Space Weather Forecasting Active Region 12371

Science, Code 674

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Abstract

Space weather forecasting addresses NASA's interests by assisting scientific research with the production of data, measurements, and models of the solar activity that drives space weather. Forecasting is also necessary to protect NASA's assets, as space weather can damage technological infrastructure, including the power grid, satellites, and other spacecraft. Some space weather events include solar flares, coronal mass ejections (CMEs), and high speed streams (HSS). This project analyzes the solar activity of active region (AR) 2371, which rotated onto the Earth-facing solar disk on June 16, 2015 and produced many space weather events that forecasters measured, modeled, and reported. The Integrated Space Weather Analysis system (iSWA), which is comprised of various cygnets that access real-time data and innovative models, was utilized to forecast the activities of AR 2371. In the case of CMEs, measurements were made utilizing programs including SWPC_CAT and STEREO_CAT. Forecasters sent notifications from the Space Weather Database Of Notifications, Knowledge, Information (DONKI), where the events are stored for later use by forecasters and researchers. The project goes into detail about the 2015-06-21T01:02Z and 2015-06-21T02:06Z solar flares and the corresponding 2015-06-21T02:48Z CME, outlining the sequential events, which included an SEP event, a geomagnetic storm, magnetopause crossing, and radiation belt enhancement, as well as aurora sightings at low latitudes.

What is Space Weather?

Space weather refers to solar activity including high speed streams (HSS), coronal mass ejections (CME), solar energetic particles (SEP) and solar flares that can influence the performance and reliability of spacecraft and ground-based technological systems, including satellite operations, communications, navigation, and electric power distribution grids. These solar events can affect spacecraft near Earth and the surrounding Earth environment in various ways, including single event effects, surface charging, radiation belt enhancements (RBE), geomagnetic storms (GST), and auroras. These solar events can usually be seen coming from regions of increased magnetic activity known as active regions. Active regions are easily viewed on the solar disk using the different wavelengths of light from the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO AIA).

Forecasting Methodology

Space weather forecasting implements the Integrated Space Weather Analysis System (iSWA) which utilizes data from various observational spacecraft including:

- Advanced Composition Explorer (ACE)
- Geostationary Operational Environmental Satellite system (GOES)
- Solar and Heliospheric Observatory (SOHO)
- Solar Dynamics Observatory (SDO)
- Solar TErrestrial RElations Observatory Ahead and Behind (STEREO A & B)

iSWA also hosts many innovative models including:

- WSA-ENLIL+CONE model
- Space Weather Modeling Framework (SWMF) Magnetopause Standoff Position
- Flare prediction models (ASSA, ASAP, MAG4, etc.)
- etc...

For CMEs, measurements are made using SWPC_CAT and/or STEREO_CAT. When space weather events of significant magnitude occur, the Space Weather Database Of Notifications, Knowledge, Information (DONKI) is used to record data and notify the various NASA mission operators of space weather activity

Solar Flare

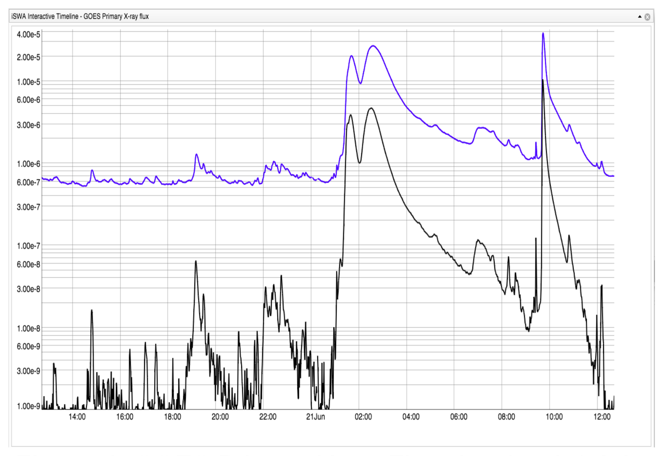


Figure 1: GOES Primary X-ray Flux showing 0.1-0.8 nm (blue) x-rays with peaks at 2015-06-21T01:02Z & 2015-06-21T02:06Z signifying two consecutive M-class flares.

