A GEOMAGNETIC REFERENCE MODEL FOR ALBANIA, SOUTH-EAST ITALY AND THE IONIAN SEA FROM 1990 TO 2005 WITH PREDICTION TO 2008.

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ABSTRACT

From the three-component magnetic field observations taken from 1988 to 2005 during the measurement of Albanian and Italian magnetic repeat station network, as well as from a selected set of Ørsted satellite total field measurements, a geomagnetic reference model is determined for the region comprising the Albanian territory, the south-east part of the Italian Peninsula and the Ionian Sea. This model is designed to represent the components X,Y,Z and the total intensity F of the main geomagnetic field for epochs between 1990 and 2005 with prediction to 2008. The model is based on an expansion of the magnetic potential in terms of spherical cap harmonics applied to a cap of semi angle $8^{\cong}$. The model can be used as a reference model to reduce magnetic surveys undertaken in the area during the time of validity of the model, including also epochs up to 2008 for which the model is predictive.

1. INTRODUCTION

The geomagnetic field changes in space and time. Its measurements provide deep insights into Earth structure and dynamics. Observatories are placed in vital points of interest for monitoring continuously the field in time, with high accuracy and resolution following to the specific standards of measurements imposed by the scientific community. Due to the high cost in running an Observatory it is usual to consider also an appropriate network of additional temporary points of measurement, designed to cover a large area as a national territory, to give more complete spatio-temporal information on the geomagnetic field. The three-component magnetic field can be measured at an interval of some years at the points of the Network, so called magnetic repeat stations. This kind of network is the Magnetic Network of Repeat Stations. The values of the magnetic components, and especially the secular variation field deduced from these measurements, can be used to define regional models to produce magnetic charts or reduce magnetic surveys to a given epoch. The Balkan region, more than other European areas, needs for a regular monitoring of the magnetic field at some given points because of the lacking of magnetic observatories in this region [1].

The relative vicinity of Italy to Albania allowed the collaboration between the geomagnetism group of the Italian Istituto Nazionale di Geofisica e Vulcanologia (INGV) with the Academy of Science of Albania, Centre of Geochemistry and Geophysics in Tirana (CGG), and Physics Department of Tirana University (PDTU) that usually perform magnetic measurements in Albania, in order to coordinate some modern campaigns of geomagnetic measurements over a specifically designed repeat station Network of that territory. INGV provided some personnel and instruments during the performance of measurements and afterwards with competence in the modeling procedure. In this paper we have used the produced datasets of magnetic measurements in Albania from 1990 to now, together with recent measurements from the Italian repeat station network and with a selected total intensity data set from the Ørsted satellite mission to develop a regional reference model for this area, Albania, southeastern part of Italy and the Ionian Sea. This model was developed by means of Spherical Cap Harmonic Analysis (SCHA)[2], representing the magnetic field better than the International Geomagnetic Reference Field (IGRF). Adding a polynomial time dependency of the model coefficients made it possible to provide a short time prediction to 2008, in order to let the model still usable for other years from now.

The paper is so composed: after this introduction, section 2 describes the data used for the model inversion, section 3 deals with the model, while the last section shows some results with conclusions.

2. DATA USED

Fig. 1(left) shows the locations of all points of land geomagnetic measurements used in the model determination and Fig.1 (right) shows the locations of the satellite points. The datasets of magnetic measurements starts with a set of total intensity F measured around 1990.0 by the ex-Geophysical Enterprise of Tirana that covered all Albanian territory over an array of 31 sites where F was measured with a proton magnetometer.

During September 1994 (epoch 1994.75) a new vector magnetic survey (measuring F,I and D, [3]) covering the Albanian territory was carried out by CGG, PDTU and INGV. Most of the logistic was coordinated by the two Albanian institutions, while most of the operational actions of geomagnetic measurements were coordinated by Italian institute. The measurements were taken by using a Geometrics proton magnetometer and a Bartington fluxgate theodolite, together with a gyro-theodolite for an absolute determination of the geographical azimuth. Another scalar field campaign was made in August 2003 (epoch 2003.6), over 6 points of the 1994 repeat station geomagnetic network and in two new points. This survey was carried out during the short visit of one of the authors (ADS) to Albania, funded by the Italian foreign Ministry. An Overhauser effect magnetometer was used to make the scalar measurements. For each site a record of 1-2 hours was taken in order to have a reasonable time of total intensity data.

