"Supersonic" magnetic poles

Semakov N. N.[1,2], Grigorevskaya A. V.[1], Kovalev A. A.[2], Pavlov A. F.[1,2], Fedotova O. I.[2]
[1]Novosibirsk State University, 2 ul. Pirogova, Novosibirsk, Russia
[2]Novosibirsk Magnetic Observatory, ASB GS RAS, pr.Koptyuga 3, Novosibirsk, Russia

The temporal changes in the magnetic field of our planet are usually analyzed through the behavior of its angular and force components. But the same temporal characteristics may be analyzed using the more integrated and comparable characteristics of the magnetic field linked to the orientation and magnetic momentum of the central dipole. Such characteristics can be obtained by converting the angular elements of geomagnetism, measured at a given point, into geographic coordinates of the magnetic pole, and further by converting the "force" components of geomagnetism into values of "local magnetic constant", which is a force characteristic that varies depending on the strength of momentum of the magnetic dipole, but does not depend on its orientation. Per-second values of components of geomagnetism, continuously recorded by magnetic observatories, produce the most accurate detailed trajectories of the magnetic poles' movements and their velocity graphs. All other values of these components—per-minute, hourly, daily, seasonal or annual—show the average position of the magnetic poles and their average movement speed.

Key words: virtual magnetic pole, declination, inclination, local magnetic constant, magnetic observatory, true magnetic pole.

1. Introduction

The question of what happens to the magnetic poles of the Earth is of interest not only to those who study them professionally, but also to the general public, particularly those people who live and work in the Polar Regions. Information on the drift of the north magnetic pole from the Canadian Arctic to Siberia at a speed exceeding 10 kilometers per year appears occasionally in the scientific press and the media. However, it is far less known that the magnetic poles can develop impressive speeds in this process in short periods of time far less than one year. The discovery that in this continuous movement the magnetic poles can reach speeds that are several times higher than the speed of sound caught by surprise even the authors of the present publication.

One of the most effective and visually-effective ways of analyzing global patters and regional peculiarities of the geomagnetic field is to convert the values of the components of geomagnetism into the coordinates of the magnetic poles and value of the local magnetic constant (Bauer, 1914; Kuznetsov V.V. et al. 1990, 1997).

2. The movement of the magnetic poles on magnetically calm days

Figures 1 and 2, below, show the movements of north magnetic poles on magnetically calm days close to the autumn and spring equinoxes, based on the data of the Novosibirsk magnetic observatory (NVS). These figures demonstrate that the average daily position of the magnetic pole may be found at a spot that it did not, in fact, cross.

Figure 2: Movement of the virtual north magnetic pole, Novosibirsk observatory data (September 28, 2013)

The path of the virtual magnetic pole (VMP), shown in figures 1 and 2, demonstrate that during daytime—for the Novosibirsk magnetic observatory daytime corresponds to 00:28–12:28 universal time (UT)—VMP moves clockwise in an oval-like path, elongated about 10 km from south-east to north-west, and at night-time (from 12:28 to 00:28 UT), the virtual magnetic pole shifts significantly less.

3. The movement of the magnetic pole in its disturbed stated

The nature of the movement of the magnetic pole in its disturbed stated cannot be described as chaotic even during a magnetic storm. For example, figure 3 shows the movements of the

