Summer air temperature anomalies in Europe during the century 1811-1910 (*)

E. PIERVITALI, M. CONTE and M. COLACINO
Istituto di Fisica dell'Atmosfera (CNR) - Roma, Italy

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Summary. — Solar cycle, volcanic eruptions, sea surface temperature anomalies (ENSO) and increase of the concentration of the greenhouse gases are the main forcing factors in the evolution of the Earth climate. Therefore, a sizeable amount of research is devoted to assess the impact of these factors on the climate parameters, as the mean air temperature. In the present work a study concerning the behaviour of the summer temperatures over Europe during the century 1811-1910 is carried out. The possible influence of the volcanic eruptions and ENSO has been also analysed. The results show the presence of a volcanic signal in the summer temperature during the year following an eruption, even if the anomalous coldest summers do not seem to be driven by the volcanic activity. The connection between thermal anomalies and ENSO events is more uncertain because of the paucity of data. Finally, the anomalous summers—both very cold and very warm—can be explained in terms of the atmospheric circulation, since cold events seem to be associated to persistent blocking systems and warm events are associated to persistent high-pressure patterns.

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1. – Introduction

The climate evolution, either at global or regional scale, is described by the trend of the meteorological parameters such as temperature, precipitations, pressure and so on [1-3].

The mean air temperature is usually considered the most representative parameter: therefore, a larger fraction of research is devoted to investigate how and how much the forcing factors of climate—solar-cycle variations, volcanic eruptions, ENSO (El Niño Southern Oscillation) events, greenhouse gas increase—modify the long-term behaviour of the thermal field [4-6].

The analyses are generally based on secular data series of the mean annual values; few works are instead devoted to the seasonal time scale. In the present paper the summer mean values of the air temperature are analysed using data collected in

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(*) The authors of this paper have agreed to not receive the proofs for correction.

European observatories during the period 1811-1910. Particular attention has been also paid to the thermal anomalies, both cold and warm, where we define anomalous a season in which the air temperature shows a difference, with respect to the reference mean 1951-1980, equal to or larger than $|\pm 1.0\,^{\circ}\mathrm{C}|$.

The patterns of the temperature and of its anomalies are analysed and the impact of the volcanic eruptions and ENSO is examined.

Volcanic eruptions could be a possible cause of a transient planetary climate modification, because the great release in the atmosphere of large amount of aerosols can modify the radiation balance of the Sun-Earth system and produce variation in the evolution of meteoclimatic parameters. Franklin [7] was the first in 1974 to talk about this topic: in a conference held in Paris, he suggested that the cold anomaly recorded during that year could be connected to the dust released into the atmosphere during the 1783 eruption of Mount Laki in Iceland. The problem was faced in more scientific terms in this century by Abbott [8]. He explained, in terms of volcanic aerosols, the reduction in solar radiation measured in the Smithsonian Institution observatories after the Katmai eruption. The same matter was examined also by Kimball [9], but only recently an exhaustive analysis of this topic has been done through the development of new methods of data process and of mathematical models. However, the opinions in this study field are quite different: while some researches [10-13] indicate an effect on the air temperature, others [14, 15] are more cautious in their evaluations, in agreement with the statement of Angell and Korshover [16], who write “while volcanic eruptions certainly do not cause warming, the evidence that they cause cooling is not overly impressive”. To estimate in quantitative way the impact of the volcanic dust, Lamb [17] defined the Dust Veil Index (DVI), which depends on the number and the intensity of the eruptions in each year and may be associated with possible climatic impact when it is larger than 100 units.

The event that is considered typical of the impact of the volcanic activity on climate is the Tambora eruption, which occurred in 1815 and was followed by the so-called “year without summer”. Actually, in 1816 low temperatures in Europe and North-Eastern America have been recorded. Mass and Portmann [18] have analysed the strongest volcanic eruptions, which occurred during the last century, and therefore concluded that “only the largest eruptions (in terms of producing a stratospheric dust cloud) are suggested in the climate record and that modest cooling ($-0.1 \div -0.2\,^{\circ}\mathrm{C}$) is observed for one or two years after these stronger events. Previous suggestions of large cooling during the first few months after volcanic events appear to be unwarranted”. The Mass and Portmann work is particularly important since they evaluate also the impact of ENSO. More recently similar analyses have been carried out by Portmann and Gutzler [19], who analyse temperature and precipitation *vs.* volcanic and ENSO events and by Kirchner and Graf [20], who try to discriminate in the winter mean temperatures of the Northern Hemisphere the ENSO and the volcanic signals. They conclude that in Europe the volcanic contribution is prevailing while in the Pacific area the winter anomaly is driven by ENSO.

The analyses carried out in the present work show the presence of a volcanic signal in the summer temperatures recorded in the year following the eruptions. No clear conclusions can be drawn about El Niño influence, because we have during the century which we have examined only few cases of temperature anomalies. These ones can be more easily explained as due to anomalies of the atmospheric circulation: persistent blocking systems for the very cold and persistent high pressure fields for the very warm summer temperature.

2. – Data set

The temperature data set has been obtained from the World Climate Disc (WCD) [21] and from "World Weather Record" of the Smithsonian Miscellaneous Collections [22] for the station network shown in fig. 1.

