Ann. Geophysicae 9, 239–241 (1991) © EGS – Springer-Verlag 1991

Annales
Geophysicae

The westward drift of the South Atlantic Magnetic Anomaly

O. Pinto Jr., W. D. Gonzalez, and I. R. C. A. Pinto

Instituto de Pesquisas Espaciais – INPE, C.P. 515, São José dos Campos, SP, Brazil

Received August 13, 1990; revised November 22, 1990; accepted December 3, 1990

Abstract. The westward drift of the South Atlantic Magnetic Anomaly (SAMA) has long been known. Recent computations based on an eccentric geomagnetic dipole, as compared with archeomagnetic data obtained in South America, seem to indicate that the SAMA region has a periodic movement around the Earth with a period of about 2 300 years. We think that this evidence may contribute to a better understanding of the complex physical processes occurring in the Earth's liquid core, where the magnetic field originates.

Introduction

The westward drift of the main features of the Earth's magnetic field has long been known. In particular, Halley (1692) found evidence that the South Atlantic Magnetic Anomaly (SAMA) was moving westward with a drift velocity of approximately 0.5°/year. The SAMA (see Fig. 1) is a region of low magnetic field intensity in the South Atlantic ocean and in the South American continent, recognized as a major sink for radiation belt particles trapped in the Earth's magnetic field (Pinto and Gonzalez, 1989a). This feature of the field can be reasonably explained by the concept of an eccentric dipole. This concept, specified by the dipole and quadrupole terms of the multipole expansion of the geomagnetic field, accounts for about 90% of the surface field (Parkinson, 1983).

In this century, based on a more accurate analysis of the geomagnetic field, the westward drift has been established quantitatively in various ways, such as the movement of the eccentric dipole (Vestine, 1953; Nagata, 1962; Pudovkin and Valuyeva, 1967) or the drift of the non-dipole field on a planetary scale (Yukutake, 1962; Adam *et al.*, 1964). However, recent investigations (e.g. Dawson and Newitt, 1982) seem to show that the dip poles, that is, the poles of the observed field, have had a predominant northward motion, at least since 1850. On the other hand, Kawai and Hirooka (1967) have shown that this result would be very different if we consider only geomagnetic data from observatories inside the SAMA region. In this case, the motion is predominantly westward. Nevertheless, these results are not necessarily contradictory. In the last decade there has been evidence supporting the idea that particular features of the field may have different movements. In fact, it is now widely accepted that they have a very different origin, namely, they could be related to different reverse flux features, known as core spots, in the core-mantle boundary due to magnetic diffusion driven by temperature variations at the core surface (Bloxham and Gubbins, 1985).

We have studied the movement of the SAMA over several years. Firstly, we used eccentric geomagnetic dipole data to calculate the position of the SAMA region since 1600. Then we compared the results with archeomagnetic data obtained in the South American region (Nagata *et al.*, 1965; Kitazawa and Kobayashi, 1968), in order to study the movement of the SAMA at previous times.

Results

Using the data catalogued by Fraser-Smith (1987) we determined the coordinates of the magnetic center, that is, the origin of the eccentric-dipole system since 1600 (Roederer, 1972). From them, we determined the approximate position of the center of the SAMA region as the point where the line connecting the magnetic center with the center of the Earth intersects the Earth's surface. Except for the minor angular dependence contained in the standard expression of the dipole field, this point corresponds to a minimum field point (Pinto and Gonzalez, 1989b).

Figure 2 shows the approximate positions of the center of the SAMA for some years since 1600. In this figure one can identify both a westward drift and a southward

