Geomagnetic anomalies registered in the Iberian Peninsula before a time period of intense seismic activity

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Abstract. Geomagnetic data registered by Geomagnetic Observatories of Almeria, Coimbra, San Fernando and Toledo, located in the Iberian Peninsula and Tenerife in the Canary Islands were used to study geomagnetic field anomalies from August 1968 to March 1969. Data used were obtained in Annals of the Observatories as average hourly values of the magnetic declination and horizontal and vertical components of the magnetic field. Magnetic field disturbances were studied using average monthly values, average daily values and average hourly values. The anomalies were quantified using IGRF model values and monthly average hourly values of the Observatories data. During the time period of our study, four earthquakes of magnitude equal or higher than 3 are registered in the seismic catalogue with two epicentres in the Gibraltar Region and two epicentres in the Gulf of Cadiz. In the early hours of February 1969, an earthquake of high magnitude (M=8) was felt in Portugal, Spain and North-Western Morocco. Near two hours later, another earthquake of magnitude 6.5 was recorded. In that day, 32 earthquakes were recorded in the region. In the second part of the work, a special attention is given to the earthquake of February 10th, 1969, due to the location of this epicentre and the temporal proximity of February 28th. The magnetic field in the region suffered three strong magnetic disturbances during the month of February in 1969. The earthquake of February 10th occurred just before the start of the second interval of intense magnetic perturbations. The third time interval of intense magnetic disturbances occurred before and during the day of February 28th. The analysis made using hourly values to time intervals including the earthquake occurrence (five earthquakes) shows “equal values” of magnetic anomalies occurring in time intervals of three hours. Strong variations of the horizontal field occurred before the earthquakes of February 10th and February 28th.

1. Introduction

In the early morning of February 28 in 1969, a seismic crisis began with epicenters located in the SW of Cabo de São Vicente (Portugal). In a time interval less than three hours, five earthquakes of magnitude 8.0, 5.6, 3.9, 4.4 and 3.8 were registered by seismic stations. The events mentioned caused 13 deaths and considerable damage. In that day, a total of 32 seismic events occurring in the region were registered by seismic observatories. Some answers to surveys carried out after the earthquake of February 28 include descriptions of phenomena that may be associated with changes in the terrestrial magnetic field. In this work, the magnetic field records (average hourly values) measured, 51 years ago, at the Observatories of Coimbra, Toledo, San Fernando and Almeria, in the Iberian Peninsula and...
Tenerife in the Canary Islands, are studied [1],[2]. Although there were time intervals without measurements at the Observatories of Coimbra, San Fernando and Tenerife, it was possible to establish relationships between the different records and to relate temporally some of the anomalies found with seismic activity detected in the SW of Cape St. Vincent, Morocco Sea and Gorringe region [3]. Using data from records obtained from July 1968 [4] to December 1969 at the Observatories of Toledo, Almeria and Tenerife it was possible to detect magnetic field anomalies that occurred in the second half of 1968. In the seismic catalogue [3] are registered some earthquakes of magnitude equal to or greater than 3 in the Gibraltar region and the Gulf of Cadis on the date mentioned. An earthquake was also identified on February 10, 1969 in the Gulf of Cadis.

2. Data used

We can see, in Table 1, the location of the Magnetic Observatories whose data were used in the present work. All of them are located in the Iberian Peninsula north of the region where the earthquakes occurred except the Tenerife Observatory located in the Atlantic Ocean, Canary Islands, SW of the referred region.

| Observatory  | Latitude N | Longitude W |
|--------------|------------|-------------|
| Almeria      | 36.853     | 2.460       |
| Coimbra      | 40.222     | 8.422       |
| Tenerife     | 28.477     | 16.277      |
| Toledo       | 39.874     | 4.047       |
| San Fernando | 36.667     | 5.945       |

Data used were taken from the Annals of Geomagnetic Data [1], [2], in the form of average hourly values, with daily average values and monthly mean values of magnetic declination, horizontal field and vertical field. The Toledo and Almeria Observatories have complete data records throughout the time studied. The Observatory of the Coimbra University did not record magnetic declination values for 12 consecutive hours on February 28th, 1969. San Fernando does not display data for some short-term intervals. Tenerife presents a long interval without data from 6 am on the 8th until 1 pm on February 26th, 1969. The magnetic field anomalies obtained in the different stations of the observatories mentioned were compared with the values provided by the IGRF2020 Model, with data of the time interval under study.

