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Comparing TWINS Ion Temperature Maps with MMS, AMPERE, and THEMIS Observations during July 26, 2017 Reconnection Event

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Abstract

The solar wind releases a constant stream of ionized particles into space which causes complex behaviors to occur within Earth’s magnetosphere. These disruptions can initiate magnetic reconnection and cause flow reversal of ions in the magnetotail. Two flow reversal events were locally detected by the Magnetospheric Multiscale Mission (MMS) on July 26, 2017 at 0700 UT and 0730 UT. The Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS) provide a global measurement of heated signatures of the magnetic field and detected an increase in ion temperature during these reconnection events without the presence of a geomagnetic storm. Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) observations also support that ionospheric disturbances occur on the nightside during these events. Observations from the All-Sky Imager (ASI) array, which are part of the Time History of Events and Macroscale Interactions during Substorms (THEMIS) project, support an increase in auroral activity during this time. It was found that TWINS observed higher ion temperature in a region of lower flow reversal, which may indicate that TWINS data can provide insight on polar phenomena during calm geomagnetic storm times.
Introduction

Magnetic Reconnection

Reaching temperatures of over one million Kelvin, the Sun’s corona is the source of a constant emission of ionized particles that travel through space. This plasma, otherwise known as the solar wind, interacts with the Earth’s magnetosphere and can be the cause of turbulence in the atmosphere. The magnetosphere (see Figure 1) is the region around Earth that harbors the magnetic field and Van Allen radiation belts. These radiation belts are torus-shaped zones around Earth that consist of magnetically trapped, highly energized particles that mostly originate from the solar wind [9]. The magnetic field has a dipolar structure that is warped due to the solar wind. Magnetic field lines on the dayside are compressed and those on the nightside are elongated, forming the magnetotail. The field lines within the magnetotail are dynamic and can stretch, break, and reconnect (see Figure 2), releasing stored energy as heat and ejecting charged particles from the radiation belts toward and away from Earth via ion jets. This phenomenon is known as magnetic reconnection. As these charged particles are sent Earthward and tailward, rapid changes in ion velocity, otherwise known as flow reversal, can be observed. Solar, terrestrial, and interstellar events create complex interactions between the magnetosphere and other regions of the atmosphere. These disturbances cause the aurora borealis and the effects can impact the power grid and satellites in orbit.

Figure 1: Diagram of Earth’s magnetosphere [18]. Note that the solar wind warps the dipole of the magnetosphere, compressing the magnetic field lines on the dayside and creating the magnetotail on the nightside.
Magnetosphere-Ionosphere Interactions

The ionosphere harbors a shell of free electrons and other charged particles and is located in Earth’s upper atmosphere, beneath the plasmasphere. Understanding magnetosphere-ionosphere (M-I) behavior is important since magnetic reconnection events directly affect the ionosphere and in turn, ion temperature. M-I interactions include, but are not limited to: poleward boundary intensifications (PBIs), bursty bulk flows (BBFs), auroral intensification, field-align currents (FACs), and particle precipitation. Ionospheric fluctuations can suggest that distant magnetic reconnection events occur due to the M-I coupled dynamic. PBIs, for example, are repetitive forms of auroral intensifications that take place at the poles. It is therefore reasonable to hypothesize that PBIs are manifested by distant magnetic reconnection due to their ionospheric polarization [15]. PBIs are not the focus of this study; however, studying them alongside other polar phenomena may prove beneficial to better understand magnetospheric behavior.

