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VARIABILITY IN TRENDS OF ANNUAL MEAN TEMPERATURE AMONG FORESTED AREAS IN THE APENNINE ALPS (MIDDLE ITALY)

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Aim of the research

In 2006 the School of Geography and Environmental Sciences of Monash University in collaboration with the Italian Forest Corps (Corpo Forestale dello Stato), Uffici Territoriali per la Biodiversità di Vallombrosa (Florence) and Pratovecchio (Arezzo) started to monitor the variability in temperature and rainfall in the Tuscan Apennine Alps (Middle Italy) (Fig.1). First results showed unexpected variability in trends of both the climate variables and in particular very high variability in similarity of trends among sites even at short distance. Although the time series are ultra-centenary in some sites, trends in temperature and rainfall at the monthly level would show an increase in temperature in the last decades. However, in some sites a relative cooling is shown in the 2000s; and, similar warm periods occurred various decades ago. In the area, climate warming appears to reach levels that may have relevant implications for forest composition and shift. The relatively fast increase in temperature during the last 3-4 decades further strengthens the importance to continue monitoring climate variability to a deeper level and extend the understanding of its effects at the local level.

After years, this uncertainty poses the question whether the phenomenon was due to some anomaly in the periodical oscillations of 6-7 years of length (spectral Fourier analysis) or the dominant trends in variability of monthly temperature are changed.

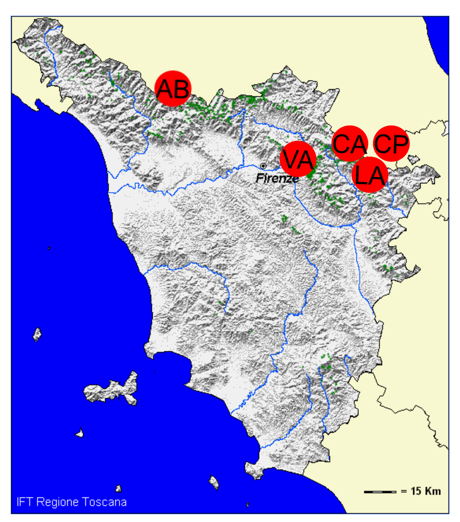

Fig. 1 – Location of the four meteorological stations on tops of the Tuscan Apennine Alps. Abetone is AB, Camaldoli is CA, Campigna is CP, La Verna is LA, and Vallombrosa is VA.

Table 1 – Elevation (m. asl), UTM coordinates, and period of data available for the four meteorological stations.

	Elev. (m. asl)	UTM Coordinates		Period available	
		N	E	Temp. (°C)	Prec. (mm)
Abetone (AB)	1345	4888677	633856	1951-2005	1921-2014
Camaldoli (CA)	1111	4854670	726599	1885-2015	1916-2014
Campigna (CP)	1050	4861300	720730	1947-2014	1934-2010
La Verna (LA)	1125	4843497	736176	1956-2014	1924-2014
Vallombrosa (VA)	975	4845229	705916	1872-2015	1872-2014

Research Question

How does temperature increase in the Apennine Alps (Middle Italy) during and after the 20th century?

Annual temperature trends

Statistical analysis show different trends in annual mean temperature at the five sites (Fig. 2). For example, the 1960s at Abetone feature a very warm period that does not occur at the other study sites; at Camaldoli, temperature decreases during the 1900s while it increases at Vallombrosa. Smoothing of the annual mean temperature series is made by moving averages; spectral Fourier analysis would suggest the presence of 6-7 years sub-periods in temperature variability.

Seven-years moving averages highlight some relevant differences in trends of annual mean temperature among sites (Fig. 3), and previous occurrence of periods warmer than in recent decades (i.e; VA during the 1940s). From the 1980s, differences in values of annual mean temperature seem to decrease among sites although the level in similarity of trends may still vary among sites in some cases.

A general moderate level of similarity among annual mean temperature series is confirmed by matrix correlation (Table 2.); in some cases, similarity is good (i.e.: CM-LA, VA-CP).

