ISSN 0016-7932, Geomagnetism and Aeronomy, 2006, Vol. 46, No. 2, pp. 266–273. © Pleiades Publishing, Inc., 2006.
Original Russian Text © V.V. Kuznetsov, 2006, published in Geomagnetizm i Aeronomiya, 2006, Vol. 46, No. 2, pp. 280–288.

What Is the Cause of the Accelerated Drift of the North Magnetic Pole: Jerk or Reversal?

V. V. Kuznetsov

Institute of Cosmophysical Research and Radiowave Propagation, Far East Division, Russian Academy of Sciences,
Mirnaya ul. 7, Paratunka, Elizovo raion, Kamchatka oblast, 684034 Russia
e-mail: vvk@ikir.kamchatka.ru

Received September 1, 2004; in final form, April 13, 2005

Abstract—For the last 20–30 years, the drift velocity of the north magnetic pole (NMP) has increased by a factor of almost 5. It is unclear whether this is the cyclic process, according to which NMP twice changed the direction of its drift (in 1580 and 1860) and should turn once again in approximately 2140, or this acceleration is related to the effect of jerk-69, or the NMP acceleration shows the beginning of geomagnetic field reversal. Both magnetic poles have been drifting poleward (toward each other) beginning from 1860: NMP, in the Western Hemisphere; south magnetic pole (SMP), in the Eastern Hemisphere. Both poles move along the paths typical of the motion of virtual magnetic poles during reversal. The velocity of SMP drift during the period of instrumental measurements slightly decreased: from 8 km/yr at the initial stage to 4 km/yr at the present. A possible cause of NMP drift acceleration and SMP drift deceleration is discussed. It has been indicated that the NMP position can be estimated based on a change in the geomagnetic field horizontal components registered at the nearest observatories. Measurements of the NMP position, which can be performed during the next three–five years, can make it possible to answer the question whether NMP continue accelerating or starts decelerating. It is discussed whether NMP acceleration and an increase in the jerk occurrence frequency are interrelated and whether these facts points to the beginning of reversal.

PACS numbers: S91.25.Mf

DOI: 10.1134/S0016793206020186

1. INTRODUCTION

Captain Ross first determined the position of the North Magnetic Pole in 1831: 70°5′ N and 96°46′ W. For the next 70 years, the NMP position has not been measured. The following NMP position was determined in 1904 during the Amundsen expedition: 70°30′ N and 95°30′ W. It turned out that, for 70 years, NMP has shifted toward the North Geographic Pole at point located at a distance of 50 km from the first position (see Fig. 1). The stage of recent observations of the NMP position begins with the measurements performed by a Canadian magnetologist Serson in 1948 [Serson, 1981]. The members of the Canadian observatory Crescent (Ottawa) observe the NMP drift more frequently than once per ten years [Newitt and Niblett, 1986; Newitt and Barton, 1996; Newitt et al., 2002]. The measurements of the NMP position in 1999 indicated that the NMP drift velocity increased by a factor of 1.5 as compared to such a velocity measured in 1994 and reached 26 km/yr. Newitt et al. [2002] reported the NMP position measured in 2001 by Canadian and French magnetologists, which continued measurements performed in 1999. Newitt et al. [2002] determined that the present-day NMP drift velocity is higher than 40 km/yr.

Analyzing an increase in the NMP drift velocity found out for the last 30 years of observations, Newitt et al. [2002] assumed that this pole acceleration is somehow related to the jerk-1969 phenomenon and the following other jerks. These researchers are possibly correct, and this phenomenon is actually related to the pole drift and even somehow affected drift acceleration. However, before discussion of this assumption, let us consider data characterizing the NMP drift direction and velocity over the time interval much longer than the last 30 years of drift acceleration. The measured (asterisks) NMP position and the position predicted for 2004 (open circle) and 2140 (filled circle) are shown on the map (Fig. 1). The line with squares shows the points where the geomagnetic field components were measured during the USSR–Canadian ski expedition in 1988. The predicted position of the virtual magnetic poles (VMPs) and the VMP position measured on the route are indicated by the dashed line and line with dots, respectively. At the beginning of the route and in the vicinity of point 1580–2140, the VMP values are sharply scattered because the measurements were performed at a very low temperature (–38°C).

2. SPECIFIC FEATURES OF THE NMP DRIFT

Figure 2 demonstrates smoothed results of observations of changes in inclination (I) and declination (D) first published for London and Boston [Bauer, 1985]

