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UP-DATING THE GEOMAGNETIC SURVEY OF SWITZERLAND

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Editor's Preface

The present publication entitled "Up-dating the Geomagnetic Survey of Switzerland" is Report N° 27 of the "Contributions to the Geology of Switzerland – Geophysical Series", published by the Swiss Geophysical Commission.

It contains a complete description of the procedure used by the authors to model the spatial and temporal variations of the geomagnetic field in Switzerland.

The model obtained permits the extrapolation of the long term variations of all the field components for the next one or two decades.

The Swiss Geophysical Commission is very grateful to Prof. Gaston Fischer and Dr. P.-A. Schnegg for having taken the initiative in realizing this up-dating.

Special thanks are due to the Swiss Academy of Natural Sciences for its financial support of this publication and to the Swiss Topographic Survey which graciously printed the maps presented in this booklet.

Zürich, May 1994

In the Name of the
Swiss Geophysical Commission
The President:

E. Klingelé

Prof. Emile Klingelé

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Summary

The last complete geomagnetic survey of Switzerland was carried out from 1974 to 1978 over a total of 448 sites. The country being rather small it is possible to represent the main field at a particular epoch in terms of a linear function of coordinates. Especially appropriate for that purpose are the kilometric coordinates of the topographic network. The remaining anomalies can then be mapped separately. Since the secular variation of the main field is known to have been particularly regular in Western Europe over the last two or three centuries, the assumption was made that, except for a position-dependent proportionality constant, this variation was the same in Switzerland as at Fürstenfeldbruck Observatory in Southern Germany. Over the period of 1978 to 1992 the Observatory data were modelled with a rational function, such as to yield an asymptotically linear extrapolation beyond 1992. The position-dependent proportionality constant was derived by modelling the data from 66 sites surveyed in the period from 1978 to 1992. With this procedure a mathematical representation of the main field as a function of position over the entire country and over the time period of 1978 to 1992 was obtained. Because of the quasi-linear extrapolation in time, and the regularity of secular variation mentioned above, our mathematical representation may constitute a reasonably credible forecast of the field variation over the next one or two decades.

Zusammenfassung

Die letzte gesamtschweizerische geomagnetische Landesaufnahme stammt aus den Jahren 1974-1978 und stützte sich auf 448 Standortmessungen. Bei den kleinen Abmessungen des Landes kann das Hauptfeld als lineare Funktion von Koordinaten dargestellt werden. Dafür besonders geeignet sind die Koordinaten des topographischen Kilometernetzes. Die vom Hauptfeld abweichenden Anomalien können dann getrennt kartographiert werden. Da in den letzten zwei bis drei Jahrhunderten die Sekularvariation des Hauptfeldes in Westeuropa bekanntlich sehr gleichmässig war, wurde die Annahme gemacht, dass bis auf eine ortsabhängige Konstante, in der gesamten Schweiz diese Variation den gleichen Verlauf wie am Observatorium in Fürstenfeldbruck in Süddeutschland aufwies. Die Observatoriumsdaten wurden deshalb für den Zeitraum 1978-1992 an eine rationale Funktion angepasst, die sich nach 1992 asymptotisch einem linearen Verlauf angleicht. Die ortsabhängige Proportionalitätskonstante wurde durch Modellieren der Daten, die an 66 Lokationen im Zeitraum von 1978-1992 gesammelt wurden, bestimmt. Mit diesem Verfahren wurde eine mathematische Darstellung des Hauptfeldes abgeleitet, die das ganze Land und den Zeitraum von 1978 bis 1992 abdeckt. Wegen der zeitlich quasi-linearen Extrapolation über 1992 hinaus und der erwähnten gleichmässigen Sekularvariation, ist es wahrscheinlich, dass unsere Darstellung für ein bis zwei Jahrzehnte eine recht gute Vorhersage erlaubt.

Résumé

Le dernier levé géomagnétique complet de la Suisse a été exécuté de 1974 à 1978 sur la base de 448 mesures. Vu la petitesse du pays il est possible de représenter le champ principal à une époque donnée par une fonction linéaire de coordonnées. Les coordonnées kilométriques du réseau topographique sont spécialement bien adaptées à cette fin. Les anomalies restantes peuvent ensuite être cartographiées séparément. Comme la variation séculaire du champ principal a été particulièrement régulière sur l'ouest de Europe depuis deux ou trois siècles, on a fait la supposition que cette variation a été la même en Suisse qu'à l'Observatoire de Fürstenfeldbruck au sud de l'Allemagne, à une constante de proportionnalité près qui ne dépend que de la position. Sur la période de 1978 à 1992 on a donc modélisé les données de l'Observatoire au moyen d'une fonction rationnelle fournissant une extrapolation qui devient asymptotiquement linéaire au-delà de 1992. La constante, ou fonction de proportionnalité, a été dérivée en modélisant les données de 66 sites visités entre 1978 et 1992. Par cette procédure une représentation mathématique a été obtenue, qui donne le champ principal sur tout le pays et pour toute la période de 1978 à 1992. Vu la régularité de la variation séculaire déjà mentionnée, il est probable que l'extrapolation temporelle quasi linéaire donne à notre représentation mathématique du champ une valeur prédictive crédible pour une ou deux décennies.

I. Introduction

The last complete geomagnetic survey of Switzerland was carried out between 1974 and 1978 (FISCHER and SCHNEGG 1977; FISCHER, SCHNEGG and SESIANO 1979) and culminated with the publication of a set of 10 maps of various magnetic elements and their anomalies (scale 1:1 250 000), and 3 larger maps of declination, inclination and total intensity on a tectonic background (scale 1:500 000). All these maps were reduced to epoch 1978.0. In the years that followed occasional measurements of the field were made for testing purposes, especially in conjunction with the development of a new vector magnetometer for survey work, the TURBOMAG (cf. FISCHER and NAUNAPPER 1980; SCHNEGG and FISCHER 1991), or to determine the magnetic azimuths of some airport runways.

In 1989 it was felt that an up-date of the survey was necessary. But the previous survey had been very detailed and the new one could therefore be devised in such a way as to reduce the necessary work to a minimum. The planned strategy (FISCHER and SCHNEGG 1991) was to select a set of well-distributed stations from the last survey whose field elements were very close to the main field. Because of the small size of the country an appropriate main field can indeed be defined as the best linear fit to the entire survey, where the linear variables are not the geographical coordinates, but are coordinates expressed in terms of the (x,y) kilometric network of Switzerland's Federal Office of Topography (cf., e.g., DUPRAZ 1976). Our strategy was based on the assumption that the decomposition of the field into main and anomalous parts would yield an anomalous field which would not vary over the time scale of a few decades. To up-date the field it would then be necessary only to survey the selected stations in order to determine the new main field. The up-dated survey would then be obtained by combining the time-invariant anomalous part with the new main field.

After surveying a number of sites in the four years from 1989 to 1992 we realized that the strategy we have described could have been implemented quite satisfactorily. However, we were somewhat disappointed to find that the standard deviation between the new main field, derived from the measurements at the various selected stations, and the individual station measurements was about double the 1' (one arc-minute) we had hoped for in declination. This seems to arise mainly from two factors: (1) inaccuracies in the time reduction, (2) violations of the assumed constancy of the anomalous field. A third factor may also play a role, inaccuracies in the measurements, but several tests of reproducibility suggest that this factor was less important.

But the purpose of the new survey was not restricted to the production of up-dated maps; we also had it in mind to follow the variations of the field elements since the last survey in order, if possible, to make short term predictions for the future. In spite of some recent "impulses" or "jerks" in the geomagnetic field (cf., e.g., ALLDREDGE 1984, COURTILLOT and LE MOUËL 1984). This seems particularly justified in this instance as the secular variation of declination is known to have been extremely regular in Western Europe over the last century and a half at least, as attested, e.g., by the graphs of Fig. 1 (reproduced from RUNCORN 1962) and Fig. 2 (from MAURER 1914), or by the secular variations recorded at observatories around Switzerland, as shown in Figs. 3 to 5 for Fürstenfeldbruck. These observations suggested a profitable modification of our strategy.