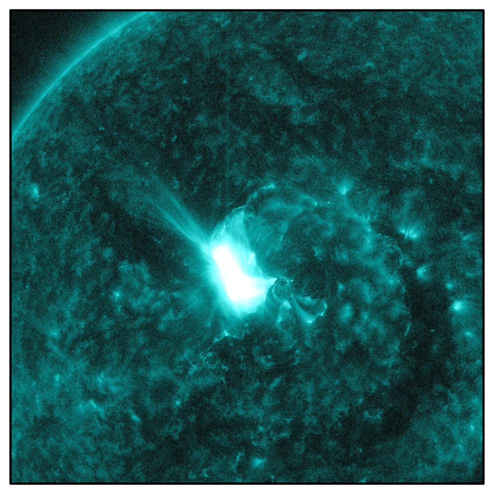


Figure 2: SDO AIA 131 image of the flares. A flare is an intense brightening on the sun.

Coronal Mass Ejection

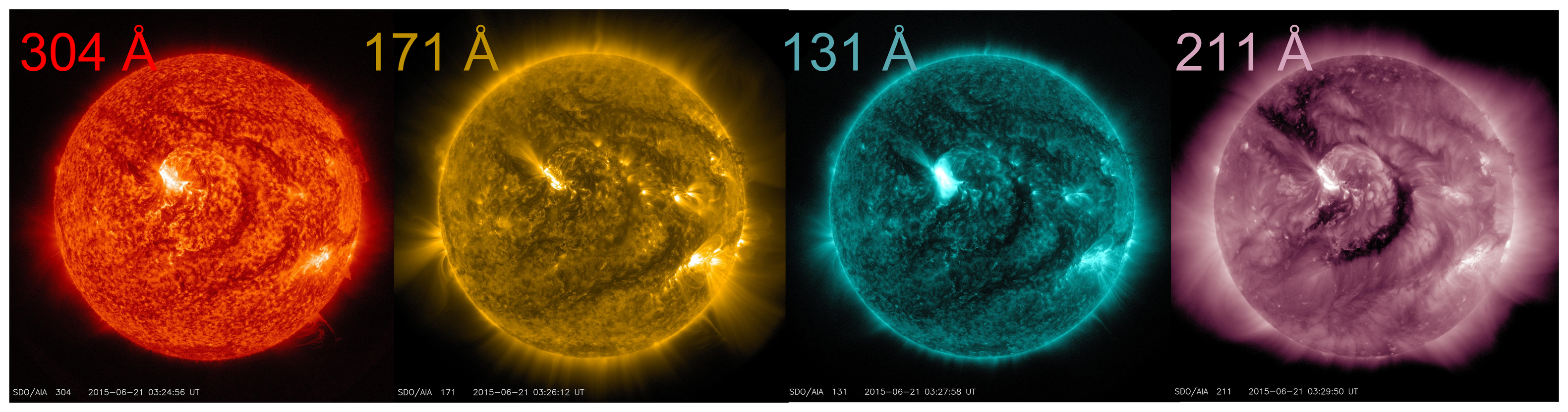


Figure 3: Series of SDO AIA images showing the 2015-06-21T02:48Z CME in four different wavelengths. The different colored images show different wavelengths of light in angstroms. Different wavelengths show different temperatures and therefore different regions of the Sun. The temperatures vary from 4000 Kelvin to 10 million Kelvin.

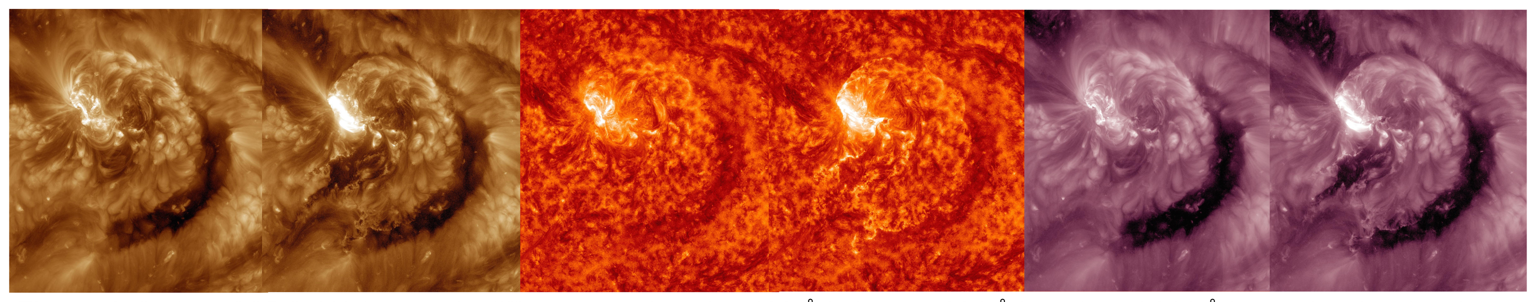


Figure 4: Series of SDO AIA images in different wavelengths, 193 Å in brown, 304 Å in red, and 211 Å in purple, showing the progression of the eruption of the 2015-06-21T02:48Z CME.