Offprint requests to: O. Pinto

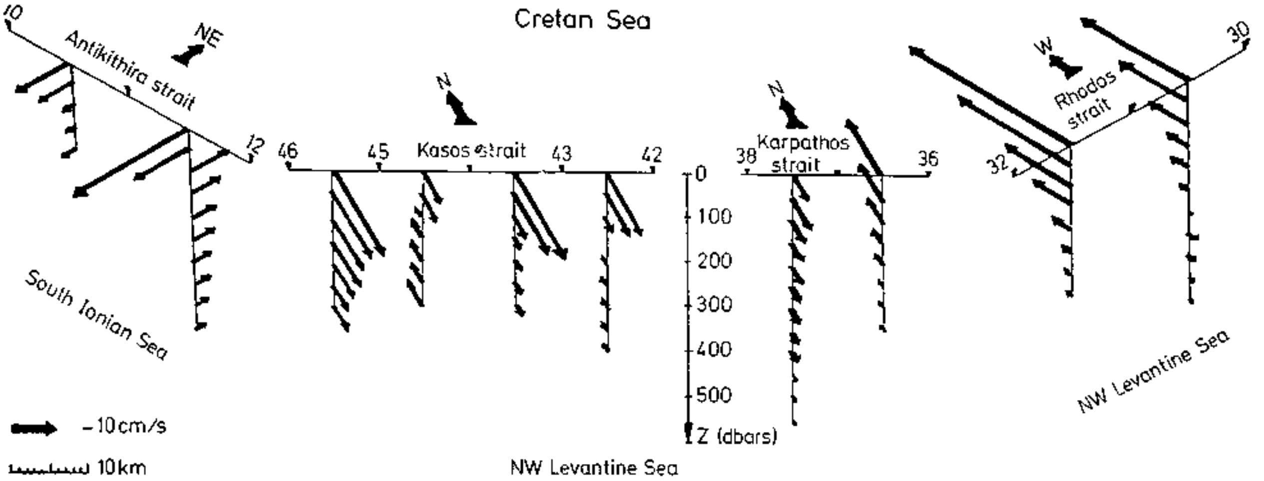

Fig. 8. Geostrophic velocities, relative to maximum observed depths, along the Cretan Arc straits, September–October 1987

Figure 8 demonstrates a strong geostrophic outflow (up to 28 cm/s) in the Kasos Strait. An inflow of less significance was calculated in the deeper layer in this strait.

A strong surface outflow (up to 32 cm/s) was calculated in the Antikithira Strait (Fig. 8). Figure 8 shows a significant inflow below 70 m in the southeastern part of the strait.

The geostrophic flow pattern and the associated thermohaline fluxes through the straits are important factors determining the distribution and the hydrographic characteristics of the Cretan Sea water masses.

Conclusion

Five different water masses were identified during the sampling period: (1) surface water with maximum salinity; (2) north Aegean Sea surface water with minimum salinity; (3) subsurface NAW of minimum salinity; (4) LIW of maximum salinity; and (5) Cretan Sea deep water with high values of salinity and temperature relative to the bulk of the East Mediterranean Sea deep water masses.

The late summer hydrographic conditions of the Cretan Sea provide evidence for the prevailing meandering flow moving from NW to E and the seasonal reversing of the main current system of the Cretan Sea. The complicated entry/exit system through the Cretan Arc straits seems to contribute to the generation of the two cyclonic and three anticyclonic flow regions in the Cretan Sea during summer.

References

Beer, T., *Environmental Oceanography, an Introduction to the Behaviour of Coastal Waters*, Pergamon Press, Oxford 141–145, 1983.

Bruce, J. T., and H. Charnock, Studies in winter sinking of cold water in the Aegean Sea, *Rapp. Comm. Int. Mer. Médit.*, **18**, 773–778, 1965.

Burman, I., and O. H. Oren, Water outflow close to bottom from the Aegean, *Cah. Oceanogr.*, **22**, 775–780, 1970.

El-Gindy, A. A. H., and S. S. H. El-Din, Water masses and circulation patterns in the deep layer of the Eastern Mediterranean, *Oceanol. Acta*, **9**, 239–248, 1986.

Georgopoulos, D., A. Theocharis, and G. Zodiatis, Intermediate water formation in the Cretan Sea (S. Aegean Sea), *IAPSO General Assempty*, Book of abstracts, Vancouver, 1987.

Gertman, I. E., Y. I. Popov, and B. G. Trigub, Evidence on deep water convection in Levantine, *VINITI*, **B87**, 6581, Sevastopol, 1987, (in Russian).

Lacombe, H., P. Tchernia, and G. Benoist, Contribution à l' étude hydrologique de la mer Egée en période d' été, *Bull. Inf. Coec*, **8**, 454–468, 1958.