II. Strategy of the New Survey

We built a data set consisting of the results from 23 stations of the previous survey and from 43 sites surveyed between 1982 and 1992. For the 23 original stations time reduction was effected to 1978.0; these data are therefore identical to those listed in (FISCHER, SCHNEGG and SESIANO 1979), except for the total intensity as will be explained below. For the more recent measurements reduction was always effected to the nearest integral year, i.e. the reduction time never exceeded 6 months. From this we obtained the data reproduced in Table 1. These data were then modelled not only for their variation with position (x,y) , but also for their change with respect to time t or **Epoch.**

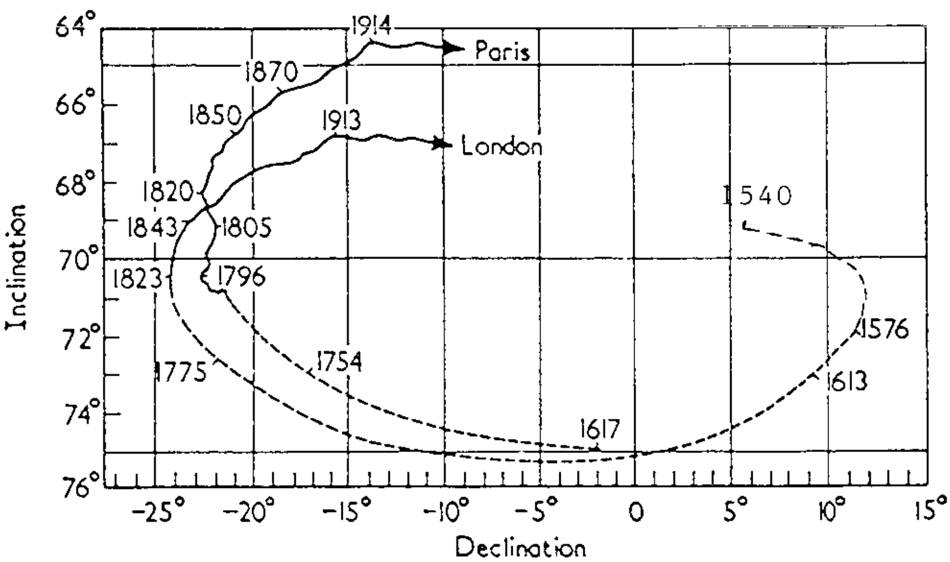

Figure 1. Vector plots of the inclinations and declinations of the geomagnetic field at London and Paris over several centuries. This plot is due originally to C. Gaibar-Puertas and is reproduced from Runcorn (1962). The data from 1540 to 1576 are taken from Malin and Bullard (1981).

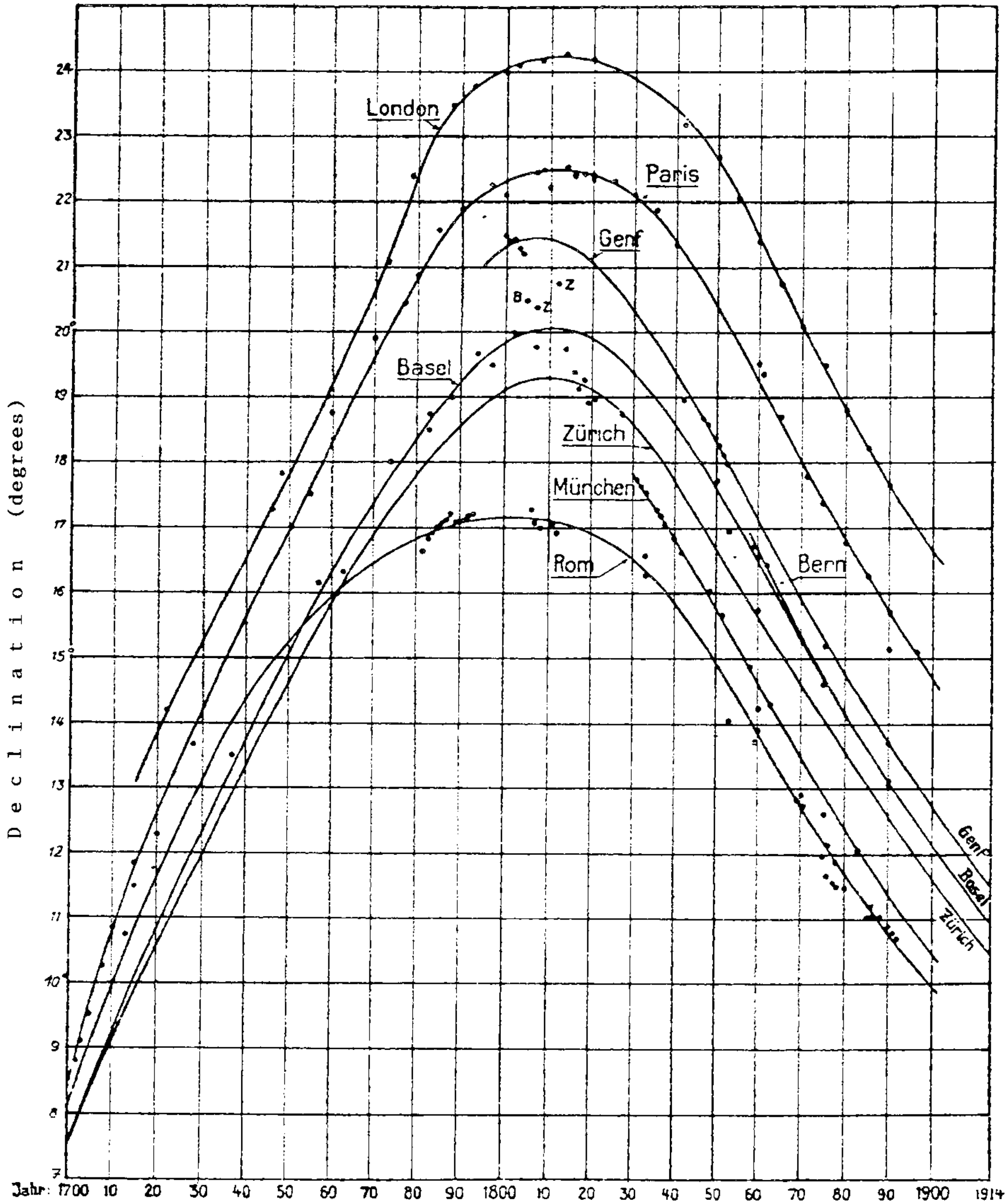

Figure 2. Declination recorded in Western Europe between 1700 and 1900. Reproduced from Maurer (1914).

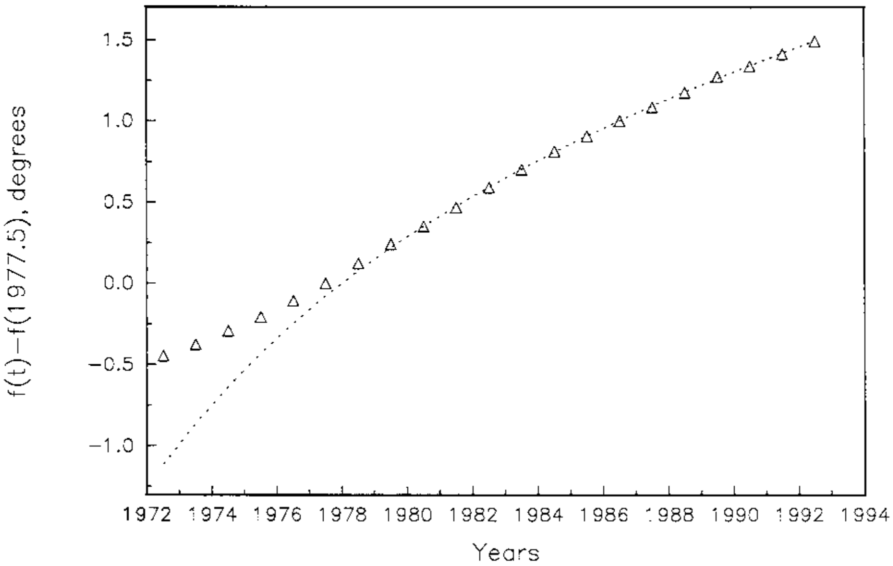

Figure 3. Variation of declination D at Fürstenfeldbruck Observatory. The triangles are yearly averages, the dotted line is a best-fitting rational function of the form of equation (2), over the period from 1978 to 1992. The behaviour before 1978 is probably a consequence of the 1969 secular variation jerk (cf., e.g., ALLDREDGE 1984, COURTILLOT and LE MOUËL 1984).