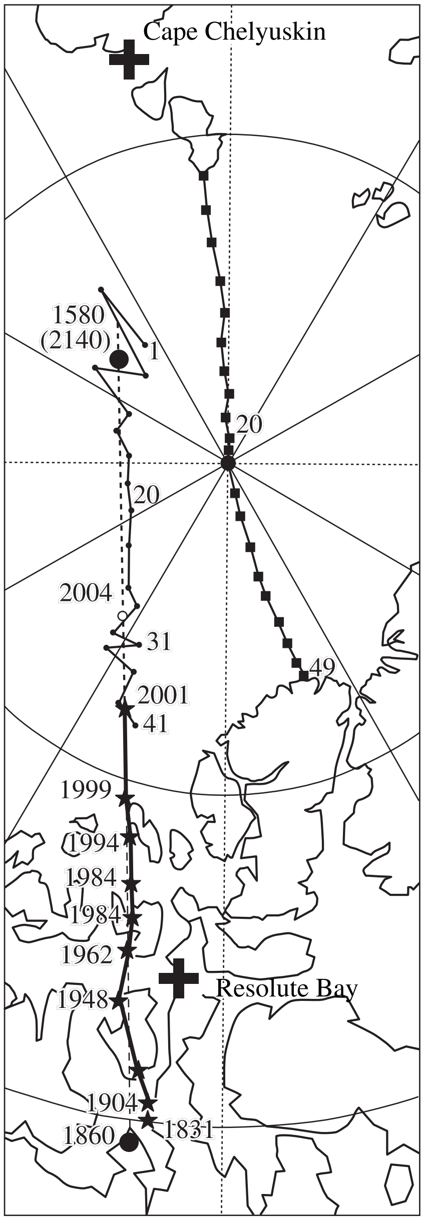

Fig. 1. North magnetic pole position: measured (asterisks) and predicted (open and filled circles); line with squares show the sites of the geomagnetic field measurements during the USSR–Canada ski expedition of 1988; dotted and dashed lines demonstrate the calculated and predicted position of the virtual magnetic poles, respectively.

and subsequently repeated in many monographs on geomagnetism. Knowing the *I* and *D* values, it is possible to determine the VMP position and to compare a change in this position with the actual drift of NMP. Figure 2 indicates that the drift direction of the virtual north magnetic pole (VNMP) changed twice for 450 years: in 1580 and 1860.

Analyzing the observations of declination and inclination in London and Boston (in Boston the observations were finished in 1900 and the data were reduced to the observations at Ottawa observatory), it is possible to obtain information about the actual NMP drift for the last 450 years. A comparison of the VNMP and NMP drift velocities for the last 95 years indicates that these velocities are very close in value and direction, especially in the last several years. This circumstance makes it possible to assume that VNMP follows the NMP drift not only in the 20th century, i.e., during instrumental measurements, but also during the previous 450 years. If we assume that NMP actually moved as it follows from Fig. 2, then the NMP position determined by Ross (1831 in Fig. 1) is erroneous: in 1831, NMP was actually located at a distance of approximately 100 km to the east. Figure 2 indicates that, from 1580 to 1860, NMP drifted in the opposite direction with respect to the present-day drift, i.e., toward the south. This is confirmed by the fact that the data of London magnetic observatory do not demonstrate the presence of an abrupt change in the NMP drift velocity between the measurements performed by Ross and Amundsen (1904). In 1860, any cause forced NMP to change the direction of its drift, to turn around, and to start moving northward. Figure 2 makes it possible to assume that NMP can close the cycle of duration 560 years at approximately 2140 and return to the point where the pole was located in 1580. The following observations will indicate whether this happen or not.

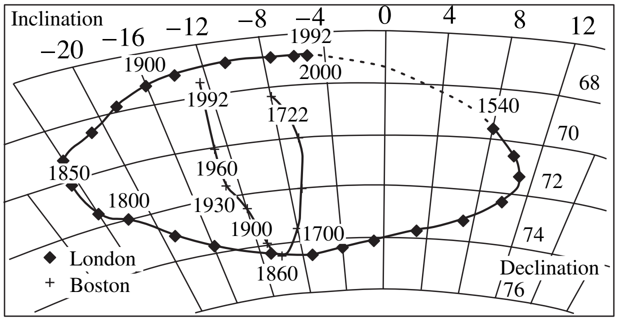

Fig. 2. Declination and inclination of the magnetic pole determined at London and Boston observatories [Bauer, 1895].

Figure 2 indicates that the present-day (~2000) NMP drift velocity should be maximal. This velocity should subsequently decrease (Fig. 3c) so that NMP should stop in 2140, turn around, and start drifting oppositely. Thus, a certain logical character of the VNMP drift has been observed for the last 450 years. Can we propose a model that will explain this phenomenon?

3. POLE DRIFT MODEL

Let us consider the NMP drift for the last 100 years. Figure 1 shows the NMP direction (asterisks) and years of pole position measurements (numerals near asterisks). It is clear that NMP drifts along the line almost joining Resolute Bay and Cape Chelyuskin observato-

