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A re-evaluation of the Italian historical geomagnetic catalogue: implications for paleomagnetic dating at active Italian volcanoes

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Abstract

Paleomagnetism is proving to represent one of the most powerful dating tools of volcanics emplaced in Italy during the last few centuries/millennia. This method requires that valuable proxies of the local geomagnetic field (paleo)secular variation ((P)SV) are available. To this end, we re-evaluate the whole Italian geomagnetic directional data set, consisting of 833 and 696 declination and inclination (respectively) measurements carried out since 1640 AD at several localities. All directions were relocated via virtual geomagnetic pole method to Stromboli (38.8° N, 15.2° E), rough centre of the active Italian volcanoes. For declination-only measurements, missing inclinations were derived (always by pole method) by French data (for period 1670–1789), and by nearby Italian sites/years (for periods 1640–1657 and 1790–1962). Using post-1805 declination values, we obtain a 0.46 ± 0.19 °/yr westward drift of the geomagnetic field for Italy. Original observation years were modified considering such drift value to derive a drift-corrected relocated data set. Both data sets were found to be in substantial agreement with directions derived from the field models by Jackson et al. (2000) and Pavon-Carrasco et al. (2009). However, the drift-corrected data set minimizes the differences between the Italian data and both field models, and eliminates a persistent 1.6° shift of 1933–1962 declination values from Castellaccio with respect to other nearly coeval Italian data. The relocated data sets were used to calculate two post-1640 Italian SV curves, with mean directions calculated every 30 and 10 years before and after 1790, respectively. Curve comparison suggests that the regional model by Pavon-Carrasco et al. (2009) yields the best available SV curve to perform paleomagnetic dating of 1600–1800 AD Italian volcanics, while the Italian drift-corrected curve is probably preferable for the XIX century. For the XX century, the global model by Jackson et al. (2000) yields more accurate inclination values, while the declinations from our drift-corrected curve seem to better represent the local field evolution, at least for the first half of the century.

1 Introduction

During the last years there has been an increasing use of paleomagnetism to provide accurate emplacement ages of products erupted by the active Italian volcanoes during the last millennia (e.g. Hoye, 1981; Rolph and J.Shaw, 1986; Tanguy et al., 1985, 2003; Carracedo et al., 1993; Incoronato et al., 2002; Lanza and Zanella, 2003; Speranza et al., 2004, 2006, 2008; Vezzoli et al., 2009). The paleomagnetic directions retrieved from loosely-dated volcanic rocks are compared to an independently-obtained reference curve of the (paleo)secular variation ((P)SV) of the geomagnetic field. This "paleomagnetic dating" method represents in principle the most powerful dating tool for recent (i.e. up to few ka) volcanics, where soils (datable by ^{14}C methods) hardly develop if the eruption rate is high, and K/Ar and Ar/Ar dates are often defined with an accuracy comparable to the absolute age values.

Clearly, a well-defined PSV reference curve is a crucial pre-requisite to efficiently use the paleomagnetic dating method. Due to the existence of non-dipolar components of the geomagnetic field, PSV curves have a regional validity, implying that Italian volcanics can be paleomagnetically dated using exclusively European and circum-Mediterranean PSV data, traditionally relocated to given Italian volcanoes via virtual geomagnetic pole method (Noel and Batt, 1990). Several archeomagnetic data sets and stacked lacustrine paleomagnetic records from several European localities have provided a valuable PSV record for Italy from ca. 10 000 years BP to the XVII century AD (see references and discussion in Speranza et al., 2008).

However, Lanza et al. (2005)have demonstrated that the relocation via pole method of geomagnetic directions from Chambon-La-Forêt (48.02° N, 2.27° E, France), to L'Aquila (42.38° N, 13.32° E, Italy) introduces errors of ca. 2° (on average), due to the non-completely dipolar nature of the geomagnetic field. To overcome relocation errors, Pavon-Carrasco et al. (2009) have recently produced a regional model for the geomagnetic field in Europe for the last 3000 years (up to 1900 AD) using spherical caps harmonics for the spatial representation of the field. This model should yield the best estimates of geomagnetic directional data expected at Italian volcanoes during the last three millennia.

The SV reference curve of the last four centuries relies on direct measurements of the Earth's magnetic field. A wealth of direct geomagnetic observations gathered in several Italian localities (1) has been reported in the Italian historical geomagnetic catalogue (Cafarella et al., 1992). Unfortunately, apart from the complete declination/inclination measurement done in 1640 by Kircher in Rome, only declinations values were gathered in Italy before 1805. Similarly, the 1933–1959 record solely relies on declination measurements from Castellaccio, near Genoa.

