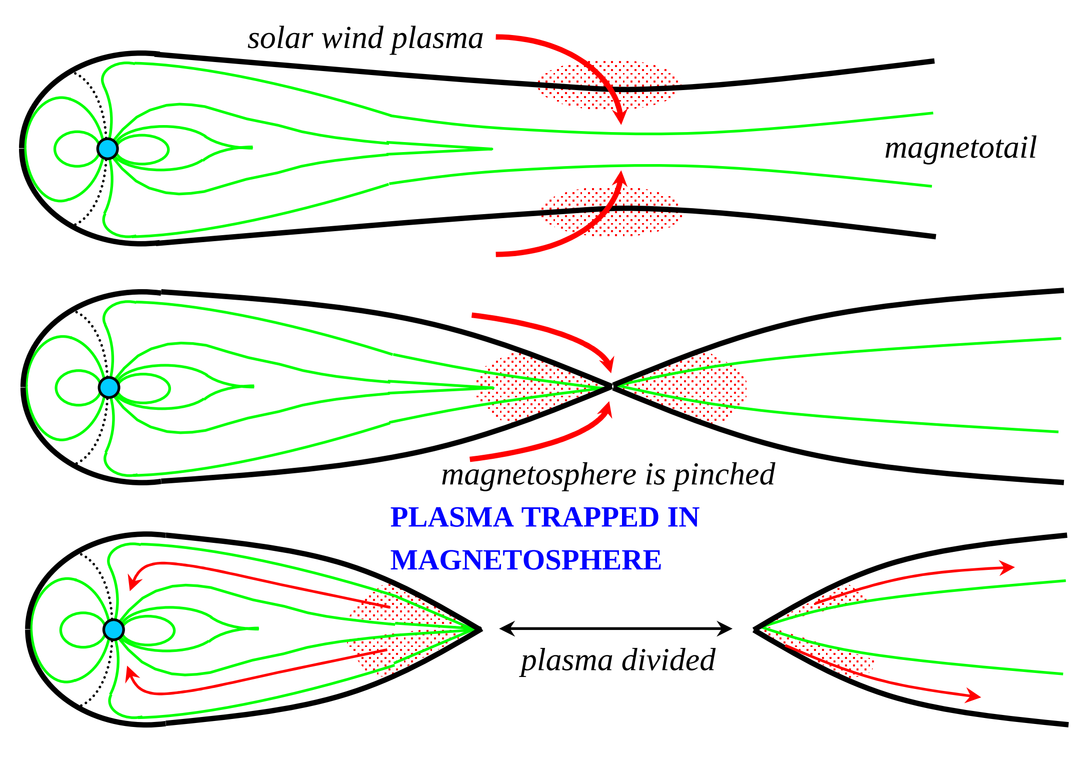
Magnetospheric Activity

Mechanism

Solar Wind and The magnetosphere. The magnetosphere is sensitive to changes in the solar wind, and therefore sensitive to solar activity that affects the solar wind. Changes in the solar wind impact the magnetosphere much like gusty winds shake an open umbrella. A shock wave in the solar wind, for example, can strike the magnetosphere, compressing its nose toward the Earth such that geosynchronous satellites are temporarily outside the magnetosphere and directly exposed to the solar wind. In such a case, the magnetosphere vibrates like a bell and charged particles in the magnetosphere are accelerated to high energies. Many of these particles strike the upper atmosphere and cause a host of communication problems and other operational impacts for days afterward. This impact on the earth's magnetosphere is called a *geomagnetic storm*.