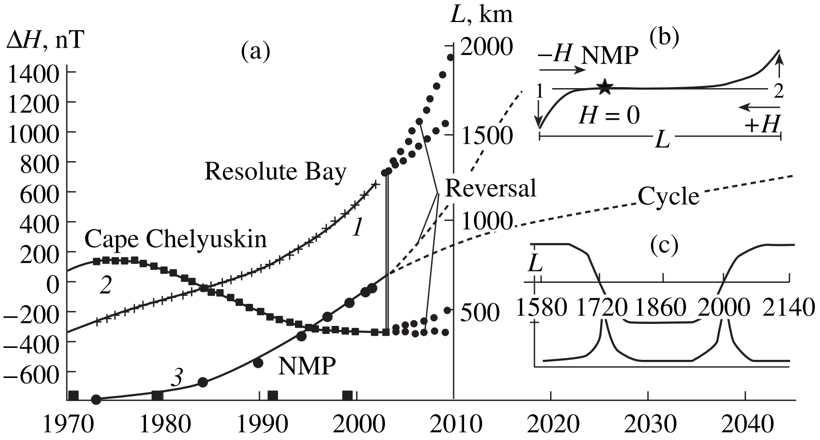

Fig. 3. (a) Variations in the *H* component: (*1*) at Resolute Bay and (*2*) at Cape Chelyuskin; (*3*) difference between the values of these components (Δ*H*) – the NMP position according to the scale (*L*, km, relative to 1973, where *L* = 0). Filled squares on the time scale correspond to jerks [Mandea et al., 2000]. (b) Schematic drift of NMP (asterisk) between two quasi-sources of the field (*1* and *2*). (c) The cyclic character of the NMP drift, *L*(*t*); drift velocity variations, *V* (*V* = *dL*/*dt*) in the interval 1580–2140.

ries. On a larger scale, this line joins two global magnetic anomalies located in Canada and Siberia. Figure 1 also indicates that the NMP drift direction coincides with the location of the virtual magnetic poles determined during of the joint Canadian–Russian ski expedition in 1988 [Weber et al., 1990]. Before this expedition, we preliminarily predicted the VMP locations [Kuznetsov et al., 1990]. Our prediction was based on all known measurements of the geomagnetic field components in the Arctic Regions. The predicted VMP position almost coincided with the position measured over the considerable leg of the expedition path [Kuznetsov, 1996]. We now try to understand why NMP moves precisely in such a manner.

Hope [1959] first assumed that the NMP drift is related to the global magnetic anomalies, the presence of which in Canada and Siberia results in compression of magnetic field lines in the region of the NMP drift to form a specific rope. The pole drifts precisely along this rope. Our studies corroborated that NMP actually drifts along this path. Is it possible to estimate the pole behavior in the nearest future, during 10–20 year, and even to determine a probable polarity reversal of the geomagnetic field?

Let us consider Fig. 3, which illustrates our model of the NMP drift that forms the basis for predicting the pole position. When discussing the model of geomagnetic pole drift, we will use the following definition. The magnetic pole is a conditional point on the Earth's surface where the horizontal component of the geomagnetic field is equal to zero. If the geomagnetic field horizontal components (*H* components) change their values at two points (1) and (2) where they have opposite directions, the location of a point where these values neutralize each other (*H* = 0) also changes (see Fig. 3b). In this case the magnetic pole moves between these points. It is apparently possible to predict at what point the magnetic pole will appear in the future if sharp spatial and temporal inhomogeneities (in particular, including jerks) are not observed in the geomagnetic field at least in the region of the pole.

Magnetic observatories regularly observe variations in the geomagnetic field components. Resolute Bay (Canada) and Cape Chelyuskin (Russia) observatories are the closest to NMP (Fig. 1). By controlling the values of the *H* components at these observatories, provided that the character of their variations is quite logical, it is possible to predict the NMP position in the future. This method was used to predict the NMP position in 1994 [Kuznetsov, 1996]. Figure 3a shows the time-variable (1973–2000) constituents of the *H* components measured at these observatories, $H_1(t)$ and $H_2(t)$ (curves *1* and *2*), and the differences between these constituents, $\Delta H = H_1(t) - H_2(t)$. The vectors of the *H* components are directed toward each other, and their values at these observatories are as follows: H_1 = 1041 nT at Resolute Bay (1989); H_2 = 3160 nT at Cape Chelyuskin (1990), etc.

To simplify the model, we assume that the difference between these values in 1973 was equal to zero ($H_1 - H_2 = 0$) and will subsequently consider only the variable part of these values. For convenience of presentation, the difference between the variable constituents of the *H* components (curve *3*) is defined as $\Delta H = H_1 - H_2 + k$, where $k = -400$ nT.

Assume that the path followed by NMP, *L*(*t*), is linearly related to Δ*H*(*t*): *L*(*t*) ~ Δ*H*(*t*). We consider a linear section of the NMP drift path (Fig. 3) and assume that *L* = 0 for NMP-1973. The assumptions made allow us to obtain the dependence *L*(*t*) (km) (curve *3* in Fig. 3a). Figure 3a indicates that the *H* components registered at Cape Chelyuskin and Resolute Bay observatories can behave in two ways. The available data of the last observations at these observatories (2004) are marked by a double line in Fig. 3a. (The last measure-

