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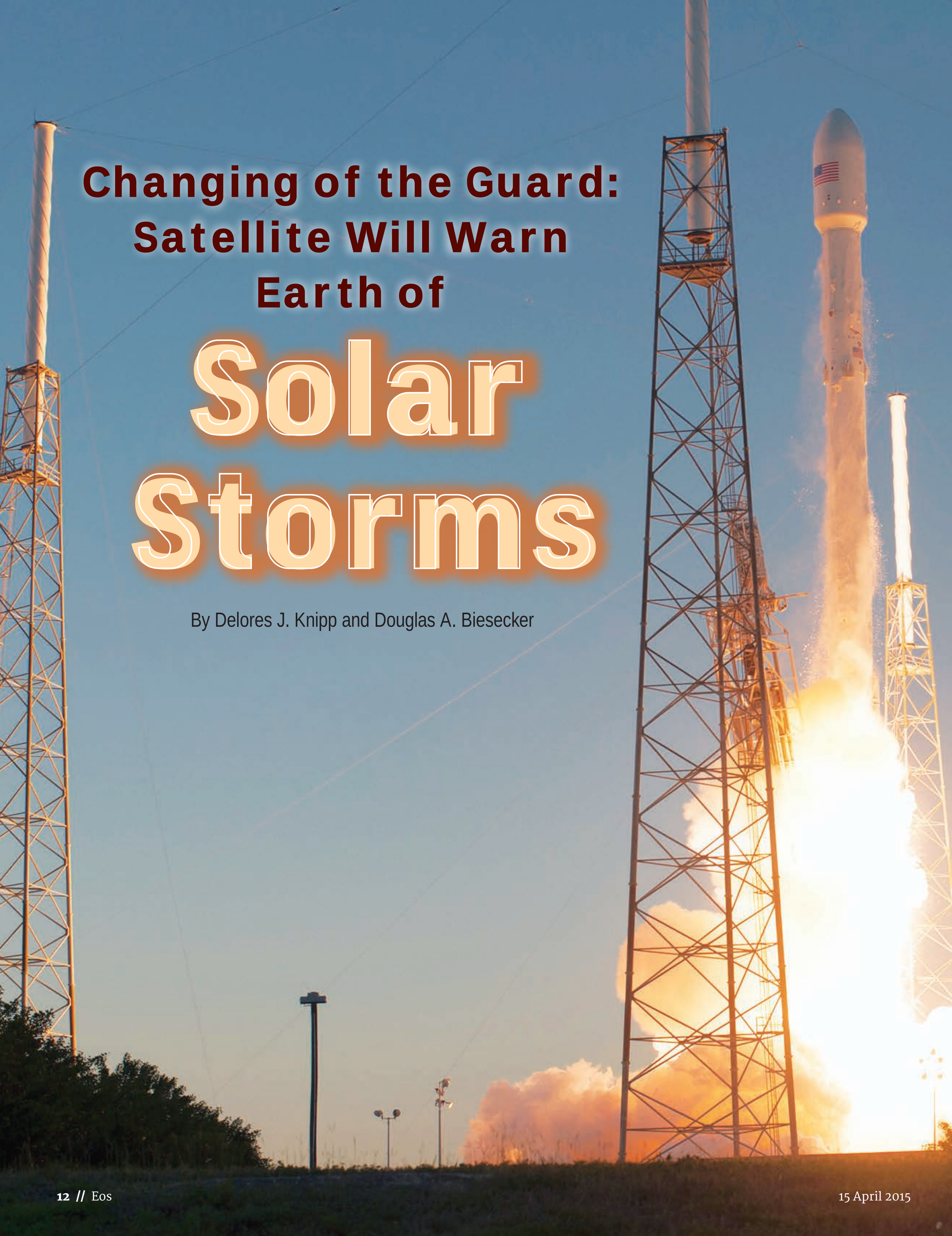
Changing of the Guard: Satellite Will Warn Earth of Solar Storms

By Delores J. Knipp and Douglas A. Biesecker



This summer, Earth gets a new guardian—the Deep Space Climate Observatory—to help warn astronauts and operators of critical planetary infrastructure about the Sun's raging magnetic storms.

When the Sun unleashes its magnetic fury in the form of solar storms, it pays to have warning. The most powerful of solar storms, if they strike Earth's magnetic field, can block communications, destabilize power grids, damage satellites, and force astronauts aboard the International Space Station to take shelter to avoid harmful radiation doses.