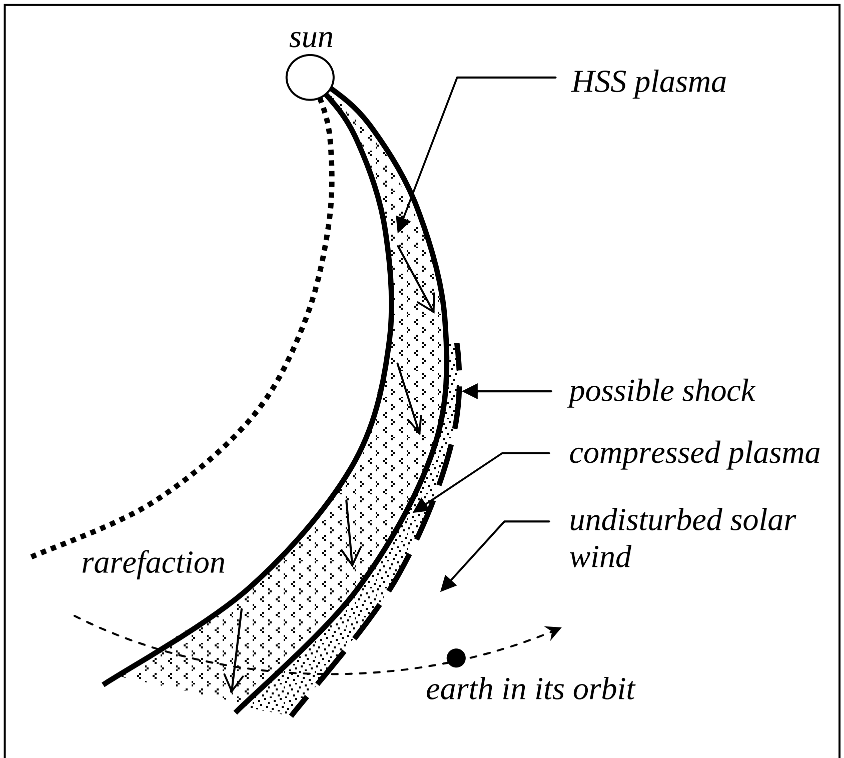
Entrained plasma. Turbulent eddies are thought to allow solar wind particles to enter the magnetosphere in the tail region, especially when discontinuities in the solar wind disturb the geomagnetic field. The figure below shows how solar wind plasma, which has been entrained into the magnetosphere, is squirted sunward toward the night side of the Earth. Since plasma follows magnetic field lines, such entrained plasma is directed into the polar regions and strikes the atmosphere in rings around the magnetic poles, the auroral ovals. Energetic particles striking the atmosphere in this oval cause the discrete aurora. The auroral oval is thicker and brighter on the night side, especially near midnight. This is because the plasma originates in the magnetotail. Weaker daytime aurora does occur and its presence is known from ultraviolet imagery; however, sunlight prevents direct visual observations. This mechanism occurs in spurts called *substorms*.