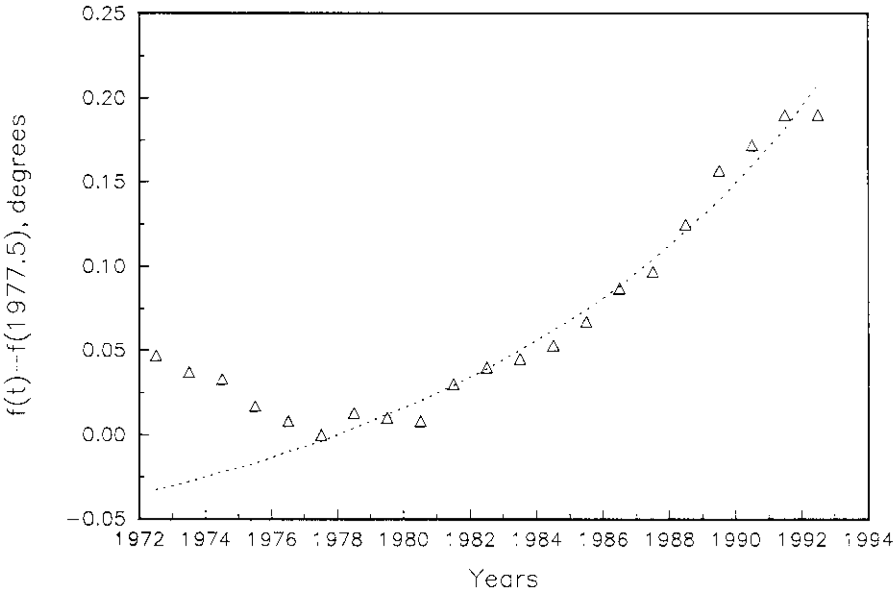

Figure 4. Variation of inclination I at Fürstenfeldbruck Observatory. The triangles are yearly averages, the dotted line is a best-fitting rational function of the form of equation (2), over the period from 1978 to 1992. The data appear scattered because inclination changed very little in the period from 1970 to 1992 and the ordinate is much expanded (compare with Fig. 3). The minimum inclination around 1987 may be a consequence of the 1969 secular variation jerk (cf., e.g., ALLDREDGE 1984, COURTILLOT and LE MOUËL 1984).

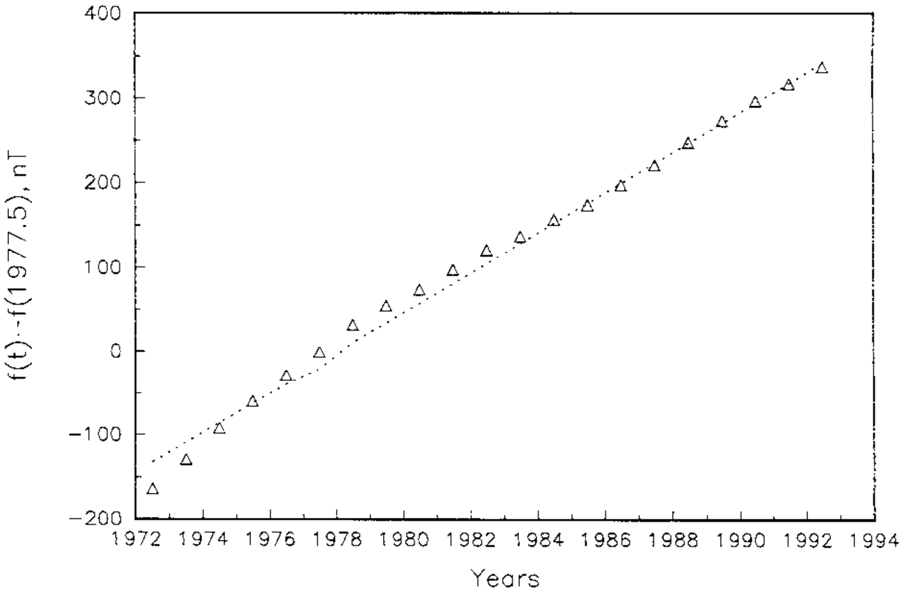

Figure 5. Variation of total intensity F at Fürstenfeldbruck Observatory. The triangles are yearly averages, the dotted line is a best-fitting rational function of the form of equation (2) over the period from 1985 to 1992. A good fit over the longer period of 1978 to 1992 would have required a more complicated equation than (2). The small bump of the dotted line around 1977.5 is a consequence of the pole of equation (2) for that date. The small amplitude oscillations in the behaviour of F is probably a consequence of the 1969 secular variation jerk (cf., e.g., ALLDREDGE 1984, COURTILLOT and LE MOUËL 1984).

At first we thought that time should be modelled with a polynomial. As is well known, however, polynomial fitting is only satisfactory over the range of the available data. Beyond that range it rapidly diverges. We therefore turned to a simple rational function yielding extrapolations which quickly become linear, somewhat similar in that respect to fitting with a spline function. Defining

$$t = \textbf{Epoch} - 1978 \qquad (1)$$

we expressed the time dependence as proportional to

$$f_{D,I,F}(t) = \frac{t + \beta_{D,I,F} \cdot t^2}{1 + \gamma_{D,I,F} \cdot t} \qquad (2)$$

where the three indices of $f_{D,I,F}(t)$ naturally refer to declination D, inclination I, and amplitude or total intensity F.

For D, I, and F we then assumed linear functions of position, as for example for D:

$$D(x,y,t) = A + Bx + Cy + \alpha[1 + bx + cy] \cdot f_D(t) \quad . \qquad (3)$$

The coefficients of equations (2) and (3) can be derived in a numerical search of the best fitting function (3) to the data set of Table 1. It turned out, however, that our data set is not distributed sufficiently evenly over the time span of 1978 to 1992. The dearth of data in the central part of the time range makes it impossible to determine the coefficients of equation (2) with great accuracy. However, it can also be seen that, except for the proportionality factor

$$\alpha[1 + bx + cy] \quad , \qquad (4)$$

our scheme assumes that the same functions $f_{D,I,F}(t)$ apply to the whole of Switzerland, and in spite of a certain degree of uncertainty as to the exact form of the time functions (2), we could verify that they are highly compatible with the time functions recorded at Fürstenfeldbruck Observatory. Since this observatory is located less than 150 km from the eastern border of our country we assumed that the time variation of its magnetic elements was also valid for Switzerland, except for the proportionality factors (4) which we have also modelled.

The modelling process was therefore carried out in two steps. First we modelled the Fürstenfeldbruck Observatory data as shown in Figs. 3 to 5. For D and I we considered the time span of 1978 to 1992, but for F only the period from 1985 to 1992. This allowed us to derive the two parameters β and γ of equation (2). It is easy to see in Fig. 5 why the shorter time span was necessary for F: over the longer period this element does not follow the simple rational function (2) very well. However, the time variations derived from the Fürstenfeldbruck data match the variations derived from our own data very well, in particular, our data also yield a minimum for inclination around 1980.

In the second step we modelled the entire data set from 66 stations for the remaining six parameters A, B, C, α, b and c of equation (3). This second process was repeated three or four times. After each step the stations with the largest standard deviations, the so-called outlyers, were discarded. For I we eliminated 14 outlyers. For D 13 outlyers were discarded and for F only 12, but for one of the original group of 43 new stations no D value had been measured, and for two stations no F value. In all, therefore, 51 data sets were modelled for D, I and F, as indicated in Table 1. With this process we obtained mathematical expressions for the suitable time-dependent main field, linear in the x and y coordinates, and we also derived the present secular variations in terms of the rational functions defined by equations (2).

III. The survey

As explained in our previous publication (FISCHER, SCHNEGG AND SESIANO 1979), we do not have, in Switzerland, a system of "repeat stations". The way we proceed is to go into the area where we intend to make a measurement. The measurement area is surveyed for constructions, fields and forests and an apparently unperturbed spot is chosen. Before deploying the instruments the site is checked for homogeneity with the proton precession magnetometer. In regions of fairly smooth topography it is in general easy to find sites with a gradient of less than 5 nT over 50 m. In rough Alpine terrain, sometimes perturbed by nearby magnetic outcrops, it may be necessary to accept situations with a variation three times stronger. When repeating a measurement many years later it is frequently possible to return to exactly the same spot, to within one or two metres, thanks to very good topographical maps to the 1:25 000 scale. But it may also happen that this is not possible, for example because of constructions in the interval, or because at this particular time the field in which the previous measurement was made has not been harvested.