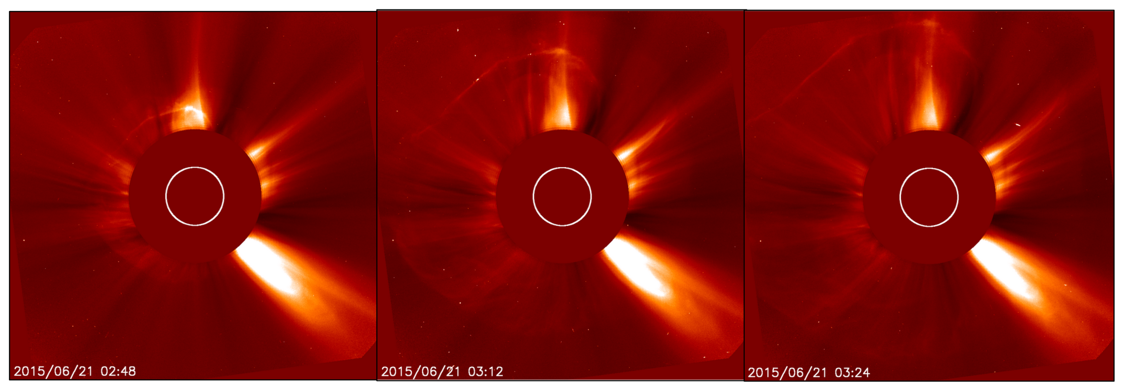
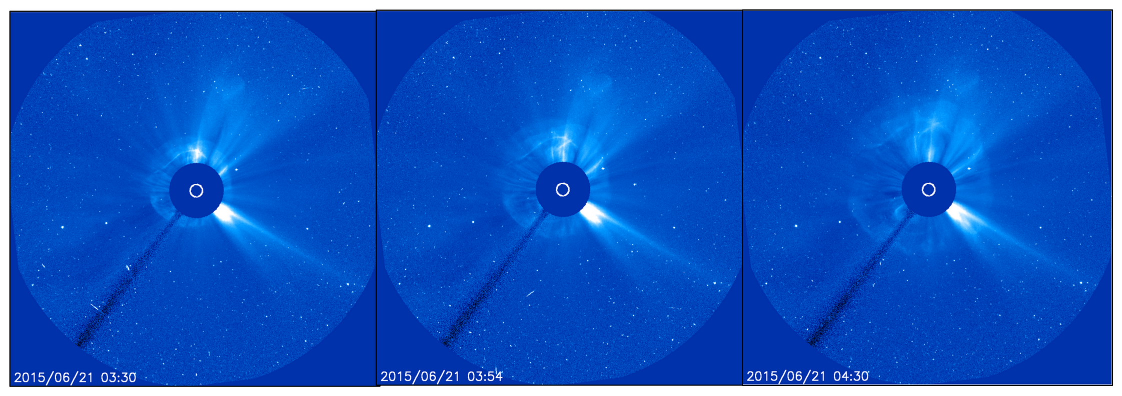


Figure 5: (left) Series of SOHO LASCO C2 coronagraph images showing the full halo 2015-06-21T02:48Z CME. Each image shows 1.5 to 6 solar radii of the solar corona by covering the brighter light of the solar disk with the red circle. The size of the solar disk is shown here as the white circle.

Figure 6: (right) Series of SOHO LASCO C3 coronagraph images showing the full halo 2015-06-21T02:48Z CME. Each image shows 3.5 to 30 solar radii of the solar corona by covering the brighter light of the solar disk with the red circle. The size of the solar disk is shown here as the white circle.



