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The Drift of Geomagnetic Equator in West Africa from 1913 to 1986

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1. Introduction

The magnetic field distribution at the earth's surface present an important temporal variation, named secular variation (SV). The secular variation is one of the important characteristics of the geomagnetism, and the extraordinary rapidity of the phenomenon, at geological scale time, allow to suppose that their origin should be a manifestation of fluid motion in the outer core of the earth (HONKURA and MATSUSHIMA, 1988).

Several attempts have been made to estimate near the core, surface motion from magnetic field data (GIRE *et al.*, 1984; LE MOUËL *et al.*, 1985; VOORHIES, 1986), but the sources of this mechanism are still partially unknown.

In central Atlantic, the secular variation of vertical Z component (and so inclination I component) of geomagnetic field is particularly important. There are here the most intense cell of SV ($dZ(t) = -210$ nT/year), like a "magnetic hurricane" (CAIN, 1969), which affect strongly the west African and Brasilian magnetic field. This cell, westward drifting, according to general trend of the drift of the geomagnetic field, carry away the magnetic equator (or dip equator), locus at the earth surface where the Z vertical component is zero. This westward drift is a little understood phenomenon whose nature and extend is debated.

In this paper, we study in West Africa the drift speed of the equator since the beginning of century. We study the differences between the observed and IGRF-computed equator in the recent past. We compare so the magnetic drift in West Africa and Brasil.

2. Data

The data, recorded at the Mbour observatory (Senegal) proceed from several magnetic surveys in West Africa. About 1913, the Carnegie Institution of Washington measured magnetic elements (declination D, inclination I and total field F) along the West African coast and the Niger and Senegal rivers (BAUER and FLEMING, 1915). These stations have been reoccupied, more or less, since about 1926 by this same institution (FISH, 1927). Then the Office de la Recherche Scientifique et Technique Outre-mer (ORSTOM) undertook between 1952 and 1958 a general magnetic land survey with nearly 400 stations (RECHENMANN and REMIOT, 1962). Later several new measurement have been made by ORSTOM, chiefly around the years 1963 (RECHENMANN, 1967), 1968 and 1974. One is able also to quote several profiles carried out in the sea by the U. S. NAVAL OCEANOGRAPHIC OFFICE (1965). Finally we have undertook a land magnetic survey in 1984–1986 with 60 measurement stations including 24 repeat stations (VASSAL and VILLENEUVE, 1987).

3. Regional Field and Dip Equator

In this paper, we use only the vertical magnetic component Z as directly measured or deduced from inclination I and total F or horizontal H component ($Z=F\sin I$ or $Z=H\tan I$).

Data are reduced to the nearest epoch following: 1913.0, 1926.0, 1950.0, 1960.0, 1970.0, 1986.0, corresponding approximately at central date of magnetic survey.

For 1913 and 1926 reductions have be done using observations made at repeat station.

From 1950 to 1986 reductions have been made using, at each station, computed values of secular variation from fifth generation of International Geomagnetic Reference Field (IGRF) (IAGA DIVISION I WORKING GROUP 1, 1988). Consequently, the reduced values include secular variation of IGRF model. But, in a previous paper (VASSAL, 1987), studying secular variation at 24 repeat stations where measurement were repeated more than twice between 1950 and 1986, we have shown that, for a short time interval, the both IGRF and data secular variation are quite similar. The time interval for reduction do not reach more than a few years, and the induced incertitude stays small (<20 nT).

Table 1 lists the data used for each reduction epoch (latitude, longitude of the stations and reduced values of Z).

Then, for each reduction epoch, the distribution of regional Z field is represented by quadratic formulas in terms of latitude Φ and longitude Γ, the coefficient of which are obtained by the method of least-squares fit:

$$Z(\Phi, \Gamma) = C_0 + C_1\Phi + C_2\Gamma + C_3\Phi^2 + C_4\Phi\Gamma + C_5\Gamma^2$$

with latitude $\Phi=\Phi_i-\Phi_0$ and longitude $\Gamma=\Gamma_i-\Gamma_0$ values where $\Phi_0=10°\text{N}$ and $\Gamma_0=5°\text{W}$ are near studded geographic field center.