In July, Earth's new sentinel in space, the Deep Space Climate Observatory (DSCOVR), is expected to be fully operational. DSCOVR will hover between the Earth and Sun to monitor the solar wind and warn of looming space weather storms. Launched on 11 February 2015 from Cape Canaveral, the satellite (Figure 1, top) is currently on a 116-day journey to its new interplanetary home—the L1 libration point, where forces balance between the Sun and Earth (Figure 1, bottom).

There, roughly 1.5 million kilometers (932,000 miles) upwind from Earth, DSCOVR will become the U.S. National Oceanic and Atmospheric Administration's (NOAA) primary solar wind monitoring sentinel, taking over from NASA's venerable Advanced Composition Explorer (ACE), which has been stationed at L1 since the late 1990s. At L1, a sentinel spacecraft can detect disturbances in the solar wind roughly 15 to 60 minutes before they strike Earth,

NASA/Tim Powers & Tony Gray

The 11 February launch of the Deep Space Climate Observatory (DSCOVR).

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providing valuable lead time for NOAA's space weather alerts and forecasts.

DSCOVR represents an important partnership between NOAA, NASA, and the U.S. Air Force to ensure the continuity of space weather information and forecasting.

The Origins of DSCOVR

DSCOVR, formerly known as Triana, was originally conceived in 1998 as a mission to monitor Earth's climate with a secondary mission to observe aspects of space weather. Lacking a ride to space, NASA put Triana into environmentally controlled storage at Goddard Space Flight Center in Maryland. It might still have been there today were it not for the multiagency interest in the craft's secondary mission: monitoring space weather.

The Space Weather Threat

Long considered interesting from a physical science perspective, space weather has also become a pressing civil and military issue addressed in many publications (e.g., http://bit.ly/AGU_SW). Humans have grown more dependent on electronics, space-based global navigation and civil and military communications, transcontinental airline flights over the poles, and interconnected power grids. All of these systems are exposed to the whims of the Sun's magnetized atmosphere, which can affect Earth's tenuous upper atmosphere and surrounding magnetic field.

NOAA is tasked with protecting life and property and monitoring day-to-day and long-term changes in the space environment. To that end, NOAA's Space Weather Prediction Center (SWPC) operates 24/7, providing real-time civil space weather forecasts and information to the nation. SWPC personnel work closely with partner centers in other countries such as Australia, South Korea, and the United Kingdom.

Since the mid-1970s, NOAA satellites in geostationary orbit (called Geostationary Operational Environment Satellites (GOES)) have monitored two forms of these dangerous disturbances. The most common are solar flares, flashes of intense radiation from the Sun's atmosphere created when local regions of its coiled magnetic field suddenly and violently reconfigure into a new shape. These can disrupt high-frequency radio communications on the dayside of Earth. Sometimes the Sun can also eject high-energy protons from its atmosphere, which, if aimed at Earth, can damage satellites, disrupt radio communications in the polar regions, and increase radiation risk to astronauts and passengers on transpolar flights.

At L1, DSCOVR will be in position to monitor the large-scale eruptions of the Sun's magnetic field that blast into interplanetary space, known as coronal mass ejections (CMEs), as well as other disturbances that develop in the solar atmosphere and its extension, the solar wind. As a particularly potent third form of space weather, CMEs are potentially very disruptive to Earth's space environment. The fastest of these can reach Earth in less than a day and generate currents that flow along magnetic field lines into the upper atmosphere, where they can deposit vast amounts of energy.

The obvious visible manifestation of these solar wind disturbances is the aurora, but there are numerous other effects. During the worst of storms, these effects include causing satellites to lose altitude by increasing their drag, inducing currents in power grids that can reduce their capacity or cause them to fail, degrading the accuracy of satellite navigation systems such as GPS, and causing aircraft that use the Federal Aviation Administration's GPS-reliant Wide Area Augmentation System for precision flight approaches to rely on the older, more limited Instrument Landing System.