3. Magnetic anomalies

The monthly average values of the various components of the magnetic field show the existence of several anomalies that were not limited to February 1969. The vertical component of the magnetic field shows greater stability than the horizontal component that undergoes appreciable changes in the different Observatories. The data provided by model IGRF2020 were compared with the values obtained in the registers, at the same time intervals, showing identical behaviours in different Observatories. We can see in Table 2 the differences between the measured value of the horizontal component of the geomagnetic field and the value obtained with Model IGRF2020 in different months of the year 1969.

The Tenerife Observatory does not provide data for the month of February and the data for July and December were not used in this work. The values shown are all positive (the measured values are higher than those obtained with the model) except in Tenerife where the values are negative (measured values lower than those obtained with the model). The smallest difference between the values obtained by the two methods occurred in February in all stations. Values are higher in March and April. The
values obtained in December 1969 in Coimbra and Almeria Observatories are higher than values obtained in July.

Table 2. Differences between the value of the horizontal component of the magnetic field measured and obtained with model IGRF2020 in the different stations studied

| Observatory  | February | March | April | July | December |
|--------------|----------|-------|-------|------|----------|
| Almeria      | 29       | 35    | 46    | 63   | 67       |
| Coimbra      | 21       | 28    | 41    | 59   | 61       |
| Tenerife     | ---      | -416  | -408  | -390 | -406     |
| Toledo       | 10       | 13    | 43    | 42   | 31       |
| San Fernando | 179      | 182   | 193   | ---  | ---      |

The analysis of the average monthly values obtained in the years 1968 and 1970 [4],[2] shows that the anomalies in the horizontal component and in the inclination of the magnetic field were already felt in the second half of 1968 and in 1970 (see Figure 1).

Figure 1. Average monthly values of the horizontal component and the inclination of the geomagnetic field measured in Toledo during the years 1968, 1969 and 1970

Figure 2 shows the differences between the monthly mean values of the horizontal component of the magnetic field in Toledo and the mean values obtained through the IGRF2020 Model from July of 1968 to December of 1969. The value corresponding to November 1968 (month 5) has an anomaly with characteristics identical to that obtained in February 1969 (month 8). In August 1968 (month 2) it is possible to identify identical behaviour to that obtained in April and August 1969 (months 10 and 14 of the graph).

Figure 2. Differences between average monthly values (DBV) of the horizontal component registered in Toledo and values obtained with the IGRF Model. The time interval is from July 1968 (month 1) to December 1969 (month 18)

An identical behavior to that shown in Figure 2 was obtained with values of the North-South component of the horizontal field. The present work uses only geomagnetic data from month 2
(August 1968) to month 9 (March 1969). Special attention is dedicated to time intervals including days with earthquake occurrences.

3.1 Average daily values
A more detailed analysis of the magnetic field values of November 1968 in Toledo showed that the low mean value of the horizontal component of the field (month 5 in Figure 2) is due to relatively low values obtained in the first days of November and the last days of October, with the lowest value on November 1st (see Figure 3). Magnetic declination values present an identical disturbance in the same time interval.

![Figure 3. Average daily values of the horizontal component of the magnetic field in Toledo, from October 25th (day 1) to November 14th (day 21) in 1968. The lowest value was obtained in day 8 (November 1st)]](image)

The first days of the graph (Figure 3) show high values increasing until day 5 (October 29th). On day 6 begins the descent of values with a minimum in day 8 (November 1st). The rise of the values occurs from day 9 to day 13 (November 6th) but values similar to those of the first days were obtained only from day 20. Figure 4 shows the values of the vertical field and magnetic inclination obtained in the same time interval. Maximum values of the vertical field and the inclination can be seen on day 8 as expected but an increase of the vertical field can be seen in day 5 (when the horizontal field shows the maximum value) and the decrease observed on day 13 is lower than expected from the descent of the inclination and the ascent of the horizontal component. The vertical field values obtained on days 20 and 21 are higher than those obtained from day 1 to day 4. An earthquake occurred on October 30th (day 6) in Gibraltar Zone with magnitude 4.1. Another earthquake occurred on November 7th (day 14) with magnitude 3.8.