Plasma Injection into the Auroral Ovals

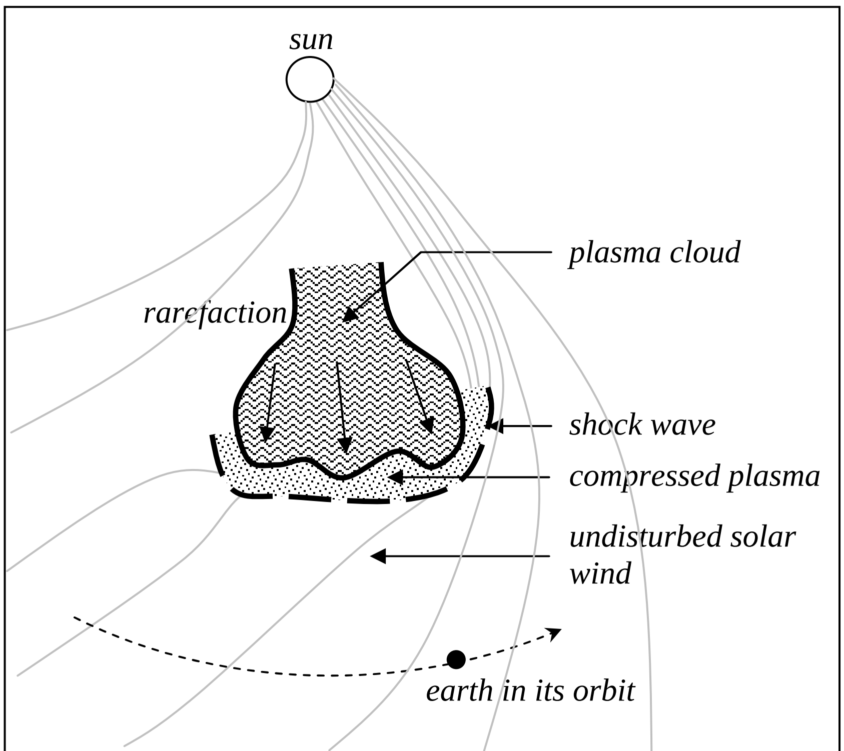
Types of Geomagnetic activity

Recurring geomagnetic activity is caused by high-speed streams (HSS) and solar sector boundary (SSB) crossings. These features are part of the solar wind, whose magnetic field (IMF) sweeps past the earth. A long-lived feature in the solar wind, such as a coronal hole, a high-speed stream, or a solar sector boundary, sweeps past the earth every 27 days or so—the rotation rate of the sun. The diagram at right shows how the earth in its orbit is overtaken by a high-speed stream, which may have a shock wave ahead if it. Geomagnetic storms caused by these recurring features are relatively weak, have a slow onset, and are long-lived.