Sources of information about volcanic eruptions are the Catalogue of the Smithsonian Institution [23] and Lamb [17].

Data concerning El Niño events are in the book "El Niño", edited by Diaz and Markgraf [24] in which a chronology of the phenomenon in the period from 620 to 1990 AD is reported. This chronology has been elaborated by Quinn, who classifies the different events as weak (W), moderate (M), strong (S) and very strong (VS) depending on their intensity and duration of the climatic related anomalies and on their impact on the society. A reliability index going from 1 to 5 is attributed to each event in proportion to the amount of information found from several sources.

The analysis of the blocking system for 1816 has been carried out using the Briffa-Jones [25] and Lamb information, whereas the more recent patterns, since 1887, have been built up using data gathered from Smithsonian Miscellaneous Collections.

In table I all the data used in the work are reported: summer temperature differences from reference average 1951-1980 ΔT, volcanic eruptions (year and DVI), El Niño events (intensity and reliability index).

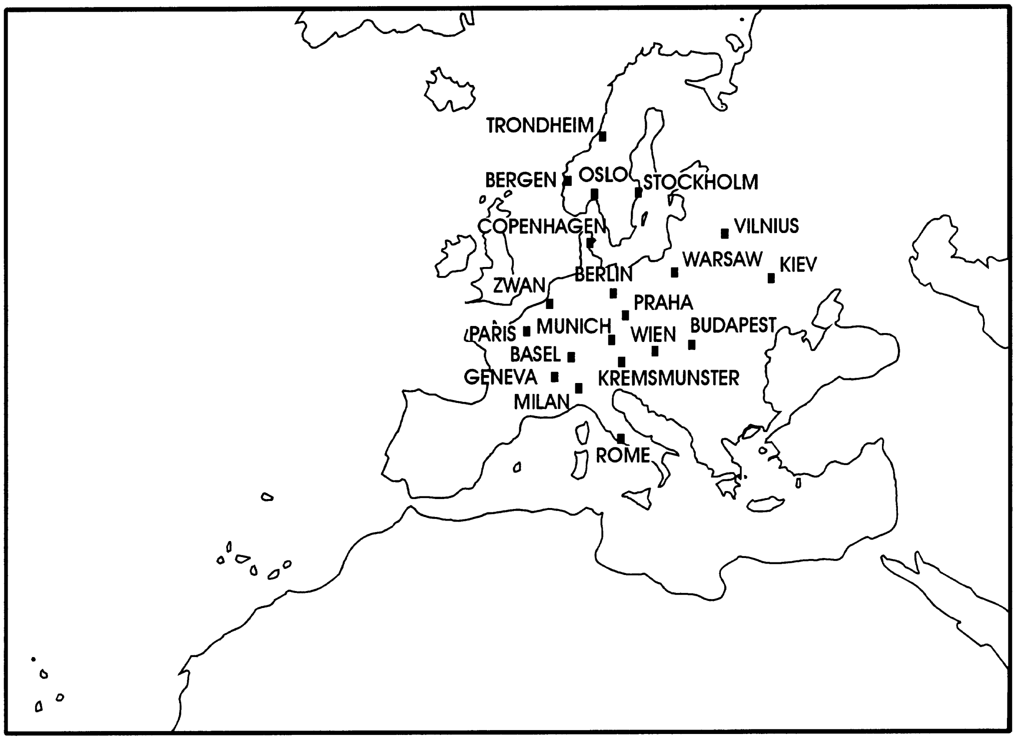

Fig. 1. – Locations of temperature stations for Europe.

TABLE I. – *Summer temperature differences from reference average 1951-1980 for Europe* (ΔT_{E}), *volcanic eruptions* (*year and* DVI), ENSO *events* (*intensity and reliability index*).

Year	ΔT_{E} (°C)	VE		ENSO	
		month	DVI	strength	confidence index
1811	*1.714*	—	—	—	—
1812	0.028	—	—	M+	3
1813	−0.625	—	—	—	—
1814	0.084	—	300	S	3
1815	−0.722	—	3000	—	—
1816	**−1.325**	—	—	—	—
1817	0.034	—	—	M	3
1818	0.324	—	—	—	—
1819	*1.121*	—	—	M+	3
1820	−0.033	—	—	—	—
1821	**−1.630**	—	100	M	3
1822	0.879	—	500	—	—
1823	−0.040	—	—	—	—
1824	−0.060	—	—	S	5
1825	−0.109	—	—	S	5
1826	*1.981*	—	300	—	—
1827	0.671	—	—	S+	5
1828	0.819	—	—	S+	5
1829	−0.271	—	—	—	—
1830	0.381	—	—	M	3
1831	0.628	1, 2, 3, 4	500	—	—
1832	−0.395	—	—	S+	5
1833	−0.733	—	—	S+	5
1834	*2.033*	—	—	—	—
1835	0.005	—	4000	M	3
1836	−0.700	—	—	M	3
1837	−0.395	—	—	—	—
1838	−0.957	—	—	S	5
1839	0.357	—	—	S	5
1840	−0.924	—	—	—	—
1841	−0.567	—	—	—	—
1842	0.624	—	—	—	—
1843	−0.448	—	—	—	—
1844	**−1.129**	—	—	VS	3
1845	−0.033	—	250	VS	5
1846	*1.795*	—	1000	—	—
1847	−0.045	—	—	—	—
1848	−0.152	—	—	—	—
1849	−0.724	—	—	—	—
1850	0.057	—	—	S	5
1851	−0.719	—	—	—	—
1852	0.933	—	200	M	4
1853	0.265	—	—	M	4
1854	0.190	—	—	S	5
1855	0.481	—	—	S	5
1856	−0.400	—	700	—	—
1857	0.581	—	—	M+	5
1858	*1.057*	—	—	—	—
1859	*1.300*	—	—	—	—

TABLE I. – (*Continued*).