The lack of Italian inclination values for several decades within the last four centuries hampered the realization of a SV curve entirely made from direct geomagnetic observations from Italy, because the relocation method requires couples of declination/inclination values. Consequently, paleomagnetic dating of volcanics erupted in Italy during the last four centuries has been routinely done by relocating direct observations from France (Alexandrescu et al., 1996), or using the historical database and global model by Jackson et al. (2000), which however considers only 101 Italian data (from L'Aquila, Castellaccio, Naples, and Pola, Fig. 1) of 1900–1980 as input directions. This problem should be definitely overcome by using the regional model of Pavon-Carrasco et al. (2009), which does not use the pole relocation method, thus can take advantage of the whole Italian data base of Cafarella et al. (1992). However, the model of Pavon-Carrasco et al. (2009) extends up to 1900 AD, and for the XX century few complete directional data from Italy exist before the 1960s (see 1908–1962 AD gap in the Italian curve adopted by Lanza et al. 2005).

Another controversial issue is whether to consider or not the westward drift of the geomagnetic field, when using data relocation via pole method. In fact, the average 0.38°/yr westward drift of the geomagnetic field for the last two millennia proposed by Merrill et al. (1996) implies that relocating observations from France or other European countries to Italy would introduce an age error of some decades for similar trends in geomagnetic elements. One first problem is that several westward drift values have been proposed for Europe relative to the last four centuries (from 0.18°/yr to 0.61°/yr, Langel, 1987, Barraclough and Malin, 1999). Second, when performing paleomagnetic dating, some paleomagnetists have considered appropriate to consider the westward drift for SV data relocation (Speranza et al., 2004, 2005, 2008), while others have decided to neglect it (Tanguy et al., 2003; Arrighi et al., 2004, 2005; Lanza et al., 2005).

In this paper we use all available geomagnetic directional measurements done in Italy (as reported in the database of Cafarella et al., 1992), and verify their mutual consistency by relocating them via pole method to a unique locality (Stromboli, 38.8° N, 15.2° E). Lacking data necessary for pole conversion (mostly inclination values) were derived by neighbour Italian localities or years (for the periods 1640–1657 and 1790–1962), and by coeval French observations reported by Alexandrescu et al., 1996 (for the period 1670–1789). We find a 0.46 ± 0.19 °/yr westward drift for the last two centuries, and show that westward drift should be definitely considered when relocating via pole historical observations from Italy. After comparing the Italian SV curve derived by us to the directions predicted for Stromboli by the Jackson et al. (2000) and Pavon-Carrasco et al. (2009) models, we find that a combination of the three SV curves likely represents the best proxy for the local field evolution during the last four centuries.

2 The Italian historical geomagnetic data set

The Italian geomagnetic record (as reported by Cafarella et al., 1992) predominantly consists of declination time series carried out at 19 Italian localities (in Fig.1, all directions are listed in the Database S1, see Supplement). Some declination-only time series come from the geomagnetic observatories of Pola (formerly Austro-Hungarian Empire, 1881–1922) and Castellaccio (1933–1962). Further 383 declination/inclination couples were gathered at other scattered localities from peninsular Italy, Sardinia, Sicily, and minor islands.

Concerning data from 1960 to 2008 (last available datum), we refer to the directions measured at L'Aquila, main Italian geomagnetic observatory (I.N.G.V., 2008). As a whole, our data set consists of 833/696 declination/inclination values, coming by 57% by sites located in northern Italy (e.g. north of Rome).

3 Data relocation to a common site and evaluation of an Italian SV curve

The time series from the 19 localities of Fig. 1 were relocated via pole method (Noel and Batt, 1990) to the common site of Stromboli (38.8° N, 15.2° E), selected as the rough centre of the active volcanoes of southern Italy (i.e. from Vesuvius to Pantelleria) where paleomagnetic dating has been used so far. This choice would allow the SV curve derived by us to be compared with few or null corrections to paleomagnetic data gathered from active Italian volcanoes.

In order to use the whole Italian dataset, lacking inclinations were derived (always by pole method) from as nearby as possible sites/years. Declination values from 1640 to 1657 were relocated using the inclination (66°) gathered in 1640 by Kircher in Rome. Conversely, declinations from 1670 to 1789 were relocated using coeval directions from France (Alexandrescu et al., 1996). Since 1790, missing inclinations were obtained by as close as possible Italian localities, or by the direction measured at the same locality few (up to 16) years before/after. Lacking inclinations from Castellaccio were derived by the 1929 direction from Alessandria (44.92° N, 8.62° E), and the1960–1962 directions from L'Aquila. Negligible errors are introduced when considering inclination values measured in nearby years of the XIX-XX centuries, as inclination values (as calculated from Jackson et al., 2000) have changed by solely ∼0.03° and 0.01°/y during 1830–1910 and 1910–1990, respectively. All Italian data relocated to Stromboli are listed in Database S2 (see Supplement).