Ten years after the first modern three-component survey, a new one was undertaken in September 2004. Analogous instrumentation was used and all points of the Albanian Magnetic Network were repeated, with few exceptions, where the anthropic disturbance was too high to make a reliable magnetic measurement, and some news were established. The total of points with vector measurements was 12. A temporary station with a fluxgate variometer was installed in Tirana during all the time of the Campaign in order to reduce all values to the closest night time.

The region of Albania is rather small and any sophisticated technique of modeling ground magnetic data would be probably as much accurate as a simple polynomial model of the field. Actually, we are also interested on a larger area comprising the southeastern part of Italy, and including the sea between the two countries. Thus the dataset of geomagnetic components includes also data from part of Southeast Italy: we have taken in account measurements of 6 locations from the Italian magnetic repeat station network [4] at epochs 1990.0, 1995.0, 2000.0, 2004.5. For a better temporal behaviour of the model and to improve the stability of the inversion, we have synthesized X,Y and Z components at 1988.0 and 2008.0 for the 12 Albanian stations reducing the real vector measurements available for 1994.75 and 2004.75 to the closest extreme epoch. Temporal reduction was made applying the secular variation predicted by the Italian geomagnetic reference model [5], a model that has been demonstrated to predict the temporal change of the magnetic field in Italy better than IGRF.

Because of the great importance of acquiring the geomagnetic information (specially declination) also for some altitude different from ground level, as for instance when flying from one country to the other, we are also interested on a real three-dimensional model, extending its validity also to some high altitudes (say, 10-100 of km). For this reason, we used a technique such as SCHA [2] that takes into account the altitude variation of the field, and included also satellite data in the model inversion. Regarding the latter point, we have included a selected subset of total intensity magnetic field measurements from the Ørsted satellite, this for a homogeneous coverage of the studied region, especially in the sea areas. The satellite data act as a boundary to develop a three dimensional model which is valid not only at sea level but also at any distance between the surface and the satellite height. In this model we took into account a total of 30 scalar satellite values measured between 1999.5 and 2002.5 with reduced presence of external field in the data. For reducing the ionospheric fields only night side data were selected for periods in which the 3-hourly index K_p was lower than 1+. The absolute value of the *Dst* index was also limited to a maximum of 10nT. The data chosen are distributed in a height range between 650 and 850 km above the earth surface. This spatial distribution is shown in figure 1 (right). The future inclusion of other satellite data from Ørsted or CHAMP together with the new mission Swarm will surely improve our model.

The different datasets were weighted according to the reciprocal of the variance of the total error of the measurements [6]. Each variance was computed as the sum of the error associated with the measurements (instrumental errors, etc.), σ_m , and the error related to the lithospheric field, σ_c. The ground data were assumed to have σ_c=50nT and σ_m=10nT, whereas no crustal contribution was assigned to satellite data, and σ_m was set equal to that of ground data.

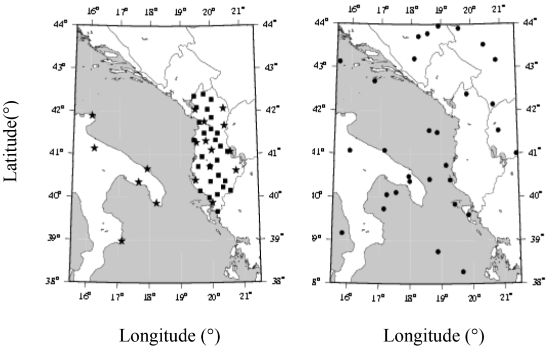

Figure 1.Left) Sites of the Albanian and Italian repeat stations from which vector and scalar(stars) and only scalar(squares) magnetic field data were used to develop the model. Right)Sites of the selected Oersted satellite data.