Lacombe, H., and P. Tchernia, Quelques traits généraux de l'hydrologie mediterranéenne, *Cah. Oceanogr.* **12**, 527–547, 1960.

Lascaratos, A., Report of the multi-disciplinary cruise 2/8 in the Aegean Sea, (Report on physical oceanography) *UNEP Publication*, **8**, Athens, 1986.

Miller, A. R., Physical oceanography of the Mediterranean Sea, a discourse, *Rapp. Com. Int. Mer Médit.*, **17**, 857–871, 1963.

Miller, A. R., Deep convection in the Aegean Sea, in: *Processus de formation des eaux océaniques profonds, Coll. Int. C.N.R.S*, Paris **215**, 1–9, 1974.

Ovchinnikov, I. M., The sixth Mediterranean expedition on the R/V "Academic S. Vavilov", *Oceanology*, 4, 143–148, 1965.

Ovchinnikov, I. M., E. A. Plakhin, L. V. Moskalenko, K. V. Neglyad, A. S. Osadchiy, A. F. Fedoseyev, V. G. Krivosheya, and K. V. Voytova, Hydrology of the Mediterranean Sea, *Gidrometeoizdat*, Leningrad, 163–219, 1976 (in Russian).

Ovchinnikov, I. M., The formation of intermediate water in the Mediterranean Sea, *Oceanology*, **24**, 168–173, 1984.

Ozturgut, E., The source and spreading of the Levantine Intermediate Water in the Eastern Mediterranean, *Saclant ASW Research Center, Memorandum SM-92*, La Spezia, Italy, 45, 1976.

Roufogalis, V., Oceanographic observations in the South Aegean Sea, Oceanogr. Study, 4, H. H. S. cruise from 14/6 to 11/07/1967, Hellenic Hydrography Service Publ., Athens 1974 (in Greek).

Theocharis, A., Deep water formation and circulation in the Aegean Sea, *Paper presented at NATO-ASI on the Atmospheric and Oceanic Circulation in the Mediterranean*, La Spezia, 1983 (in press).

Theocharis, A., D. Georgopoulos, G. Zodiatis, and S. Christianidis, Distribution of the LIW in the NW Levantine and SE Aegean, *First POEM Workshop*, Part 2., Erdemli, 1986.

Theocharis, A., D. Georgopoulos, and G. Zodiatis, Hydrological characteristics and dynamical structure of Rhodos strait (Dec. 1985–Nov. 1986), B'Panhelenic Symposium Oceanography & Fisheries, Athens, 268–281, 1987 (in Greek).

Theocharis, A., D. Georgopoulos, G. Zodiatis, Late winter hydrological characteristic and circulation of the Cretan Sea (S. Aegean), Abstract Ann. Geophysicae, Special Issue, 13 General Assembly E.G.S., Bologna, 1988.

Wust, G., On the vertical circulation of the Mediterranean Sea, *J. Geophys. Res.*, **66**, 3261–3271, 1961.