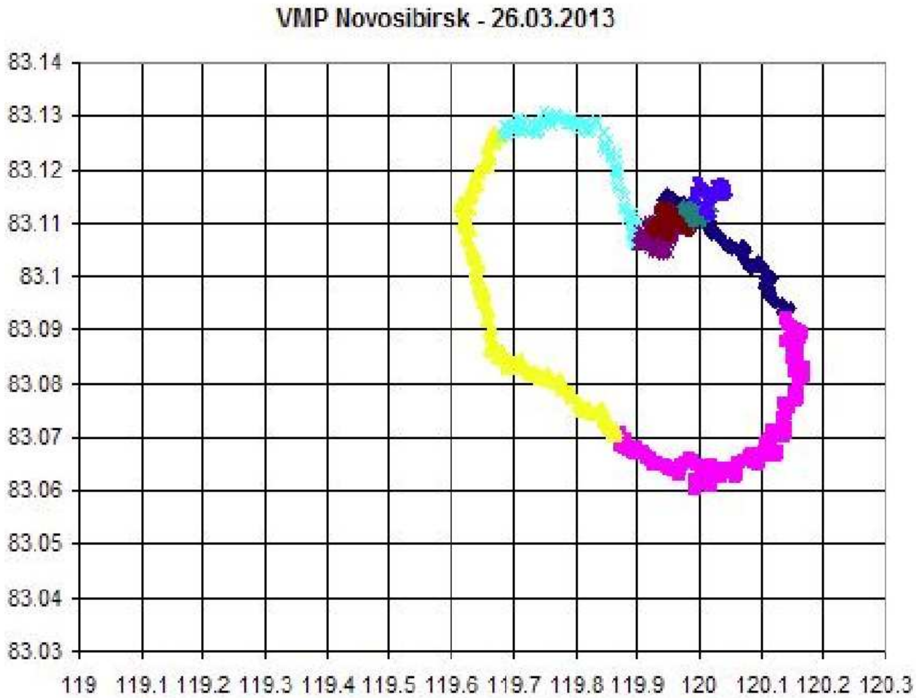
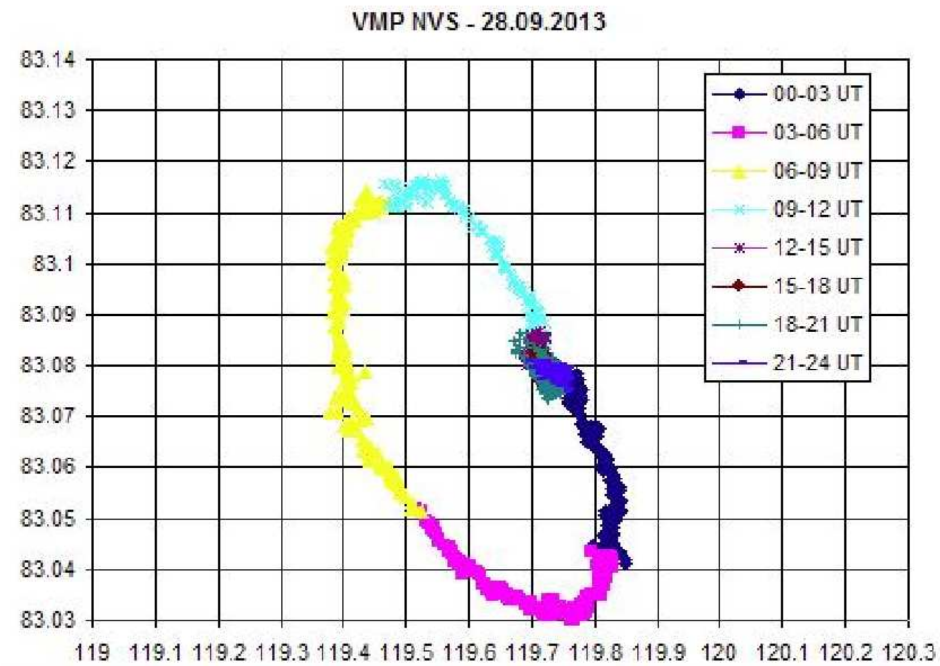


Figure 1. Movement of the virtual north magnetic pole, Novosibirsk observatory data (March 26, 2013)



magnetic pole on March 17, 2013, after 6:00 UT, based on per-second magnetic measurements in the Novosibirsk observatory during one disturbed hour (15.40-16.40 UT).

