Six years in space for THEMIS: Understanding the magnetosphere better than ever

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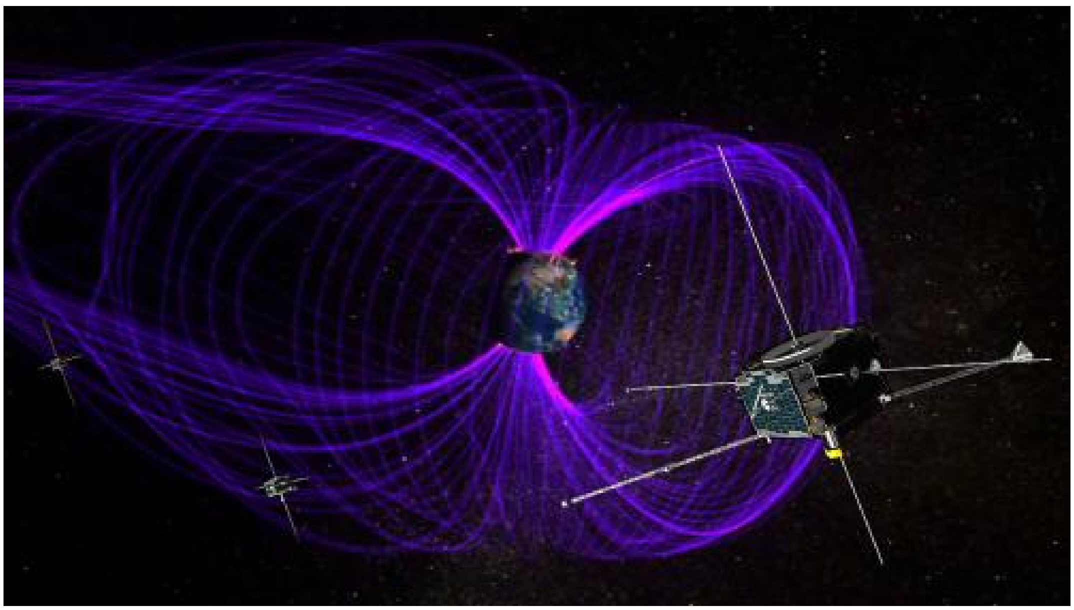


Earth is surrounded by a giant magnetic bubble, called the magnetosphere. Over six years in space, five spacecraft from the THEMIS mission have helped map out this area and improve our ability to predict dynamic space weather events – events that at their worst can impact satellites in space. Credit: NASA

(Phys.org)—On Earth, scientists can observe weather patterns, and more importantly can predict them, through the use of tens of thousands of weather observatories scattered around the globe. Up in the space surrounding Earth—a space that seethes with its own space weather made of speeding charged particles and constantly changing magnetic fields that can impact satellites – there are only a handful of spacecraft to watch for solar and magnetic storms. The number of observatories has been growing over the last six years, however. Today these spacecraft have begun to provide the first multipoint measurements to better understand space weather events as they move through space, something impossible to track with a single spacecraft.

Helping to anchor that team of spacecraft is a NASA mission called THEMIS (Time History of Events and Macroscale Interactions during Substorms). THEMIS launched on Feb. 17, 2007, with five nearly identical spacecraft nestled inside a Delta II rocket. Simply orchestrating how to expel each of the five satellites without unbalancing the rocket was an engineering tour de force – but it was only the preamble. Over time, each spacecraft moved into formation to fly around Earth in a highly-elliptical orbit that would have them travelling through all parts of Earth's space weather environment, a giant magnetic bubble called the magnetosphere. With five different observatories, scientists could watch space weather unfold in a way never before possible.

In its sixth year in space, scientific papers using THEMIS data helped highlight a number of crucial details about what causes space weather events in this complex system.