Year	ΔT_E (°C)	VE		ENSO	
		month	DVI	strength	confidence index
1860	−0.610	—	—	M	3
1861	*1.038*	—	800	—	—
1862	−0.510	—	—	M−	2
1863	0.043	—	—	—	—
1864	−0.890	—	—	S+	5
1865	−0.081	—	—	M+	4
1866	0.257	—	—	M+	4
1867	−0.367	—	—	—	—
1868	*1.414*	—	—	S	5
1869	−0.571	—	—	—	—
1870	0.105	—	—	—	—
1871	−0.271	—	—	M	3
1872	0.362	—	—	—	—
1873	0.976	—	—	M+	5
1874	0.214	—	—	M+	5
1875	0.809	—	300	—	—
1876	0.828	—	—	—	—
1877	0.390	—	—	VS	5
1878	−0.100	—	poss. 1250	VS	5
1879	−0.095	—	—	—	—
1880	0.314	—	—	M+	5
1881	−0.109	—	—	M+	5
1882	−0.400	—	—	—	—
1883	−0.143	—	1000	—	—
1884	−0.562	—	—	M+	4
1885	0.014	—	—	M+	4
1886	−0.243	—	—	—	—
1887	0.324	—	—	—	—
1888	−**1.00**	—	500	S+	5
1889	−0.467	—	—	—	—
1890	−0.498	—	—	—	—
1891	−0.499	—	—	M	5
1892	−0.038	—	—	—	—
1893	0.190	—	—	—	—
1894	−0.067	—	—	—	—
1895	0.214	—	—	—	—
1896	0.209	—	—	M+	5
1897	0.852	—	—	M+	5
1898	−0.386	—	—	—	—
1899	−0.052	—	—	VS	5
1900	0.419	—	—	VS	5
1901	*1.105*	—	—	—	—
1902	−**1.233**	—	about 1000	S+	5
1903	−0.652	—	—	—	—
1904	0.243	—	—	S	5
1905	0.919	—	—	S	5
1906	0.128	—	—	—	—
1907	−**1.030**	—	150	M+	5
1908	−0.143	—	—	—	—
1909	−**1.00**	—	—	—	—
1910	−0.371	—	—	—	—

3. – Data analysis

3.1. *Analysis of the different parameters.* – The summer temperature deviations ΔT are shown in fig. 2. The ΔT distribution is Gaussian with $\overline{\Delta T} = 0.04$ °C and $\sigma = 0.72$ °C. In addition, with reference to our definition of thermal anomaly, we recorded 7 cold and 10 warm anomalous seasons.

To assess the influence of the volcanic eruptions, the superposed epoch analysis on the global set has been carried out. The zero year is the one of the eruption, and temperature data of the 3 preceding and following years have been considered. Figure 3 shows, together with the results of the analysis, the presence of a negative signal on the summer temperatures in the year that follows the eruption. However, the study of the thermal anomalies, in the hypothesis that only volcanic events with DVI $\geqslant$ 500 could have climatic impact, indicates that a cold summer has been only recorded in 1816 after an eruption: that of Tambora in 1815. In particular, the thermal anomaly in 1821 ($\Delta T = -1.68$ °C), the strongest of this century, is not connected to volcanic activity. Also the strong eruption of Coseguina (1835; DVI $\sim$ 4000), Armagora (1846; DVI $\approx$ 1000), Ghaia (1878; DVI $\sim$ 1250) and Krakatoa (1888; DVI $\sim$ 1000) seem not to have influence on the thermal cold summer anomalies.

It can be observed that in North-Eastern America the behaviour seems quite different, since after the Coseguina eruptions in 1836 and 1837 cold summers occurred, traces of which are clearly evident in the tree rings [26]. We can then say that while

