

# Teacher's Guide

# Anatomy of a CME Storm

## Introduction

Coronal Mass Ejections (CMEs) are large clouds of gas ejected into space by the Sun which disable satellites, and can even cause power outages. Many of these CMEs cannot be easily detected on the solar surface so that adequate warning can be provided. NASA has begun to use satellites placed in orbit between the Earth and the Sun to provide early warning for detecting 'stealthy' CME events less than 1 hour from arrival at Earth. This exercise lets students analyze simplified data obtained from the SOHO and WIND satellites during the January 10, 1997 CME event which may have damaged a billion-dollar AT&T satellite.

## Objective

Students will compare and interpret four graphs involving the Speed, Temperature, Magnetic Field Strength and Density of a CME event.

## Procedure

1) Because there are four different graphs for the students to analyze, this activity lends itself to a 'Four Corners'-style of execution. Divide the students into four groups in different parts of the room, and assign each group a specific graph to interpret. Have the students determine what happens to their respective graph as the CME Front passes.

2) Have individually prepared transparencies of the graphs (suggestion; make a copy and cut it apart for the groups). Have each group present their findings to the class.

3) Have prepared transparencies of all the graphs. Facilitate a discussion of the combined results using the transparency and the summary of the graph events. For a concluding event you may wish to discuss 'Combining the Clues'.

## Materials

- Graph paper
- Prepared transparencies
- Graph Summaries
- Combining the Clues

## Summary

The students should determine that the Temperature dropped 50,000 C as the CME Front passed the satellites, and then it rose sharply as the satellites were inside of the cloud. The Density remained constant as the CME Front passed, then it rose sharply inside the CME Front, then dropped below the solar wind value before rising back to the normal solar wind level. The Speed was constant at the solar wind-level until the CME passed, then the satellites were affected by the fast moving gas inside the CME cloud. The Magnetic Field in the CME Front was three times higher than the average solar wind value which is near 5 nT. The CME Front traveled at about 600 kilometers/sec (about two million miles/hour) so that for spacecraft at one million miles from Earth, the 'ETA' time is about 30 minutes.

## Key Terminology:

**Solar Wind:** A flow of matter from the surface of the Sun passing through interplanetary space.

**CMEs:** Coronal Mass Ejections, which are sudden ejections of matter from the Sun's outer layers.

## Graph Summaries:

**Temperature:** This trace shows a 50,000 C dip in the temperature of the leading edge of the cloud between January 10 and January 11. This is followed by a sharp rise in the gas temperature inside the cloud, which then decreased the farther the leading edge of the CME cloud was from the satellite. The typical solar wind temperature is about 100,000 C.

**Density:** There was little change in the density of the gas near the satellite until January 11. When the satellites encountered the interior of the CME, just behind the leading edge, it appears there was a 'wall' of high-density gas. Directly behind this wall is a low density cavity which contained nearly half the density of the gas typically detected in the solar wind.

**Speed:** The satellites detected the steady flow of the solar wind at about 450 kilometers/sec. Once the satellites were inside the main body of the CME cloud on January 11, they encountered the fast moving gas with speeds of 600 km/sec. This continued to be the case until the back of the cloud passed the satellites on January 12. Then, the contact with the slower-moving, normal solar wind flow was re-established.

**Magnetic Field:** Before January 10, the satellites were in contact with the solar wind's magnetic field which had a strength of about 5 nT (The unit 'nT' means nanoTesla and is a measure of magnetic field strength. The Earth's magnetic field is 50,000 nT at the surface). As the satellites encountered the leading edge of the CME between January 10 and January 11, the magnetic field tripled in strength. It then returned to the normal solar wind level after the back-side of the CME Front was encountered on January 11.

## Combining the Clues:

Once the students have interpreted each trace, we can combine them into a simple model of the CME cloud, but not what the entire cloud looks like in three dimensions.

The solar wind, in this instance, has a temperature near 100,000 C, a density of about 10 particles per cubic centimeter, a speed near 400 kilometers/sec, and a magnetic field strength of 5 nT.