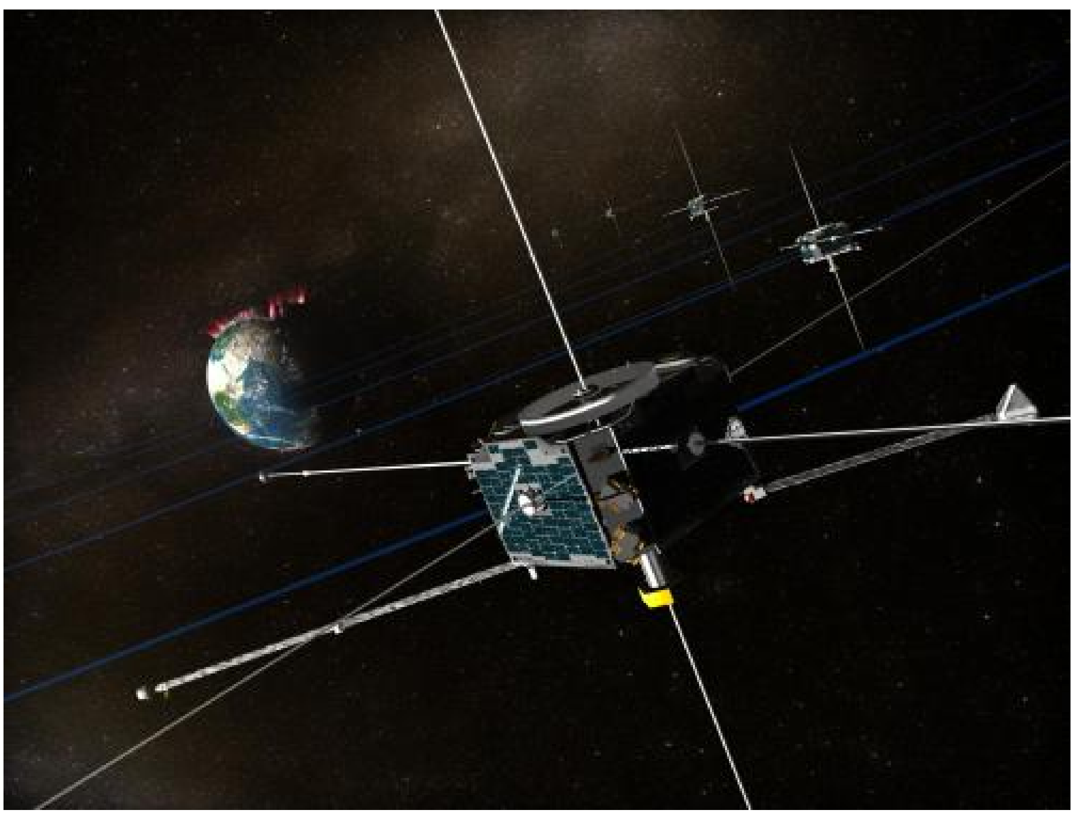
"Scientists have been trying to understand what drives changes in the magnetosphere since the 1958 discovery by James Van Allen that Earth was surrounded by rings of radiation," says David Sibeck, project scientist for THEMIS at NASA's Goddard Space Flight Center in Greenbelt, Md. "Over the last six years, in conjunction with other key missions such as Cluster and the recently launched Van Allen Probes to study the radiation belts, THEMIS has dramatically improved our understanding of the magnetosphere."

Since that 1958 discovery, observations of the radiation belts and near Earth space have shown that in response to different kinds of activity on the sun, energetic particles can appear almost instantaneously around Earth, while in other cases they can be wiped out completely. Electromagnetic waves course through the area too, kicking particles along, pushing them ever faster, or dumping them into the Earth's atmosphere. The bare bones of how particles and waves interact have been described, but with only one spacecraft traveling through a given area at a time, it's impossible to discern what causes the observed changes during any given event.

"Trying to understand this very complex system over the last 40 years has been quite difficult," says Vassilis Angelopoulos, the principal investigator for THEMIS at the University of California in Los Angeles (UCLA). "But very recently we have learned how even small variations in the solar wind – which buffets Earth's space environment at a million miles an hour—can sometimes cause extreme responses, causing more particles to arrive or to be lost."

Near Earth, THEMIS has now traveled through more than 50 solar storms that caused particles in the outer radiation belts to either increase or decrease in number. Historically, it has been difficult for scientists to find commonalities between such occurrences and discover what, if anything consistently caused an enhancement or a depletion. With so many events to study, however, and a more global view of the system from several spacecraft working together – including, in this case, ground based observations and NOAA's GOES (Geostationary Operational Environment Satellites) and POES (Polar Operational Environmental Satellites) data in addition to THEMIS data – a team of scientists led by Drew Turner at UCLA could better characterize what processes caused which results.