As seen in Table 1, up to 1989 we used the vector magnetometer we have described before (FISCHER 1973, 1975; FISCHER and SCHNEGG 1977; FISCHER, SCHNEGG and SESIANO 1979). The principle of this instrument is based on a rotating fluxgate sensor and is therefore designated by the letter F in the Table. Afterwards we mainly worked with the TURBOMAG instrument, a turbine functioning as an inductor and designated with the letter T (FISCHER and NAUNAPPER 1980; SCHNEGG and FISCHER 1991), and occasionally we compared the two instruments.

Time reduction of the data was effected with the help of the permanent recordings at Fürstenfeldbruck Observatory. Table 1 lists all the sites used in the present survey up-date in terms of latitude (North) and longitude (East of Greenwich), as well as in metres, referred to the Swiss topographic, or kilometric network. These data can therefore be used as input for international maps, e.g. to up-date IGRF.

IV. Results

The results were very gratifying in two respects:

1) The standard deviation between the data from individual stations, each at its particular epoch, and the time-dependent mathematical model of the main field was very low. For D this RMS deviation is 1.65' with a maximum of 3.67'; for I it is only 1.19' with a maximum of 2.17'; and for F it is 16.4 nT with a maximum of 44.2 nT.

2) Having assumed that the time variations $f_{D,I,F}(t)$ of the magnetic elements were the same as those recorded at Fürstenfeldbruck, we compared the observatory data with those predicted by our scheme. This required converting the geographic coordinates of Fürstenfeldbruck Observatory to the Swiss kilometric net, even though this observatory is not located within the network of these coordinates. For 1985.5 and 1992.5 this comparison gives the figures reported in Table 2. Considering that Fürstenfeldbruck lies far outside the range covered by our survey and that its magnetic elements were not included among those that were modelled, the agreement must be counted as very good.

It is also interesting to compare the main field which we had chosen in the last survey with the one we obtain now for epoch 1978. In the last survey we had not derived the main field by a least squares method, but by taking the field at a central point in the country (φ = 47°N, λ = 8°E; i.e., x = 205.443 km, y = 642.618 km) and estimating the gradients of the field elements along the coordinate directions x and y. This procedure gave the expressions

$$D = -2.613 + 0.005 \cdot (y-600) \quad , \qquad (5)$$

$$I = 62.655 + 0.0083333 \cdot (x-200) \quad , \qquad (6)$$

$$F = 46{,}681 + 2.8 \cdot (x-200) + 0.6 \cdot (y-600) \quad . \qquad (7)$$

We should like to note, here, that when setting up these expressions we had, for reasons of simplicity, deliberately ignored the small though apparent gradient in x for D and the gradient in y for I. The above expression for F was corrected by subtraction of 28 nT. This difference arises because during the previous survey we were reducing our F values with respect to the Fürstenfeldbruck Observatory reference, instead of the IMS (International Magnetic Reference) reference (see the Fürstenfeldbruck Observatory Yearbook for 1980). In effect the total intensity data published after the last survey should be corrected by this amount to bring them in line with the International Magnetic Reference.

The figures appearing in the brackets involving x and y arise from the choice of origin for the Swiss military coordinate network, the Observatory in Berne, where x = 200 km and increases northward, whereas y = 600 km and increases eastward.

In the present up-date the mathematical formulations derived for the main field elements at epoch 1978.0 reduce to

$$D = -2.6142 - 9.289 \cdot 10^{-4} \cdot (x-200) + 4.9061 \cdot 10^{-3} \cdot (y-600) \quad , \qquad (8)$$

$$I = 62.6145 + 8.1494 \cdot 10^{-3} \cdot (x-200) + 3.732 \cdot 10^{-4} \cdot (y-600) \quad , \qquad (9)$$

$$F = 46{,}684.6 + 3.106 \cdot (x-200) + 0.392 \cdot (y-600) \quad . \qquad (10)$$

Quite clearly these expressions are very similar to the preceding equations (5) to (7).

In the Appendix we give the complete mathematical expressions derived from the present up-date of the Swiss geomagnetic survey, and the coefficients of these expressions are listed in Table 3.

V. Maps

Having derived a time-dependent main field from data which cover the entire time span from 1978 to 1992 at least, we now consider an expanded data set, those from the last survey as well as the ones from the 1982-1992 period which were not rejected because of somewhat larger standard deviations. With these we constructed new geomagnetic maps of D, I, and F for epoch 1994.0. These are the present Maps 1 to 3.

Except for a small area in the easternmost part of Switzerland, declination for Epoch 1994.0 is still everywhere westerly. We therefore decided to continue with past Swiss traditions and have plotted this westerly declination as positive in Map 1, against accepted international conventions. Future maps will have to show easterly declinations as negative. For use in Switzerland we also constructed Map 4 of declination D_K, i.e., declination with respect not to the local meridian, but to the y-coordinate of the kilometric network. Such a chart is useful to anyone working with a Swiss topographical map. In Map 4 we have again plotted westerly declinations D_K as positive, as these are still positive everywhere in the country.

Map 5 represents declination anomalies ΔD, calculated as difference between measured and computed declinations, both reduced to Epoch 1994.0. In combination with the appropriate mathematical expression of the Appendix ΔD gives the same local declinations as Map 1. Since the mathematical expressions of the Appendix follow the international convention, Map 5 also follows them, giving easterly deviations as positive. In Maps 1 and 5 declination anomalies therefore appear with opposite signs.

A look at Map 1 shows that declination D vanishes in 1994 in the easternmost part of Switzerland. Our mathematical expression for the secular variation also tells us that the zone or line of zero declination will gradually move through the country from East to West over the next two decades. Assuming that we can extrapolate our mathematical expression over a time span of two decades in the future, we can draw Map 6 which shows the progress of this line of vanishing declinations through the country. We see that D will be zero in Zurich around the year 2003, in Basel around 2007, Berne 2008, Neuchâtel 2010 and Geneva around 2014. The region between Lausanne and Vevey is centred on the famous Jorat magnetic anomaly (cf. FISCHER and LE QUANG 1980); in the west of the city of Lausanne the changeover will occur before 2006, and to the east the area of Vevey will see the change only around 2015.

It is well known that, in general, secular variation cannot be predicted with much confidence. In the present situation, however, the predictions we are venturing are probably somewhat more reliable. Several factors speak in favour of this claim: (1) the time span of 20 years over which we believe the extrapolation to be credible is reasonably short, and (2) as we have seen before, declination has varied in a surprisingly regular manner over the last 150 years (see Figures 1 to 3) in Western Europe, in spite of a geomagnetic secular variation impulse centred around 1969 (cf., e.g., ALLDREDGE 1984, COURTILLOT and LE MOUËL 1984).

APPENDIX

Over the area of Switzerland the main geomagnetic field can be represented in terms of the three elements $E_{D,I,F}(t)$ we have surveyed, i.e., declination D, inclination I, and amplitude or total intensity F, by the following set of equations:

$$E_{D,I,F}(t) = G_{D,I,F}(x,y) + g_{D,I,F}(x,y) \cdot f_{D,I,F}(t) \quad . \qquad (11)$$

where

$$G_{D,I,F}(x,y) = A_{D,I,F} + B_{D,I,F} \cdot \Delta x + C_{D,I,F} \cdot \Delta y \quad . \qquad (12)$$

$$g_{D,I,F}(x,y) = \alpha_{D,I,F} \cdot [1 + b_{D,I,F} \cdot \Delta x + c_{D,I,F} \cdot \Delta y] \quad . \qquad (13)$$

$$\Delta x = x - 200 \quad , \qquad \Delta y = y - 600 \quad . \qquad (14)$$

and $f_{D,I,F}(t)$ has the form given in (2).

If D and I are expressed in decimal degrees and F in nT the coefficients appearing in equations (2) and (11-13) are those given in Table 3.

Acknowledgments

This survey was carried out as a joint project of the Swiss Geophysical Commission, the Institute of Geology of the University of Neuchâtel, and the Swiss Federal Office of Topography. The first two institutions provided financial support whereas the Office of Topography gave us logistic assistance and produced the attached set of maps.

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Table 1. Selection of sites used in the present survey, with station coordinates given both in terms of latitude and longitude (East of Greenwich), and in metres (referred to the Swiss topographical network). Declination D and inclination I are given in degrees, total intensity in nT. Instr (F for rotating fluxgate and T for TURBOMAG, see text under III) specifies the instrument used and the last column signals the data rejected as outlyers. All angles (latitude, longitude, D, and I) are expressed in degrees, minutes and tenths of minutes, i.e. as DD.MMm. The magnetic data listed are reduced to the beginnings of the corresponding years.

