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Will the Magnetic North Pole Move to Siberia?

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The magnetic dip poles, defined as the surface points in the Northern and Southern hemispheres where the Earth's magnetic field is vertical, have been the topic of various research activities over time. In addition, their location, and especially their motion, has attracted a large amount of public interest, and this interest will probably increase during the next few months due to the focus on polar regions stimulated by the International Polar Year (IPY) that started in March of this year.

This article provides an overview of the current and historic migration of the magnetic poles, and delves into theories of why dip poles move. The future position of magnetic north and south is also discussed.

Current Dip Pole Location

Traditionally, the locations of the dip poles have been determined directly from ground surveys of the relevant polar region. Positions calculated using global models of the Earth's magnetic field often disagree with the directly determined positions since many of these models are not well constrained at polar latitudes due to a lack of data. However, the agreement on positions has improved significantly during the past decade as magnetic measurements taken by satellites such as Ørsted, CHAMP, and SAC-C have provided unprecedented global coverage of magnetic observations. Recent satellite-based magnetic field models therefore make it possible to accurately determine the dip pole positions as well as to monitor their movement.

The north dip pole is presently located in the Canadian Arctic, moving in a northwest direction, while the south dip pole is located off the coast of Antarctica, south of Australia. *Mandea and Dormy* [2003] summarize the ground observations and discuss the movement of the north magnetic dip pole, the velocity of which "has more than doubled in the last 30 years, reaching the huge velocity of about 40 kilometers per year in 2001." A recently derived model of the time change of Earth's magnetic field [*Olsen et al.*, 2006] shows that the north dip pole has accelerated to even higher velocities, passing 50 kilometers per year in 2000 and reaching almost 60 kilometers per year in 2003. However, since 2003 the north dip pole has decelerated and currently moves with a velocity of only slightly above 50 kilometers per year. In contrast, during the same time span, the south dip pole has kept its speed of movement around only 5–10 kilometers per year.

The locations of the north and south dip poles, as given by an updated version of the CHAOS model of *Olsen et al.* [2006], which includes more recent satellite data, are shown in Figure 1 together with ground survey determinations. Ground surveys of the north dip pole were made by Canadian-French expeditions in 2001 [*Newitt et al.*, 2002] and, most recently, at the end of April 2007. The determined position for 2001 is in excellent agreement with that given by the field model; the determined position for 2007 is not yet available. The discrepancy is larger in the presatellite era, especially for the south dip pole, as shown by *Mandea and Dormy* [2003]. However, since the difference between model values and ground survey determinations seems to vary only slowly in time (and reflect mainly small-scale features of the field that can be modeled only with the global data coverage provided by satellites), a determination of pole velocity from field models is possible even if the pole positions are biased.

Historic Movements of the North and South Dip Poles

How fast do the poles move? *Mandea and Dormy* [2003] determined the velocity of the north and south dip poles between 1900 and 1990 using the GUFM field model of *Jackson et al*. [2000]. An extension to more recent years, by adding field predictions from the CM4 model of *Sabaka et al*. [2004] (for 1965–2000) and the extended CHAOS model (for 1999–2007), is shown in Figure 2.

While the north dip pole moves at up to 60 kilometers per year, the speed of the south dip pole has been generally below 20 kilometers per year during all of the past century. A connection between the speed of the north dip pole and geomagnetic jerks—abrupt changes in the trend of the secular variation of the geomagnetic field—has been noticed by *Mandea and Dormy* [2003]. One might speculate whether the recent change in the north dip pole speed, from a state of accelerated to decelerated motion around 2003, is connected to the recently detected geomagnetic jerk of 2003 [*Olsen and Mandea*, 2007].

What causes such different motions in the dip poles? The magnetic poles move because the core magnetic field changes with time, and the rather different rate of north and south pole movement has been explained by the different field morphology in the Northern and Southern hemispheres [*Mandea and Dormy*, 2003].

To add to this complexity, the magnetic field at the core-mantle boundary (at a depth of about 2900 kilometers) reveals a pattern that is much more complex than the dipole-like structure at and above the Earth's surface. Indeed, a concentration of 'reversed-flux patches' exists in the north polar region. In these patches, the magnetic field points upward, opposing the normally downward pointing field in the Northern Hemisphere. Growth and poleward motion of the Canadian reversed flux is responsible for much of the dipole field decrease during the past 150 years and accounts for the present north dip pole migration, which is indeed inside this patch (see the animation in the electronic supplement to this *Eos* edition at http://www.agu.org/eos_elec/).

Most likely, the pole starts to decelerate when it moves away from the minimum of the reversed-flux patch toward the normal flux lobe under Siberia. If the flux concentration in the Siberian lobe decreases, the dip pole changes its direction of movement, probably quite abruptly, as has happened already around 1630, 1730, and 1860, according to the GUFM model of *Jackson et al.* [2000]. The velocity of the pole would remain high if the pole is located in a region of strong reversed flux, and one may expect decreasing velocity once it has crossed the reversed-flux area. However, linking the dip poles at the Earth's surface to the magnetic field at the core-mantle boundary must be

