Interplanetary Shocks Trigger Magnetic Field Disturbances in Geospace

Researchers from the State Key Laboratory of Space Weather, National Space Science Center (NSSC) have recently reported a puzzling phenomenon of geospace magnetic field changes in response to interplanetary shocks. Contrary to the intuitive view that compressions brought about by interplanetary shocks always lead to an increase of the terrestrial magnetic field, the field may actually decrease in specific regions. By analyzing data from both satellite observation and numerical simulations, the researchers studied the generation mechanism and evolution properties to its dependence on solar wind disturbances, as well as the chain response of magnetic field in geo-space and on the ground.

A solar activity such as coronal mass ejection often drive a discontinuity before it, i.e. the interplanetary shock, just like a high-speed boat which drives a bow shock ahead of it. This shock brings about apparent changes in solar wind parameters such as the density, velocity, etc. on a very short time scale, significantly enhancing the solar wind dynamic pressure. When the shock hits the magnetosphere, which is a protective layer formed by the terrestrial magnetic field preventing the direct entry of solar wind particles to the geo-space environment, it introduces severe perturbations.

Magnetic field in the day-side magnetosphere always shows an abrupt enhancement after the shock arrival, as observed by the spacecraft. However, satellites at the geosynchronous orbit can sometimes observe sudden decrease of the magnetic field in the night-side magnetosphere. This contradicts the intuitive view that interplanetary shocks would always lead to the increase of the magnetic field as they compress the magnetosphere.

In fact, negative response regions where the magnetic field decreases coexist with the positive response ones in which magnetic field increases after the shock impact, as confirmed by both satellite observations and numerical simulations. When the shock passes by the dawn-dusk meridian plane, it tends to drag the magnetic field line anti-sunward. Whereas, the field line has a tendency to return to its original position under the force of the magnetic tension, similar to an elastic string. As a result, flow vortices are aroused in these regions. The magnetic field line “freezes in” with the earthward disturbance flow and thus moves toward the Earth, resulting in the decrease of the magnetic field.

The magnetic field variation observed by a geosynchronous-orbit satellite depends on the position of the negative response region when it originally forms. If it is located relatively closer to Earth and thus covering the night-side geosynchronous orbit, the satellite will record a sudden drop of the magnetic field. However, if it is far on the tail side, the satellite will observe an increase of the magnetic field. The position of the negative response region is determined by the upstream solar wind dynamic pressure. Interplanetary shocks with a larger upstream dynamic pressure correspond to negative response regions closer to Earth.

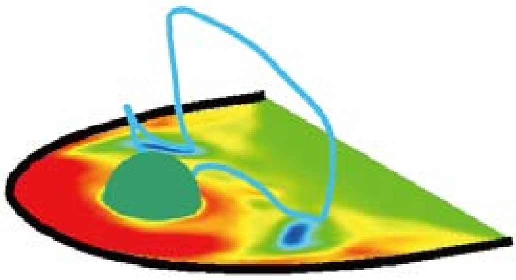

Illustration of the chain response of the magnetic field in the magnetosphere and on the ground. The dark curve marks the boundary of the magnetosphere, and the green sphere is the Earth (not to scale). The red and blue regions are positive and negative magnetic field response regions on the equatorial plane. The electric current generated from the negative response region is shown by the blue curve, flowing into/out of the ionosphere and causing the magnetic field variations on the ground. This forms the chain response of the magnetic field in the magnetosphere and on the ground.

The boundary between negative and positive response regions is a dynamo according to the laws of electromagnetism. The electric current generated by the dynamo flows into and out of the ionosphere along the magnetic field lines, powering the ionospheric current. Then the ionospheric current further leads to the sudden impulse of the magnetic field on the ground during its main phase. Therefore, this forms a chain response of the magnetospheric and ground magnetic field to interplanetary shocks. This connection between widely-separated regions in geospace has been first identified using a powerful 3D global MHD simulation.

“Our systematic study on this interesting phenomenon helps to understand the solar wind-magnetosphere interactions and further predict the geo-space responses to solar activities,” says group leader WANG Chi, who is a researcher and deputy director of NSSC based in Beijing.