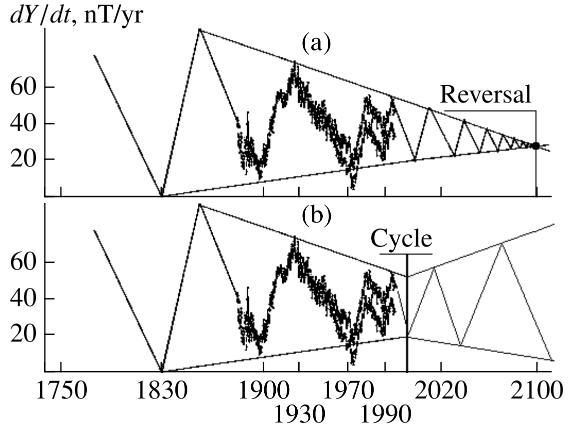

Fig. 4. Secular variations in the geomagnetic field eastward component (*dY/dt*). Abrupt changes in the derivative according to the Niemegk data from 1883 to 2000: jerks [Mandea et al., 2000]. Predicted time variations in the jerk occurrence frequency. (a) Formation of the stationary state of the system and beginning of reversal; (b) a decrease in the jerk occurrence frequency after 2000 and cyclicity.

ments of the NMP position were performed in 2001.) If in the future the H component, e.g., begins to increase in the region of Cape Chelyuskin ($H_2(t)$) and to decrease at Resolute Bay ($H_1(t)$), then the situation can appear when the rates of a change in the H components will become equal and $\Delta H = 0$. In such a situation, the pole will stop and can start moving backward. This will probably occur precisely in 2140 (Fig. 3c). In this case the NMP drift is oscillatory. If such a situation does not appear, and $H_2(t)$ and $H_1(t)$ continue decreasing and increasing, respectively, NMP can pass over point 1580 (2140) (Fig. 2) and move toward SMP (Fig. 5). In this case reversal or the next excursion can begin on the Earth.

The last (up to 2004) measurements of the H components at polar observatories indicate that it is still impossible to unambiguously select the scenario of development of events related to the NMP drift. Cape Chelyuskin data are absent for 2001 and 2002 but are available for 2003 and 2004. If the latter data are confirmed, this means that the H component in Siberia continues decreasing, and, correspondingly, the NMP drift accelerates as before. If the events develop according to another scenario, the NMP drift velocity will begin to decrease. If the NMP drift velocity continues increasing, the pole will pass over point 2140 and will continue moving with increasing velocity toward Cape Chelyuskin observatory. In principle, further motion of NMP along the Eastern Hemisphere toward SMP is also possible. Meanwhile, SMP (as well as NMP) changed the direction of its drift in 1860 and, although with an insignificant deceleration, drifts northward, toward the magnetic anomaly. For the nearest two–three years, (relative to 2005), the situation should become clear. Note that it is planned to perform the long-term observations of the NMP and SMP drift within the scope of the International Polar Year program (2007–2008) precisely at that time.

Let us return to our model of the NMP drift. A change in the NMP drift distance (L) in the course of time t, beginning from 1860 and up to the last measurement in 2001, is defined by the formula $L = kt^2$. Here k varies from 5 at the beginning of 1900 to 6 at the beginning of 2000, and $t = 0.1\ (T - 1860)$, where T is the current year. The formula makes it possible to predict the NMP position on the assumption that the drift direction will remain unchanged. Otherwise, prediction is made for NMP drift during reversal. In this case NMP will cross the 180° meridian and enter the Eastern Hemisphere in approximately 2040, and will reach the position of SMP in approximately 2400, etc.

In the other version, Fig. 3c indicates that NMP can close the time cycle of duration 560 years in approximately 2140 and return to the point where it was located in 1580. Future observations will show whether this situation is actual or not. An analysis of Fig. 3c indicates that in this case the present-day (~2000) drift

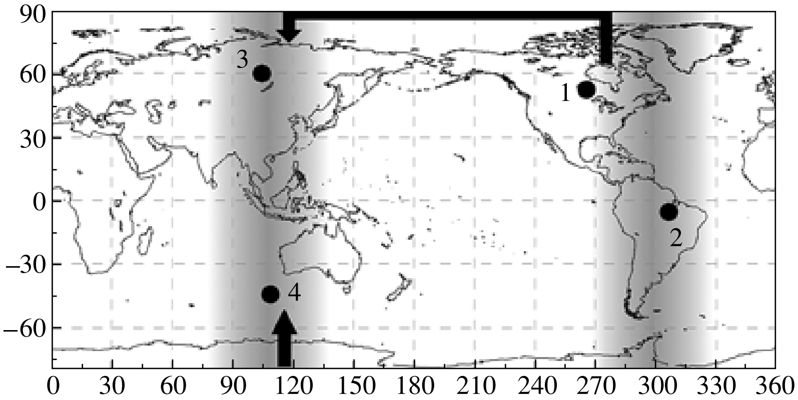

Fig. 5. Predicted position of NMP and SMP (arrows). Bands show the magnetic pole drift direction during reversals; circles with numerals, GMAs [Kuznetsov, 1999].

velocity (V) should be maximal and should subsequently decrease so that NMP would stop in 2140, turn around, and start drifting backward. Thus, one can see that a certain logical character of the NMP drift has been observed for the last 450 years.