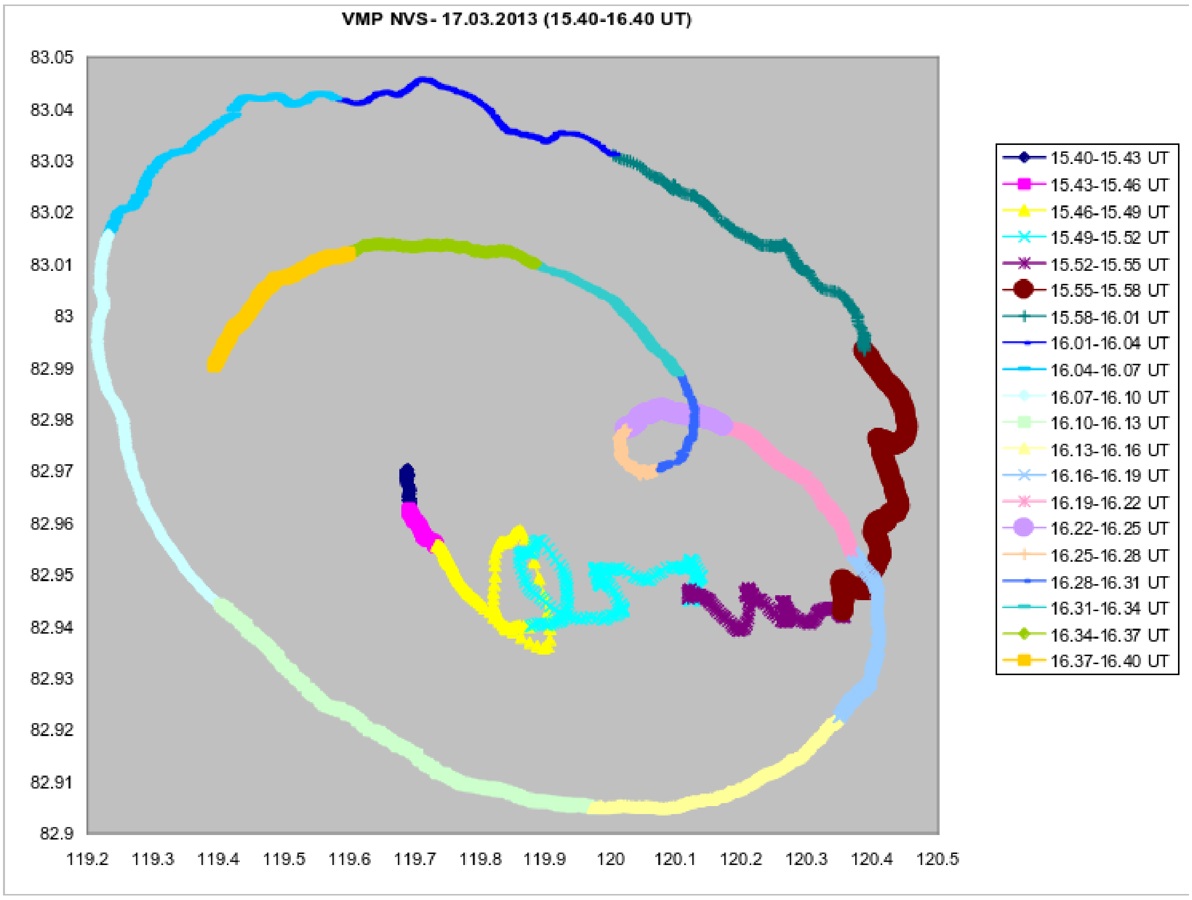


Figure 2. Movement of the virtual north magnetic pole from 15:40 to 16:40 UT, Novosibirsk observatory data (March 17, 2013)

1. All coordinates of the magnetic poles obtained based on the currently available actual values of the declination (D) and inclination (I) at the point with the latitude φ and longitude λ are "virtual" in the sense of being based on available factual data. Their coordinates (latitude Φ and longitude Λ) are calculated using the well-known formulas of spherical trigonometry:$\sin\Phi = \sin\varphi \cos\vartheta + \cos\varphi \sin\vartheta \cos D$

2. $\sin(\Lambda - \lambda) = \sin\vartheta \sin D / \cos\Phi$

$\text{ctg}\vartheta = 0.5\text{tg}I$ Based on these formulas, the north and south virtual magnetic poles are located at the distance of 180^0 of the arc of the great circle and are the points at which the continuation of the axis of the central dipole intersects with the Earth's surface. It should be noted that the term "magnetic pole" and the formula for calculating its coordinates are tied to the dipole located at the center of the globe. This is identical to the calculation of the virtual magnetic poles (VMP) in paleomagnetism (see Merrill et all.,1998).

4. The virtual and the true magnetic poles

As we approach the value of inclination of $I=90^0$ we can be increasingly confident that the obtained coordinates of the virtual north pole are nearing those of true magnetic north pole. Using formulas (i)–(iii), we can obtain the coordinates of not only the virtual north magnetic pole, but also those of the south magnetic pole. However, in respect of its proximity to the true south magnetic pole there is no similar certainty because such calclations would be based on data generated at a very significance distance from the true south magnetic pole.True north and south magnetic poles are not opposed precisely because the virtual magnetic poles, which are used for their determination, are poles of different dipoles. These dipoles are of different orientation, the most reliable information on which can be obtained only in the Arctic or off the cost of Antarctica.