Turner's group recently presented evidence linking specific kinds of electromagnetic waves in space – waves that are differentiated based on such things as their frequencies, whether they interact with ions or electrons, and whether they move along or across the background magnetic fields – to different effects. Chorus waves, so called because when played through an amplifier they sound like a chorus of singing birds, consistently sped up particles, leading to an increase in particle density. On the other hand, two types of waves known as hiss and EMIC (Electromagnetic Ion Cyclotron) waves occurred in those storms that showed particle depletion. Turner also observed that when incoming activity from the sun severely pushed in the boundaries of the magnetosphere this, too, led to particle drop outs, or sudden losses throughout the system. Such information is helpful to those attempting to forecast changes in the radiation belts, which if they swell too much can encompass many of our spacecraft.



An artist's concept of the THEMIS spacecraft orbiting around Earth. Credit:

NASA

Another group has a paper in print in 2013 based on 2008 data from the five THEMIS spacecraft in conjunction with three of NOAA's GOES (Geostationary Operational Environmental Satellites) spacecraft, and the ESA/NASA Cluster mission. Led by Michael Hartinger at the University of Michigan in Ann Arbor, this group compared observations at the bow shock where the supersonic solar wind brakes to flow around the magnetosphere to what happens inside the magnetosphere. They found that instabilities drive perturbations in the solar wind particles streaming towards the bow shock and that these perturbations can be correlated with another type of magnetized wave – ULF (ultra low frequency) waves—inside the magnetosphere. ULF waves, in turn, are thought to be important for changes in the radiation belts.

"The interesting thing about this paper is that it shows how the magnetosphere actually gets quite a bit of energy from the solar wind, even by seemingly innocuous rotations in the magnetic field," says Angelopoulos. "People hadn't realized that you could get waves from these types of events, but there was a one-to-one correspondence. One THEMIS spacecraft saw an instability at the bow shock and another THEMIS spacecraft then saw the waves closer to Earth."

Since all the various waves in the magnetosphere are what can impart energy to the particles surrounding Earth, knowing just what causes each kind of wave is yet another important part of the space weather puzzle.

A third interesting science paper from THEMIS's sixth year focused on features originating even further upstream in the solar wind. Led by Galina Korotova at IZMIRAN in Troitsk, Russia, this work made use of THEMIS and GOES data to observe the magnetosphere boundary, the magnetopause. The researchers addressed how seemingly small perturbations in the solar wind can have large effects near Earth. Wave-particle interactions in the solar wind in the turbulent region upstream from the bow shock act as a gate valve, dramatically changing the bow shock orientation and strength directly in front of Earth, an area that depends critically on the magnetic field orientation. The extreme bow shock variations cause undulations throughout the magnetopause, which, launch pressure perturbations that may in turn energize particles in the Van Allen radiation belts.

All of this recent work helps illuminate the nitty gritty details of how seemingly small changes in a system can lead to large variations in the near-Earth space environment where so many important technologies – including science, weather, GPS and communications satellites all reside.

Much of this work was based on data from when all five spacecraft were orbiting Earth. Beginning in the fall of 2010, however, two of the THEMIS spacecraft were moved over the course of nine months to observe the environment around the moon. These two satellites were renamed ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun). In their new position, the two ARTEMIS spacecraft spend 80% of their time directly observing the solar wind, offering a vantage point on this area outside our magnetosphere that is quite close to home.

The THEMIS spacecraft continue to work at their original levels of operation and all the instruments function highly effectively. With their current positioning and the ability to work in conjunction with other nearby spacecraft, scientists look forward to the stream of data yet to come.

"What we have with THEMIS and ARTEMIS and the Van Allen Probes, is a whole constellation we are developing in near-Earth space," says

Turner. "It's crucial for developing our forecasting ability and getting a better sense of the system as a whole."

THEMIS is the fifth medium-class mission under NASA's Explorer Program, which was conceived to provide frequent flight opportunities for world-class scientific investigations from space within the Heliophysics and Astrophysics science areas. The Explorers Program Office at Goddard manages this NASA-funded mission. The University of California, Berkeley's Space Sciences Laboratory and Swales Aerospace in Beltsville, Md., built the THEMIS probes.

More information: For more information about the associated missions, visit:

- THEMIS website
- ARTEMIS website
- Van Allen Probes website

Provided by NASA

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