Station	Year	Latitude	Longitude	x (m)	y (m)	D	I	F	Instr	Reject		
										D	I	F
Sierne	1978	46°11.4'	6°11.1'	114489	503125	-2°59.6'	61°53.5'	46396	F			
Les Jorats	1978	46°42.1'	6°24.9'	171573	521634	-2°58.4'	62°23.8'	46529	F		x	
St Sulpice	1978	46°55.9'	6°34.3'	197319	533895	-2°57.4'	62°34.6'	46637	F			
Boncourt	1978	47°29.3'	7°02.5'	259579	570064	-2°50.2'	63°06.2'	46877	F			
Mardern	1978	47°05.4'	7°19.7'	215350	591580	-2°39.1'	63°46.3'	46719	F		x	
Granges (VS)	1978	46°15.7'	7°28.0'	123139	602110	-2°31.7'	61°56.4'	46460	F		x	
Satarma	1978	46°02.7'	7°29.3'	99125	603779	-2°30.1'	61°43.7'	46164	F		x	x
Altreu	1978	47°11.6'	7°27.7'	226859	601709	-2°36.4'	62°50.5'	46751	F			
Utzigen	1978	46°57.5'	7°33.8'	200560	609360	-2°33.6'	62°38.3'	46691	F			
Wichtrach	1978	46°50.8'	7°35.1'	188199	611110	-2°31.0'	62°32.7'	46662	F			
Grindelwald	1978	46°37.6'	8°00.8'	163619	643924	-2°21.2'	62°19.7'	46593	F			
Entlebuch	1978	47°47.9'	8°04.0'	293944	647020	-2°23.1'	62°39.8'	46733	F			
Eigental	1978	46°59.2'	8°13.0'	203500	659090	-2°18.6'	62°39.8'	46725	F			
Baldingen	1978	47°33.8'	8°18.7'	267639	665572	-2°22.9'	63°11.8'	46909	F			
Someo	1978	46°17.9'	8°39.7'	126630	694194	-2°06.1'	62°04.4'	46470	F			
Bisistal	1978	46°58.2'	8°49.7'	201055	705645	-2°05.0'	62°39.3'	46740	F			
Reichenburg	1978	47°12.0'	8°58.0'	226454	715652	-2°05.0'	62°52.6'	46826	F			
Wattwil	1978	47°20.0'	9°06.2'	240939	725759	-2°02.4'	62°59.3'	46852	F			
Bottighofen	1978	47°39.4'	9°12.9'	276817	733427	-2°01.8'	63°18.2'	46965	F			
Mesocco	1978	46°25.9'	9°14.0'	140448	737902	-1°54.0'	62°09.4'	46519	F			
Maienfeld	1978	47°02.6'	9°32.7'	207960	759955	-1°51.0'	62°44.0'	46781	F			
S. Antönien	1978	47°01.1'	9°48.8'	204630	780490	-1°41.9'	62°43.5'	46763	F			
S-Charl	1978	46°47.5'	10°20.0'	177970	821020	-1°31.3'	62°31.6'	46747	F			
Frochaux	1982.5	47°02.6'	7°00.3'	210100	567000	-2°11.0'	62°40.8'	46817	F			
Avully	1983	46°11.0'	5°59.7'	113538	488424	-2°27.6'	62°01.1'	46491	F	x	x	
Coppet	1983	46°20.7'	6°10.1'	131662	502194	-2°21.9'	62°02.5'	46545	F			
Siviez	1988	46°08.1'	7°18.6'	109065	589980	-1°23.7'	62°22.9'	46722	F		x	x
Tortin	1988	46°07.6'	7°18.7'	108150	590060	-1°27.4'	62°30.8'	46530	F		x	x
St Sulpice	1989	46°55.9'	6°34.3'	197320	533895	-1°34.2'	62°39.8'	46836	T/F			x
Frochaux	1989	47°02.6'	7°00.3'	210100	567000	-1°24.1'	62°46.3'	46942	F			
Galmiz	1989	46°56.5'	7°10.0'	198790	579280	-1°22.7'	62°40.1'	46894	F			
Marsens	1990	46°39.6'	7°02.4'	167510	569459	-1°29.1'	62°25.8'	46801	T	x		
Dorénaz	1990	46°09.7'	7°02.6'	111950	569335	-1°28.5'	61°57.8'	46664	T	x		
Illgraben	1990	46°17.6'	7°38.0'	126670	614940	-1°15.0'	62°02.2'	46710	T	x	x	
Oberwald	1990	46°32.2'	8°21.1'	153444	669950	-1°32.1'	62°21.2'	46768	T	x		x
Disentis	1990	46°43.2'	8°51.4'	173180	708383	0°48.4'	62°35.8'	46875	T			
Sardasca	1990	46°55.1'	10°00.4'	193015	795599	0°34.2'	62°45.0'	47066	T	x		x
Maienfeld	1990	47°02.6'	9°32.7'	207960	759995	0°47.8'	62°52.6'	46939	T	x		x
Reichenburg	1990	47°12.0'	8°58.2'	226445	715930	0°51.1'	62°59.3'	47078	T	x		
Wichtrach	1990	46°50.8'	7°35.1'	188160	611130	-1°09.4'	62°39.0'	46913	T			
Eigental	1990	46°59.2'	8°13.0'	203500	659090	0°16.7'	62°46.7'	46976	T	x		
Frochaux	1990	47°02.6'	7°00.3'	210100	567000	-1°18.3'	62°46.9'	46970	F			
Frochaux	1990	47°02.6'	7°00.3'	210100	567000	0°00.0'	62°46.5'	46976	F	x		
Montherod	1990	46°30.7'	6°22.3'	150465	518014	-1°28.6'	62°19.6'	46768	T		x	
Altreu	1990	47°11.6'	7°27.7'	226859	601709	-1°38.7'	62°57.0'	47002	T	x		
Oberehrendingen	1990	47°30.2'	8°21.1'	260924	668700	-1°03.6'	63°16.2'	47144	T	x		
Cernier	1990	47°03.3'	6°55.0'	211350	560300	-1°23.0'	62°47.0'		T			x
Frochaux	1991	47°02.7'	7°00.4'	210250	567100	-1°18.6'	62°48.0'		T			x
Utzigen	1991	46°57.6'	7°33.3'	200750	608800	-1°08.1'	62°47.2'	46961	T			
Siberen	1991	46°59.0'	7°50.1'	203320	630075	-1°03.1'	62°49.9'	46977	T			

Table 1, continued.

Station	Year	Latitude	Longitude	x (m)	y (m)	D	I	F	Instr	Reject D	Reject I	Reject F
Hasle/Schüpfh.	1991	46°59.4'	8°03.4'	203920	646960	0°55.8'	62°50.7'	46999	T			
Wichtrach	1991	46°50.8'	7°35.1'	188175	611135	-1°04.4'	62°41.3'	46919	T			
Hardern	1992	47°05.5'	7°19.7'	215455	591585	-1°08.7'	62°56.0'	47018	T			
Reichenburg	1992	47°12.1'	8°58.3'	226550	716140	0°42.2'	63°04.6'	47139	T	x		
Maienfeld	1992	47°02.7'	9°32.6'	208070	759890	0°27.3'	62°57.8'	47096	T			
S. Antönien	1992	47°01.1'	9°48.8'	204640	780530	0°19.1'	62°55.4'	47076	T			
S-Charl	1992	46°47.5'	10°20.1'	177965	821040	0°12.9'	62°55.2'	47056	T		x	x
Martina	1992	46°57.3'	10°27.5'	195850	829785	0°05.5'	62°50.9'	47048	T	x		
Bottighofen	1992	47°39.4'	9°12.9'	276840	733410	0°31.1'	63°31.7'	47277	T			
Granges (VS)	1992	46°15.7'	7°27.9'	123175	601990	-1°00.6'	62°05.3'	46756	T			
Montmollin	1992	46°59.8'	6°50.1'	204765	554075	-1°15.4'	62°44.1'	46995	T		x	
Sierne	1992	46°11.4'	6°11.1'	114500	503090	-1°25.1'	62°00.0'	46707	T			
Avully	1992	46°11.0'	5°59.7'	113400	488485	-1°30.6'	61°59.1'	46733	T			x
Montherod/U.	1992	46°31.0'	6°20.4'	151005	515610	-1°18.1'	62°23.4'	46854	T	x	x	x
Zinal	1992	46°06.9'	7°38.1'	106840	615065	0°56.5'	61°54.0'	46623	T		x	x
Tutmann	1992	46°13.0'	7°42.6'	118145	620810	0°56.1'	61°57.6'	46669	T		x	x

Table 2. Observed and computed field elements at Fürstenfeldbruck.