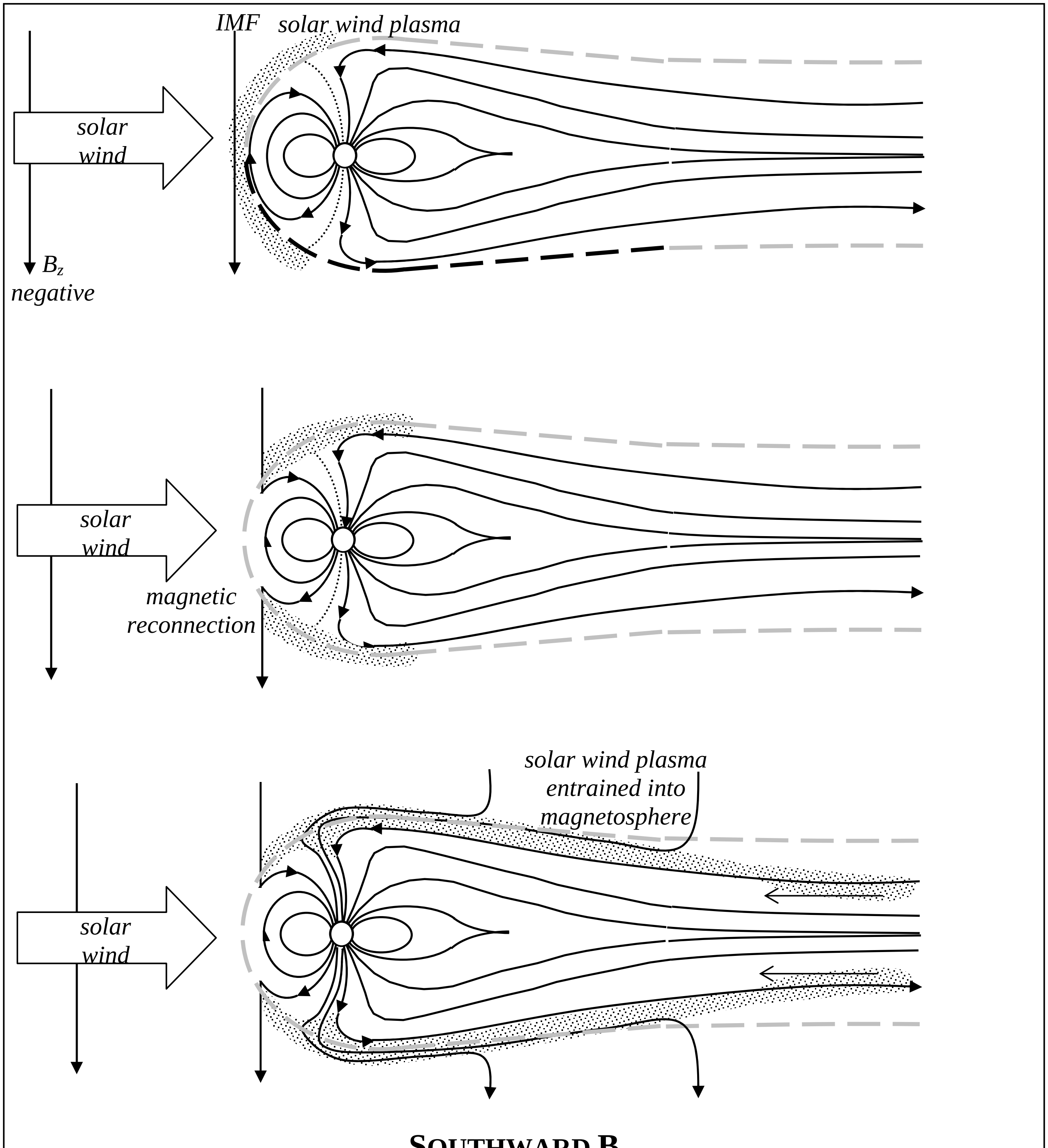
HSS OR SSB IN SOLAR WIND

Sporadic geomagnetic activity is caused by coronal mass ejections (CMEs) and other violent disruptions in the solar wind. These energetic plasma clouds carry their own magnetic fields and so interact dynamically with the earth's magnetic field. The orientation of the magnetic field inside these plasma clouds is crucial in determining whether a significant geomagnetic storm will occur. The diagram at right shows a plasma cloud approaching the earth from the sun, not following the IMF spiral.