Reviving DSCOVR

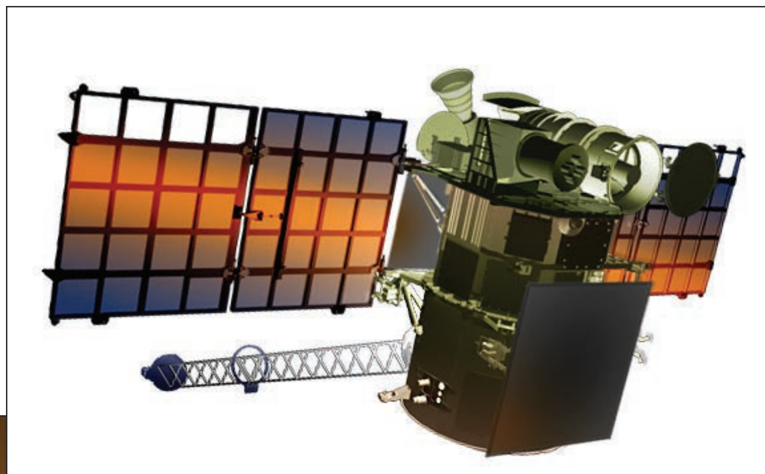
In the mid-2000s, as space weather became a growing societal concern—and as NASA's ACE mission aged well beyond its intended lifespan—the three agencies recalled Triana's space weather capabilities and sought to revive the carefully stored craft, since renamed DSCOVR. Under a series of interagency agreements, NOAA funded NASA to refurbish the satellite for a primary space weather mission while retaining most of the instruments to perform climate monitoring as a secondary role. The U.S. Air Force funded the Falcon 9 launch vehicle through its launch services contract with the commercial space company SpaceX, and NOAA became responsible for mission operations.

To ready the craft for its new job, NASA installed new electrical components and a fresh battery and recalibrated all of the science instruments. In addition, the agency relocated the position of some space weather instruments to ensure that the highest-priority measurements would meet NOAA requirements.

DSCOVR's Solar Instruments

DSCOVR's three solar wind sensors are collectively known as PlasMag. The first is a Faraday cup—a conductive metal cup that measures the solar wind's positive ions—and the second is a "top-hat" electron spectrometer that provides high temporal resolution observations of the electrons in the solar wind. Together, they collect data on the solar wind's speed, temperature, and density.

Finally, a magnetometer senses the strength and direction of the magnetic field embedded in the solar wind plasma. This information is important to