3. MODEL

To develop the reference model, we applied SCHA [2] to the data described above, after IGRF values at the central epoch of 1998 were removed. This choice represents an improvement with respect to previously presented polynomial models for the region [7] due to the fact that a SCHA model allows for the computation of the field component values through expressions that satisfy Laplace's equation. The corresponding solution over a spherical cap in spherical coordinates (r,θ,ϕ) for the magnetic potential due to internal sources is [2]:

$$V = a\sum_{k=0}^{K}\sum_{m=0}^{k}\left(\frac{a}{r}\right)^{n_k(m)+1} P^m_{n_k(m)}(\cos\theta)\cdot$$
$$\cdot\sum_{q=0}^{Q}\left\{g^m_{k,q}\cos(m\phi)+h^m_{k,q}\sin(m\phi)\right\}\cdot t^q \qquad (1)$$

where it is included a polynomial time dependency. $g^m_{k,q}$ and $h^m_{k,q}$ are the spherical cap harmonic coefficients that determine the model, $P^m_{n_k(m)}(\cos\theta)$ are associated Legendre functions, that satisfy the boundary conditions (zero of the potential or its derivative with respect to colatitude at the border of the cap; [2]). The associated Legendre functions have integer order m and non-integer degree $n_k(m)$ (where k is an index to sort the different roots for a given order), and K and Q are the maximum spatial and temporal indices of the expansion, respectively . The magnetic components are obtained as the spatial derivatives of equation (1) in spherical coordinates, since the potential is non-observable. In this case, it was used a first order Taylor expansion of the total magnetic field intensity, as a square root function of the X, Y and Z components because of the fact that vector measurements are combined with total field measurements introducing a non linearity in the equations involved to obtain the coefficients of the model [6]. The coefficients that define the best model correspond to K=2 and Q=1 covering the period between 1988.0 and 2008.0. These coefficients were obtained through a least squares regression procedure.

As happened in a previous paper [8], at the beginning the model was originally defined in a cap with semi angle of 3º . With respect to that work, we hoped that a better distribution in time and space would have allowed to use a cap as small as necessary to include all data. Nevertheless, we found the same problems when such small cap was considered. Figure 2 shows the behaviour of the magnetic field components at 1990.0 over the studied region. The occurrence of fictitious oscillations (especially for the **Y** component) is caused by the presence of some harmonics in the spherical cap harmonic expansion (1), shorter than the real wavelengths (for a 3º cap, the minimum degree $n_k(m)$ involved was roughly 45). For this reason the spherical cap in which the model was finally defined was chosen with a semi-angle of 8º, in order to cover the most significant harmonics (the minimum degree is approximately equal to 12 for this cap with a maximum spatial index K=2). The final model has a total of 18 coefficients (Table I).

4. RESULTS AND CONCLUSIONS

Table II details the root mean square fit to the input observatory data and satellite data for SCHA and IGRF10. Although the differences are small, SCHA improves the fit to **X, Y** and F elements of the magnetic field with respect to the global IGRF model, whereas it is a bit worse in the case of the **Z** component measured at the ground and the satellite total field, F.

Figure 3 shows the contour difference between the SCHA and IGRF models for epoch 2005.0. This difference is between 40 and –80 nT for all the components in the area from which data were available, being a bit higher as we move towards areas without data.

Once the validity of the model has been demonstrated, we can recommend its use as reference model over the investigated region, with particular application to the production of regional charts as those shown in fig.4 for epoch 2005.0 at sea level, to reduce to a fixed epoch the magnetic surveys developed in the area or to study phenomena related to the earth's internal magnetic field. The temporal evolution of the isolines in the magnetic charts for the **Y** component shows a clear westward drift of the east component of the magnetic field (fig.5). [9]

Table I. Coefficients of the Albanian Italian Geomagnetic Reference Model developed by SCHA. The final values are obtained with the addition of IGRF values at 1998.

k	m	$n_k(m)$	$g^m_{k,0}$	$h^m_{k,0}$	$g^m_{k,1}$	$h^m_{k,1}$
0	0	0.0000	12.209		-280.81	
1	0	16.7209	-5.960		1.869	
1	1	12.7139	0.631	14.020	5.563	-54.63
2	0	26.9471	3.588		-1.493	
2	1	26.9471	-0.846	-3.962	-0.667	12.144
2	2	21.4163	-6.960	-7.381	-1.886	0.043