Solar Energetic Particles

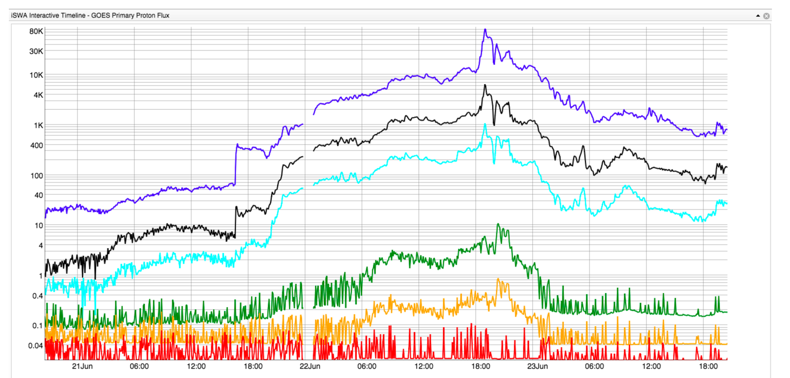
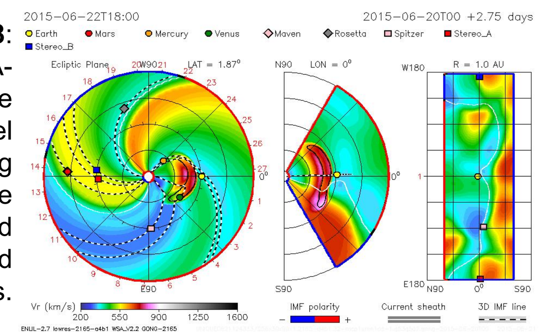


Figure 7: GOES primary proton flux showing 2015-06-21T20:35Z SEP event with the >10 MeV proton flux (cyan) exceeding the 10 pfu threshold. Enhanced fluxes of energetic protons, like those pictured here, can lead to single event effects.

Figure 8: WSA-ENLIL+Cone Model showing density of the CME and predicted arrivals.



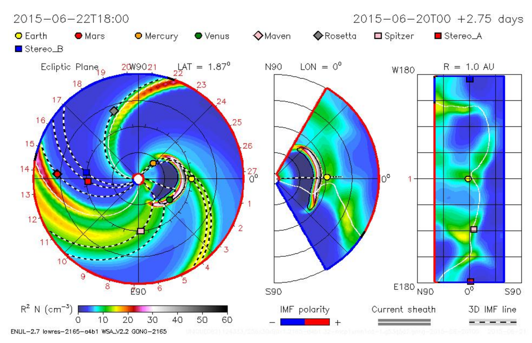


Figure 9: WSA-ENLIL+Cone Model showing velocity of the CME and predicted arrivals.

CME Arrival

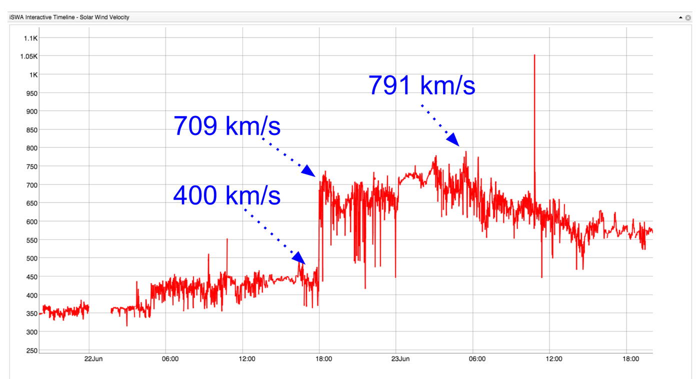


Figure 10: Solar wind velocity from ACE showing a jump from around 400 km/s to 700 km/s at 2015-06-22T17:59Z.

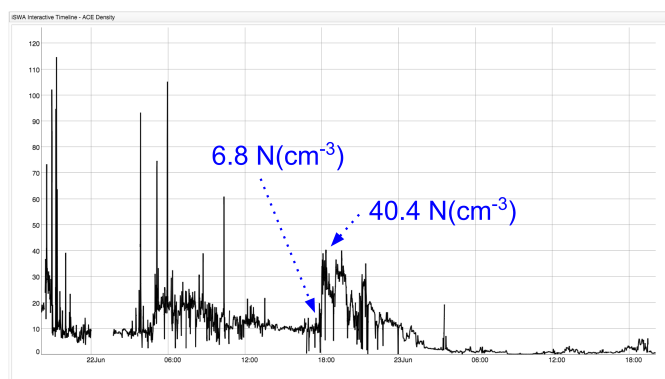


Figure 12: Solar wind density from ACE with an increase at 2015-06-22T17:59Z.