We obtain following numeric coefficients in nano-Tesla:

Epoch	C_0	C_1	C_2	C_3	C_4	C_5	rms
1913	4913	1220.31	− 343.30	9.4709	9.8875	7.2896	75
1926	3383	1263.91	− 286.63	17.8631	7.1944	7.6312	178
1950	1592	1306.26	− 204.76	11.9027	6.1014	6.8457	81
1960	944	1318.41	− 186.72	12.0965	10.7254	5.5731	103
1970	99	1319.93	− 139.38	10.7156	6.7422	7.6123	76
1986	− 1245	1356.58	− 84.39	10.2445	5.0988	5.1079	86

The magnitude of root mean square (rms) differences between observed and computed values are small. It may thus be concluded that the computed regional Z field provide a good fit for determination of Z values in this geografic area.

For each epoch, Figure 1 shows the spatial distribution of the measurements sites and the geographic position of magnetic equator land track as computed from regional model.

Table 1. List of the used data: Latitude north, longitude west (−) or east (+) of the stations, and Z_0 (nT) reduced values at epoch.

Epoch 1913

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.700	− 17.442	15679	12.867	− 7.567	9453	6.117	1.267	− 1761
13.450	− 16.600	13960	13.441	− 6.280	9655	13.503	2.000	7514
16.680	− 14.963	16850	7.728	− 5.072	2130	7.183	2.067	− 703
9.517	− 13.733	7736	7.700	− 5.033	2148	6.350	2.433	− 1849
6.300	− 13.000	3995	6.633	− 4.800	745	8.033	2.467	236
8.150	− 12.467	5905	5.317	− 4.000	− 866	9.350	2.617	1841
7.983	− 11.817	5335	5.200	− 3.683	− 1251	10.217	2.633	2901
6.317	− 10.850	2918	6.683	− 1.567	− 261	11.550	3.133	4664
8.033	− 10.817	4973	5.500	− 0.183	− 1955	6.450	3.400	− 1942
5.000	− 9.083	832	6.900	0.650	− 667	11.867	3.450	5044

Epoch 1926

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.700	− 17.442	14194	4.383	− 7.683	− 2526	5.550	− 0.183	− 3199
9.517	− 13.733	5475	12.867	− 7.567	7867	13.508	2.117	6506
8.500	− 13.267	4096	13.441	− 6.280	8245	6.350	2.433	− 2912
8.150	− 12.467	3981	7.728	− 5.072	650	8.033	2.517	− 820
7.983	− 11.817	3512	7.700	− 5.000	662	9.350	2.667	818
5.883	− 11.800	1040	5.317	− 4.033	− 2345	6.450	3.400	− 2980
6.367	− 10.800	1435	5.200	− 3.750	− 2679	11.867	3.450	4083
5.183	− 10.783	− 157	4.933	− 1.700	− 3794			
5.017	− 9.083	− 861	6.683	− 1.567	− 1541			

Epoch 1950

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.700	− 17.417	11329	10.983	− 4.917	2901	14.208	1.450	6409
14.392	− 16.958	10866	5.883	− 4.833	− 3572	9.700	1.667	141
14.652	− 16.192	10806	13.100	− 4.133	5625	9.000	1.667	− 789
15.395	− 15.121	11329	11.200	− 3.900	2947	12.067	1.783	3347
15.600	− 13.317	11180	12.200	− 3.583	4390	7.183	2.067	− 3176
12.617	− 11.417	6469	11.550	− 3.250	3293	13.100	2.367	4781
14.183	− 11.233	8404	11.683	− 3.117	3491	6.350	2.417	− 4310
12.833	− 11.230	6784	11.750	− 2.933	3469	8.033	2.483	− 2160
13.817	− 10.833	7928	12.050	− 2.233	3893	9.350	2.617	− 438
12.633	− 8.017	5702	12.583	− 1.300	4410	10.217	2.650	714
11.667	− 7.600	4308	13.083	− 1.100	5244	13.050	3.200	4579
12.867	− 7.558	6008	12.183	− 0.367	3739	9.933	3.217	352
12.758	− 7.000	5639	11.083	0.150	2202	14.350	3.333	6826
11.400	− 6.850	3852	12.058	0.357	3505	11.867	3.450	3013
13.441	− 6.280	6504	10.367	0.467	1215	10.933	3.700	1631

Table 1. (continued).

