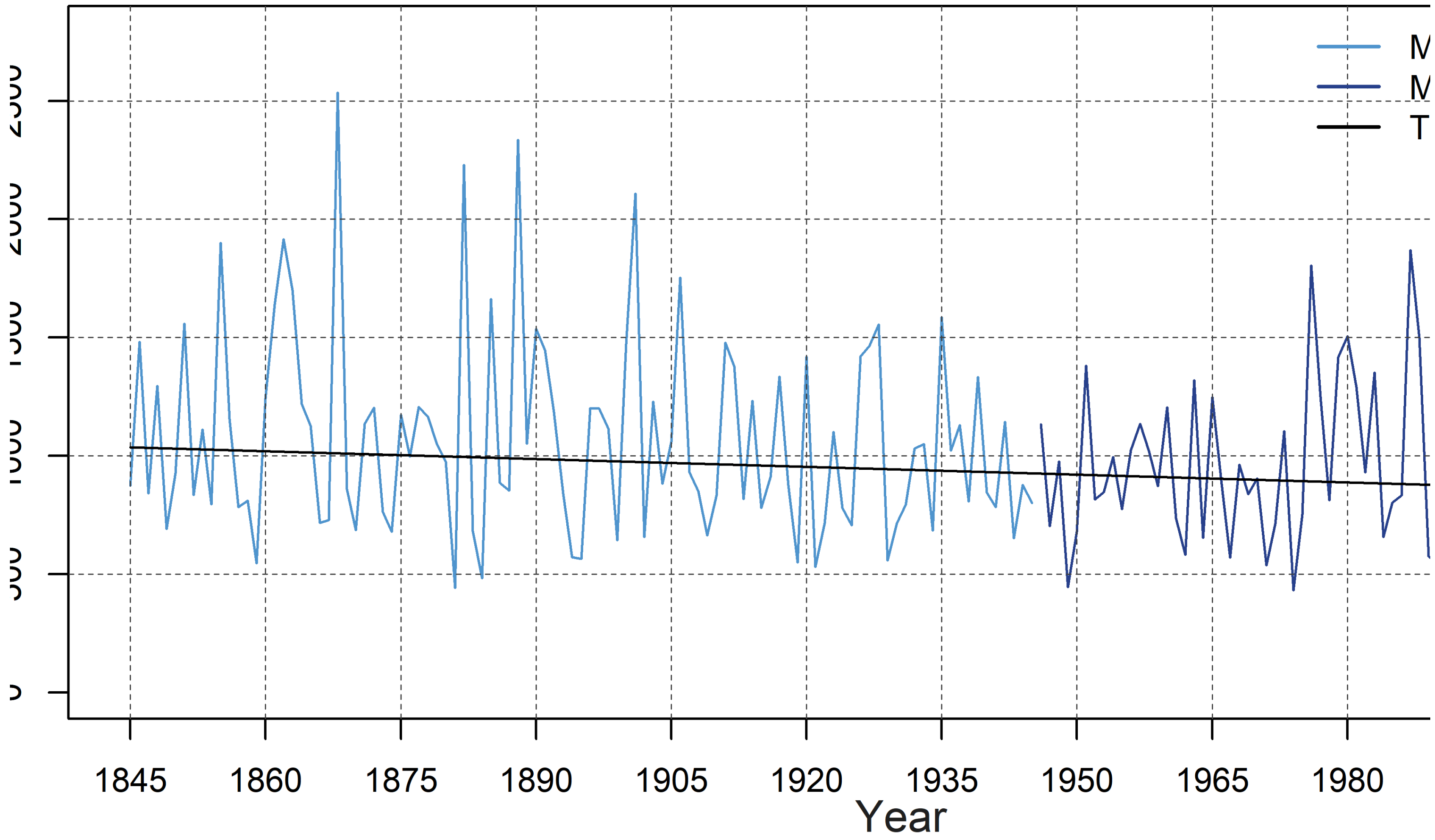


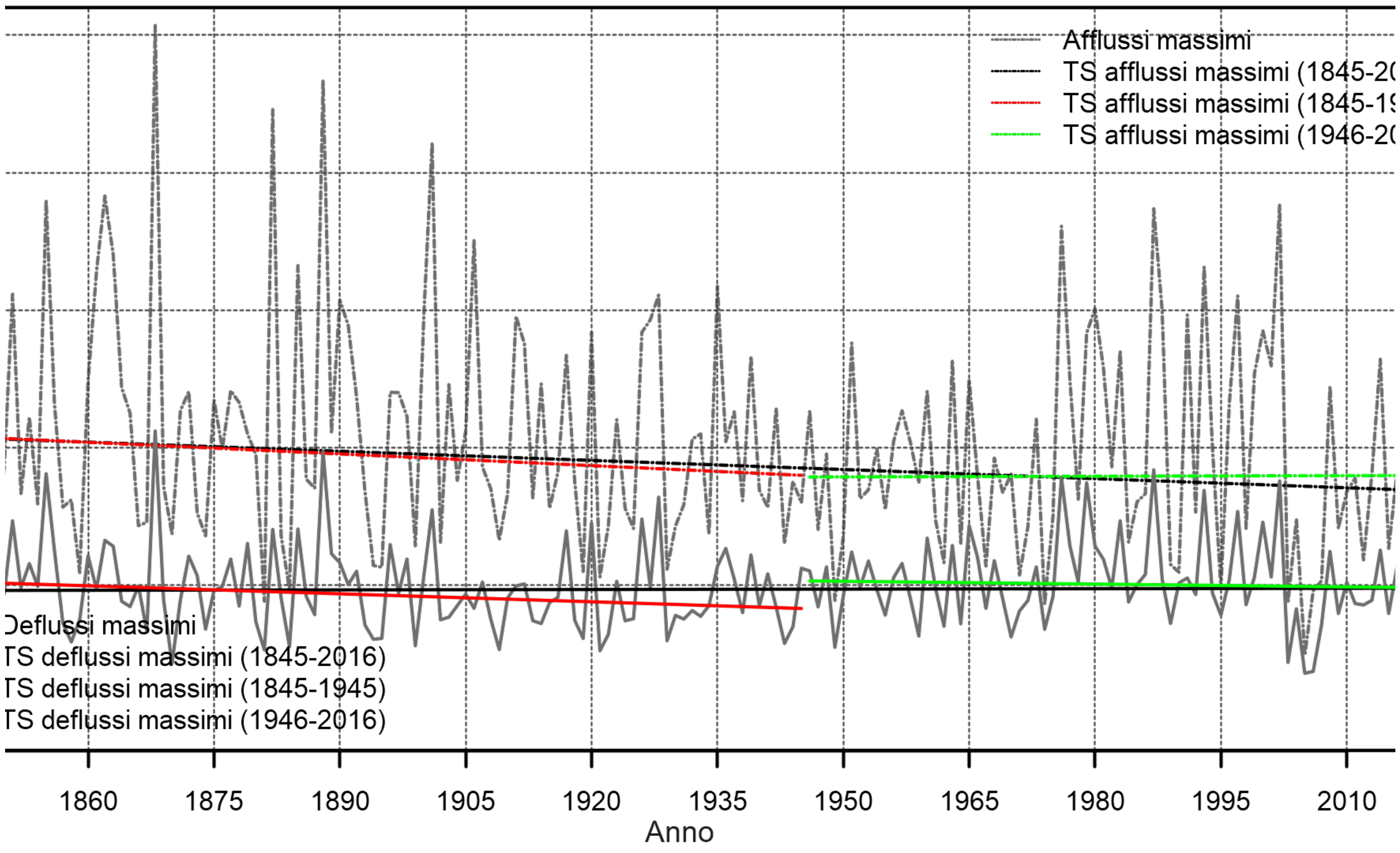
Fig. 3 Crescita del volume totale dei serbatoi alpini stagionali nel bacino dell'Adda prelacuale

Discussion (3-effect of reservoirs and Lake’s management)





Annual maxima of daily inflow show a decline with Z_{MannK}=-1.86, very close to the 5% significance limit



…but annual maxima of daily outflow are constant because of a combination of the effect of upstream reservoirs and lake's regulation

The Olginate dam at the Como Lake's outlet increases the discharge capacity, with a final neutral effect on extremes

Conclusions

- New data series collected confirm results of previous studies for the Italian Alps indicating a stationarity of annual rainfall and a significant decrease of runoff, about -1.45 mm/year at regional scale
- Increased hydrological losses can be attributed to both climate warming but also to expanded forested areas enhancing evapotranspiration losses.
- Weak teleconnection with sunspot and AMO signals is observed
- Land use changes monitored at 7000 km^2 scale indicate a 20% increase of woodland corresponding to +500 km^2. They can be one of the reasons of the decrease of flood extremes together with reservoirs upstream Lake Como
- However Lake’s regulation with Olginate dam is the reason of a neutral effect on the trend of outflow extremes