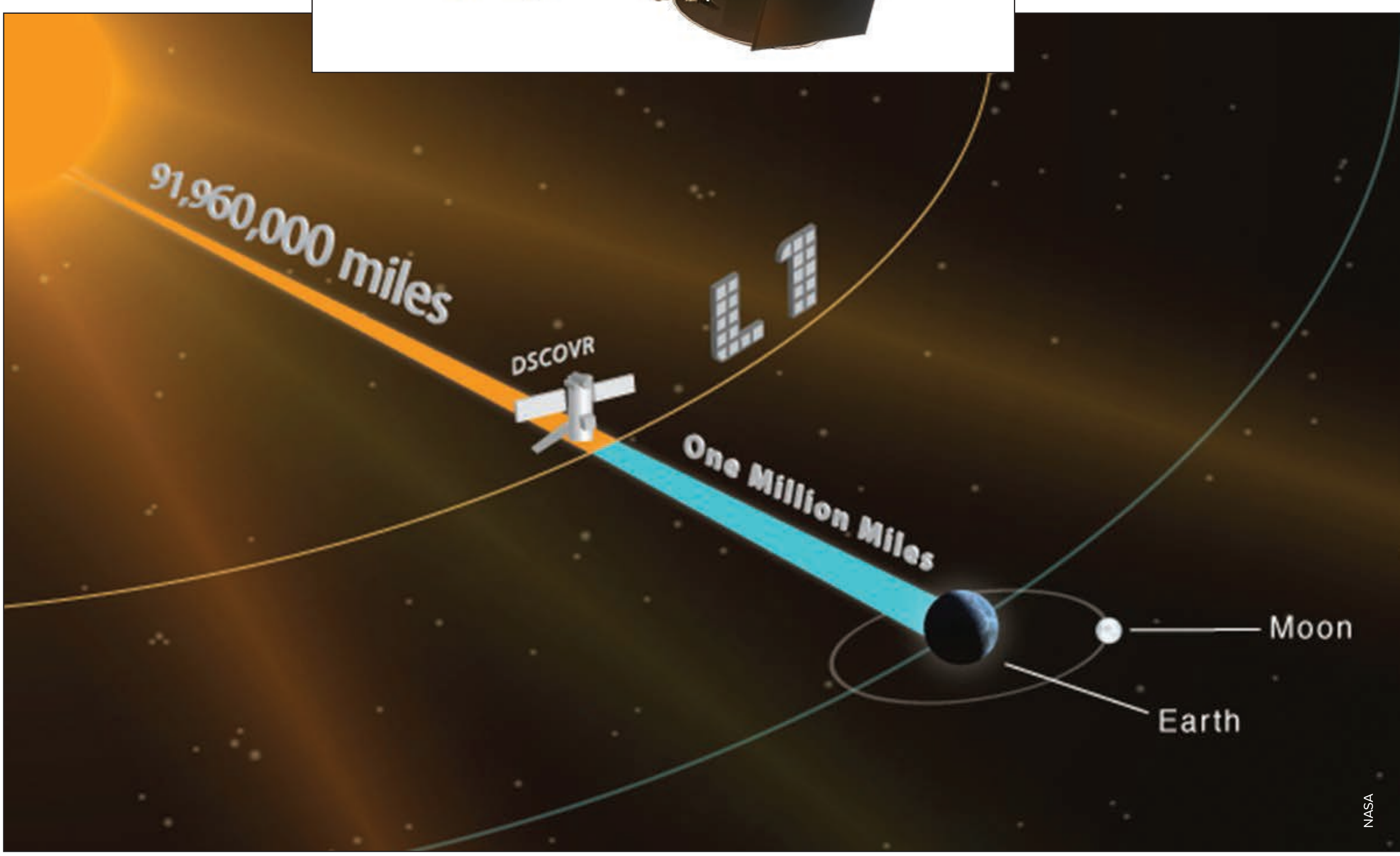


Fig. 1. (top) An artist's rendering of the Deep Space Climate Observatory (DSCOVR) satellite, which will detect potentially hazardous solar storms on their way to Earth and provide up to 60 minutes of early warning. (bottom) DSCOVR will be located roughly 1.5 million kilometers (932,000 miles) away from the Earth at the L1 libration point, where the balance of gravitational and centripetal forces allows satellites to remain in nearly stable orbit. At L1, DSCOVR can hover in place with a minimum amount of fuel consumption.

forecasters because it determines how the Sun's magnetic field connects to Earth's magnetic field. If the fields are in opposite directions, they can merge more easily, thus allowing solar wind energy access to Earth's space environment. Knowing the solar wind magnetic field orientation is crucial for accurate short-term space weather forecasts.

Replacing ACE

DSCOVR's observations will maintain the continuity of observations of the solar wind at L1, which is essential for space weather forecasting, and it will also bring some improvements over ACE's capabilities. Powerful storms sometimes saturated the ACE plasma sensor. With DSCOVR, NOAA expects to have data coverage for all but portions of the rarest, most severe space weather events.

In addition, measurements of the solar wind will be made at a cadence several times faster than ACE's. NOAA will be providing averages of these high-cadence data every second for the magnetometer and every 3 seconds for the Faraday cup. As with NASA's ACE, NOAA will publicly release the PlasMag data to scientists for sensor calibration, validation, and research purposes.

As DSCOVR transits to L1, its space weather instruments are operational and performing well. Scientists from NASA, NOAA, and the Harvard Smithsonian Astrophysical Observatory are comparing DSCOVR's transit data with similar observations from ACE and NASA's Wind spacecraft—which focuses on measuring solar wind dynamics at L1—with encouraging results.

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An Earth Observatory Realized

DSCOVR's original mission—to act as an Earth climate observatory—has also been revived. For this investigation, DSCOVR carries two instruments designed to work in tandem.

One is a radiometer called the National Institute of Standards and Technology Advanced Radiometer (NISTAR). It will measure the total amount of sunlight that Earth reflects and the energy it emits on its sunlit face.

The second is the Earth Polychromatic Imaging Camera (EPIC), which will provide global images of Earth's dayside in numerous wavelength filters. EPIC's observations will be used to measure ozone and aerosols in the atmosphere, to measure properties of clouds and land and vegetation, and to estimate the amount of ultraviolet radiation at Earth's surface.

By combining EPIC's images with NISTAR's radiation measurements, scientists hope to better understand how aerosols and clouds affect the balance of radiation striking and leaving the Earth. EPIC's snapshots of the whole Earth will also be posted online.

Maintaining Vigilance

Upon DSCOVR's arrival at L1 in early June, NASA will test and calibrate its instruments for 40 days. If all goes as planned, the satellite will be turned over to NOAA, and SWPC will begin using DSCOVR as its primary solar wind sentinel in mid- to late July 2015. The mission will last at least 5 years.

The main limitation is propellant, which was sized for a 5-year life. However, the launch trajectory provided by SpaceX was near perfect, and fuel usage on the way to L1 is coming in under budget. Once DSCOVR is in orbit, a better determination of the fuel-constrained lifetime will be possible.

Plans are already afoot to ensure solar wind data remain flowing from L1 after the DSCOVR mission ends. A replacement, known as the Space Weather Follow-on, is planned to take over. The replacement mission is proposed in President Obama's fiscal year 2016 budget request and will provide continuity of solar-observing data products essential for space weather specification and forecasting.

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