Epoch 1950

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
11.317	−5.717	3506	11.050	0.967	1936	13.642	4.058	5446
11.317	−5.667	3389	8.317	0.983	−1590	14.865	4.258	7153
12.498	−5.544	5102	8.983	1.133	−765	13.967	5.667	5785
6.817	−5.283	−2282	7.533	1.133	−2674	13.650	6.867	5236
8.783	−5.233	36	6.133	1.217	−4585	13.758	7.983	5363
8.000	−5.083	−972	6.117	1.267	−4486	13.796	8.977	5440
10.283	−4.917	1924	10.483	1.433	1217			

Epoch 1960

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.392	−16.958	9708	9.167	−10.117	844	10.450	−3.983	1415
14.130	−16.033	8829	10.650	−9.883	2789	5.250	−3.933	−5271
13.967	−14.833	8260	5.033	−9.750	−4049	9.617	−3.667	181
7.917	−13.767	387	14.017	−9.550	7132	10.950	−3.267	1982
8.250	−13.733	702	13.033	−9.482	5779	10.333	−3.183	1101
7.333	−13.250	−246	8.517	−9.467	316	9.267	−2.983	−434
7.900	−12.883	372	10.383	−9.300	2216	8.017	−2.700	−1871
7.700	−12.717	−76	11.400	−9.183	3560	12.250	−2.367	3481
7.533	−12.600	−265	9.267	−9.017	1154	11.317	−1.883	2201
6.900	−12.550	−900	7.817	−8.700	−1211	6.700	−1.567	−3944
7.367	−12.433	−542	8.700	−8.700	−164	12.383	−1.500	3628
11.333	−12.300	4144	6.583	−8.417	−2548	11.183	−1.150	1899
12.083	−12.292	5346	9.583	−8.133	796	11.667	−1.067	2617
7.183	−12.283	−521	7.233	−8.117	−1883	9.417	−0.883	−608
7.000	−12.133	−988	8.283	−7.683	−803	12.983	0.150	4373
6.650	−11.850	−1414	9.500	−7.567	722	11.233	0.717	1876
6.833	−11.733	−1311	6.550	−7.483	−2848	12.882	0.785	4062
11.433	−11.667	3993	5.867	−7.467	−3660	13.483	2.183	4905
6.333	−11.533	−1999	10.467	−7.450	2007	13.103	2.370	4324
6.533	−11.467	−1770	9.517	−6.483	664	13.662	4.092	5072
4.283	−11.400	−4405	6.867	−6.467	−2615	14.900	5.267	6831
4.500	−11.283	−4196	10.500	−6.400	1878	14.500	6.767	6282
5.983	−11.150	−2335	6.133	−5.950	−3815	13.500	7.100	4892
4.700	−11.150	−4005	9.417	−5.617	262	13.528	7.918	4886
6.233	−11.117	−2193	8.850	−5.617	−373	14.650	8.017	6503
6.200	−11.067	−2312	6.817	−5.283	−3040	12.983	8.933	4000
4.917	−11.033	−3796	5.517	−5.250	−4629	13.783	8.990	5180
5.350	−10.800	−3416	8.783	−5.233	−590	13.305	9.775	4407
11.283	−10.717	3865	8.133	−5.100	−1470	13.677	9.838	5036
5.800	−10.583	−2886	7.733	−5.067	−1982	13.287	10.463	4408
4.250	−10.533	−4741	5.883	−4.833	−4396	13.555	11.713	4918
4.017	−10.533	−4981	5.900	−4.817	−4344	13.652	12.525	5058
4.500	−10.517	−4490	6.667	−4.750	−3461	13.453	12.798	4822
4.967	−10.500	−3967	9.400	−4.483	103	13.455	14.715	4723
6.017	−10.467	−2716	8.367	−4.433	−1274	13.650	16.497	5103
5.517	−10.450	−3358	7.450	−4.333	−2455			
5.517	−10.183	−3476	11.167	−4.333	2425			

Table 1. (continued).

Epoch 1970

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.392	− 16.958	8558	9.617	− 6.967	− 64	10.367	0.467	132
9.567	− 13.617	1409	9.583	− 6.683	− 163	9.967	0.567	− 467
8.617	− 13.200	− 65	9.533	− 6.500	− 252	9.633	0.617	− 904
9.017	− 12.950	662	6.867	− 6.467	− 3579	8.317	0.983	− 2864
12.633	− 12.817	5023	9.533	− 6.200	− 291	9.967	1.067	− 447
13.050	− 12.733	5472	9.533	− 6.000	− 450	8.983	1.150	− 1908
12.567	− 12.217	4833	9.517	− 5.817	− 470	6.117	1.217	− 5457
8.883	− 12.033	− 17	9.417	− 5.617	− 588	9.750	1.317	− 818
12.417	− 12.000	4614	6.900	− 5.367	− 3856	14.208	1.450	5427
6.250	− 10.350	− 3589	7.733	− 5.067	− 2821	12.067	1.783	2381
6.250	− 10.350	− 3680	11.167	− 4.317	1594	13.483	2.183	4462
9.500	− 7.567	− 208	6.717	− 3.467	− 4373	6.350	2.383	− 5488
9.517	− 7.567	− 157	8.000	− 2.750	− 2656	13.353	2.497	4193
9.550	− 7.317	− 176	12.333	− 1.517	2961	13.050	3.200	3652
9.583	− 7.167	− 205	12.350	− 1.517	3002	13.088	3.680	3794