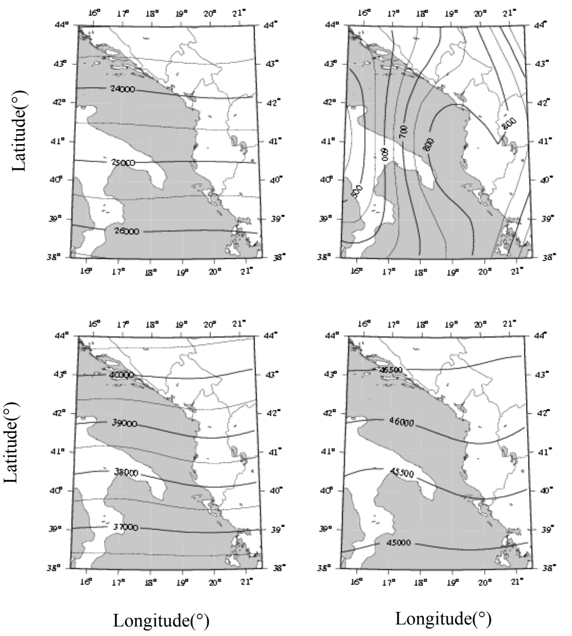

Figure 2. Maps (in nT) for X (top left), Y (top right), Z (bottom left), and F (bottom right) elements for epoch 1990.0 at sea level obtained from a SCHA model developed on a 3° semi angle cap. Clear large oscillations appear as symptom of lack of the proper spatial spectral content .

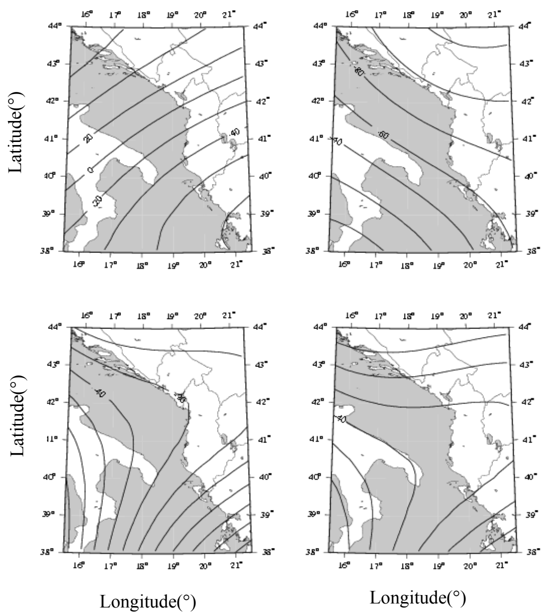

Figure 3. Difference (in nT) for X (top left), Y (top right), Z (bottom left), and F (bottom right) elements between SCHA and IGRF model at sea level for epoch 2005.0.

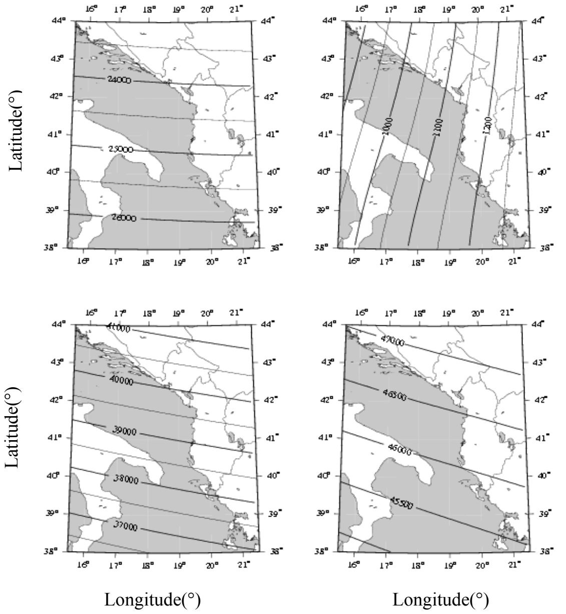

Figure 4. Maps (in nT) for X (top left), Y (top right), Z (bottom left), and F (bottom right) elements for epoch 2005.0 at sea level obtained from SCHA model developed on an 8° semi angle cap.

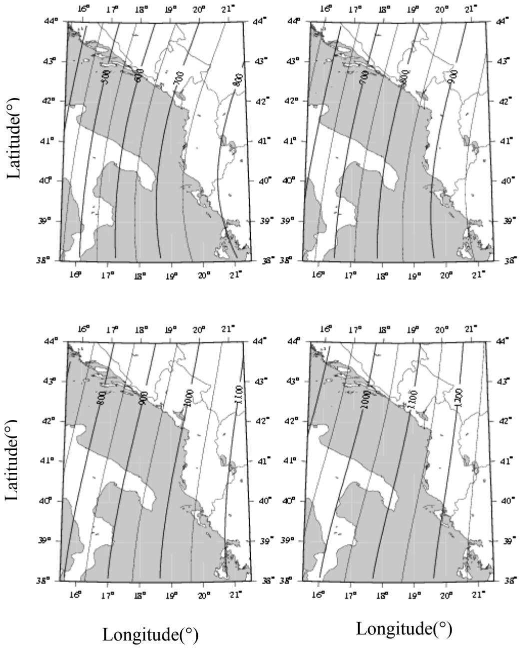

Figure 5. Maps (in nT) for Y components for epochs 1990.0 (top left), 1995.0 (top right), 2000.0 (bottom left), and 2005.0 (bottom right) at sea level obtained from the SCHA model developed on an 8° semi angle cap.