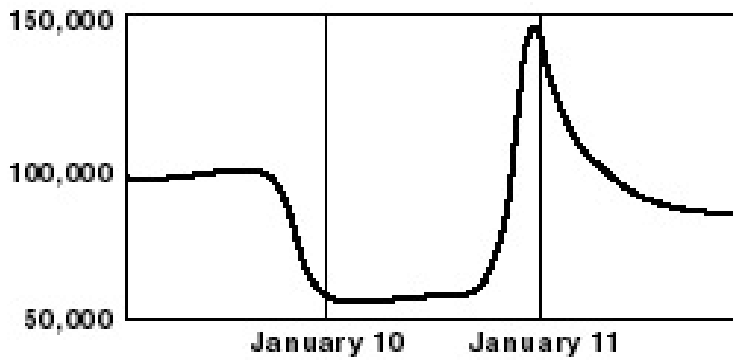
The leading edge of the CME contains a strong magnetic field. Although there is no change in the gas density and the solar wind speed, the entire magnetic field of the CME seems to be concentrated there. The magnetic field is responsible for the drop in solar wind temperature in this region. Scientists call this the CME 'magnetic cloud' region.

The back edge of this 'magnetic cloud' coincides with a sharp increase in gas density and temperature which defined the CME cloud boundary in what scientists call a 'shock front'. Behind this shock front there is a fast-moving, but low density gas. In the interior of the CME cloud 'bubble' region, the gas density decreases with distance from the shock front, until it eventually returns to the temperature of the solar wind. Behind the fast-moving interior bubble is the back-side of the CME which is where the conditions have returned to those of the normal solar wind.

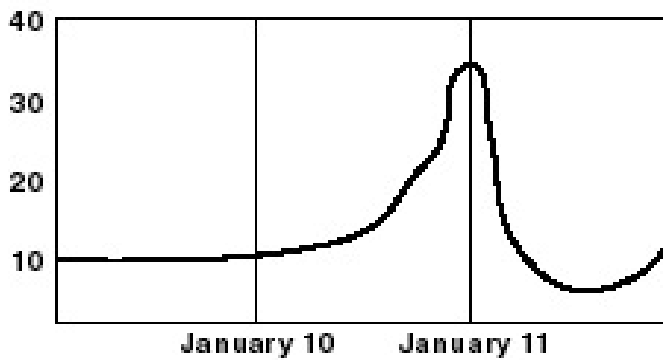
Traveling at a top speed of 500 kilometers/sec, the entire cloud took two days to pass the satellites. This means the thickness of the CME was about 86 million kilometers ( 500 km/sec x 2 days x 86,400 sec/day). This is about half the distance between the Sun and the Earth. Since the satellites were located about two million kilometers from the Earth, it took the cloud only about 30 minutes to reach the Earth on January 12.

Name \_\_\_\_\_

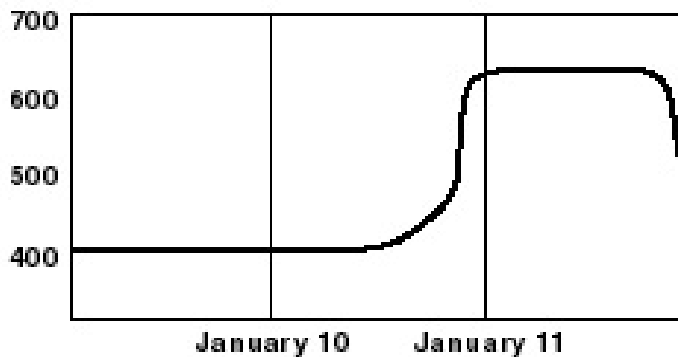
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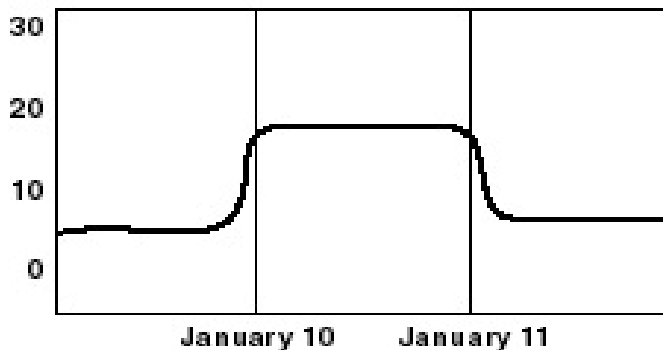
**Temperature**  
(in degrees Celsius)



**Density**  
(in particles per cubic centimeter)



**Speed**  
(in kilometers/second)



**Magnetic Field**  
(in nanoTeslas)