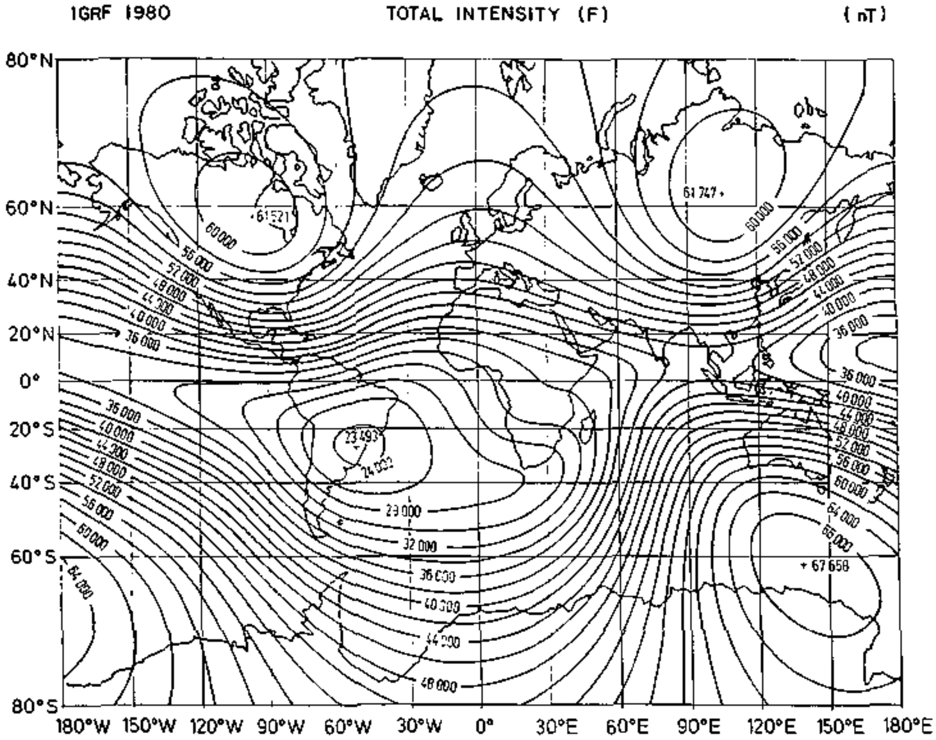

Fig. 1. The total intensity of the Earth's magnetic field at the surface (in nT) using the International Geomagnetic Reference Field (IGRF) for 1980

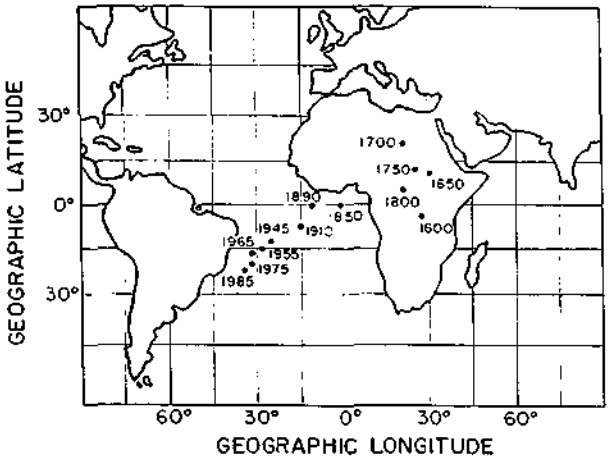

Fig. 2. The approximate position of the center of the SAMA region for some years in the interval 1600 - 1985

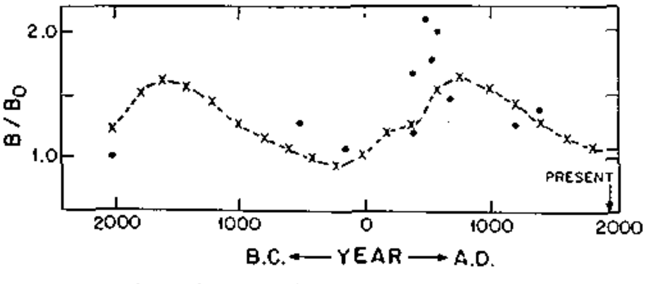

Fig. 3. Intensity ratio B/B_0 of the geomagnetic field in the South American continent from ancient times to the present obtained by archeomagnetic data (*black dots*) and considering a drift model for the SAMA region (*curve*)

drift. The center of the SAMA region, which now lies in the South Atlantic ocean, near the coast of Brazil, has moved there from the African continent during the last 200 years. In order to extend these calculations to even earlier times, we need to compute the coordinates of the magnetic center at those times. Unfortunately, such information is not available. However we can infer, at least qualitatively, the location of the SAMA for the past assuming, as suggested by several authors (e.g. Vestine, 1953; Nagata, 1962; Pudovkin and Valuyeva, 1967), the rotation of the eccentric dipole around the Earth. Based on such an approach, we should expect a periodic movement of the SAMA region around the Earth, during a timescale (considering our results since 1600 and assuming an average constant velocity) of about 2 300 years.