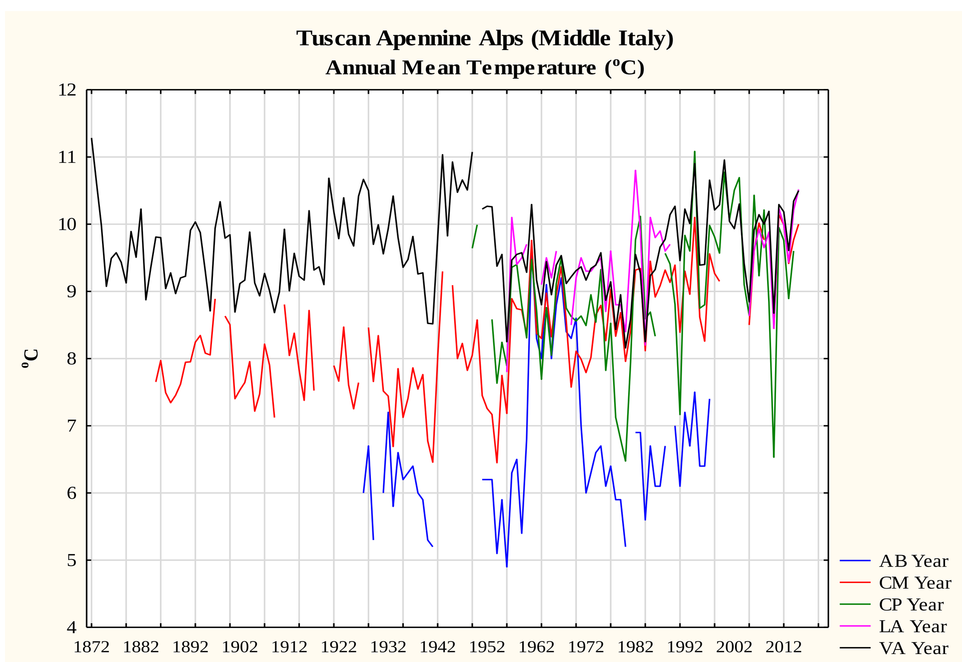

Fig. 2 – Annual mean temperature at the five study sites. AB is Abetone, CM is Camaldoli, CP is Campigna, LA is La Verna, and VAL is Vallombrosa.

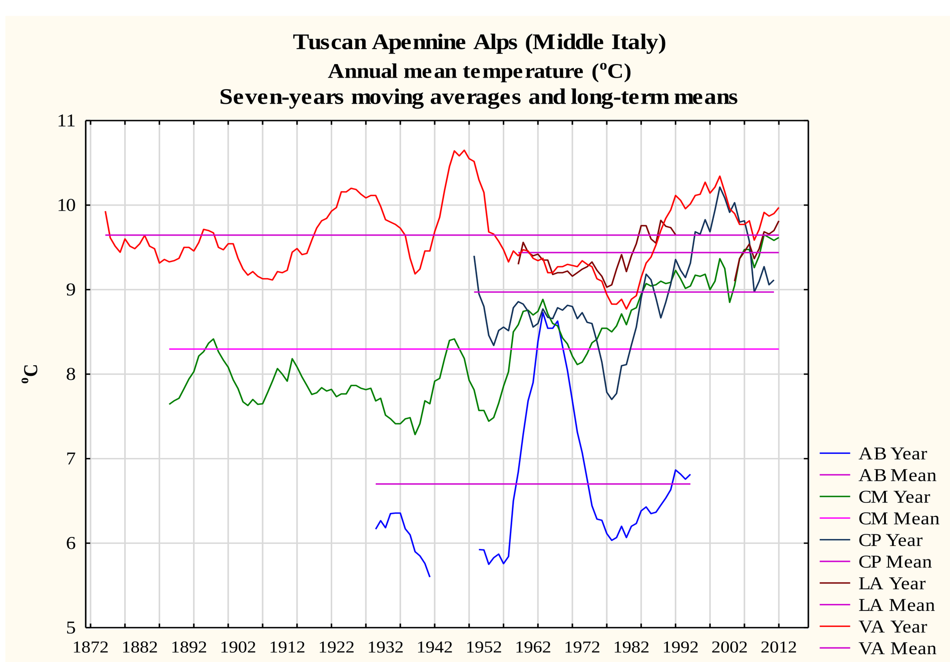

Fig. 3 – Seven-years moving averages of annual mean temperature at the five study sites. AB is Abetone, CM is Camaldoli, CP is Campigna, LA is La Verna, and VA is Vallombrosa.