Geomagnetic Storms

Solar wind interactions can sometimes result in turbulence that is strong enough to cause geomagnetic storms, which are major disturbances in Earth’s magnetosphere that trigger intense energy transfers during magnetic reconnection. Coronal mass ejections (CMEs) are solar events in which the Sun releases a significant expulsion of plasma and are a primary cause of geomagnetic storms. The Disturbance Storm-Time (Dst) index is an indicator
of magnetic activity and geomagnetic storm strength. The current criterion for a large geomagnetic storm is a Dst value of –80 nT [3], but a Dst value of less than –50 nT indicates high magnetic activity and is distinguishable from calm storm time. Strong magnetic reconnection caused by a geomagnetic storm can result in intense aurora and changes in the radiation belts. High storm activity also increases the density distribution in the upper atmosphere causing extra drag in low-earth orbit satellites and can add heat energy to the ionosphere [16]. This increase in heat energy is associated with ion precipitation, which occurs when charged particles escape from the radiation belts and enter the ionosphere. Magnetic reconnection and a significant Dst index are not mutually exclusive; reconnection can still occur without the presence of a geomagnetic storm.

Methodology

Magnetospheric Multiscale (MMS) Mission Data

The Magnetospheric Multiscale (MMS) mission investigates magnetic reconnection and observes energetic transfers in the magnetotail during reconnection events. The mission is composed of a tetrahedral configuration of four identical satellites (see Figure 3), two of which (MMS1 and MMS2) are located ∼20-30 Earth radii ($R_E$) from Earth, while the other two (MMS3 and MMS4) are located at ∼10$R_E$ [5]. All four satellites are able to measure particle flow reversal from the ion jets. Detecting flow reversal motivates ion temperature analysis as both phenomena can indicate the presence of geomagnetic and substorm activity.

Creating Ion Temperature Maps using TWINS

Energetic neutral atom (ENA) data provides a measurement of ions and are used to calculate ion temperature in the inner magnetosphere [12]. As seen in [11], the ion temperature increases in the presence of magnetic reconnection and geomagnetic storm activity. Thus, it is helpful to create ion temperature maps to observe ion activity during reconnection events (see Figure 5). These maps are integral to plasma modeling and are generated by the Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS), which are a pair of identical NASA satellites that measure ENAs and help to understand the dynamic behavior of the magnetosphere. Magnetospheric data, such as particle and field measurements, are measured locally by MMS, whereas TWINS takes measurements remotely. This feature allows TWINS to acquire a global picture for magnetospheric measurements, where MMS measurements can be limited due its locality in orbit. TWINS enables three-dimensional visualization of large-scale, magnetospheric structures due to their wide spacing, high altitude and high inclination, which also aids in ENA analysis [14]. Flow reversal was detected twice by MMS between 0700-0800 UT (see Figure 4) on July 26, 2017. The first flow reversal occurred close to 0700 UT, and the second, less intense flow reversal occurred closer to
Figure 3: Schematic of the four MMS satellites flying through a reconnection region [4]. The blue and red regions are representative of the IDR and EDR, respectively. The tetrahedral configuration of MMS ensures three-dimensional observations of the EDR and flow reversal.

Figure 4: MMS particle velocity data for the July 26, 2017 event [6]. The blue, green, and red lines are the $v_x$, $v_y$, and $v_z$ components of the velocity, respectively. The first shaded region depicts the larger flow reversal (near 0700 UT), and the second is less intense (near 0730 UT). We primarily look at the $v_x$ for flow reversal indication since that is the component that represents particle flow via the ion jets. When $v_x$ crosses zero, the particles change direction which is indicative of flow reversal and magnetic reconnection.

0730 UT\(^1\). TWINS observed this event remotely, and focuses on the ion temperature of the magnetosphere during this time. Note that TWINS observes a region of higher ion temperature between 0723-0727 UT, which corresponds to the flow reversal detected by MMS at 0730 UT. Such an increase in ion temperature may indicate the presence of a geomagnetic storm, as a CME or other powerful solar event can increase magnetic reconnection activity. Thus, noting the Dst and Auroral Electrojet (AE) indices (see Figure 6) for this event may provide insight on the cause and effects of this increase in ion temperature.