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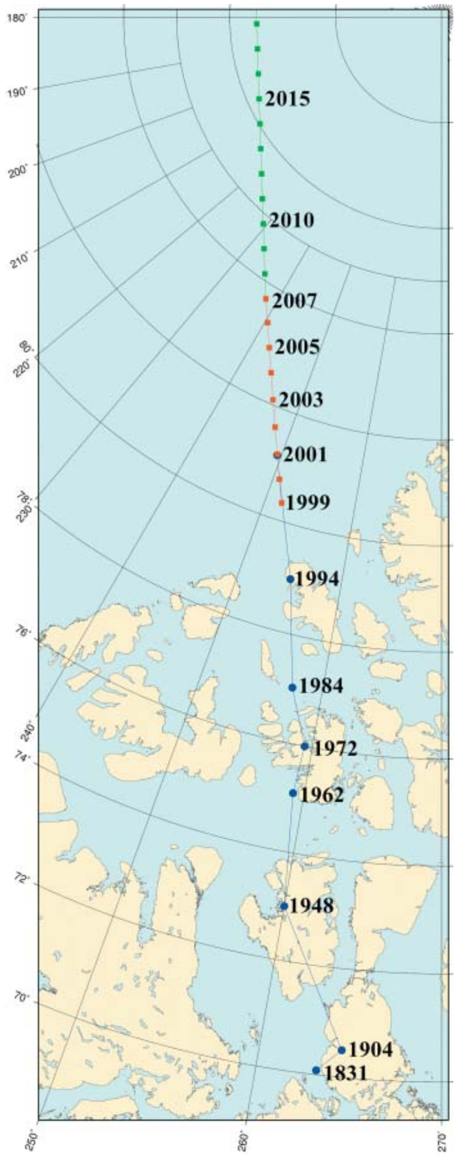

Fig. 1. Positions of the north dip pole from direct surface measurements (blue circles) and from computations based on the CHAOS model (red squares). Predicted positions (green squares) for the next few years are made assuming a mean velocity of 50 kilometers per year in the same direction as in 2007.

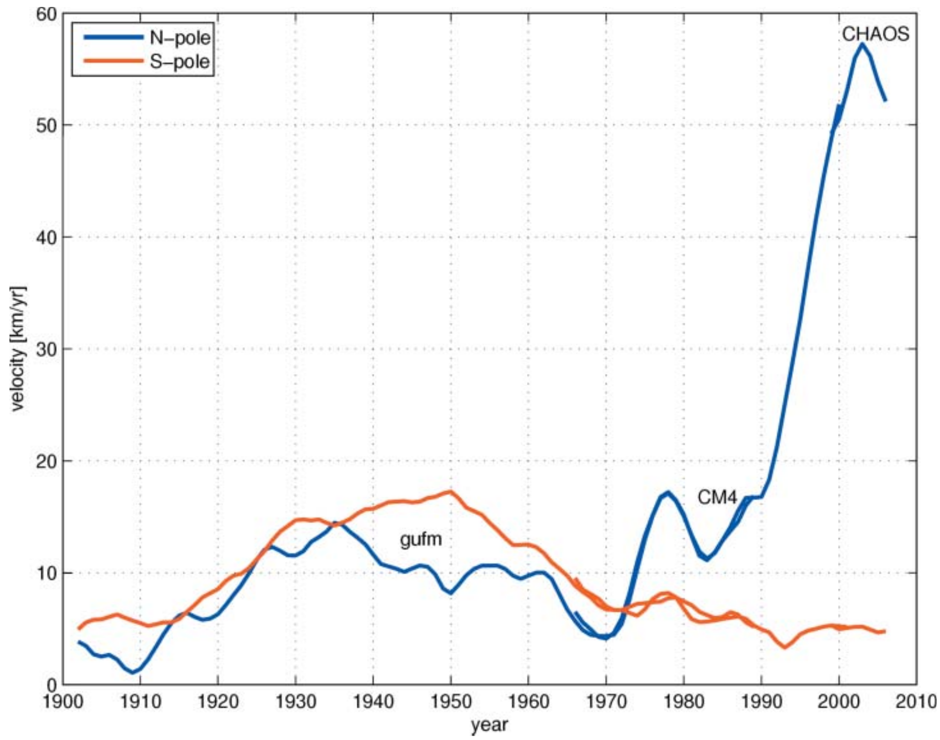

Fig. 2. Velocity of the north and south dip poles as given by three field models: GUFM (1900–1990), CM4 (1965–2000), and CHAOS (1999–2007).

taken with caution, since the present pole positions are very sensitive to small changes in field morphology.

Future Dip Pole Locations?

A difficult question to answer is therefore, Where will the dip poles be during the coming years? Predicting the Earth's magnetic field over long time spans is challenging because of the chaotic nature of the core processes generating the field. However, the rather regular movement of the north dip pole over the past decade has encouraged us to extrapolate its position for the next 10 years. Predictions of the north dip pole location, assuming a constant velocity of 50 kilometers per year in the same direction as in 2007, are also shown in Figure 1. According to these predictions, the dip pole will be closest to the geographic north pole (400-kilometer distance) in 2018, continuing thereafter toward Siberia. Predictions longer than 10 years, however, have to be considered with extreme care.

Precise monitoring of the pole positions will be possible with Swarm, a European Space Agency mission consisting of three identical spacecraft designed to investigate the Earth's magnetic field [*Friis-Christensen et al.*, 2006]. Swarm will be launched in 2010 and is expected to measure the Earth's magnetic field with unprecedented accuracy during its 5-year lifetime. This mission will allow our current predictions to be evaluated and will enhance future road maps for the magnetic poles.

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