What Caused Recent Acceleration of the North Magnetic Pole Drift?

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The north magnetic pole (NMP) is the point on the Earth’s surface where the geomagnetic field is directed vertically downward. It drifts in time as a result of core convection, which sustains the Earth’s main magnetic field through the geodynamo process. During the 1990s the NMP drift speed suddenly increased from 15 kilometers per year at the start of the decade to 55 kilometers per year by the decade’s end. This acceleration was all the more surprising given that the NMP drift speed had remained less than 15 kilometers per year over the previous 150 years of observation.

Why did NMP drift accelerate in the 1990s? Answering this question may require revising a long-held assumption about processes in the core at the origin of fluctuations in the intensity and direction of the Earth’s magnetic field on decadal to secular time scales, and hints at the existence of a hidden plume rising within the core under the Arctic.

From Field Surveys to Satellite Monitoring

On 1 June 1831, James Clark Ross made the first determination of the location of the north magnetic pole. He found it on Boothia Peninsula, in the Canadian Arctic: “Amidst mutual congratulations, we fixed the British flag on the spot, and took possession of the north magnetic pole and its adjoining territory, in the name of Great Britain and King William the Fourth” [Ross, 1835]. This success was hailed as the greatest achievement of the 5-year polar expedition led by John Ross (James’s uncle) in search of the Northwest Passage. Indeed, knowing the pole’s position was important for navigation, which at that time relied heavily on the use of compasses and accurate declination charts. Seventy-three years passed before Roald Amundsen made a second determination of the location of the NMP, in 1904, during the first successful navigation of the Northwest Passage. The locations by Amundsen and Ross were different, hence suggesting some drift, but still very close to each other (less than 50 kilometers apart).

Similar navigational motivations led Natural Resources Canada (NRCan) to initiate regular measurement campaigns from 1948 to 1994 to follow the slow drift of the NMP. Two additional NMP locations have recently been determined, in 2001 [Newitt et al., 2002] and 2007 [Newitt et al., 2009]. These were derived from data gathered during two campaigns that resulted from the successful international collaboration between Association Poly-Arctique (a French fund-raising group), NRCan, the Institut de Physique du Globe de Paris (IPGP), and France’s Bureau de Recherches Géologiques et Minières (BRGM). As the NMP drifts away from the nearest airfield in Eureka (a small research base in Nunavut, Canada) toward Siberia, measuring the field in the vicinity of the NMP has become increasingly difficult due to the limited flying range of aircraft able to land on sea ice.

Fortunately, the recent drift over the Arctic Ocean has happened at a time when low-Earth-orbiting satellites carrying high-precision magnetometers, such as Ørsted and the Challenging Minisatellite Payload (CHAMP), have made it possible to calculate global geomagnetic field models with unprecedented spatial and temporal resolution [e.g., Olsen et al., 2009]. As the highly successful Ørsted and CHAMP missions are reaching an end (CHAMP ceased on 19 September), geomagnetic measurements from space are expected to be continued thanks to the European Space Agency’s Swarm mission, to be launched in 2012 [Friis-Christensen et al., 2006].

Sudden Acceleration in the 1990s

Observations from satellites, magnetic observatories, and field surveys show that the NMP drift speed suddenly increased in the 1990s [Newitt and Barton, 1996; Newitt et al., 2002], from 15 kilometers per year in 1990 to about 60 kilometers per year in 2002, after which it slowly decreased [Olsen and Mandea, 2007; Newitt et al., 2009]. This phenomenon was observed in both field survey measurements and global geomagnetic models (Figure 1a). It followed more than 150 years of slow drift at less than 15 kilometers per year, starting with the first location of the NMP by Ross. This sudden acceleration contrasts with the behavior of the south magnetic pole, which has a drift speed that has never exceeded 15 kilometers per year since the beginning of the twentieth century [Olsen and Mandea, 2007].