4. POLE ACCELERATION AND JERKS

Jerk (push) is a geomagnetic phenomenon when sharp (over a year and shorter periods) changes in the dB/dt derivative take place. That is, jerk is a sharp change in the rate of increase (decrease) in the intensity of the geomagnetic field induction components (B). The term jerk was first applied by Courtillot and Besse [1987], who paid attention to an uncommon behavior of the secular variation in the geomagnetic field Y component in Europe in 1969–1970. The series of the average annual values of dY/dt, beginning from the 1940s to the late 1960s, was adequately approximated by parabola for each observatory. Then (from 1969), the observed data sharply deviated from the model. This difference was eliminated by using the second parabola for data after the event of 1960–1970. Precisely this phenomenon was called jerk. Beginning from this work, in many studies a similar technique was used to estimate jerk of 1969–1970 and to detect similar jerks in other epochs [Alexandrescu et al., 1996]. To find out jerk, researchers plot the time variation in the first derivative of the geomagnetic field component. As a rule, this dependence looks like an inclined straight line. If this line cannot be continued at any instant and should be replaced by another line with different inclination, then precisely this event is jerk. Jerks are most evident in the time variation in the Y component (Fig. 4), are less pronounced in the X component, and are even less perceptible in the Z component of the geomagnetic field. According to [Gavoret et al., 1986], the jerk continued for six months.

Can jerks and magnetic pole drifts be interrelated, as was assumed for the first time by Newitt et al. [2002]? To answer this question, we represent the magnetic pole drift as

$$V = dL/dt = (dH/dt)/(dH/dL), \tag{1}$$

where dH/dt is the total change in the geomagnetic field horizontal component in the region of the magnetic pole. For NMP and SMP, this value is ≈40 nT/yr. The spatial gradients of the geomagnetic field H component (dH/dL) in the region of pole drifts considerably differ from each other: $dH/dL \approx 1$ and 10 nT/km in the regions of NMP and SMP, respectively. Inclusion of the spatial and temporal gradients of the field H component [Parkinson, 1983] into formula (1) shows that they coincide with the measured velocities of the magnetic pole drift. As was mentioned above, the present-day drift velocities are 40 and 4 km/yr for NMP and SMP, respectively.

Mandea et al. [2000] demonstrated the dY/dt (dD/dt) dependence, from which it follows that the jerk occurrence frequency (ω) (the quantity inverse to the time interval between events when $d^2Y/dt^2 = 0$) increases with decreasing dY/dt amplitude in the course of time (Fig. 4). Jerk occurrence frequency increases so that the product $Y \times \omega(dY/dt \times \omega)$ remains approximately constant. A similar process can be described (formally) by the equation of oscillations with a soft elastic force (equation for oscillator with damping) [Berge et al., 1988]

$$m(d^2x/dt^2) + \varphi(dx/dt) + f(x) = F\cos\omega t. \tag{2}$$

The first term in Eq. (2) characterizes the inertia force; the second term, the resistance (damping) force; the third term, the restoring (elastic) force. The external (disturbing) force is shown in the right-hand side of Eq. (2). If this force is equal to zero, Eq. (2) characterizes damped oscillations. For example, the equation

$$m(d^2x/dt^2) + \varphi(dx/dt) + f(x) = 0 \tag{3}$$

describes swing of pendulum in the presence of resistance forces. Not going into details of the physics of jerks and geomagnetic field generation, we replace Eq. (3) by the Van der Pol equation [Whittaker and Watson, 1962]:

$$d^2Y/dt^2 - \gamma[1 - Y^2/Y_0^2]dY/dt + \omega^2 Y = 0. \tag{4}$$

Here Y_0 is the initial amplitude, γ is the damping factor, ω is frequency, and $\omega^2 Y$ is the elastic force. Equation (4) shows the behavior of oscillator with driving force, where oscillations with small amplitude are enhanced and oscillations with large amplitude damp. The solution to this equation

$$Y(t) = Y_0\exp(-\gamma t/2)\cos(\omega t + \varphi),$$

with adequately selected coefficients can rather correctly describe the observed time variation in dY/dt. Equation (4) with elastic force corresponds to the experimentally observed dependence of the form $\omega^2 \sim 1/Y$.

In the considered case, the phase-plane portrait of Eq. (4) is a convergent spiral: $\gamma > 0$. A mechanical equivalent of such a system can be a model with a ball swinging in a spherical volume with an opening at the sphere bottom, whose dimensions slightly exceed a ball diameter. When a ball reaches the state of equilibrium and stops moving ($dY/dt = 0$), it falls into an opening (bifurcation takes place) and enters another volume similar to the first one, etc. The process proceeds repeatedly if openings of these volumes do not coincide. When a ball enters the lower volume, it loses part of its potential energy.

Let us consider the process of jerk origination in the context of the geomagnetic field behavior before reversal. It is unclear whether it is possible, on the one hand, to relate jerk occurrence frequency to bifurcation that appears after reaching the state of unstable equilibrium in the system and, on the other hand, to try to reveal the phenomenology of the experimentally observed relation between increasing NMP drift velocity and jerk occurrence frequency ω: $V \sim dH/dt \sim \omega$. As follows from our discussion, $\omega^2 \sim 1/Y$. Velocity V is uniquely related to dH/dt according to the model; however, the actual geomagnetic relation between dH/dt and dY/dt is ambiguous. Consequently, a direct relation between V and ω is absent.