Similarly to all other European data sets, the relocated declinations show a trend of decreasing values after 1640, with a declination minimum of ca. −17° around 1800, followed by a roughly linear value increase up to Present (Fig. 2). The Castellaccio declination series is visibly shifted by 1.6° with respect to the other data. In principle, the Castellaccio declination shift might arise from several possible sources, such as the westward drift of the geomagnetic field, errors introduced by data relocation via pole method, local (due to the Castellaccio fortress walls) and/or regional magnetic anomalies. The latter source can be excluded, as the area of Castellaccio is characterized by a negative magnetic anomaly of less than —100 nT— at ground level (Chiappini et al., 2000), which definitely cannot account for a declination shift as great as 1.6° (see also discussion in Zanella, 1998).

Relocated inclination data increase from ~64° to ~68° from 1640 to 1670, then decrease to a minimum of 54°–55° in 1910–1920, and slowly increase afterwards. In Fig. 2 we have also plotted the geomagnetic directions expected at Stromboli considering the historical records database and global model by Jackson et al. (2000), hereinafter referred to as JM2000, and the regional European model by Pavon-Carrasco et al. (2009), hereinafter referred to as PM2009. Declination values derived from Italian data are at first glance consistent with declinations calculated from JM2000 and PM2009. The several Italian declinations values available for 1640 (0.1–6.1°) are roughly consistent with the declination derived from PM2009 (2.6°), but slightly greater than the null declination predicted by the JM2000 model.

Conversely, systematic differences exist when the inclination dataset is considered. The inclination measured by Kircher at Rome in 1640 is ca. 2° and 1° smaller than that predicted by JM2000 and PM2009 (respectively), whereas all remaining Italian-derived inclination values of 1670–1790 are systematically greater by 1°–2° than coeval values derived from JM2000 and PM2009. This significant mismatch occurs in the period for which French directions were used to relocate Italian-only declinations. The 1810–1860 inclinations derived from PM2009 are greater by ca. 1° than both Italian data and inclinations from JM2000. A small (~0.5°) but systematic difference of Italian data with respect to JM2000 inclinations exists even for 1960–1990, a period for which Italian inclinations are relocated from the directions carefully measured at the L'Aquila geomagnetic observatory.

The directional values shown in Fig. 2 were used to derive a mean Italian SV curve for 1640–2010. Declination data from Castellaccio were arbitrarily increased by 1.6°, to annul the mismatch evident in Fig. 2. We used a nine-degree polynomial best-fit curve (non linear least square minimization) to adequately represent data evolution. By means of the polynomial coefficients found, we have calculated mean directions every 30 and 10 years before and after 1790, respectively (Fig. 3). The errors associated to the calculated data were computed using the 90% confidence interval of the predicted polynomial values (Table 1). Confidence intervals were calculated by the QR decomposition of the Jacobian technique. We also tried to use the same fitting technique adding the other 383 declination/inclination couples from scattered Italian localities, but found >10% higher errors, and consequently decided to eliminate the 383 value couples by further consideration.

We have also superimposed on Fig. 3 the ages of the geomagnetic jerks (rapid changes of given geomagnetic field elements) documented in Europe at the observatory of Chambon-La-Forêt since 1900 to 1980 (e.g. Lanza and Meloni, 2006). Both for the Italian and the JM2000 curve, the 1969 and 1978 jerks correspond to visible steps separating rather rectilinear slopes of directional variation, while 1901 and 1925 jerks do not occur along any “cusp” of the secular variation path. This is likely due to the greater accuracy of measurements carried out at geomagnetic observatories during the last decades.

4 Westward drift of the geomagnetic field

It has long been known that geomagnetic field elements directly measured during the last four centuries have undergone a detectable westward drift. The largest changes in the direction of the Earth’s magnetic field are associated with the non-dipole part of the field. Bullard et al. (1950) adopted at a global scale a 0.18° /yr drift value (see alsoLangel, 1987), while Barraclough and Malin (1999) have calculated a 0.61 ± 0.08°/yr value considering the declination minimum recorded between 1750 and

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1860 at different European sites. By considering also archeomagnetic data, Merrill et al. (1996) have proposed a global 0.38 ± 0.07°/yr value for the last 2000 years. The westward drift has been routinely neglected, when relocating via pole method direct geomagnetic observations or archeomagnetic data to active Italian volcanoes (with the exception of paleomagnetic studies on Stromboli carried out by Speranza et al., 2004, 2008). Recently, Speranza et al. (2006) and Arrighi et al. (2005) have specifically contended on the necessity (or not) to add the westward drift correction to data relocation.