Epoch 1986

Lat.	Long.	Z_0	Lat.	Long.	Z_0	Lat.	Long.	Z_0
14.392	− 16.958	6553	12.657	− 7.932	2622	12.382	− 1.503	1871
13.783	− 16.480	5554	7.354	− 7.597	− 4359	16.250	0.000	7564
12.555	− 16.280	3828	11.450	− 7.517	848	10.857	0.195	− 371
16.437	− 15.657	9057	13.441	− 6.280	3605	10.800	0.250	− 368
15.398	− 15.102	7418	13.425	− 6.277	3592	12.042	0.361	1460
16.680	− 14.963	9182	11.338	− 5.695	567	10.374	0.473	− 1004
12.878	− 14.958	3889	9.413	− 5.623	− 2058	8.994	1.150	− 3019
11.807	− 13.493	2201	7.728	− 5.072	− 4318	7.517	1.200	− 4812
11.920	− 13.468	2498	6.584	− 5.065	− 5842	6.175	1.210	− 6850
15.600	− 13.328	7519	11.167	− 4.327	281	13.558	2.050	3643
11.738	− 13.203	2152	5.325	− 4.133	− 7438	14.157	5.365	4541
10.893	− 13.037	924	14.512	− 4.090	5009	13.500	7.100	3736
10.000	− 12.867	− 310	15.930	− 3.990	7007	17.052	8.055	9130
12.565	− 12.217	3075	5.251	− 3.928	− 7485	13.783	8.990	4139
11.638	− 12.110	1715	16.730	− 3.005	8204	13.705	11.183	4128
13.070	− 9.493	3315	15.283	− 1.700	6121	14.243	13.100	5022

To estimate validity of this numeric determination, we compare with IGRF computed equator: For each longitude degree on studded field we compute the difference between latitudinal position of the dip equators as defined by both regional model and IGRF model at epochs 1950, 1960, 1970 and 1986. We obtain differences and rms following:

Epoch	1950	1960	1970	1986
Diff.	0.115	0.163	0.182	0.056
rms	0.071	0.096	0.022	0.035

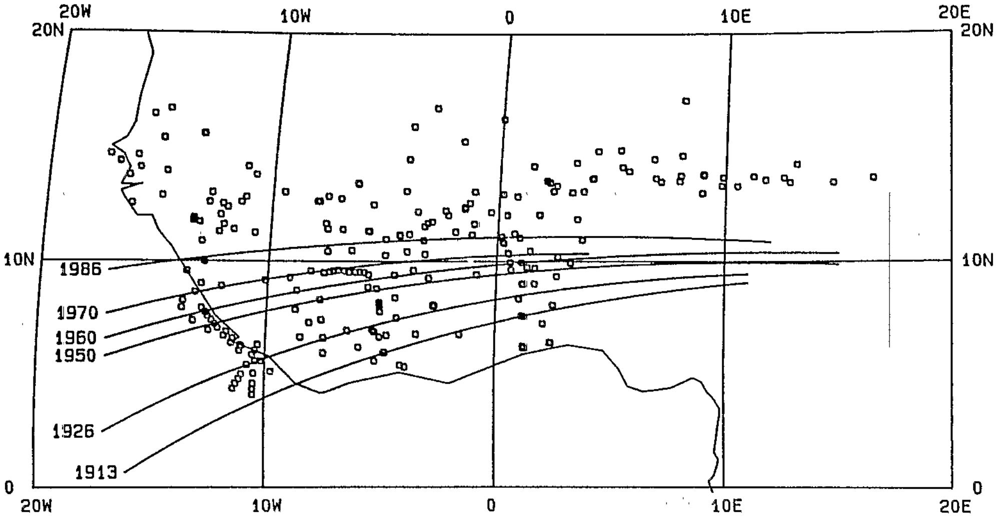

Fig. 1. Location of used measurement points (O) and land track of regional magnetic dip equator for years 1913, 1926, 1950, 1960, 1970 and 1986.