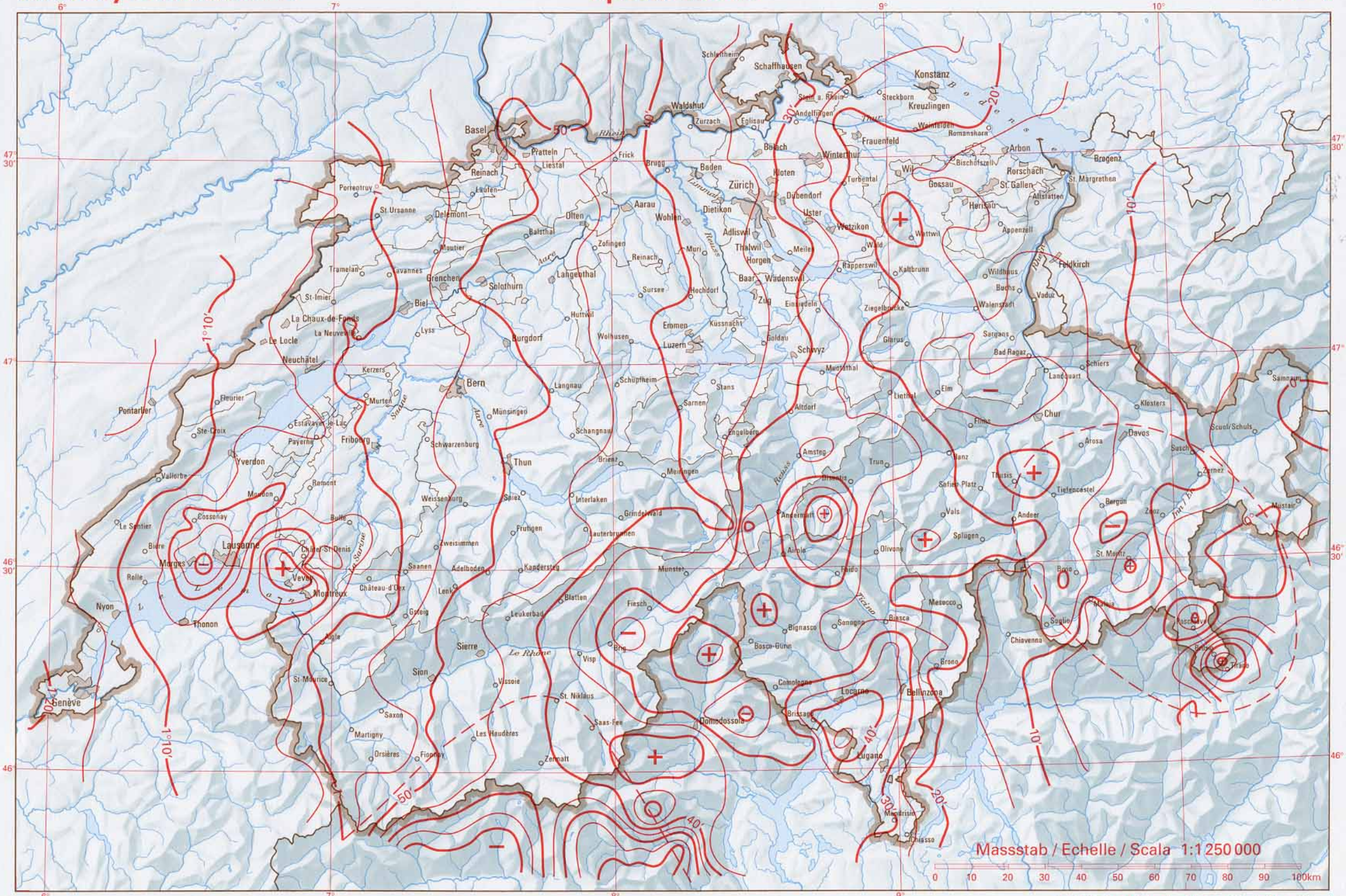
	1985.5	1992.5
D_{Obs}	−24.2'	10.9'
D_{Comp}	−29.3'	4.0'
I_{Obs}	63°57.0'	64°04.4'
I_{Comp}	63°57.6'	64°03.0'
F_{Obs}	47 416	47 580
F_{Comp}	47 393	47 539

Table 3. Coefficients of equations (2) and (11-13) which give D and I in decimal degrees and F in nT.

	D	I	F
A	−2.6142	62.6145	46 684.6
B	$-9.289\cdot10^{-2}$	$8.1494\cdot10^{-3}$	3.106
C	$4.9061\cdot10^{-3}$	$3.732\cdot10^{-4}$	0.392
b	$4.6682\cdot10^{-4}$	$2.958\cdot10^{\text{[illegible]}}$	$-1.9362\cdot10^{-4}$
c	$-6.36624\cdot10^{-4}$	$1.163\cdot10^{\text{[illegible]}}$	$-5.39\cdot10^{\text{[illegible]}}$
α	0.16527	$5.9432\cdot10^{\text{[illegible]}}$	16.035
β	$1.1662\cdot10^{\text{[illegible]}}$	$6.9979\cdot10^{\text{[illegible]}}$	3.5757
γ	$5.1943\cdot10^{\text{[illegible]}}$	$-3.0357\cdot10^{\text{[illegible]}}$	2.6553

LIST OF MAPS

Westerly Declination D **Epoch: 1994.0** **MAP 1**



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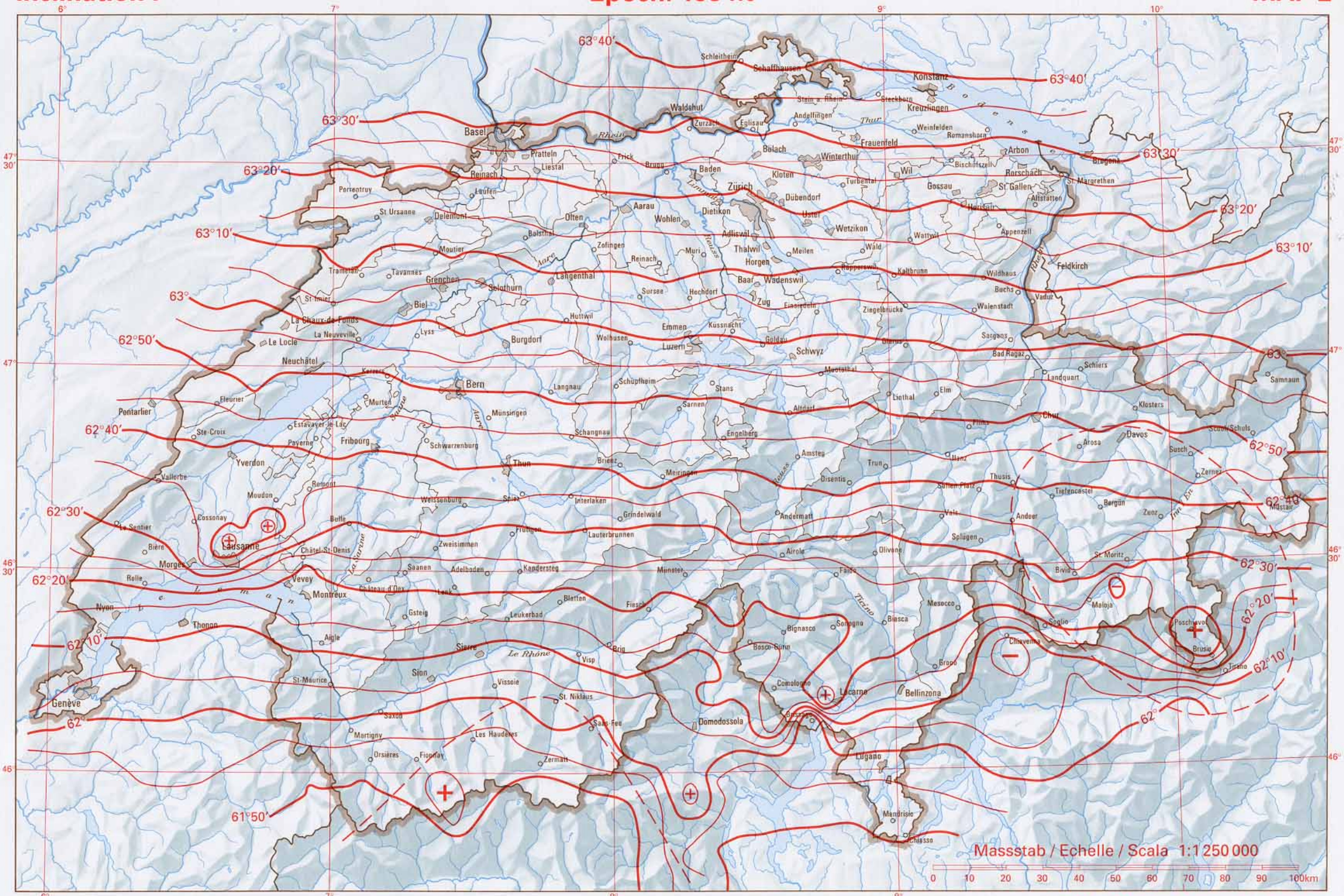
Inclination I **Epoch: 1994.0** **MAP 2**