The wealth of declination values from different Italian localities reported by the catalogue of Cafarella et al. (1992) offers the opportunity to better evaluate the westward drift occurring in Italy (roughly between 7° and 18° E longitude) during the last few centuries. In Fig. 4 we show the declination values measured in the same years at two (or more) sites from 1805 to 1962. The slopes of the best-fit lines considered for each year define Δdecl/Δlong values varying between 0.66 and −0.20 (Fig. 5). The Δdecl/Δlong average is 0.22 ± 0.12, after excluding the very high values of years 1831 and 1848 (>1.2, whereas most of the data are <0.4).

The westward drift (Δlong/Δyr) of declination is the ratio between the declination variation vs. time (Δdecl/Δyr) between 1805 and 1962 (we consider the 0.101 ± 0.003°/yr value calculated from 1840 to 1960, Fig. 2), and the average 0.22 ± 0.12 Δdecl/Δlong value calculated from Fig.5. We eventually get a 0.46 ± 0.19°/yr westward drift value for Italian post-1805 declination values, which is statistically undistinguishable from both the 0.38 ± 0.07°/yr global value calculated by Merrill et al. (1996) for the last two millennia, and the 0.61 ± 0.08°/yr value calculated by Barraclough and Malin (1999)for the European declination minimum of 1750–1860.

We have modified the years of the relocated directions of Fig. 2 taking into account the 0.46 ± 0.19°/yr westward drift value calculated above (Fig. 6). All relocated and westward drift-corrected data are listed in Database S3 (see Supplement). Italian declinations are again in gross agreement with those derived from the JM2000 and PM2009 models, and the discrepancy of declinations measured in Italy in 1640 with respect of declination derived from JM2000 is reduced. Surprisingly, the shift of declinations data from Castellaccio gathered at 1933–1962 (with respect to both other Italian data and JM2000, Fig. 2) is annulled. We conclude that the mismatch of declination data from Castellaccio as evident in Fig. 2 is entirely due to the westward drift of the geomagnetic field, and no other factors (such as errors arising from data relocation via pole method or local/crustal magnetic anomalies) are involved.

Inclination data corrected for the westward drift (Fig. 6) show a better agreement than non-corrected data of Fig. 2 with respect to JM2000 and PM2009, though inclination differences for pre-1800 and post-1900 years persists. A similar 1°–2° difference exists between the inclination relocated from the measurement of 1640 of Rome by Kircher, and the coeval inclinations calculated by the JM2000 and PM2009 models. The 1640 inclination was measured by the angle of inclination, or dip, of a suspended magnet. Due to several problems, inclination was more difficult to measure accurately than declination, but the few measurements available for this period (such as Kircher's one) are very valuable, even if not fully reliable.

Again, for 1810–1860 the PM2009 model predicts inclinations higher by ca. 1° than both Italian inclinations and those derived from JM2000. Furtehermore, the same ∼0.5° shift with respect to JM2000 is apparent even for Italian inclinations of 1960–1990, relocated by the directions carefully measured at the L'Aquila observatory. Conversely, the 1960–1990 inclinations derived from JM2000 for L'Aquila are in good agreement with those effectively measured at L'Aquila in the same years (differences are always less than 0.1°). We conclude that data relocation via pole method from L'Aquila to Stromboli (located 420 km apart) introduces a ∼0.5° inclination error, at least after 1960.

Data corrected for the westward drift were used to derive an additional post-1640 Italian SV curve (Fig. 7 and Table 2), using the same method adopted for Fig. 3. Mean directions calculated every 30 and 10 years (before and after 1790, respectively) are defined with a similar precision. Drift corrected data show a grater and smaller precision on declination and inclination data (respectively), and this is likely the consequence of using declination data to calculate the westward drift value. When the geomagnetic jerks recorded at Chambon-La-Forêt between 1900 and 1980 are considered, the 1901 jerk is effectively located at the cusp between two rather rectilinear SV paths of the Italian curve, while this definitely did not occur for data of Fig. 3.