Magnetic recordings from polar cap observatories, in Resolute Bay (in Nunavut, Canada) and Qaanaaq (formerly the city of Thule, Greenland), combined with global models, revealed that the first time derivative of the field of internal origin (i.e., the secular variation) also experienced an unusually large increase over the 1990s, by more than 50 nanoteslas per year in the northern component. A detailed analysis of the relationship between geomagnetic secular variation and NMP drift speed has shown that the increase in the secular variation was indeed responsible for about 75% of the increase of the drift speed, the remainder being caused by changes in the local gradient of the main field [Chulliat et al., 2010]. That is, the NMP accelerated primarily because the rate of change of the magnetic field originating in the core suddenly changed at the Earth’s surface in the north polar region.

It is important to note that the NMP position does not seem to have any special physical meaning with respect to the geodynamo. This is unlike geomagnetic poles, which are defined as the intersections of the Earth’s surface with the axis of the dipole part of the core field (Earth’s northern geomagnetic pole is located north of Greenland, and the south geomagnetic pole is antipodal). Geomagnetic poles are distinct from the magnetic poles because the core field is not exactly dipolar. Also, for the same reason, the NMP position on the Earth’s surface cannot be continued radially downward to the core surface and is not even a unique point at the core surface.

Core Plume Hypothesis

Why should scientists and society pay attention to the acceleration of NMP drift? The answer lies in what this acceleration may reveal about the Earth’s core, a region that can be studied only through indirect means. Studies show that the large change in secular variation observed in the north
polar region in the 1990s is mainly caused by a similar change of the secular variation at the core surface in a relatively small area (about 1000 kilometers in diameter) located under the New Siberian Islands (Figure 1b). This can be seen by how the observed main field and secular variation continues downward from the Earth’s surface to the core-mantle boundary (CMB), assuming that the effect of the mantle electrical conductivity is negligible. In fact, analysis of the mathematical function that relates the magnetic field at the CMB to that at the Earth’s surface [Chulliat et al., 2010] shows that the NMP—which is to some degree independent of dynamics vertically under it at the CMB—was at the right place (2000 kilometers from New Siberian Islands) at the right time to bear the full force of the large secular variation change under the New Siberian Islands in the 1990s.

Interpretation of the observed secular variation at the CMB is usually made by solving an inverse problem yielding core surface flows, assuming that magnetic diffusion is negligible on decadal to secular time scales, an assumption referred to as the frozen-flux hypothesis [Roberts and Scott, 1965]. However, inferring core flows that would generate the NMP acceleration proved to be problematic due to the geometry of the secular variation under the New Siberian Islands, which does not seem to be compatible with the frozen-flux hypothesis. Global core field models based upon satellite data indicate that some magnetic flux was expelled from the core in this area during the 1990s (Figures 1c and 1d) through a necessarily diffusive process as shown by Backus [1968].

Further insight into core processes at the origin of the NMP acceleration is provided by recent three-dimensional numerical simulations of the geodynamo. According to some recent models [Aubert et al., 2008], plumes of less dense fluid form at the inner core boundary and subsequently rise within the cylinder tangent to the inner core whose central axis is the Earth’s rotation axis. Such plumes undergo a strong helical motion due to the Earth’s rapid rotation, a phenomenon also observed in laboratory experiments with water [Aurnou et al., 2003]. In the core, helical plumes advect and twist the magnetic field lines, forming what scientists call “polar magnetic upwellings.” Upon reaching the CMB, a polar magnetic upwelling leads to the expulsion of magnetic field lines into the mantle and the formation of a pair of magnetic flux concentrations, detectable as patches of an intense radial field at the core surface, each having a flux opposite to the other. Numerical simulation scaling laws suggest that such magnetic flux expulsion could happen in only a few decades.