Table 2 – Higher values of Pearson coefficients of correlation of annual mean temperature when tested versus the seasonal mean temperatures at the other study sites (Camaldoli, La Verna, and Vallombrosa)

	Correlations of 7-Years Moving Averages of Annual Mean Temperature. Pearson's *r*. Correlations are significant at $p < 0.0500$. N=33 (Casewise deletion of missing data)				
	AB Year	CM Year	CP Year	LA Year	VA Year
AB Year	$r = 1.00$ p = ---	$r = -0.18$ $p = 0.33$	$r = 0.35$ $p = 0.05$	$r = -0.21$ $p = 0.23$	$r = 0.22$ $p = 0.22$
CM Year	$r = -0.18$ $p = 0.33$	$r = 1.00$ p = ---	$r = 0.41$ $p = 0.02$	$r = 0.83$ $p = 0.00$	$r = 0.49$ $p = 0.04$
CP Year	$r = 0.35$ $p = 0.05$	$r = 0.41$ $p = 0.02$	$r = 1.00$ p = ---	$r = 0.61$ $p = 0.00$	$r = 0.78$ $p = 0.00$
LA Year	$r = -0.21$ $p = 0.23$	$r = 0.83$ $p = 0.00$	$r = 0.61$ $p = 0.00$	$r = 1.00$ p = ---	$r = 0.60$ $p = 0.00$
VA Year	$r = 0.22$ $p = 0.22$	$r = 0.49$ $p = 0.004$	$r = 0.78$ $p = 0.00$	$r = 0.60$ $p = 0.00$	$r = 1.00$ p = ---

Variability in similarity of annual mean temperature trends

Annual mean temperature over time shows that similarity in trends among sites is highly non-stationary and varies irregularly during the previous and the current centuries (Fig.4a). Similarity spans between moderate and highly positive values and negative values.

However, a change in trends' similarity seems to occur from the 1980' (Fig. 4b); the variability of similarity appears reduced and/or occurring relatively more regularly.

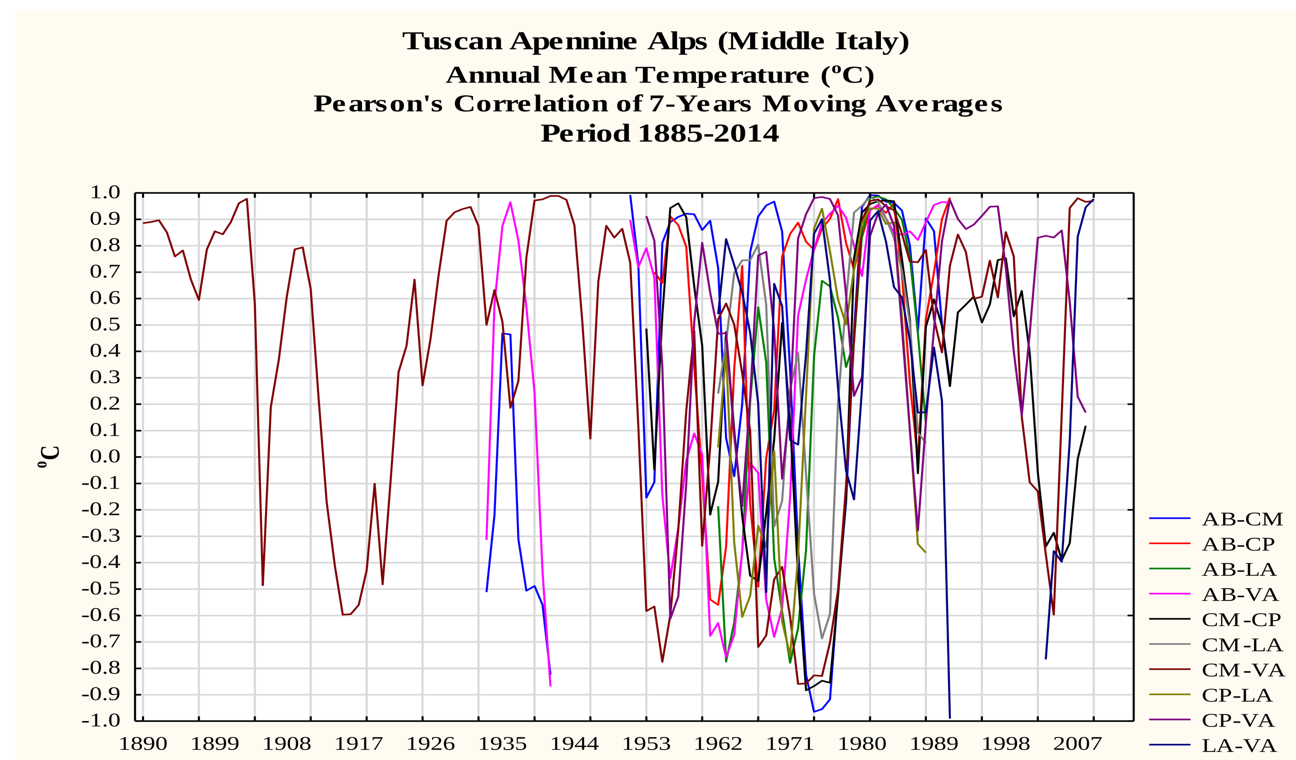

Fig. 4a – Pearson's *r* correlation of 7-yrs moving averages between paired sites.