5 Best SV curve(s) to perform paleomagnetic dating of volcanics erupted in Italy during the last four centuries

The analysis of Italian data, compared to the directions predicted for Italy by the JM2000 and PM2009 models, may suggest which SV curves are best suited to perform paleomagnetic dating at active Italian volcanoes. We propose that the PM2009 model should be adopted for the 1600–1800 period. In fact, PM2009 takes advantage of the whole Italian data set of Cafarella et al. (1992) , and does not suffer of probable inclination errors introduced in the Italian curve by the use of French directions during 1670–1789, when no Italian inclination are available. For the period 1810–1860, the Italian drift-corrected data are in good agreement with directions derived from the JM2000 model (which however uses no Italian data in such time window), while the PM2009 models yields inclinations values higher by ca. 1°. Thus we suggest that the drift-corrected Italian curve may be preferable for the XIX century, as in this time span a wealth of declination/inclination values from Italy are available. Concerning the XX century, declination values of our drift-corrected SV curve (averaging some 110 Italian declination values) seem more realistic than those derived from the JM2000 model (using a total number of 101 declination/inclination values from four localities), at least for the first half of the century (only the drift-corrected Italian curve shows a cusp in correspondence of the 1901 geomagnetic jerk). Conversely, a systematic ~0.5° bias introduced by pole relocation from L'Aquila to Stromboli implies that inclinations derived from JM2000 are better suited to perform paleomagnetic dating of volcanics erupted in Italy during the XX century.

6 Conclusions

Directional (mostly declination) time series gathered from 19 Italian localities since 1640 AD Cafarella et al. (1992) were relocated to Stromboli (38.8° N; 15.2° E) via pole method (Noel and Batt, 1990) . Since data relocation requires a complete directional measurement, missing inclinations were derived (always by pole method) by French (1670–1789 period) and nearby Italian (1640–1657 and 1790–1962 periods) directions. A 0.46 ± 0.19°/yr westward drift derived from post-1805 Italian declination values was applied to the relocated data and yielded an additional Italian drift-corrected data set. Both data sets were compared to the directions expected at Stromboli using the data sets and models by Jackson et al. (2000) and Pavon-Carrasco et al. (2009) (both avoid errors arising from data relocation via pole method).

The westward drift correction eliminates the significant discrepancy (1.6°) of declination data from Castellaccio with respect to both other Italian declination values, and the declinations derived from the field model of Jackson et al. (2000). Drift correction also reduces the differences between the remaining Italian data and the field models. Two different Italian SV reference curves, yielding mean directions every 30 years from 1640 to 1790, and every 10 years afterwards, were calculated from the two data sets by using a polynomial fitting technique. The drift-corrected curve shows a better accuracy of the mean declination values, and reveals a cusp in correspondence of the 1901 geomagnetic jerk (while both the uncorrected curve and the model by Jackson et al. (2000) do not). Therefore we suggest that westward drift (if properly determined for a given period) should be considered when relocating geomagnetic/archeomagnetic data via pole method.

The comparison between the Italian SV curves derived by us and the field models by Pavon-Carrasco et al. (2009) and Jackson et al. (2000) suggests that the former model probably yields the best available 1600–1800 SV curve for Italy to be used for paleomagnetic dating at active Italian volcanoes, while the drift-corrected Italian curve seems to be preferable for the XIX century. For the XX century, the model of Jackson et al. (2000) yields the more accurate inclination values, while our SV curve suffer of systematic bias arising from pole relocation procedure. Conversely, declination values of our drift-corrected SV curve are probably more realistic, at least for the first half of the century.

Supplementary material related to this article is available online at: http://www.solid-earth-discuss.net/3/19/2011/sed-3-19-2011-supplement.zip.

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Table 1. Mean directions calculated after having relocated all Italian data to Stromboli (38.8° N, 15.2° E) via pole method, and having systematically increased declination values of the Castellaccio series (years 1933–1962) by 1.6° (see text).

Year	D(°)	ΔD(°)	I(°)	ΔI(°)
1640	2.61	1.32	63.63	0.86
1670	−3.08	1.38	66.74	0.9
1700	−9.51	1.37	66.72	0.89
1730	−12.7	1.38	65.09	0.9
1760	−14.6	1.33	63.48	0.87
1790	−16.38	1.3	61.12	0.84
1800	−16.74	1.29	60.18	0.84
1810	−16.86	1.29	59.23	0.84
1820	−16.68	1.28	58.34	0.84
1830	−16.19	1.28	57.56	0.83
1840	−15.4	1.28	56.92	0.83
1850	−14.38	1.28	56.4	0.83
1860	−13.22	1.28	55.98	0.83
1870	−12.01	1.28	55.62	0.83
1880	−10.85	1.28	55.27	0.83
1890	−9.77	1.28	54.91	0.83
1900	−8.77	1.28	54.56	0.83
1910	−7.75	1.28	54.29	0.84
1920	−6.6	1.29	54.2	0.84
1930	−5.19	1.29	54.38	0.84
1940	−3.55		54.76	
1950	−2.34		54.88	
1960	−1.36		54.95	
1970	−0.79		55.08	
1980	−0.01		54.93	
1990	0.84		55.14	
2000	1.62		55.28	
2010	2.48		55.42	

Table 2. Mean directions calculated after having relocated all Italian data to Stromboli (38.8° N, 15.2° E) via pole method, and having corrected the observation years considering a 0.46°/yr westward drift (see text).