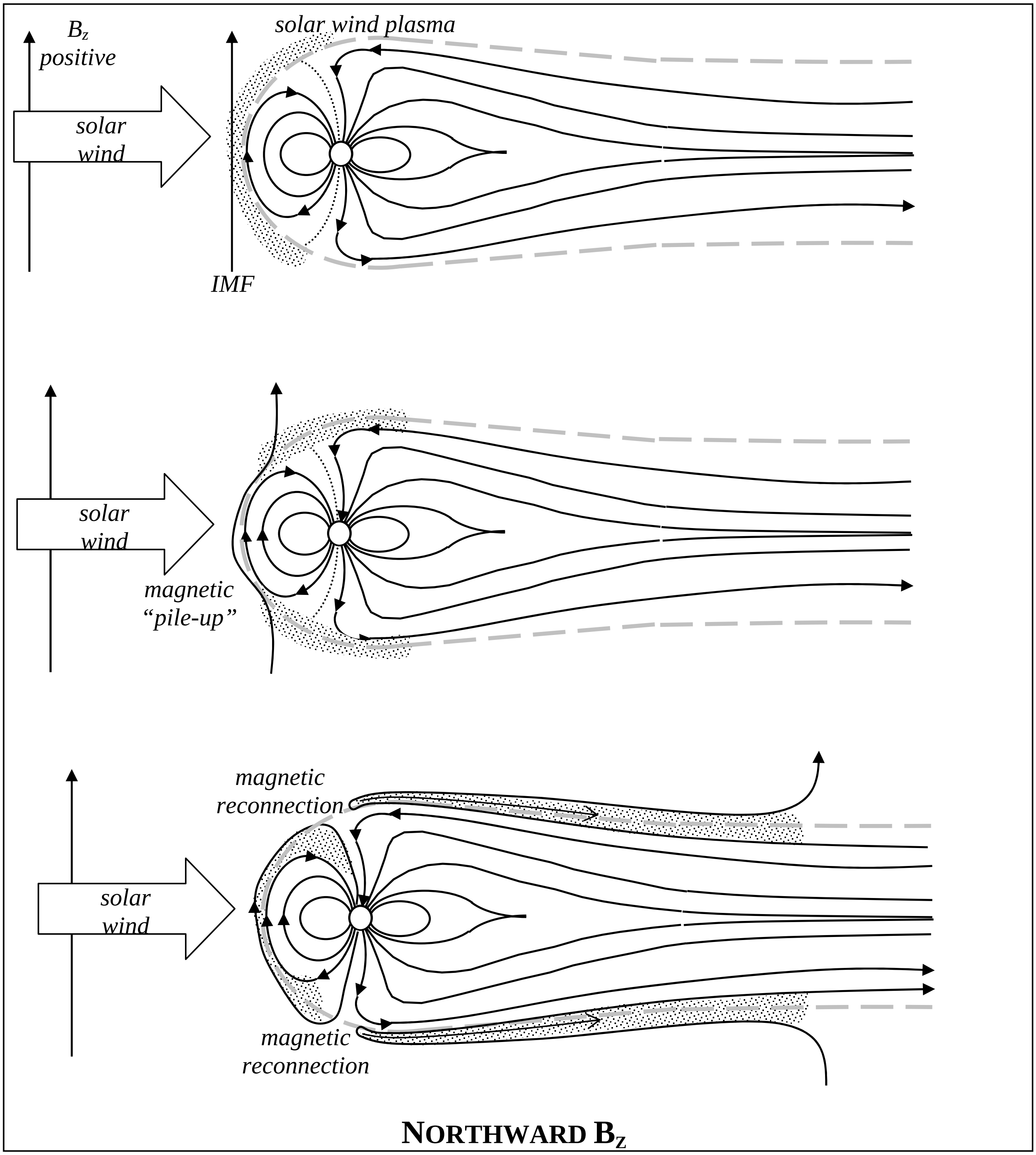
PLASMA CLOUD FROM A MASS EJECTION

Negative B_z (southward). If the IMF or the magnetic field in a plasma cloud has a strong negative B_z component, then it causes a magnetic reconnection event on the "nose" of the magnetopause. Solar wind plasma is readily entrained into the night-side magnetosphere. The entrained plasma in the magnetotail then accelerates toward the earth and causes stunning auroral displays. The following simplified schematic illustrates this mechanism. The exact nature of this mechanism is complicated and under continuing research.



SOUTHWARD B_Z

Positive B_z (northward). If the IMF or the magnetic field in a plasma cloud has a strong negative B_z component, then it causes magnetic field lines to "pile up" on the earth's magnetopause. Magnetic reconnection occurs in the tail region. This accelerates much of the solar wind plasma away from the earth; the remaining is left behind where it is too close to the earth to appreciably accelerate. The exact nature of these mechanisms is extremely complicated and undergoing further research. The following schematic illustrates a possible mechanism for this event.



Geomagnetic Storm Phases

Many geomagnetic storms follow a pattern of development. Let us examine this pattern, using as a example the H and D traces for a geomagnetic storm that occurred on 29 May 1998, which was measured by the magnetometer at Boulder, Colorado (on next page).

Sudden Storm Commencement (SSC). A geomagnetic storm (or "geostorm") begins with a sharp increase in the H component at all latitudes, almost simultaneously observed at all stations. A sudden storm commencement is caused by the arrival of a shock front in the solar wind associated with a high-speed stream (SSB or coronal hole) or mass ejection (CME, DSF, flare). The shock wave compresses the magnetic field of the earth inward, causing the field strength to increase globally. The arrival of the shock front itself is not, in itself, sufficient to cause the onset of a geo magnetic storm. Of more importance is the IMF orientation of B_z. A north-to-south turning of the B_z component (or a sudden intensity increase in the B_z component) is much more effective than a south-to-north turning of B_z.