5. Parameters of movement of the north and south magnetic poles Modern magnetic observatories measure per-second values of the components of geomagnetism, although data of the **INTERMAGNET** (International Real Magnetic Network) is currently available mostly in a per-minute format (http//www.intermagnet.org). But analyzing even the average per-minute values of observatories located in different regions of the globe shows surprisingly high movement velocity of the magnetic poles, as well as some fascinating features and patterns of this movement.

One could hardly hypothesize that the speed of movement of magnetic poles in a given minute could significantly exceed the speed of sound. However, calculations made based on the data of various magnetic observatories demonstrate that magnetic poles can move at certain moments not only at the speed of a pedestrian or a car, but at a speed several times higher than that of a straight jet.Table 1 shows data on the average (Vvmp) and maximum (max Vvmp) speeds of movement of the virtual magnetic poles based on per-minute values of declination and inclination, collected by different observatories around the globe March 17, 2013 (24-hour period), which saw both calm and disturbed states of the magnetic field. In addition to the speed values, Table 1 shows the path traversed by the magnetic pole throughout the day (L) and the maximum spread of positions of the pole (∇).

Table 1. Parameters of movement of the north and south magnetic poles, calculated based on the data of several magnetic observatories (March 17, 2013)

Station Name	**CODE**	φ	λ	**Vvmp, km/h**	**max Vvmp, km/h**	**L, km**	**∇, km**
Resolute Bay	RES	74.69	265.105	161.4	3922.8	3869	275
Novosibirsk	NVS	55.03	82.9	33.5	284.3	804	41
Irkutsk	IRT	52.167	104.45	27.4	211.3	658	39
Alibag	ABG	18.638	72.872	5.5	77.4	132	15
Addis Ababa	AAE	9.035	38.766	5.6	75	131	12
Vassouras	VSS	-22.4	316.35	16.7	279.2	400	43
Casey	CSY	-66.283	110.533	127.6	1796.6	3061	184
Mawson	MAW	-67.604	62.879	256.4	3702.4	6150	264

Notably, according to the data of observatories located in low and medium latitudes (NVS, IRT, ABG, AAE, VSS), the average and maximum speeds of movement of the virtual magnetic poles are significantly lower than the speeds calculated based on the data from the Artic and the Antarctic (RES, CSY, MAW). However, the regions that are located closer to the true magnetic poles provide the most accurate information about their movement.

Figure 4 shows the fluctuations in the speed of the magnetic pole movement based on per-minute data of Resolute Bay observatory, which is the closest observatory to the true north magnetic pole.

The most accurate information regarding the annual movement of the magnetic pole is produced by magnetic observatories. Different observatories presently show this speed to be between 2 and 65 km per year, with significant variations over time. But these speeds are