Year	D(°)	ΔD(°)	I(°)	ΔI(°)
1640	0.92	1.67	62.59	1.26
1670	−5.11	1.21	67.42	0.92
1700	−10.33	1.23	65.93	0.93
1730	−13.59	1.22	64.75	0.93
1760	−15.08	1.17	63.15	0.88
1790	−16.59	1.14	60.31	0.86
1800	−16.84	1.14	59.3	0.86
1810	−16.77	1.13	58.38	0.86
1820	−16.33	1.13	57.61	0.86
1830	−15.54	1.13	56.99	0.86
1840	−14.47	1.13	56.51	0.85
1850	−13.27	1.13	56.13	0.86
1860	−12.12	1.13	55.79	0.86
1870	−11.1	1.13	55.43	0.86
1880	−10.25	1.13	55.06	0.85
1890	−9.5	1.13	54.7	0.86
1900	−8.59	1.13	54.44	0.86
1910	−7.34	1.14	54.37	0.86
1920	−5.83	1.14	54.5	0.86
1930	−5.03	1.28	54.61	0.97
1940	−3.55		54.91	
1950	−2.55		54.8	
1960	−1.09		55.06	
1970	−0.53		54.95	
1980	0.4		55	
1990	1.13		55.18	
2000	1.95		55.33	
2005	2.48		55.42	

Fig. 1. The 19 localities of Italy where declination / inclination time series were gathered since 1640 (Cafarella et al., 1992; data are listed in Database S1, see Supplement). Stromboli is the site to which all geomagnetic directions were relocated.

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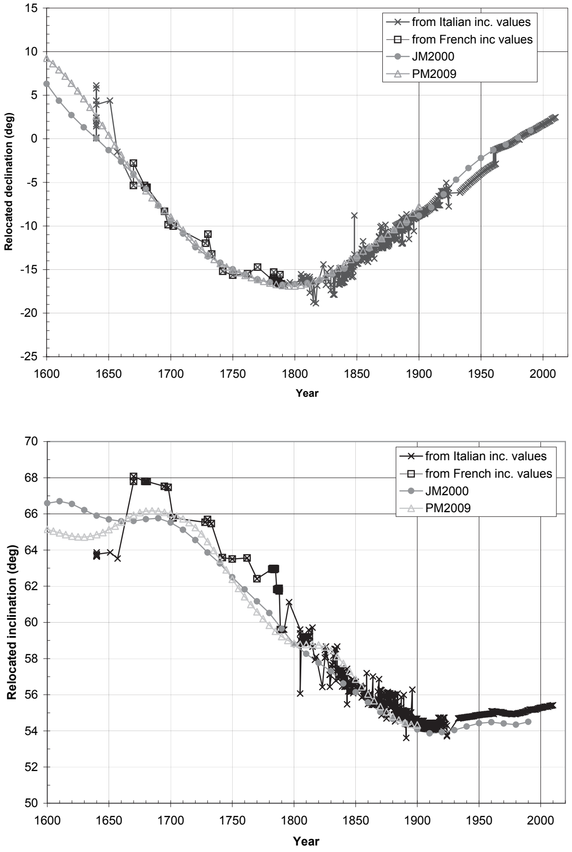

Fig. 2. Italian geomagnetic observations relocated to Stromboli (38.8° N, 15.2° E) via pole method, along with 1600–1990 (and 1600–1900) directions derived for Stromboli from JM2000 (and PM2009) models. Italian declinations gathered between 1670 and 1789 were relocated using coeval French geomagnetic observations (Alexandrescu et al., 1996).