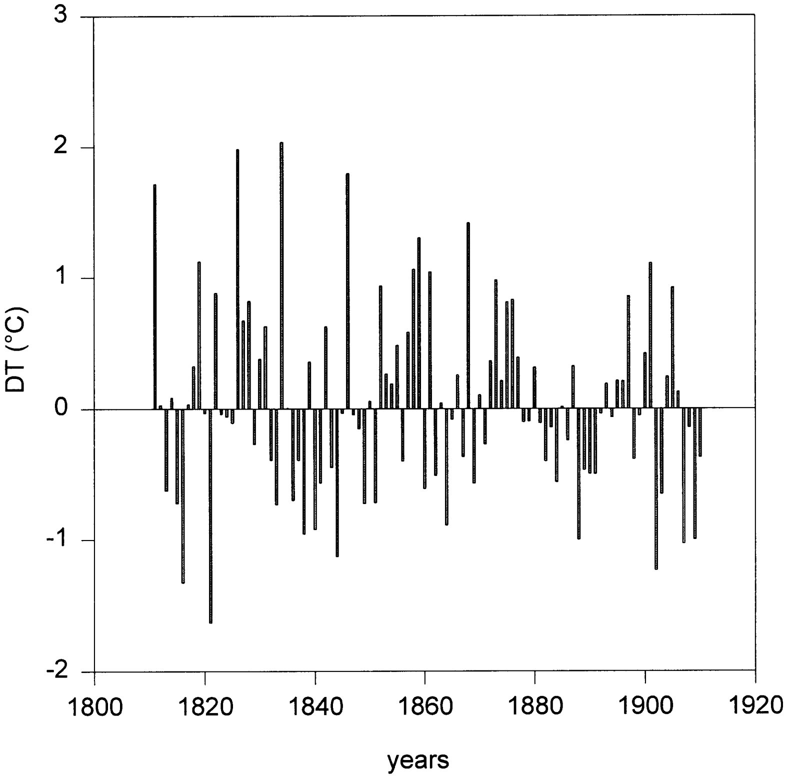

Fig. 2. – Summer temperature deviations from the reference average 1951-1980.

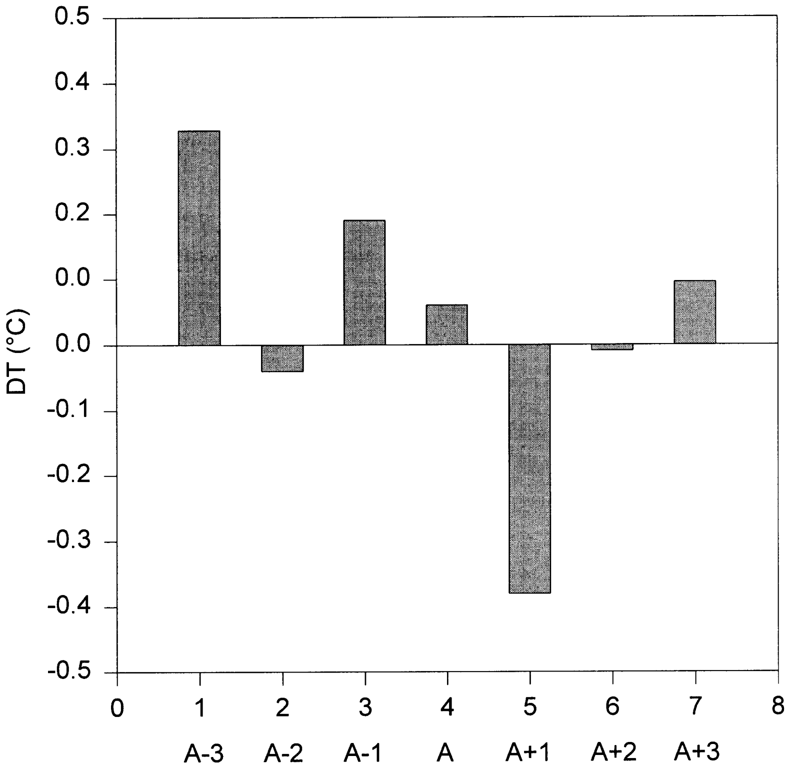

Fig. 3. – Superposed epoch analysis on temperature data ($A =$ year of the eruption; $A-1$, $A-2$, $A-3 = 3$ years preceding the eruption; $A+1$, $A+2$, $A+3 = 3$ years following the eruption).

there exists an impact of the volcanic activity on the temperature, the eruptions cannot be believed to be direct responsible for the strong cold summer anomalies.

Considering ENSO effects, 5 of the 7 cold summers occurred during El Niño, that has shown an intensity going from moderate (M) to very strong (VS) and confidence index 5. Only in 1821 the confidence index is 3.

The warm seasons have been, instead, recorded in 8 cases when an ENSO was not occurring: actually only in 1819 and 1821 the El Niño has been observed with moderate intensity and reliability index 3 and strong intensity and reliability index 5, respectively.

3˙2. *Thermal anomalies and atmospheric circulation.* – The connection between cold summers and atmospheric circulation has been investigated first of all in 1816, that is the most controversial cold event since, as seen before, it could be a consequence of the eruption of the Tambora volcano. Figure 4 shows the pattern of the thermal field: low temperatures are observed also over Southern France and North-Western Italy. Figure 5 gives, instead, the surface pressure field as obtained by Briffa and Jones. The