The similarity between the CMB radial field pattern from simulations of the dynamo and that observed under the New Siberian Islands is striking. Whether the observed magnetic flux expulsion at the origin of the NMP acceleration could result from such a polar magnetic upwelling remains a hypothesis [Chulliat et al., 2010], the validity of which will have to be assessed by more detailed modeling and numerical simulations. Interestingly, the existence of another magnetic plume was hypothesized under the large patch of field lines directed opposite to its surroundings located under the NMP [Olson and Aurnou, 1999], where some magnetic flux also seems to be expelled from the core, but this plume would not contribute to the NMP drift (according to the mathematical function relating the CMB field to the surface field); for geometrical reasons, only the plume under the New Siberian Islands has an effect on the NMP drift.

Magnetic Flux Expulsions at the Core Surface

The interpretation of the NMP acceleration in terms of magnetic flux expulsion would probably not have been easily accepted only a decade ago. At that time it was widely believed that the frozen-flux hypothesis was valid on decadal to secular time scales and that the contribution of magnetic diffusion to magnetic field variations was only significant on longer time scales. Yet both numerical simulations [Amit and Christensen, 2008] and recent observational studies relying on satellite data [Chulliat and Olsen, 2010] have shown that this hypothesis might be significantly violated in some areas of the core surface, casting doubts about core flows inferred from main field and secular variation observations in these regions.

One such area is located under the southern Atlantic Ocean, where at least two patches of magnetic flux directed opposite to their surroundings are at the origin of a large area of anomalously low field intensity referred to as the “South
Atlantic anomaly. The regular deepening of this anomaly, i.e., the decrease in minimum field intensity and increase in the anomaly size, seems to be related to a regular increase of the magnetic flux being expelled through these two patches at the core surface [Bloxham et al., 1989]. Precise knowledge of the long-term behavior of this anomaly is lacking because prior to 1980 models based on high-quality satellite data did not exist.

Magnetic flux expulsions at the core surface, whether under the South Atlantic anomaly or within the cylinder tangent to the inner core, can be seen as Earth’s analogs of sunspots. Future magnetic satellite missions as well as more sophisticated numerical simulations should lead to a better characterization of this phenomenon and a better understanding of its relationship with deeper geodynamo processes.

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NEWS

Eos Interviews John Holdren, President Obama’s Science Advisor

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With the Obama administration about to face a Republican-led House of Representatives in January, presidential science advisor John Holdren sat down with Eos for an exclusive and wide-ranging interview following a policy speech he delivered on 13 December at the AGU Fall Meeting in San Francisco. During the interview, Holdren, who also is director of the White House Office of Science and Technology Policy (OSTP), focused on the challenging congressional and budgetary environment, the administration’s priorities related to the Earth sciences, and the responsibility of scientists in helping to communicate the societal benefits of science, educate the public, and improve science education and literacy.

Holdren said the Obama administration’s top priorities related to the Earth sciences include improving observations of the Earth, making progress in dealing with climate change, and rebalancing NASA’s focus.

Continuing to invest in and build up the nation’s capacities for Earth observations of all kinds, including from the air, from space, and on and under the oceans, is a top priority, he said. “We don’t yet have the observation networks and capacities that we ought to have to keep track of what’s happening on and to the Earth,” he said.

“That priority on maintaining and expanding the data sets, the observations, the monitoring, is absolutely key. If you don’t do that, you can never make up for it, in the sense that we will never know what the Earth was doing in places and times when we weren’t monitoring it,” aside from through such studies as paleoclimatology, he said.

“We will be ashamed of ourselves if we allow the kinds of data sets from space that we have had from LandSat and we are having from the current generation of polar-orbiting satellites, if we allow those sequences, those series, to lapse. We’ll never forgive ourselves, and our successors in Earth science will never forgive us,” he said.

Regarding climate change, Holdren said the failure in getting comprehensive climate and energy legislation passed during the administration’s first 2 years in office “is discouraging” but that the administration is not giving up on making significant progress in the area.

“I don’t think by any means we have missed the moment. What needs to be recognized is this is not a challenge that is going away. It’s only going to become more obvious,” he said, indicating that 2010 likely will be the hottest or second-hottest year in the instrumental record. “Eventually, everybody is going to catch on.”