It is interesting how long the NMP accelerated motion can continue. Magnetic pole drift velocity is defined as $V = dL/dt$, where $L = kt^2$, or $V \sim t$; i.e., the NMP drift velocity will continue increasing in the course of time according to Eq. (1). The process will proceed until the dH/dL gradient remains small, which is typical of the polar region. The NMP velocity will decrease as soon as the dH/dL gradient increases since $V \sim dL/dH$, and precisely such a situation should be observed as NMP approaches one of the magnetic anomalies. This situation apparently takes place in the region of SMP, which drifts slower with decreasing distance to the magnetic anomaly.

5. ROLE OF GLOBAL MAGNETIC ANOMALIES

We now draw attention to a very interesting and important aspect for our model. Both north and south present-day magnetic poles move not randomly; they drift along paths typical of a drift of the virtual magnetic poles during reversal (see Fig. 5). As was shown in [Kuznetsov, 1999], the global magnetic anomalies (1–4 in Fig. 5) affecting drift of the poles during reversal are located precisely on these paths. Assume that an increase in the velocity V and jerk occurrence frequency ω means that reversal (or excursion) of the magnetic pole will begin (or already began) on the Earth rather than jerk, as was proposed by Newitt et al. [2002]. To make sure of the plausibility of such an assumption, we consider global magnetic anomalies.

According to our model, global magnetic anomalies (GMAs) are long-living hydrodynamic vortices (Rossby vortices [Kuznetsov, 1995]). Vortices are located in a thin F layer at the boundary of the inner core. Long-living vortices (cyclones and anticyclones) in the atmospheres of Jupiter and Saturn are hydrodynamic analogs of such global magnetic anomalies as Rossby vortices. It is known that the Rossby system of vortices in the atmospheres of Jupiter and Saturn is most stable when it consists of three anticyclones and one cyclone [Nezlin and Snezhkin, 1990]. The situation is similar for GMAs: the geomagnetic field increases in three of them (anticyclones) and decreases in one anomaly (Brazilian cyclone). During reversals, when the dipole part of the geomagnetic field decreases, the magnetic field in the magnetic anomalies remains unchanged for a certain time. Precisely this fact is responsible for attraction of pole drift paths to GMAs during reversal.

Why jerks most effectively manifest themselves in the Y field component? Assume that the geomagnetic field Y component characterizes the degree of quadrupole polarization of the field generation source. Indeed, the dipole source of the geomagnetic field generation, symmetric about the axis of rotation, should not result in the appearance of the Y component. The presence of this component and quadrupole polarization of the geomagnetic field can be related to the existence of four global magnetic anomalies which represent four current rings outside the Earth's rotation axis. The distribution of jerks-1969 over the Earth's surface [Madden and Le Mouel, 1982] argues for such a model. These researchers indicated that the epicenters of maximal jerk values almost coincide with those of the global anomalies.

6. DISCUSSION OF RESULTS AND CONCLUSIONS

The author of the comment [Campbell, 2003] on the works [Newitt et al., 2002; Barton, 2002] prejudices the expediency of the idea of magnetic pole drift registration. As an argument he cites the mathematical model describing the geomagnetic field in the form of a dipole shifted relative to the Earth's center. The author of the comment assumes that, in such a situation, the fact that the field vector is vertical and the horizontal component is zero means nothing and is merely the consequence of the shift of the field generation axis relative to the Earth's rotation axis. Barton and Newitt [Campbell, 2003] object to such an approach, explaining Campbell that the actual physical model of the geomagnetic field cannot be replaced by a mathematical model. The mathematical description of the field proposed by Campbell is far from a single example. For instance, we can refer to the cycle of works [Alldridge, 1987] where the author describes the geomagnetic field by selecting an unlimited number of radial dipoles rather then by expanding the field into the spectrum, as Campbell did it. In this case, as well as in the first example, the mathematical model in no way explains the origin of the actual geomagnetic field. As is known, in any actual model of geomagnetic field generation, the magnetic field is the consequence of the electric current flow (or motion of a conducting fluid with frozen-in magnetic field) in a conducting current ring. In this aspect the Alldridge's ideas are, in essence, much closer to the geomagnetic field physical model than the field expansion into the Gaussian series.

By minimizing the location of current rings, Alldridge arrived at the conclusion that the most optimal location of these rings corresponds to the inner core boundary. This conclusion is in agreement with the idea of geomagnetic field generation at the inner core boundary (in the F layer), following the hot Earth model [Kuznetsov, 1990]. In this model the dipole source represents a differential current ring, lateral inhomogeneities of which exactly correspond to the