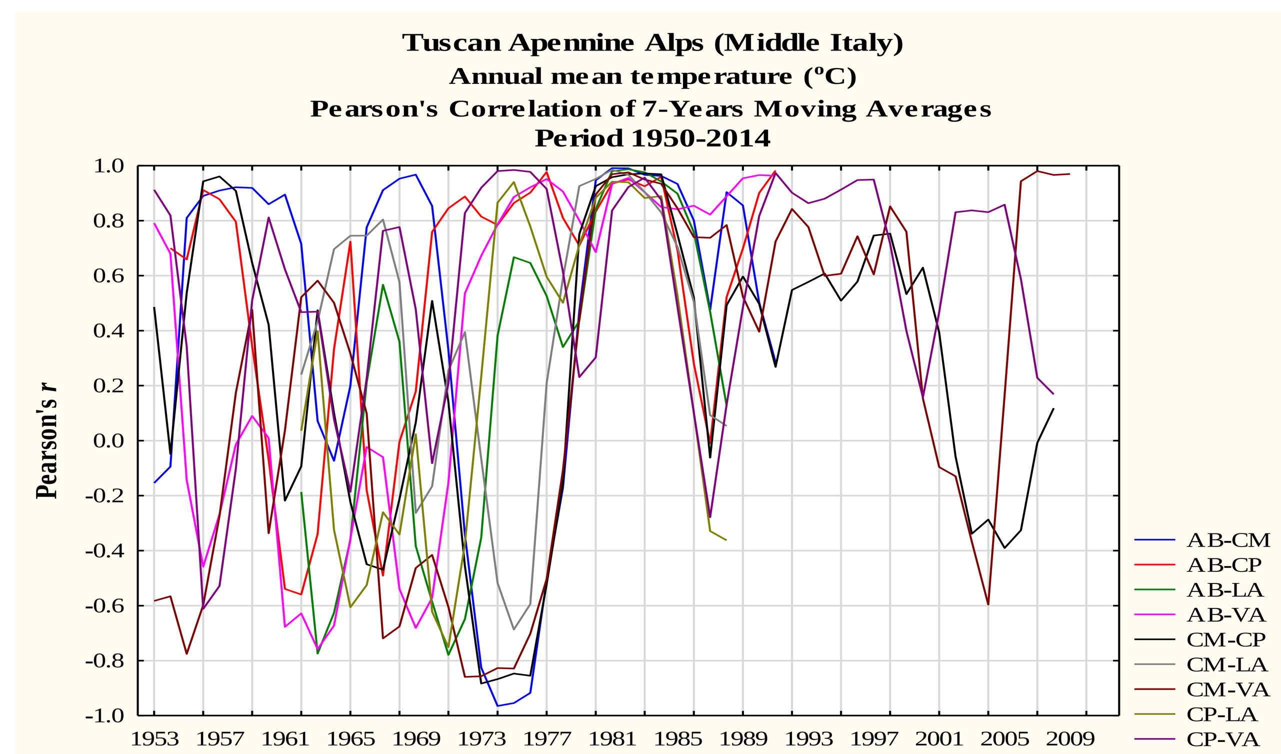

Fig. 4b – Pearson's *r* correlation of 7-yrs moving averages between paired sites.

Modification of season length?

At the monthly level (Fig. 5a), agglomeration of months seems to cluster a way different from the traditional D-J-F (winter), M-A-M (spring), J-L-A (summer), and S-O-N (autumn). At first glance, winter and summer seem to extend against spring and autumn. If so, schematically (warmer) winter might be formed by December, January, February, and March; spring by April and May; summer by June, July, August, and September; and autumn by October and November. This tendency, if confirmed, appears to be more marked during the last decades (Fig. 5b).