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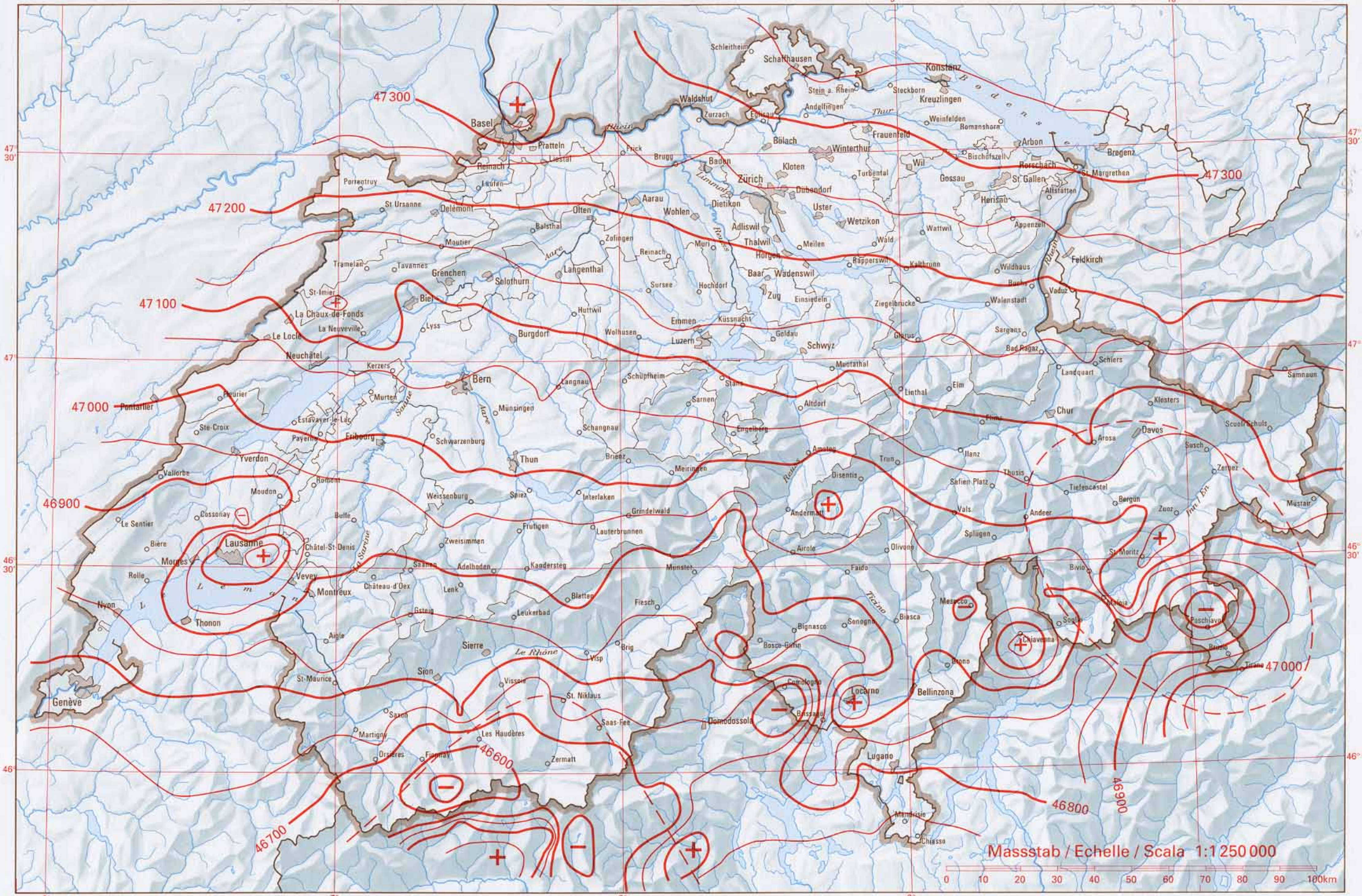
Amplitude F — Epoch: 1994.0 — MAP 3



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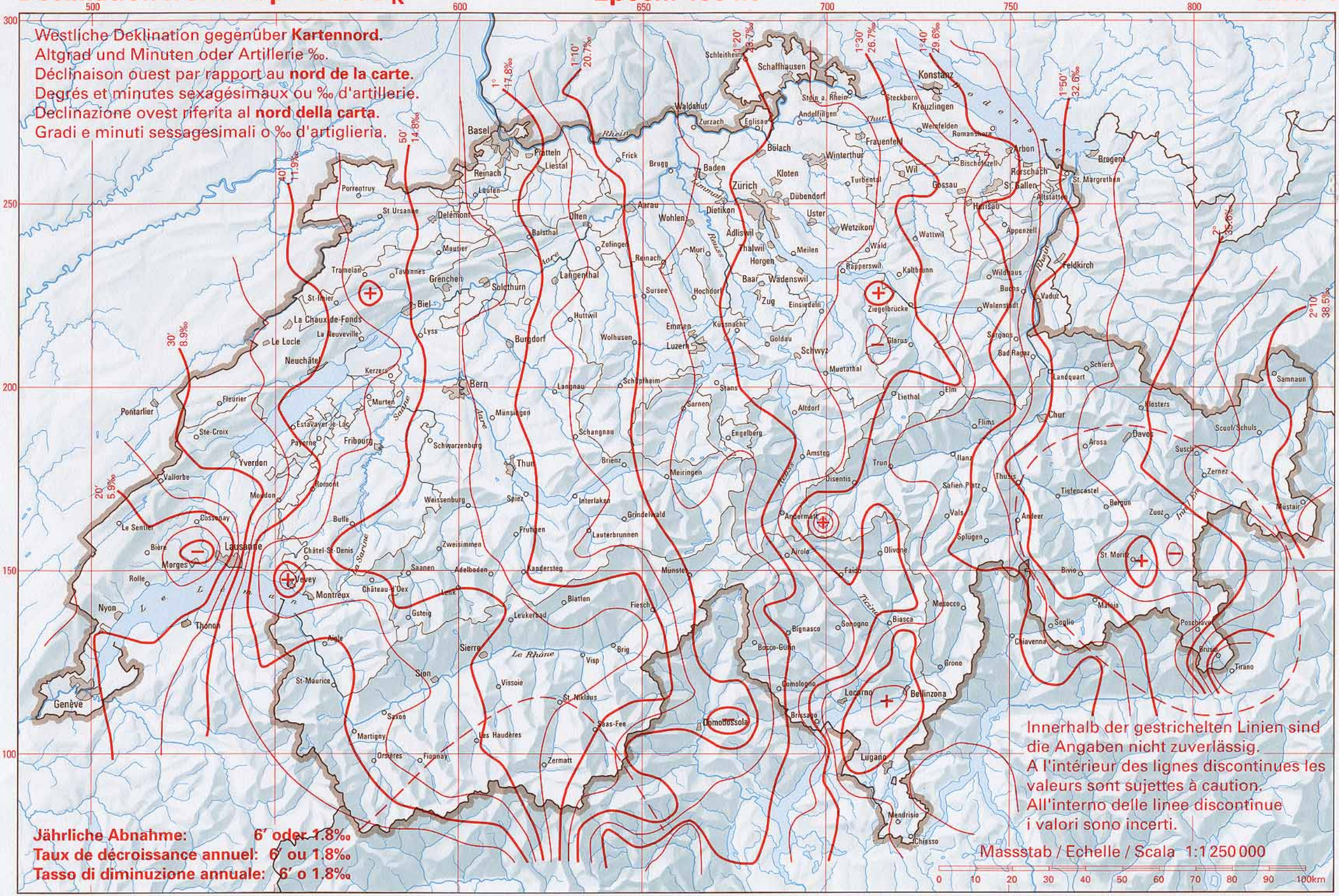
Declination from Map North D_K — Epoch: 1994.0 — MAP 4