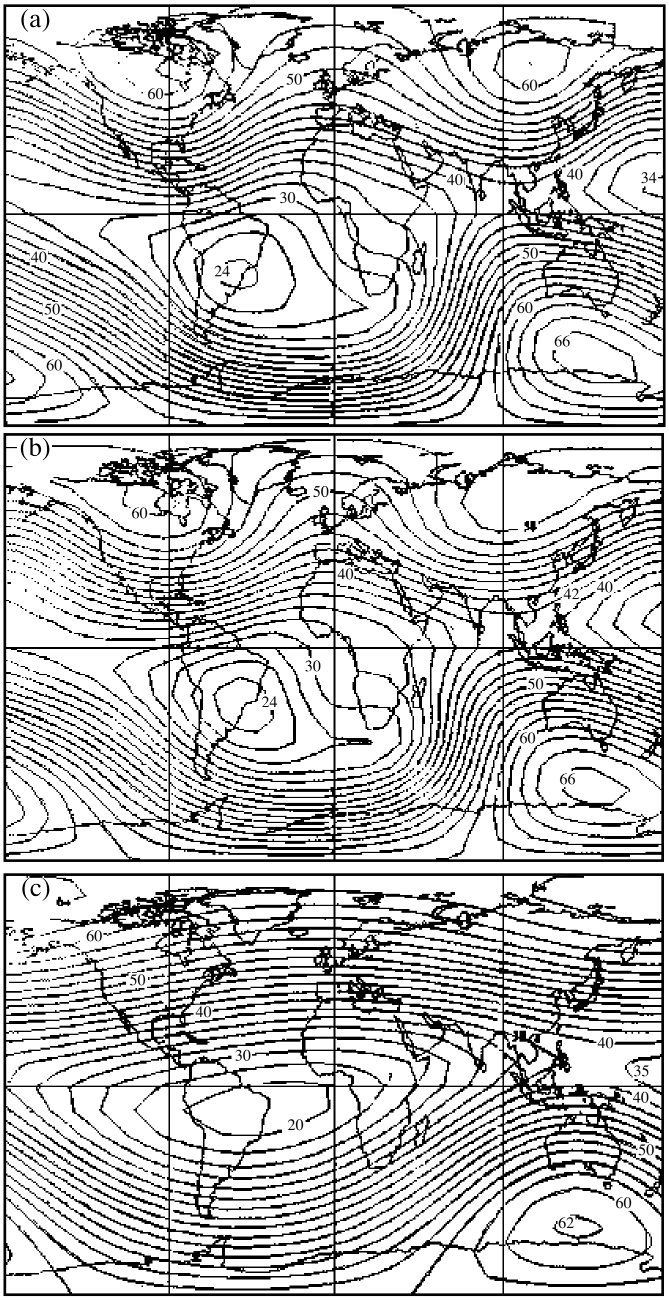

Fig. 6. (a) Map of the complete field module. (b) Map of the complete field module synthesized as the sum of the dipole source in the form of the differential current ring and the field of four sources in the form of radial current rings. (c) The field of the differential current ring.

revealed lateral anisotropy of the inner core. Note that the results of studying the inner core anisotropy disprove the possibility of locating an actual field source in the form of a displaced dipole. The data on anisotropy indicate that the Earth's core is highly symmetrical [Kuznetsov, 1997].

The model of geomagnetic field generation, including four radial dipoles in addition to the axial non-symmetrical dipole, is illustrated in Fig. 6. Figure 6a demonstrates the map of the complete field module; Fig. 6b, the map of the complete field module synthesized as the sum of the dipole source in the form of a differential current ring (Fig. 6c) and the field of four sources in the form of radial current rings representing GMAs. By selecting the intensities of these field sources, we can obtain one-to-one correspondence of the computer model with the map of the actually observed field (see Figs. 6a, 6b). By changing the intensities of the dipole and anomaly field sources, we can obtain actually observed magnetic pole drift directions and velocities. Thus, drift of the magnetic poles (drift direction and velocity) is one of the most important characteristics of geomagnetism. This is of special significance since the drift directions and velocities of paleomagnetic poles during the periods of a quiet field [Tarling and Abdeldayem, 1996] substantially differ from the directions and velocities of the present-day magnetic poles.

We noted that GMAs play an important part in the motion of the poles during reversal. In the hydrodynamic model, these anomalies are Rossby vortices and transport heat in the *F* layer between the inner and outer cores, where phase transitions of the first order take place according to the field generation model. Phase transition temperature at a specified pressure is a constant, and a thermodynamic system tends to maintain this temperature at a specified level. If we accept this idea, it turns out that the phenomena called jerks in geomagnetism are temperature variations marked by the magnetic field when the system relaxes to the temperature of phase transition. Since these processes of transfer proceed in the electric field, jerks are naturally indicators of a change in the current system generating the geomagnetic field. An increase in the jerk occurrence frequency and a decrease in the jerk amplitude mean that the system approaches an unstable asymptote (Figs. 4a, 4b) at which a change in the regime (bifurcation) takes place. In such a model, an acceleration of the poles and an increase in the jerk occurrence frequency can also characterize the beginning of reversal. However, the available data on jerks and drift of the magnetic poles do not make it possible to definitely answer the question whether reversal has started or not. The fact that the accelerated drift of the magnetic poles, increased occurrence frequency of jerks, and beginning of reversal (excursion) are related phenomena, at least in the model of hot Earth and geomagnetic field generation developed by the author, can be considered as an answer to the question put in the heading of the work.