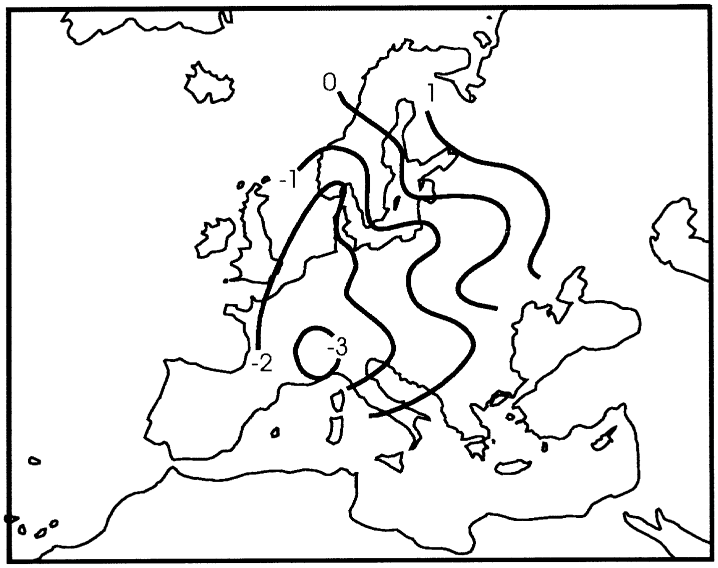

Fig. 4. – Temperature anomaly map relative to summer 1816, for Europe.

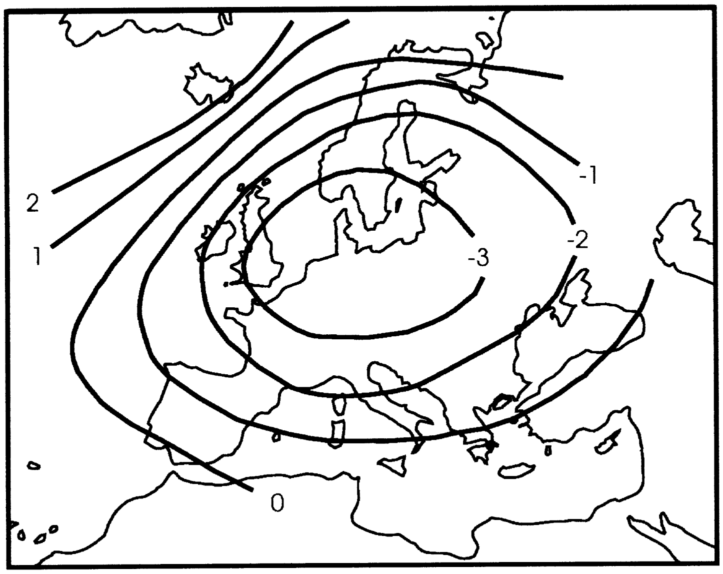

Fig. 5. – Pressure anomaly map relative to summer 1816, for Europe, obtained by Briffa and Jones.

distribution is similar to a dipole with a low over Europe and a high pressure over the North Atlantic and Iceland. This pattern could correspond to frequent blocking situations with a cold air flow coming from high latitudes toward the Central-Southern regions of Europe.

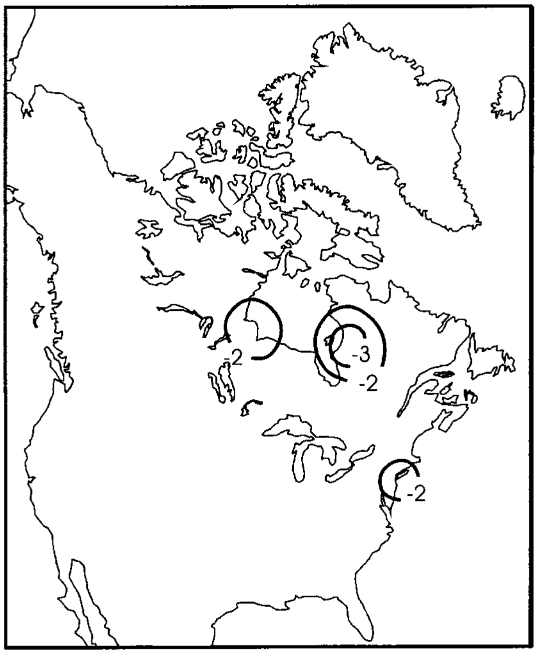

Fig. 6. – Temperature anomaly map relative to summer 1816, for North-America, as proposed by Guiot.

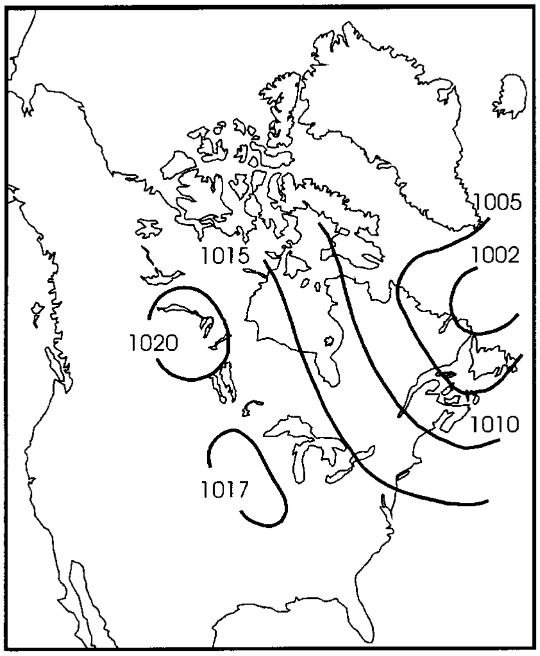

Fig. 7. – Pressure map relative to July 1816, for North-America, produced by Lamb.