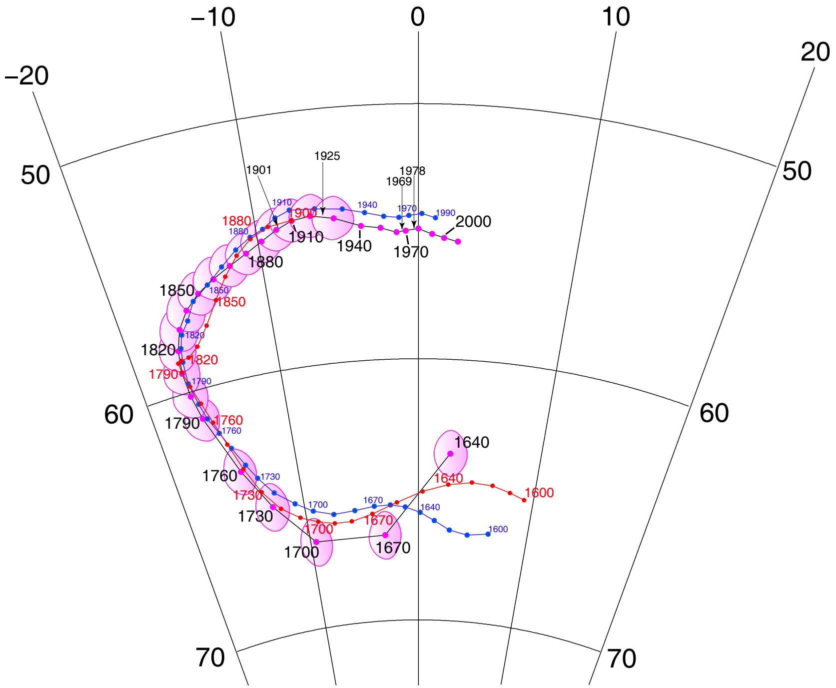

Fig. 3. Equal-area projection (lower hemisphere) of post-1640 mean Italian SV directions calculated from data of Fig. 2, and post-1600 directions derived for Stromboli from JM2000 (blue dots and lines) and PM2009 (red dots and lines) models. Numbers adjacent to directions indicate ages AD. Ellipses indicate ΔD/ΔI values of the mean Italian directions as listed in Table 1. The years of geomagnetic jerks observed at Chambon-La-Forêt (France) from 1900 to 1980 (e.g. Lanza and Meloni, 2006) are also shown by arrows.

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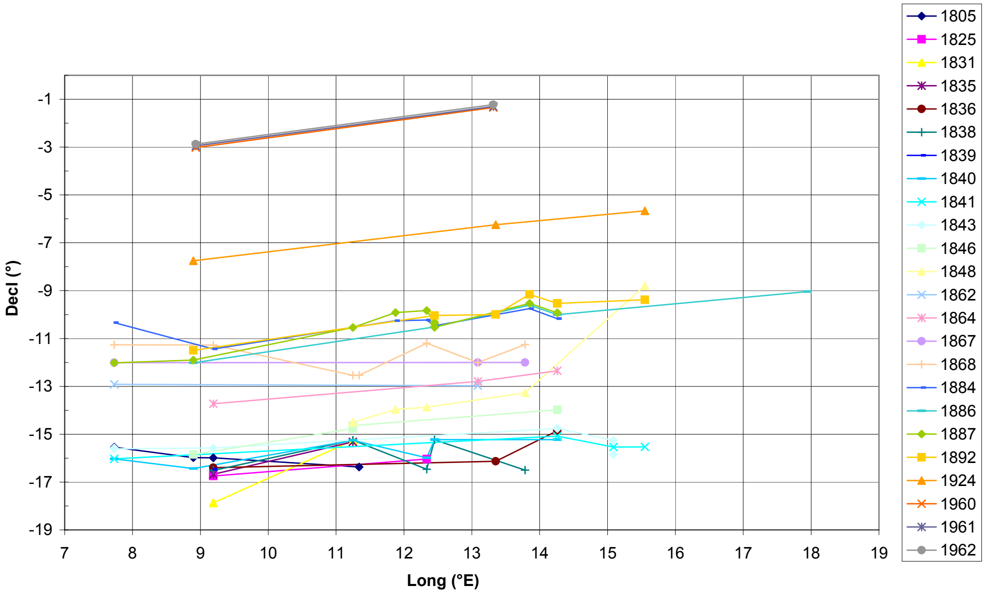

Fig. 4. Declination values measured during the same year at different Italian sites (since 1805) versus site longitude values.

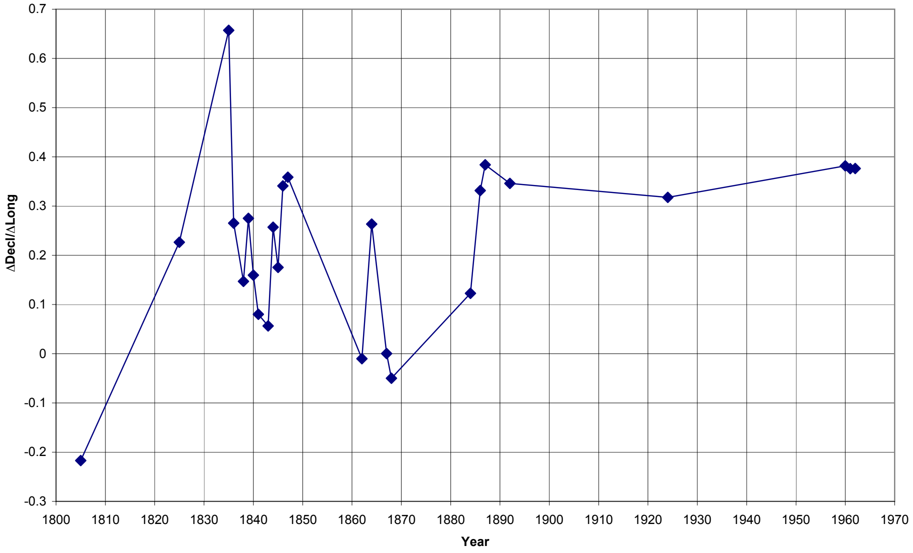

Fig. 5. Δdecl/Δlong values as derived from data of Fig. 4 versus corresponding years of observation. Significantly greater (>1.2) values for years 1831 and 1848 were omitted.