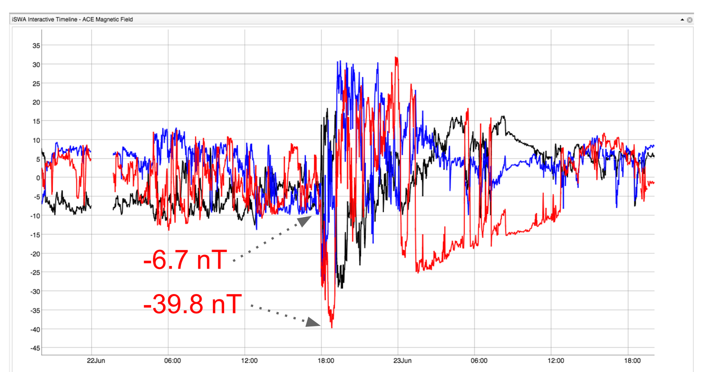


Figure 11: X, Y, and Z components (black, blue, and red) of the solar wind magnetic field from ACE with a jump in strength at 2015-06-22T17:59Z.

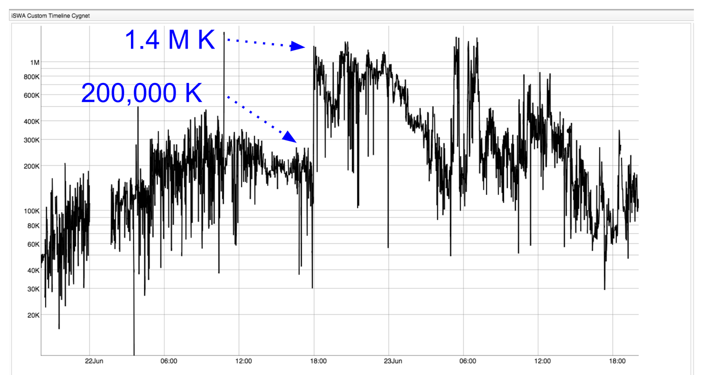


Figure 13: Solar wind temperature from ACE with an increase from around 200,000 K to 1,000,000 K at 2015-06-22T17:59Z.

Geomagnetic Storm

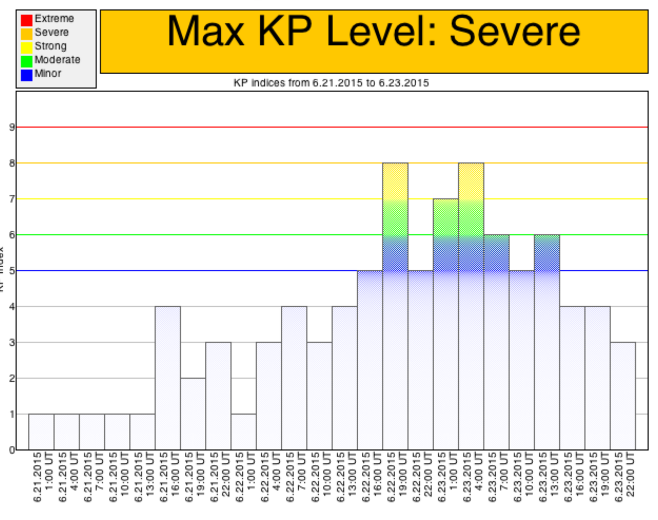


Figure 14: The Kp index, a 0-9 scale of the level of geomagnetic activity in the Earth's magnetosphere, reached 8 at 2015-06-22T18:00Z.

Aurora

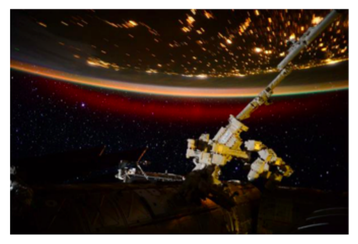


Figure 15: Aurora from ISS caused by geomagnetic storm.

Figure 16: Aurora from Virginia.