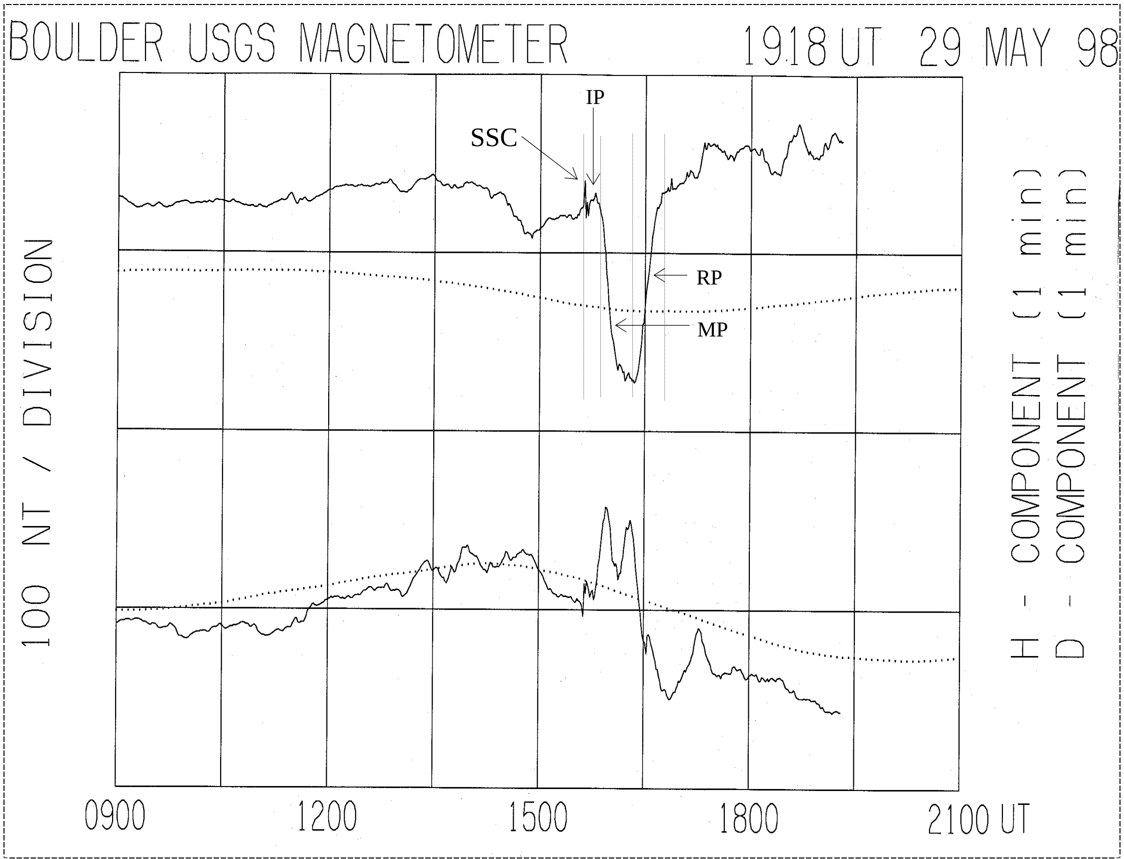
Initial Phase (IP). For about ½ to several hours the H component may remain above pre-storm values. The initial phase is caused by the earth's magnetosphere being submerged in the post-shock plasma, which is high-speed, high density, and has a relatively high magnetic field strength.

Main Phase (MP) begins with a decrease in the H component, typically lasting several hours to more than a day. The main phase is caused by an enhanced ring current, which, on its earthward side, generates a magnetic field that opposes the geomagnetic field. This ring current field is detected by ground-based magnetometers as a *decrease* in the H component, especially at low to mid latitudes. Accompanying the enhanced ring current is an enhanced auroral electrojet, which causes the high latitude portion of the geomagnetic storm.

The ring current and auroral electrojet aren't continually enhanced during a geomagnetic storm. They are pumped up during "substorms," which typically last 1 – 3 hours apiece separated by periods of lower activity of 2 – 3 hours. Subsequent substorms during the main phase of the geomagnetic storm continue to enhance the ring current and auroral electrojet, causing further decreases in the H component.

Recovery Phase (RP). A slow recovery of the H component to pre-storm levels typically occurs over a period of hours to several days. Once the disturbance in the solar wind passes, the substorm charging of the ring current and the auroral electrojet will cease. The ring current will gradually return to normal pre-storm levels. The stronger the geomagnetic storm, the closer the ring current will move to the earth and the *faster* the recovery. The weaker the storm, the *slower* the recovery.

The trace below shows a fairly strong, but short, geomagnetic storm (as measured by the magnetometer at Boulder, Colorado). The sudden storm commencement (SSC) occurred around 1540Z. The initial phase (IP) lasted about ½ hour. The main phase (MP), which saw the H component of the earth's magnetic field drop almost 100 nT, lasted another ½ hour or so, then the recovery phase (RP) lasted about an hour. A magnetometer located near the geomagnetic equator would have seen these features persist longer.


BOULDER USGS MAGNETOMETER
1918 UT 29 MAY 98
IP
SSC
RP
MP
100 NT / DIVISION
H - COMPONENT (1 min)
D - COMPONENT (1 min)
0900
1200
1500
1800
2100 UT