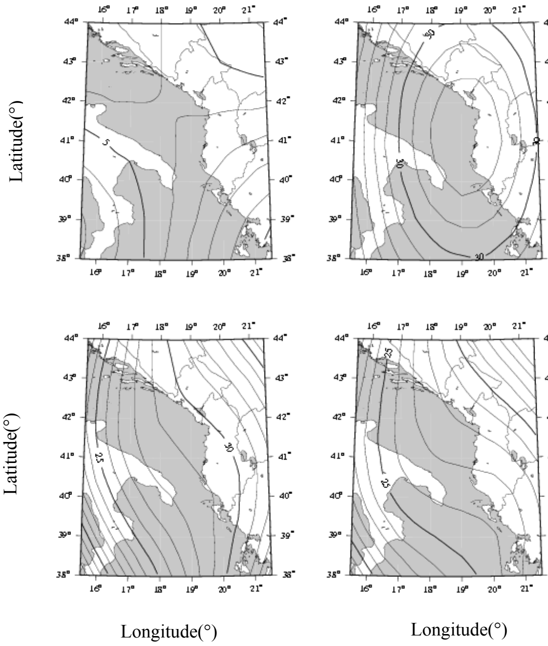

Figure 6. Maps for the secular variation of X (top left), Y (top right), Z (bottom left), and F (bottom right) magnetic elements for epoch 2000.0 at sea level obtained from the SCHA model. Contour lines are shown at 1nT/year interval.

Other kind of studies can be developed through the inspection of the secular variation of the magnetic field. For instance, the secular variation of all the magnetic elements for epoch 2000.0 (fig.6), obtained from the SCHA model as the field differences between epochs 1999.5 and 2000.5, confirms that the region under study presents low values for the temporal variation of the geomagnetic field for this period (less than 32 nT/year for all components). [10]

Figure 7 shows the behaviour of the mean square value of the geomagnetic field $<B^2>$ (said also spatial power of the field) from 1990.0 to 2008.0 over the studied region: this increases with a linear growth that can be explained by the westward drift of the isolines in the region.

The use of further satellite data will improve the model in this region and all over the Balkan area, so as other models for these areas of the Earth surface where there are no Observatories and magnetic repeat stations are sporadically measured. Swarm mission will provide a considerable set of data that will allow the determination of better models of the geomagnetic field over local or global scales.

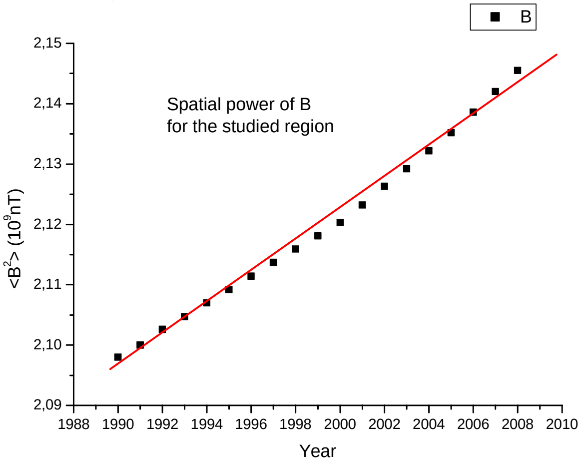

Figure 7. Annual mean square value of B over Albania and south eastern Italy from 1990 to 2008 estimated from the SCHA mode mostly due to westward drift of magnetic isolines.

Table II. RMS fit to input data of SCHA and IGRF models (in nT)

	Ground	Ground	Ground	Ground	Ørsted
Model	**RMS$_X$**	**RMS$_Y$**	**RMS$_Z$**	**RMS$_F$**	**RMS$_F$**
IGRF	47.2	77.2	49.3	59.7	2.5
SCHA	38.4	62.2	52.3	46.3	3.9

5. ACKNOWLEDGMENTS

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6. REFERENCES

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