\(^1\)The lower intensity event could be due to the satellite’s position with respect to the x-line during that time. This would lead to purely an observational difference, not a physical one.
Figure 5: TWINS ion temperature maps for July 26, 2017 event [11]. Each figure depicts the average ion temperature over an interval of 3-4 minutes, with blue and red representing low and high energy, respectively. The figure on the left is the ion temperature map close to 0700 UT, and the map on the right depicts the ion temperature close to 0730 UT. The center figure is a measurement in between these two times. The triangle is the location of MMS at the time of measurement, and the diamond and cross-section symbols represent the Van Allen Probes (data not used for this study).

Figure 6: Dst [7] and AE [8] indices for July 26, 2017 reconnection event. The top figure depicts the Dst index over the course of 24 hours, with the yellow line indicating the time of the event. The bottom figure depicts the AE index during a two hour interval, where the red lines indicate the 0700-0730 UT interval.

The Dst index does not drop below -24 nT over the course of the day, and hovers near -18 nT at the time of the event. Since the Dst index is not sufficient to support the presence of a geomagnetic storm during this time, it can be concluded that reconnection occurred during calm storm time and there was no radical solar event to occur that resulted in an increase in ion temperature. Conversely, the AE index, which is indicative of auroral zone magnetic activity, increases between 0700-0730 UT. This indicates that there is an increase in polar activity that may correspond with the higher ion temperature during this period. Observing an increase in polar activity motivates the investigation of the ionosphere since polar phenomena is coupled with magnetospheric behavior.
AMPERE Ionospheric Data

The Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) is an Earth-orbiting system that provides real-time magnetic perturbation data and is used to forecast weather in space to better understand M-I physics. These magnetic perturbations observed by AMPERE are used to calculate the resulting current density in the ionosphere at both poles. An increase in downwards current was detected in the northern hemisphere on the nightside between 0726-0736 UT (see Figure 7), which supports the increase in ion temperature TWINS detected near this time. Current density fluctuations may also support the increasing AE index detected during this interval.

Figure 7: AMPERE plots during the July 26, 2017 flow reversal event [1]. From left to right, these plots depict the reduced magnetic perturbations, spherical harmonic fit to the magnetic perturbation data, and the radial current density during ten-minute time frames in the northern hemisphere. Time progresses from top to bottom with the first and third rows of plots corresponding to the first and second flow reversal events, respectively.
THEMIS All-Sky Imager Observations

The Time History of Events and Macroscale Interactions During Substorms (THEMIS) mission establishes substorm intervals, explores the interactions between components of substorms (including the aurora), and helps to identify the correspondence between local disruptive phenomena and global substorm activity in the atmosphere. The requirement of the mission is to utilize an array of all-sky imagers (ASIs), with 20 Ground Based Observatories (GBOs) deployed in the North American arctic region. A map of the deployed stations is seen in Figure 8.

Figure 8: A map depicting the location of the deployed GBOs for the THEMIS mission [2]. The circles represent the fields of view of the all-sky cameras for each station.

The ASI provides near-complete coverage of the sky in these regions. Analyzing THEMIS observations is motivated by the increasing AE index and higher current density measured during the 0723-0727 UT time interval. An increase in auroral activity was observed by the GILL station, located in Gillam, Manitoba, Canada (see Figure 9).
Conclusion & Future Work

An increase in heated ion signatures as observed by TWINS motivates ionospheric and auroral observations as seen by AMPERE and THEMIS data. TWINS may be beneficial in further investigations of the aurora and other polar phenomena. PBIs are known to be the result of magnetic reconnection; localized signatures of the tail activities in the ionosphere are represented by PBIs [10]. Studying FACs (the currents that flow along the geomagnetic field lines and transport energy to the polar regions of the upper atmosphere, triggering high-energy aurora [1]), alongside other M-I interactions in comparison to high ion temperature signatures, may also prove useful. These are just some examples of M-I interactions that can be studied to better understand the correlation between ion temperature and the aurora. OpenGGCM simulation methods as seen in [10] may also be applied to study BBFs during the July 26, 2017 event. Methods seen in [17] involving the analysis of IDR and EDRs may provide insight on local ion behavior in the magnetotail at the site of reconnection events.

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References