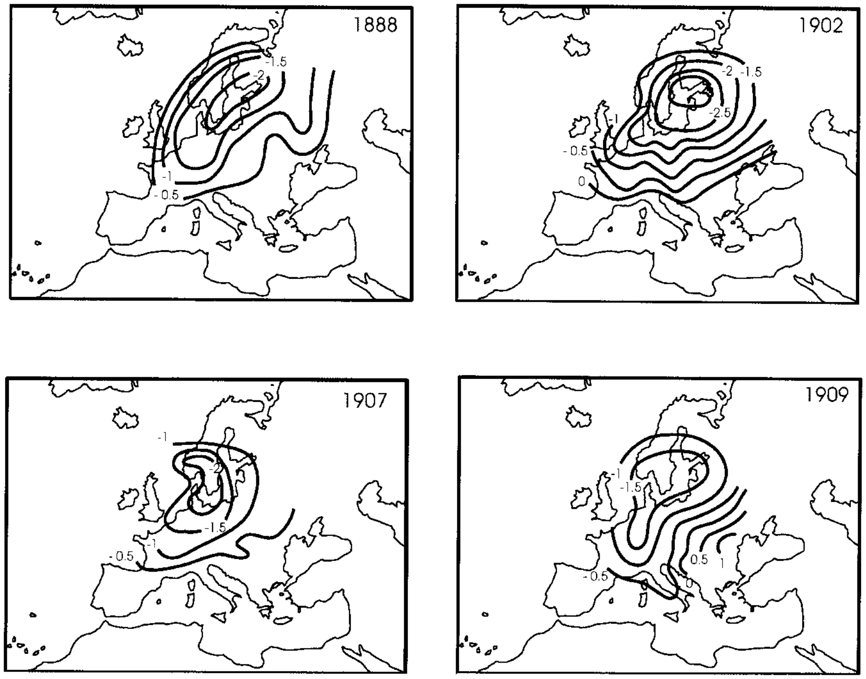

Fig. 8. – Maps of temperature deviations for summer 1888, 1902, 1907, 1909.

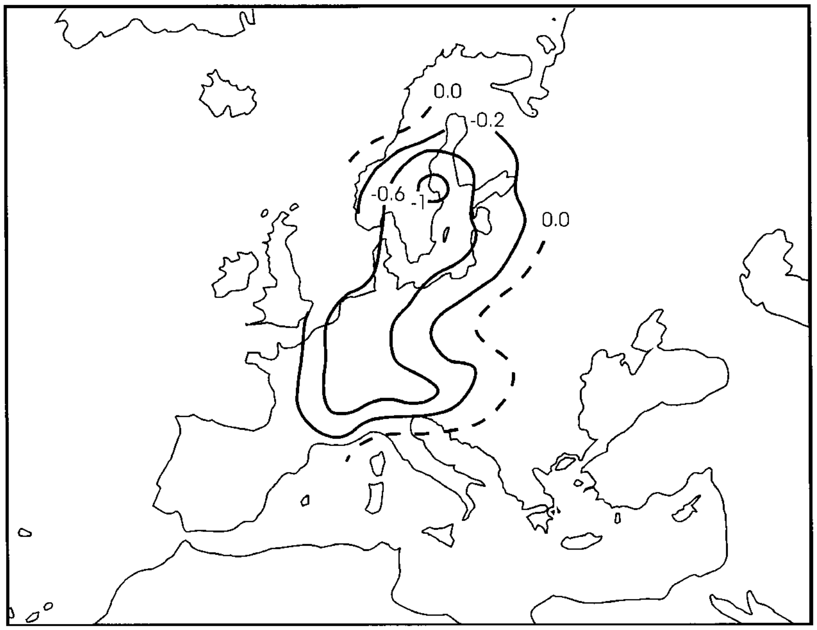

Fig. 9. – Temperature pattern obtained by the mean of the data recorded in the 11 summers following volcanic eruptions.

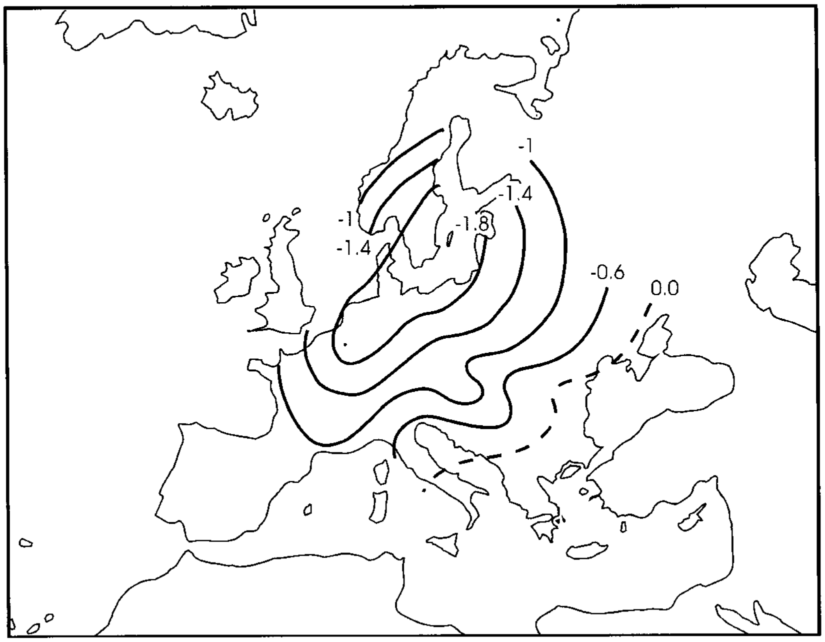

Fig. 10. – Temperature pattern obtained by the mean of the data recorded in the 7 summers linked to blocking systems.