![Figure 4. Average daily values of the vertical component and the Inclination of the Geomagnetic field in Toledo from October 25th (day 1) to November 14th (day 21)]](image)

Average daily values of the horizontal and vertical component of the geomagnetic field registered in Toledo from August 25th to September 5th (Figure 5) shows an increase of the horizontal field in the
first days of the graph with maximum values on days 4 and 5 (August 29th). From day 6 to day 8 a
decrease of values of the horizontal field occurs but the vertical field shows the same value on days 4
and 5 as expected but the lowest value of the vertical field occurs on day 6. A great increase in the
vertical field is observed in day 7 (August 31st). An earthquake with magnitude 4.1 occurred on
August 31st in the Cadis Gulf.

Figure 5. Average daily values of the Horizontal and Vertical components of the Geomagnetic field in
Toledo from August 25th (day 1) to September 5th (day 12) of 1968

Figure 6 shows the daily average values of the horizontal field obtained in February 1969 in
Coimbra. Minimum values can be seen on days 3 and 11. A great increase in values (46 nT) can be
seen from day 3 to 4 and a great decrease in values (-57 nT) occurs from day 10 to day 11. An
earthquake with magnitude 3.0 occurred in day 10 in the Gulf of Cadis (origin time: 19 h 29 min 41.9
s). No earthquake is registered in the region on days 3 or 4. The values of the horizontal field are
higher than 24360 nT from day 6 to day 10 and from day 16 until day 28. An increase of the field can
be seen from days 7 to day 9 and a small decrease occurs on day 10. At the end of the month, a
maximum occurs on day 26 and a decrease can be seen on day 27. Similar graphs were obtained with
data from Toledo and San Fernando Observatories.

Figure 6. Average daily values of the horizontal component of the magnetic field in Coimbra in the
month of February 1969

Daily average vertical field values can be seen in figure 7. As expected maximum values of the
vertical field were obtained in days 3 and 11. The vertical field decreases from day 7 to day 9 as
expected and a small increase (2 nT) occurs on day 10. A decrease of the field is observed from day 21
to day 26 with equal values on days 24 and 25. An increase is observed in the vertical component of
the field in day 27 and day 28. An earthquake occurred on February 10th in the Cadis Gulf, with
magnitude 3.0 and the first of the 32 seismic events registered on day 28th with magnitude 8.0.
3.2 Average hourly values
Daily average values show earthquakes occurring in time intervals with decreasing components of the horizontal geomagnetic field and increase of vertical values of the same field. Average hourly values can give a more detailed analysis of the magnetic field near the earthquake occurrence.

Data from Toledo and Tenerife Observatories shows that in August 31st 1968 the horizontal magnetic field in time interval 13-14 h had a lower value than the average hourly month value. The horizontal field value was decreasing until interval 17-18 h when the minimum value was registered. The deviation from the average hourly value at that time was -51 nT in Toledo and -33 nT in Tenerife. The vertical component of the field shows an increase (8 nT) that remains equal for 4 hours in Toledo and 2 hours in Tenerife (0 nT). The intensity of the field is lower than the average monthly values for the hours studied. The inclination is higher than the average value and its variation seems to be related to the variation of the horizontal field.

Data from Toledo Observatory on October 30th show variations similar to that obtained for August 31st. The horizontal field was decreasing until interval 13-14h, with a deviation of -56 nT in Toledo and -54 nT in Tenerife. The vertical component of the field shows an increase (14 nT) that remains equal for 3 hours in Toledo. The inclination is higher than the average value and its variation seems to be related to the variation of the horizontal field.