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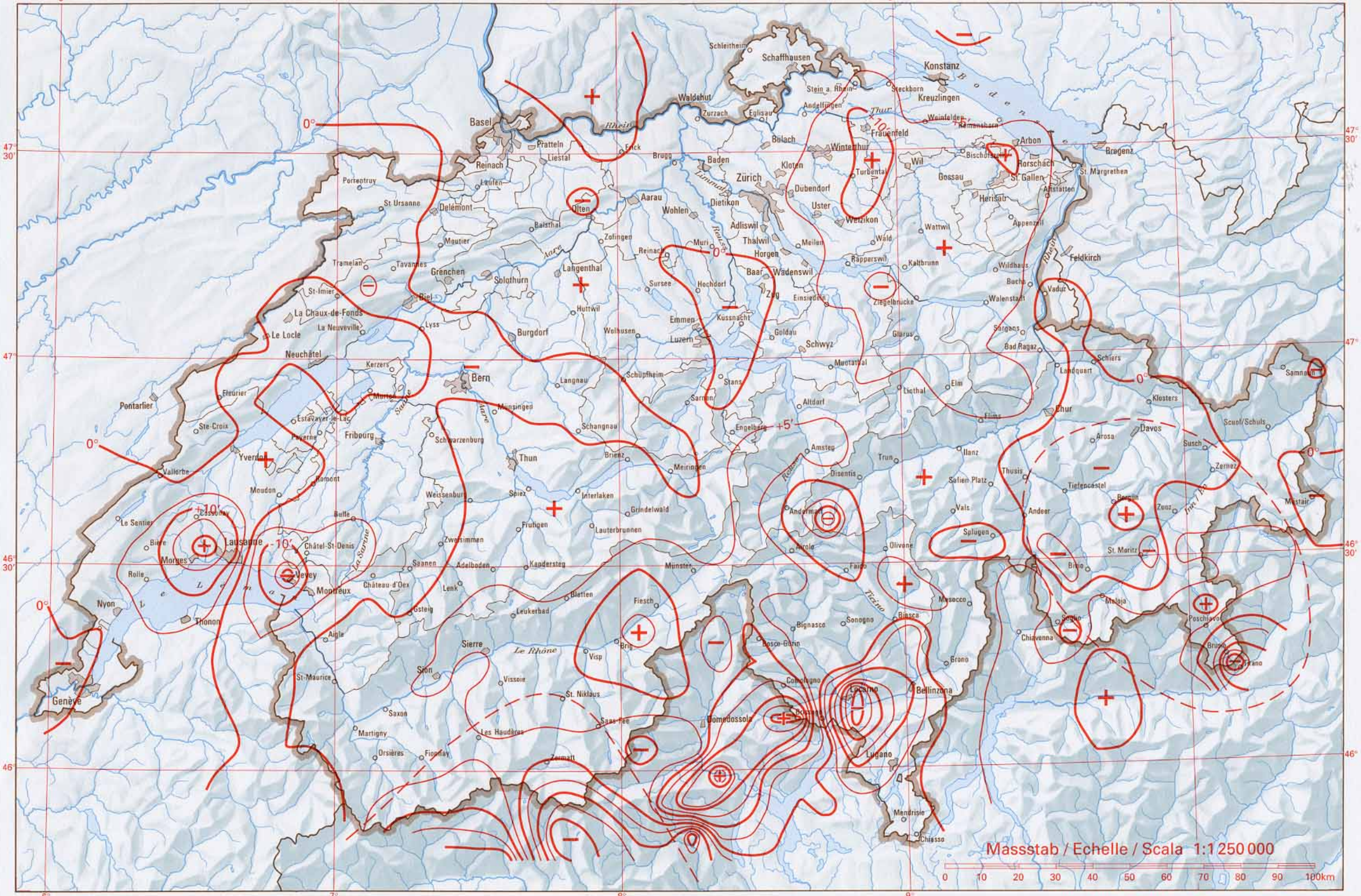
Declination Anomaly ΔD Epoch: 1994.0 MAP 5



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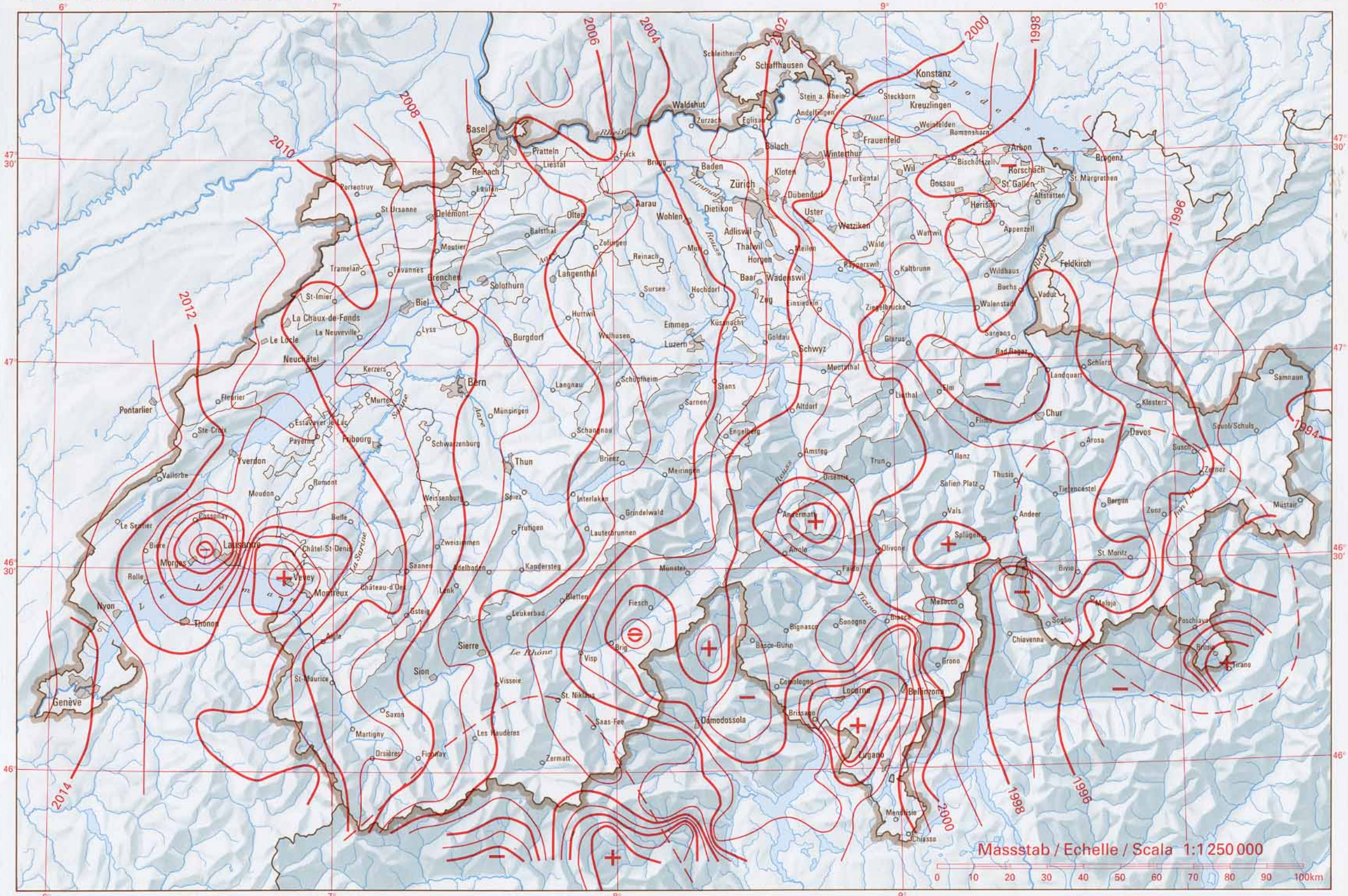
Year when Declination D= 0

MAP 6



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