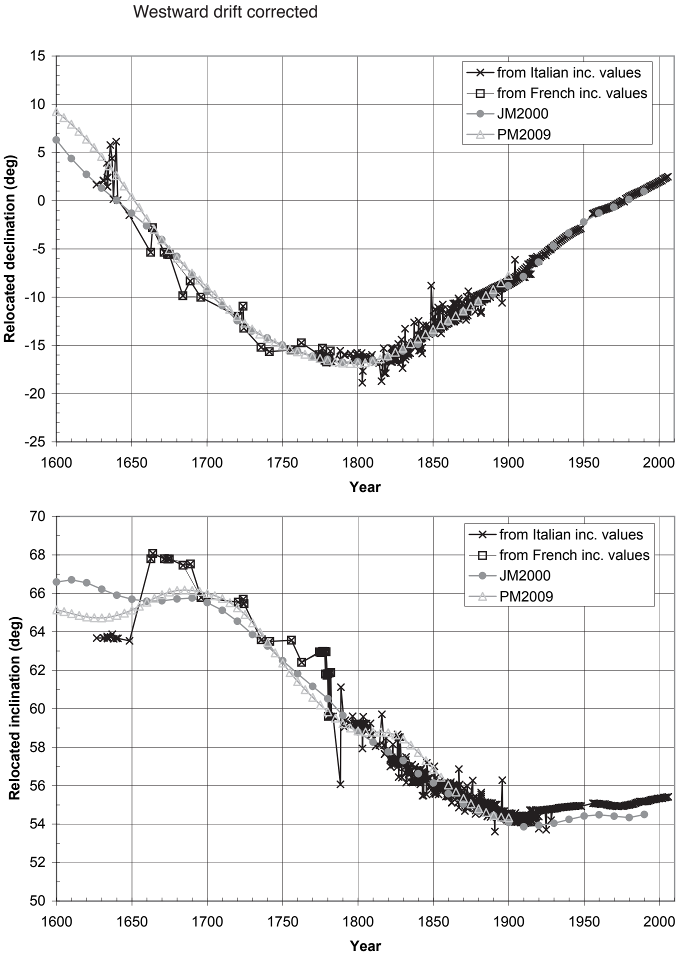

Fig. 6. Same figure as Fig. 2, modified by correcting years of Italian observations according to the 0.46 ± 0.19°/yr westward drift calculated for Italian data.

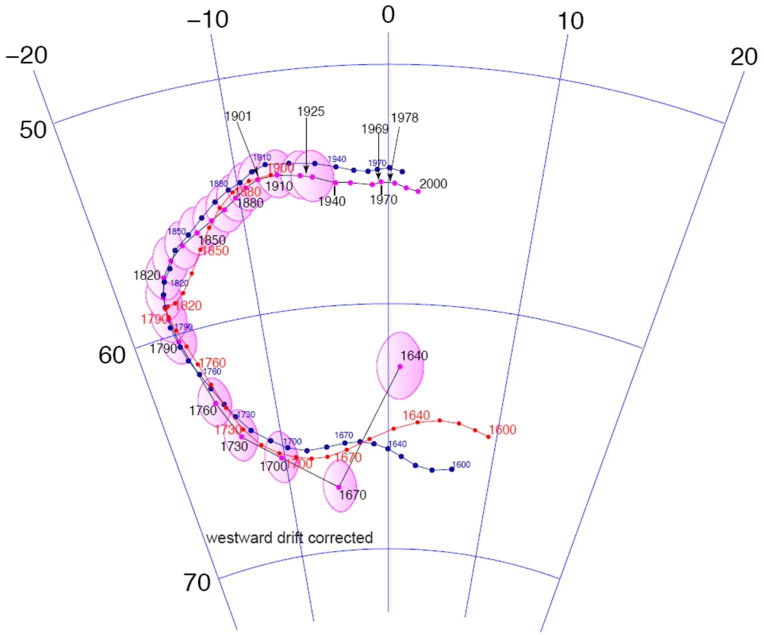

Fig. 7. Same figure and symbols as Fig. 3, but considering drift-corrected Italian data of Fig. 6. Ellipses indicate ΔD/ΔI values of the mean drift-corrected Italian directions as listed in Table 1.

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