ACKNOWLEDGMENTS

I am grateful to L. Newitt and O.A. Troshichev for information about the behavior of the field *H* components at Resolute Bay and Cape Chelyuskin observatories, respectively. I also thank L. Newitt for discussion of the model and made remarks.

This work was supported by the integration project of Presidium of the Russian Academy of Sciences (no. 13.13).

REFERENCES

1. M. Alexandrescu, D. Gibert, G. Hulot, et al., “Worldwide Wavelet Analysis of Geomagnetic Jerks,” J. Geophys. Res. **101**, 21 975–21 994 (1996).
2. L. R. Alldridge, “Current Loops Fitted to Geomagnetic Model Spherical Harmonic Coefficients,” J. Geomagn. Geoelectr. **39**, 271–296 (1987).
3. C. E. Barton, “Survey Tracks Current Position of South Magnetic Pole,” EOS. Trans. AGU **83**, 291 (2002).
4. L. A. Bauer, Dissertation (Univ. Berlin, 1895).
5. P. Berge, Y. Pomeau, and C. Vidal, *L’Ordre dans le chaos* (Cop. Paris, 1988; Mir, Moscow, 1991).
6. W. H. Campbell, Comment on “Survey Tracks Current Position of South Magnetic Pole” and “Recent Acceleration of the North Magnetic Pole Linked to Magnetic Jerk”," EOS. Trans. AGU **84**, 42 (2003).
7. V. Courtillot and J. Besse, “Magnetic Field Reversal, Polar Wander, and Core–Mantle Coupling,” Science **237**, 1140–1147 (1987).
8. J. Gavoret, D. Gibert, M. Menvielle, and J.-L. Le Mouel, “Long-Term Variations of the External and Internal Components of the Earth’s Magnetic Field,” J. Geophys. Res. **91**, 4787–4796 (1986).
9. E. R. Hope, “Geotectonics of the Arctic Ocean and the Great Arctic Magnetic Anomaly,” J. Geophys. Res. **64**, 407–427 (1959).
10. V. V. Kuznetsov, “A Model of Virtual Geomagnetic Pole Motion During Reversals,” Phys. Earth Planet. Inter. **115**, 173–179 (1999).
11. V. V. Kuznetsov, “Anisotropy of the Inner Core Properties,” Usp. Fiz. Nauk **167** (9), 1001–1012 (1997).
12. V. V. Kuznetsov, “Foci of the Secular Variations as Rossby Hydrodynamic Vortices,” Dokl. Akad. Nauk **340** (5), 685–687 (1995).
13. V. V. Kuznetsov, “Position of the North Magnetic Pole in 1994,” Dokl. Akad. Nauk **348** (3), 397–399 (1996).
14. V. V. Kuznetsov, *Physics of the Earth and Solar System* (IGG, Novosibirsk, 1990) [in Russian].
15. V. V. Kuznetsov, I. V. Pavlova, and N. N. Semakov, “Estimation of the Position of Virtual Magnetic Poles (Based on Soviet–Canadian Measurements in the Central Arctic Regions),” Geol. Geofiz. **31** (2), 115–116 (1990).
16. T. Madden and J.-L. Le Mouel, “The Recent Secular Variation and the Motion at the Core Surface,” Philos. Trans. R. Soc. (London), A: 271–280 (1982).
17. M. Mandea, E. Bellander, and J.-L. Le Mouel, “A Geomagnetic Jerk for the End of the 20th Century?,” Earth Planet. Sci. Lett. **183**, 369–373 (2000).
18. L. R. Newitt and C. E. Barton, “The Position of the North Magnetic Dip Pole in 1994,” J. Geomagn. Geoelectr. **48**, 221–232 (1996).
19. L. R. Newitt and E. R. Niblett, “Relocation of the North Magnetic Dip Pole,” Can. J. Earth Sci. **23**, 1062–1067 (1986).
20. L. R. Newitt, M. Mandea, L. A. McKee, and J. J. Orgeval, “Recent Acceleration of the North Magnetic Pole Linked to Magnetic Jerk,” EOS Trans. AGU **83**, 385 (2002).
21. M. V. Nezlin and E. N. Snezhkin, *Rossby Vortices and Helical Structures* (Nauka, Moscow, 1990) [in Russian].
22. W. D. Parkinson, *Introduction to Geomagnetism* (Scottish Acad. Press, Edinburg, 1983; Mir, Moscow, 1986).
23. P. H. Serson, “Tracking the North Magnetic Pole,” New Sci. (1981).
24. D. H. Tarling and A. L. Abdeldayem, “Palaeomagnetic-Pole Errors and a “Small-Circle” Assessment of the Gondwanan Polar-Wander Path,” Geophys. J. Int. **125**, 115–122 (1996).
25. E. T. Whittaker and G. N. Watson, *A Course of Modern Analysis. Part II* (Cambridge Univ. Press, Cambridge, 1962; Gos. Izd. Fiz.–Mat. Lit., Moscow, 1963).
26. R. Weber, L. Dexter, Ch. Holloway, and M. Buxton, *Polar Bridge an Arctic Odyssey* (Key Porter Books Limited, Ontario, 1990).