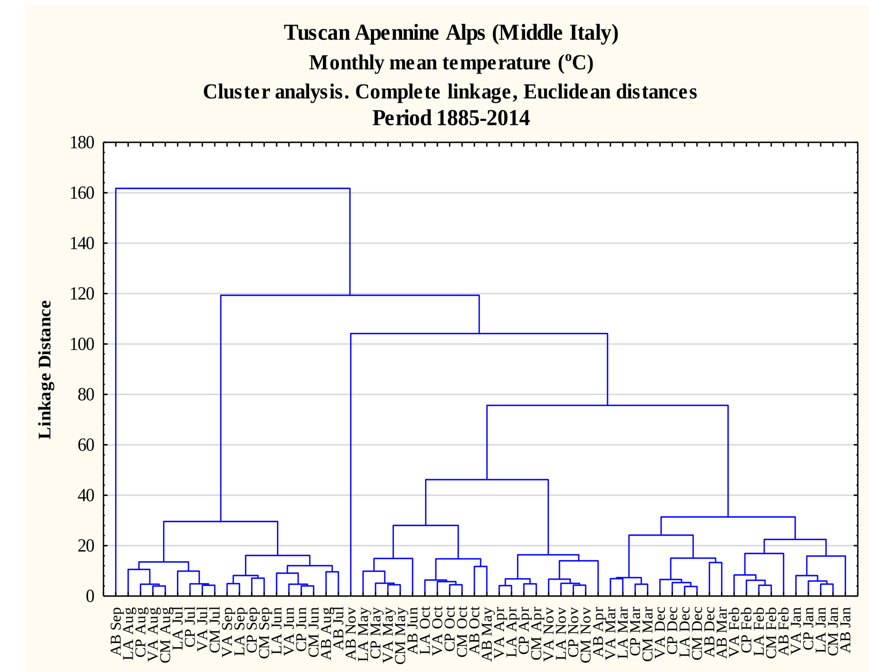

Fig. 5a – Dendrogram of monthly mean temperature series among sites produced by agglomerative hierarchical clustering.

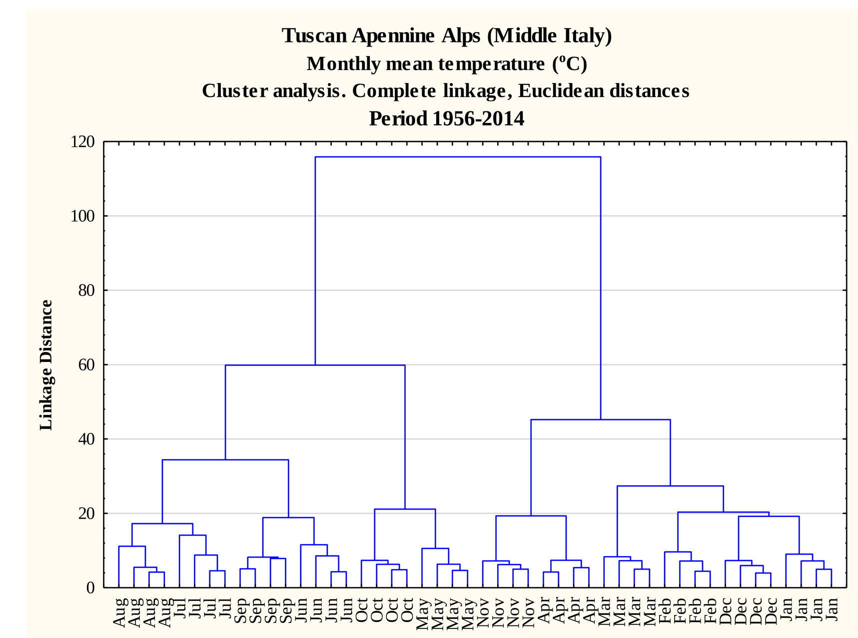

Fig. 5b – Dendrogram of monthly mean temperature series among sites produced by agglomerative hierarchical clustering.

Conclusions

This study contributes to highlight the importance of further exploring the causes of variability in trends of temperature at the local level when effects of climate variability are investigated;

In some sites, warmer periods have occurred in the past. This would suggest continuing to monitor climate variability at the site level and spatial scale;

Master series of mean temperature may fail in detecting alterations that occur at the monthly level and especially when climate variability is implemented in planning and management of natural resources in mountain regions. In forested areas, trends in temperature at the regional or higher scale may smooth variability at the local level that can have relevant effects on tree growth and health instead.

Although a main tendency of temperature to increase over recent decades seems to be present, any potential tendency to the homogenization of trends and changes in the extent of seasons may have strong effects on mountain forest ecosystems. If so, the causes of this phenomenon, which has to be verified at the regional scale, need to be investigated.

Changes in the length of seasons can also have relevant impacts in the phenology and growth of plant species. This would require to approach the monitoring of trends in climate variability by implementing phenological and/or plant growth monitoring.