Magnetopause Crossing

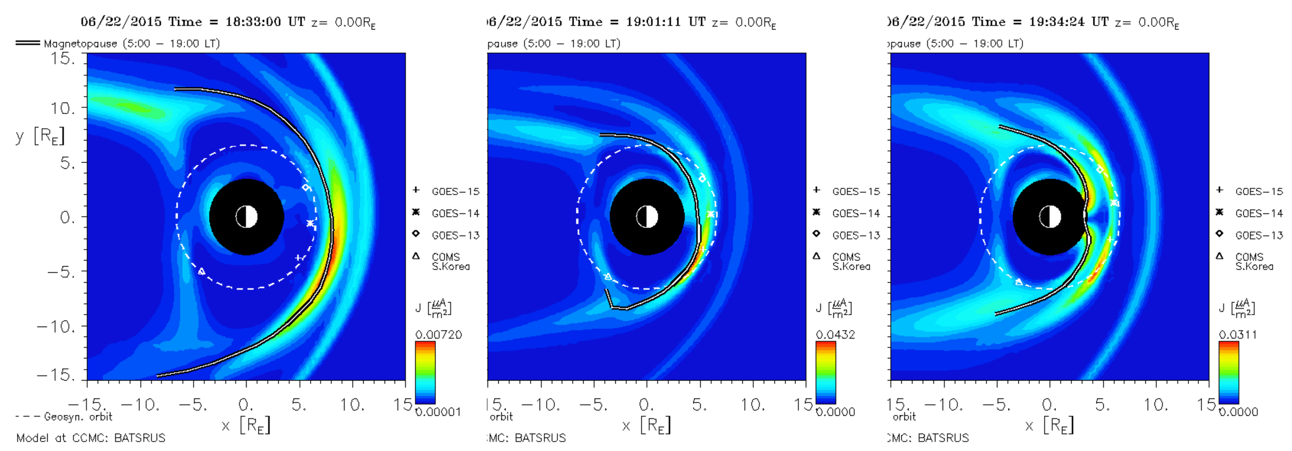


Figure 17: The SWMF Magnetopause Position showing the magnetopause (black line) compressing past geosynchronous orbit (dotted line) which began at 2015-06-22T18:49Z. This exposes spacecraft at geosynchronous orbit directly to the solar wind.

Radiation Belt Enhancement

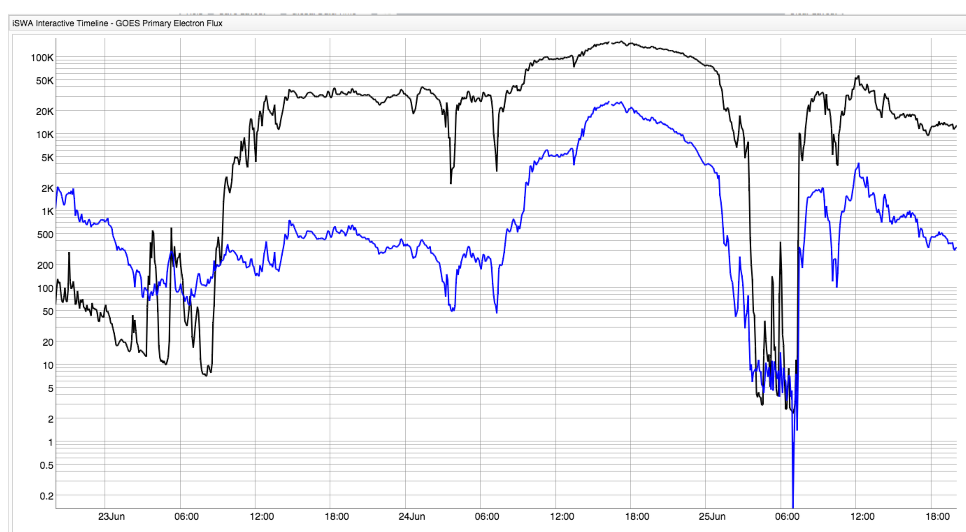


Figure 18: The GOES > 0.8 MeV electrons (black) were at enhanced levels, exceeding the threshold of 100,000 pfu at 2015-06-22T17:59Z. This was caused by not only by the arrival of the July 21st CME, but also the CMEs on June 18th, 19th. Spacecraft travelling though the radiation belts are at higher risk of surface charging and single event effects.

Conclusion

In total, AR 12371 produced 7 major solar flares, 10 coronal ejections, 5 interplanetary shocks, 1 magnetopause crossing, 2 strong geomagnetic storms, and 1 radiation belt enhancement. Of the 10 CMEs that came from AR 12371, 8 were modeled and 6 forecasted an impact at Earth. AR 12371 was visible on the Earth facing solar disk for a total of 15 days. Understanding the space weather events produced by highly active regions such as AR 12371 helps NASA diagnose the impacts that space weather has on its missions.

Acknowledgments

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References

Figures 1, 7-14, 17-18: iSWA (http://iswa.gsfc.nasa.gov/iswa/iSWA.html)
Figures 2-6: SDO (http://sdo.gsfc.nasa.gov/data/aiahmi/)
Figure 15: Terry Verts (https://twitter.com/astroterry?lang=en)
Figure 16: David Murr
CCMC (http://ccmc.gsfc.nasa.gov/)