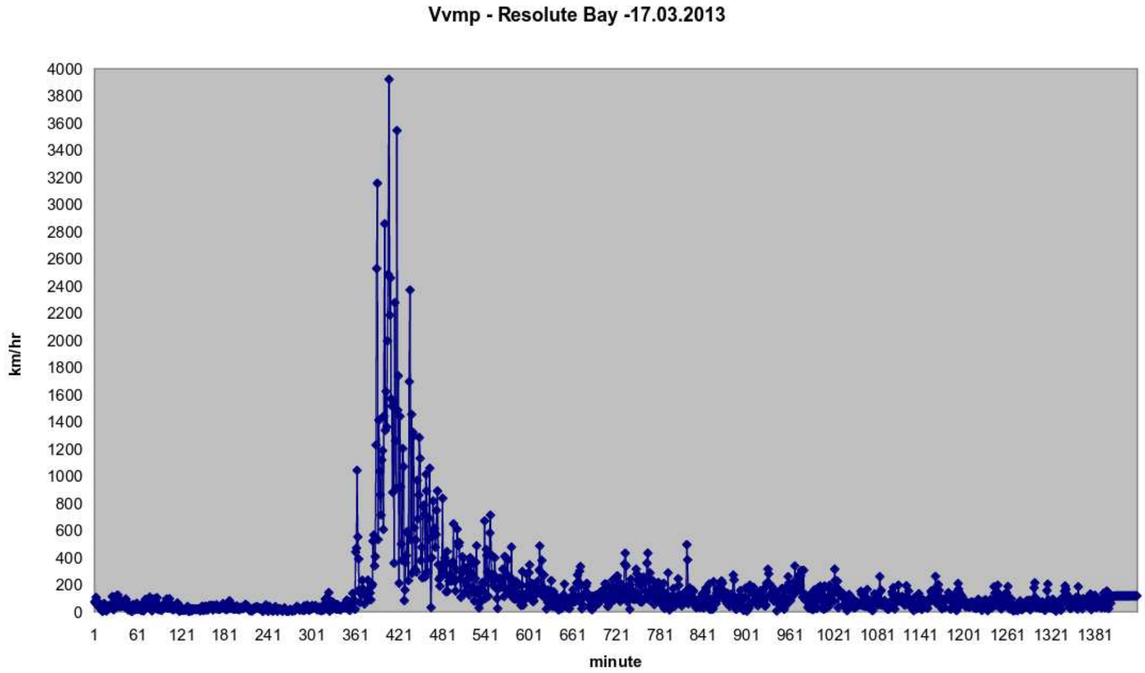


Figure 3. Movement speed of the virtual magnetic pole, calculated based on the data of Resolute Bay observatory (March 17, 2013)

significantly lower than the speeds developed by the magnetic pole at the time intervals shorter than a year. In reality, stationary observatories and field observations usually deal with actual snap-shot values of measured components of geomagnetism that are tied to each specific second when the measurement was taken. High movement speed of virtual magnetic poles highlights the complexity of the efforts to locate the true north magnetic pole. This work has been carried out for several decades by Larry Newitt and other our Canadian colleagues (Newitt and Barton, 1996; Newitt et all., 2009; Newitt and Niblett, 1986).Per-minute, hourly, daily, and annual values of these components are obtained through the process of averaging, respectively, per-second, per-minute, hourly, and daily values. In the process, the pole trajectories become straightened, and its velocity reduces with each subsequent averaging. Assuming that the true magnetic poles continue to move in the direction of the equator with an average speed of 10 kilometers a year, their inversion—that is, the transition of the north magnetic pole into the Southern hemisphere, and vice versa—may happen in approximately 1,000 years. But if the magnetic poles could consistently maintain ultrasonic speed that they are capable of developing, the inversion could happen in a matter of hours.

6. Conclusions

The analysis of the movement of the magnetic poles demonstrates that:

- The data of magnetic observatories, translated into coordinates of corresponding virtual magnetic poles, shows surprising mobility of the magnetic poles, which at time develop ultrasonic speed.

- The trajectory of the magnetic poles both in calm time and during magnetic calamities is not a chaotic movement but a series of "loops" of varying shapes and sizes.

- The differences in identified locations of the virtual magnetic poles, produced by each magnetic observatory, depend in addition to the level of disturbance of the magnetic field, on the proximity of each observatory to the true magnetic pole. These differences can be between 5–10 km and 200–300 km of the arc of the great circle a day.

Acknowledgments. We express our gratitude to the staff of the magnetic observatories at Resolute Bay, Irkutsk, Alibag, Addis Ababa, Vassoras, Casey, Mawson and Novosibirsk, whose

data was used in the preparation of the present work.

References

1. Bauer L.A. The local magnetic constant and its variations // Terr. Mag. –sept.1914.- V.19.- P.113-125.- Washington.

2. Kuznetsov V. V., Pavlova I. V., and Semakov N. N.. Estimation of the Position of Virtual Magnetic Poles (Based on Soviet–Canadian Measurements in the Central Arctic Regions)// Geol. Geofiz.-V. 31(2),- P. 115–116, 1990.

3. Kuznetsov V. V., Pavlova I. V., Semakov N. N., Newitt L.R. Virtual magnetic poles,magnetic anomalies,and the location of the north magnetic pole//Russian Geology and Geophysics.- V.38(7).-P.1312-1320, 1997.

4. Merrill, R.T., M.W. McElhinny, and P.L. McFadden, The magnetic field of the Earth, paleomagnetism, the core and the deep mantle, Academic Press, 531 pp., 1998.

5. Newitt, L.R. and C.E. Barton, The position of the North Magnetic Pole in 1994, J.Geomag. Geoelectr., 48, 221-232, 1996.

6. Newitt, L.R., A.Chulliat, and J.-J. Orgeval, Location of the North Magnetic Pole in April 2007, Earth Planets Space, 61, 703-710, 2009.

7. Newitt, L.R. and Niblett E.R. Relocation of the north magnetic dip pole//Can. J. Earth Sci.- 1986.- Vol. 23.- P.1062-1067.

8. INTERMAGNET (International Real Magnetic Network, 2013) register. http://www.intermagnet.org/data-donnee/