In order to test the approach, we compared the above results with archeomagnetic data obtained by measuring the natural remanent magnetization of potteries from Bolivia, Peru and Ecuador, on the South American continent (Nagata *et al.*, 1965; Kitazawa and Kobayashi, 1968). These potteries cover the period from about 2000 B.C. to A.D 1400. Figure 3 shows the intensity ratio B/B_0 of the geomagnetic field in ancient times to that of the present. In this figure, we have also plotted a curve of the intensity ratio B/B_0 assuming that the SAMA region rotates in the westward direction maintaining the same latitude as at present. We can see that, even considering this simple assumption, there exists a reasonable agreement between this curve and the archeomagnetic data. It is worth noting that the archeomagnetic data also suggest a periodic variation of the ancient geomagnetic field in the South American region with a period of about 2 000 years, in clear contrast with the general tendency of monotonic decrease in the Earth's dipole moment during the last 3 000 years, which is now accepted by most of the investigators. However, most of the data supporting this general tendency (related to the dipole field) have been obtained from other continents. It is possible that in the South American region, the tendency might be screened out by the non-dipolar field responsible for the SAMA.

Conclusion

We have computed the approximate position of the SAMA since 1 600 and compared the results with archeomagnetic data obtained in the South American region. We have found evidence that the SAMA region has a periodic movement around the Earth with a timescale of about 2 300 years. Nevertheless, until we attain a better understanding of the time variation of the non-dipole components of the field, such evidence can not be considered as definitive. However, we do feel that this evidence should be considered in any attempt to associate different physical phenomena with the SAMA over a long time interval.

References

Adam, N. V., N. P. Ben'kova, V. P. Orlov, and L. O. Tyurmina, Western drift of the geomagnetic field, *Geomagn. Aeron.*, **4,** 434–441, 1964.

Bloxham, J., and D. Gubbins, The secular variation of Earth's magnetic field, *Nature,* **317,** 777–781, 1985.

Dawson, E., and L. R. Newitt, The magnetic poles of the Earth, *J. Geomagn. Geoelectr.*, **34,** 225–240, 1982.

Fraser-Smith, A. C., Centered and eccentric geomagnetic dipoles and their poles, 1600–1985, *Rev. Geophys.*, **25,** 1–16, 1987.

Halley, E., An account of the cause of the change of the variation of the magnetical needle; with an hypothesis of the structure of the internal part of the earth, *Phil. Trans. Roy. Soc.*, **17,** 563–578, 1692.

Kawai, N., and K. Hirooka, Wobbling motion of the geomagnetic dipole field in historic time during these 2 000 years, *J. Geomagn. Geoelectr.*, 19, 217–227, 1967.

Kitazawa, K., and K. Kobayashi, Intensity variation of the geomagnetic field during the past 4 000 years in South America, *J. Geomagn. Geoelectr.*, **20,** 7–19, 1968.

Nagata, T., The main aspects of geomagnetic secular variation-westward drift and non-drifting component, *Proc. Benedum Earth Magn. Symp.*, 39–55, 1962.

Nagata, T., K. Kobayashi, and E. J. Schwarz, Archeomagnetic intensity studies of South and Central America, *J. Geomagn. Geoelectr.*, **17,** 399–405, 1965.

Parkinson, W. D., *Introduction to Geomagnetism,* Scottish Academic Press, Edinburgh, 433 pp., 1983.

Pinto, O., Jr., and W. D. Gonzalez, Energetic electron precipitation at the South Atlantic magnetic anomaly: a review, *J. Atmos. Terr. Phys.*, **51,** 351–365, 1989a.

Pinto, O., Jr., and W. D. Gonzalez, South Atlantic Magnetic Anomaly: For how long?, *EOS Transactions,* AGU, **70,** 17, 1989b.

Pudovkin, I. M., and G. Y. Valuyeva, Causes of the so-called westward drift of the geomagnetic field, *Geomag. Aeron.*, **7,** 754–757, 1967.

Roederer, J. G., Geomagnetic field distortions and their effects on radiation belt particles, *Rev. Geophys. Space Phys.*, **10,** 599–630, 1972.

Vestine, E. H., On variations of the geomagnetic field, fluid motions, and the rate of the Earth's rotation, *J. Geophys. Res.*, **58,** 127–145, 1953.

Yukutake, T., The wastward drift of the magnetic field of the Earth, *Bull. Earthq. Res. Inst.*, **40,** 1–65, 1962.