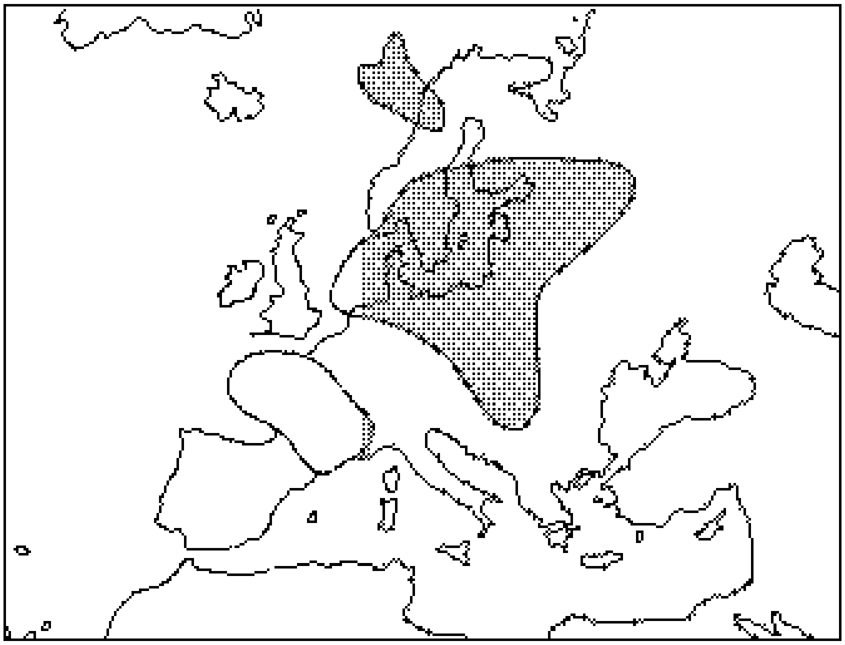

Fig. 11. – Map of temperature differences between the summers linked to blocking systems (fig. 10) and the summers following volcanic eruptions (fig. 9).

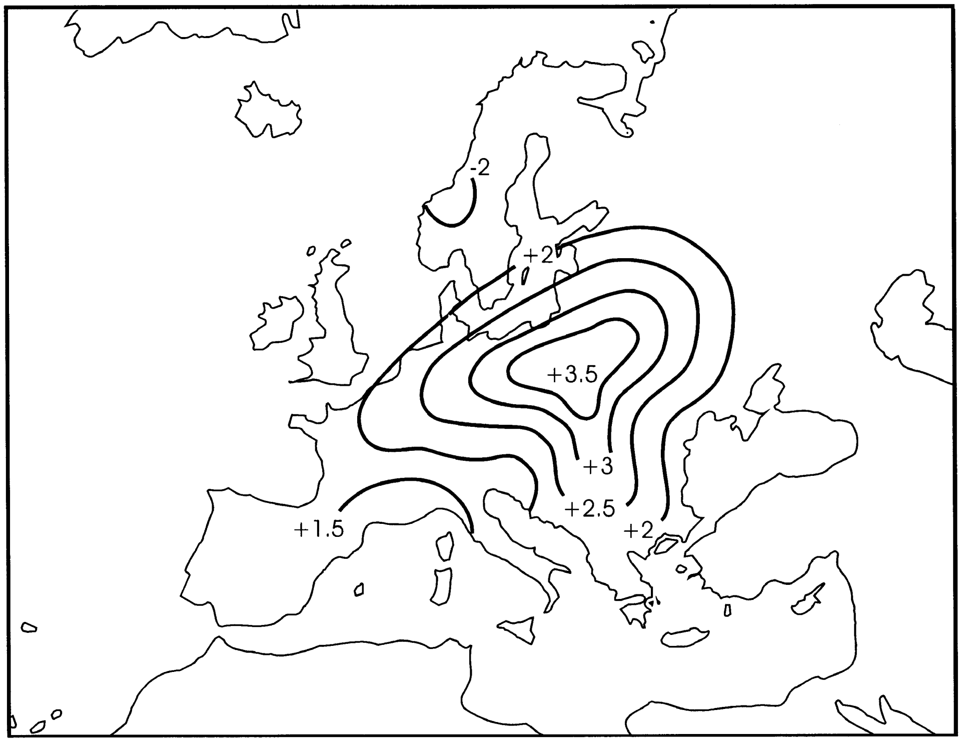

Fig. 12. – Temperature anomaly map for summer 1834.