The earthquake of November 7th occurred early in the morning at 02h 08 min 48.1 s. Data from Toledo and Tenerife Observatories shows an increase in the horizontal and vertical components and in the intensity of the field at the hour of the earthquake.

No data from Tenerife Observatory are available for February 10th, 1969 but Toledo, Coimbra and San Fernando values were analyzed (Table 3). The horizontal component of the magnetic field had a higher value than the average monthly value for the hours used. The horizontal increase remains equal for 3 hours. The vertical component of the field was decreasing and its value was lower than the average monthly value for the hour considered in Toledo and Coimbra and equal in San Fernando. The intensity of the field shows an increase of 3 nT in Toledo, 9 nT in Coimbra and 7 nT in San Fernando. The inclination of the field decreases. The deviation from the average values is negative and shows a relative maximum associated with the hour of the earthquake occurrence.
Table 3. Magnetic Field deviations from the average value (nT), associated with the earthquake occurrence on February 10th 1969 in the Cadis Gulf.

| Observatory      | Horizontal Field 18-19; 19-20; 20-21 | Vertical Field 18-19; 19-20; 20-21 |
|------------------|-------------------------------------|----------------------------------|
| Coimbra          | 20; 22; 20                          | -3; -4; -3                       |
| Toledo           | 13; 13; 13                          | -4; -6; -5                       |
| San Fernando     | 11; 11; 11                          | 1; 0; 0                          |

The coordinates of the epicenter of this earthquake are 36.120 N and 7.599 W. Using the coordinates of the location of the Observatories in Table 1, it is possible to obtain a relation between the increase of field intensity and the differences in longitude between earthquake location and Observatories with the higher increase associated to the minimum difference in longitude.

By filtering in Figure 6 the values related with the anomalies of day 3 and day 11 it is possible to see that in February the horizontal component values range from 24360 nT to 24381 nT. This means that the horizontal component suffered small changes from day 14 until the end of the month. In the same way, it is possible to see that the vertical component of the field presents values from 36117 nT to 36134 nT. This means an average intensity value of 43992.7 nT. This is the intensity value on February 27th (Figure 8).

The analysis of the average hourly values shows a reality quite different from that observed with average daily values. Strong and rapid changes in horizontal and vertical magnetic field components were recorded in all the Observatories used in this work. The last part of the perturbation is a great increase in the vertical field with high values only exceeded for the same hour in February 11th. The differences between the maximum and the minimum values of the vertical field in each Observatory seems to increase with the longitude, the highest value was found in Coimbra. Tenerife located in the Canary Islands in the Atlantic Ocean shows a small value for the difference mentioned suggesting that the maximum value of the perturbation may be located west of Coimbra but east of Tenerife. Similar perturbations have been found for the horizontal component of the magnetic field but the differences between the maximum and the minimum values in each Observatory are higher than the values obtained for the vertical field.

Figure 8. Strong variations of the vertical field in February 27th in Coimbra. Differences between the maximum (B) and the minimum (A) values registered in the Observatories studied.

4. Conclusions
Strong variations of the geomagnetic field including a decrease of the horizontal component were recorded at the beginning of February 1969 (day 3 and day 11) that may be related with descriptions
made in the surveys of March 1969. Strong and fast alterations were also registered in the afternoon of February 27th.

The magnetic anomalies recorded in the time intervals associated with the occurrence of five earthquakes from August 1968 to February 1969 shows an increase of the horizontal component (average daily values) followed by a decrease that can occur during a few days. The increase of the vertical component may occur before or after the initial reduction of the horizontal component but the earthquake only occurs during the increase of the vertical field. The location of the February 10th earthquake relative to the Observatories used in the work made possible to detect changes occur at intervals of 2 or 3 hours (including the hour of the earthquake occurrence) and the longitudinal distance between the site of the earthquake and the observatories. From February 14th until February 26th the horizontal field showed high values with small variations (not more than 20 nT). From the day 22 to the day 26, the horizontal field shows the same value. The vertical field shows a decrease from the 14th until 26th. On the 27th, there was an increase in the vertical field and the earthquake occurs in February 28th.

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