We cannot conduce this computation for 1913 and 1926 because there are no global model available.

We can see that, from 1950 to 1986, the IGRF equator is situed more southward than regional equator, but the distance between both IGRF and regional equator is approximately smaller than 20 km. This result allow us to think that for 1913 and 1926 the dip geographic position as computed above is acceptable.

4. Discussion

The most prominent features of these results is the relative regularity and the importance of northward movement.

Since 1913, the displacement of the dip-equator is very important. The velocity of this drift is varying in respect of the longitude and epoch, as showed Fig. 2. Along the 15° West we find a northward slipping of 8.65° (about 960 km) between 1913 and 1986, with average velocity of 0.12°/year (13 km/year). At 0° longitude, we observe a movement of 3.83° (0.05°/year or 6 km/year) and only 1.23° (0.02°/year or 2 km/year) at 10° East.

This drifting is not regular according to epoch and is varying in accordance of the general secular acceleration. For example, it seems to be faster between 1970 and 1980 (0.11°/year at 15° West) than from 1950 to 1960 (0.07°/year), corresponding with the change in acceleration of the SV field observed after 1969, that is to say the 1969 jerk.

We can compare together these African results with the dip drift as observed in South American area. So, for example in Brasil (BARRETO, 1987), along 40° West the movement Northward of dip-equator is about 7.8° (866 km) between 1904 and 1960 (0.14°/year) and 4.0° between 1960 and 1985 (0.16°/year). Along 60° West the displacement is weaker, with 1.4° between 1960 and 1985 (0.06°/year).

So, there are a strong likeness symmetrically on the both side of Atlantic ocean,

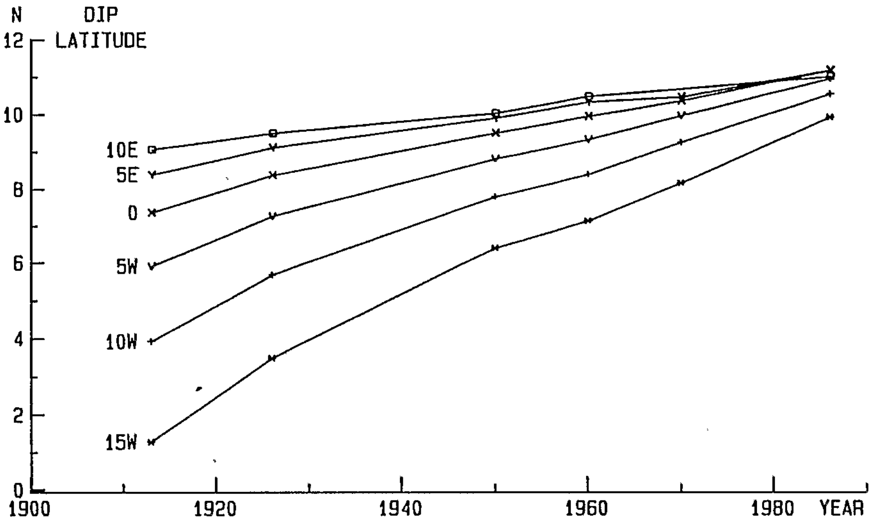

Fig. 2. Temporal position of dip equator at differents longitude.

between which ondulate the dip equator.

The geomagnetic pole motion, remaining at a constant latitude from 1945 until 1955 and slowly northward moving since then, nor the rate of change of strength of centered dipole, decreasing of about 3% since 1945 (LANGEL *et al.*, 1988) cannot explain the very important variation of latitudinal dip position in central Atlantic. Only an intensive cell of SV in north Atlantic having a tendency to move northwestward could explain the dip drift. So, we have computed from IGRF models, the geographic position of north Atlantic cell focus for each SV components $\dot{X}$, $\dot{Y}$, $\dot{Z}$ and $\dot{F}$ at each studded epoch. The general trend of focus position is SE-NW, but with rapid variations. Only focus of $\dot{F}$ SV component is drifting regularly. The maximum magnitude of SV cells remain more or less constant.

5. Conclusion

The studies of land survey magnetic data allow to follow with good accuracy the real displacement of equator, but further theoretical and observational studies are needed to explain the different contributions, like straight of SV, drift of general magnetic field or most local cell, to this phenomenon.

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