A similar analysis can be carried out also for North-Eastern America, for which following Stommel [27], the year without summer, which caused sizeable damages to the agriculture, has been determined by the Tambora eruption. In fig. 6 the pattern of the temperature is shown as proposed by Guiot [28]. Strong negative values are present over the Labrador peninsula. In fig. 7 the pressure map produced by Lamb is shown. It indicates high pressure eastward the Rocky Mountains and low over Terranova. As a consequence, cold air from the subpolar region flew towards North-Eastern America. This explanation is confirmed by the study of Catchpole [29] on the log books of the ships of the Hudson Bay Company, from which it results that during summer 1816 the prevailing winds blew from North-North West.

Concerning other cold anomalies, the systematic comparison between temperature and pressure fields has been developed only since 1887, year from which pressure data are available to us. In fig. 8 the maps of temperature deviations for different cold anomalies are reported: the greatest differences are over Northern (Scandinavia) and Central Europe. Only in 1909 the anomaly reaches lower latitudes. The pressure field shows in all the events, with some uncertainties in 1909, low pressure values over continent and high ones over the ocean, the Iceland and Greenland. We can then hypothesise that many blocking situations could have occurred with a splitting in the western prevailing atmospheric currents: a branch toward North and a branch toward South. The general pattern brings cold air from the subpolar regions towards Europe. We have, then, elaborated two different maps. The first one, fig. 9, is the pattern ob-

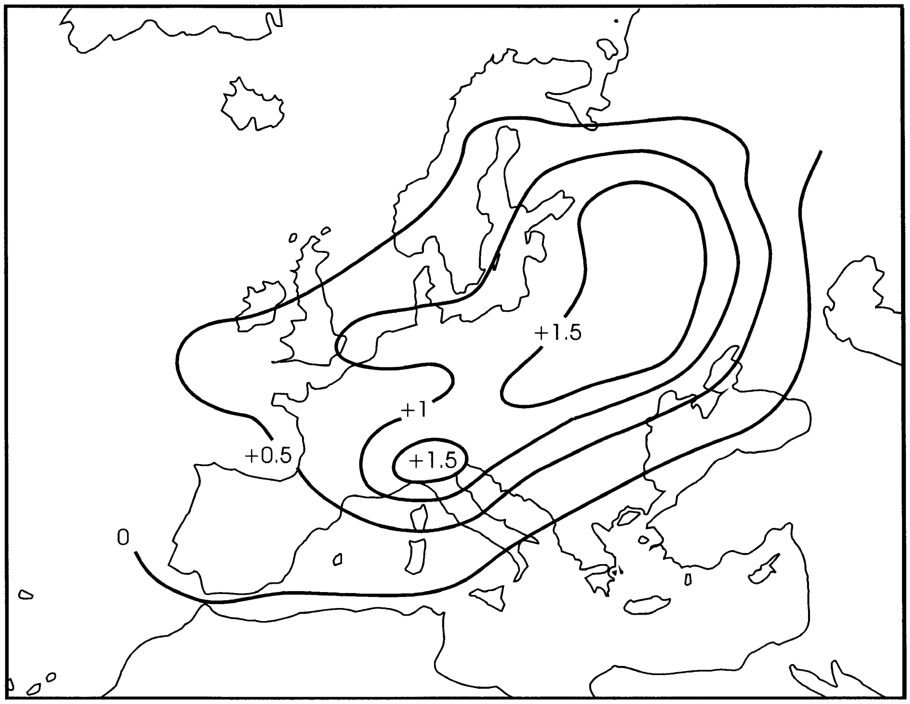

Fig. 13. – Pressure anomaly map for summer 1901.

tained with the temperature data recorded in the 11 summers following volcanic eruptions; the second one, fig. 10, with data of 7 anomalous summers, which are probably linked to blocking systems. The map difference, fig. 11, shows large values in which the anomalies, due to the blocking, and those after volcanic activity are different in a significant way following the test of Student at confidence level of 95%. This confirms that thermal seasonal anomalies at regional scale are connected to circulation anomalies and are, instead, not explainable by the action either of volcanic eruptions or ENSO.

The warm anomalies present the maximum over Central-Western Europe (in fig. 12 the case of 1834 is reported) and only in two years, 1858 and 1901, the maximum difference is over Scandinavia.

Figure 13 shows the surface pressure field for 1901: the high is centred over Central-Eastern Europe reaching also the Alps and France. The pattern implies a flux from South towards higher latitudes, with a clear sky, strong solar radiation and probable subsidence with noticeable warming of the air temperature in the Central Europe.

4. – Conclusions

From the analysis carried out we can draw the following conclusions:

i) The summer temperatures in Europe during the examined century are very similar to those found in more recent years: in particular the mean value is close to the reference average, computed using the data set of 30-year period: 1951-1980.

ii) A volcanic signal is present in summer temperatures in the year following an eruption.

iii) The very cold anomalies in Europe seem to be completely anticorrelated with the volcanic eruptions. The strongest eruptive events, in fact, are not followed by summer temperature reduction.

iv) Because of paucity of data, connection with El Niño cannot give quantitative information: we can only say that in Europe the occurrence of ENSO corresponds to cold temperature.

v) Finally, the strongest anomalies can be explained in terms of atmospheric circulation anomaly: the cold ones are usually related to the presence of blocking systems; the warm, instead, are recorded in the presence of high-pressure field centred over central Europe.

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