Atmospheric drag effect on LAPAN A1 orbit during geomagnetic storm 2017

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Atmospheric drag effect on LAPAN A1 orbit during geomagnetic storm 2017

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Abstract. Satellites moving through the atmosphere and experience a drag force in the opposite direction of their orbital motion. Atmospheric drag is the largest perturbations for low earth orbit satellites beside earth gravitation. We calculate the atmospheric drag on LAPAN A1 in a sun-synchronous circular orbit with an inclination of 97.60◦, eccentricity of 0.0014, period of 99.039 minutes and an altitude of 630 km, during September in 2017. Data of orbital elements (Two Line Elements) taken from *www.celestrak.com*. Geomagnetic activity data (Dst index) taken from *https://omniweb.gsfc.nasa.gov*. The purpose of this study is to determine the relationship between atmospheric drag, orbital elements, and a geomagnetic storm. In 2017, hourly Dst index had a minimum value of -124 nT at 18:00 UTC, on September 8. But the geomagnetic storm in 2017 didn't influence significantly to drag acceleration of LAPAN A1. During geomagnetic storm period in 2017, the changes of orbital elements were really small and the data is too scattered to be concluded as the effect of the geomagnetic storm.

1. Introduction

Atmospheric drag gives uncertainty to satellites position determination and prediction for low earth orbit satellites. An important parameter for the drag force is total mass density in local atmospheric over the satellite's orbital path. Atmospheric densities increase by as much as 134% during a large geomagnetic storm [1]. Satellite drag significantly increases because atmospheric densities increase. Geomagnetic storm consists of charged particles such as protons, electrons, and ions. It is driven by solar eruptions. During a large geomagnetic storm, atmospheric ionization process increases extremely. In the altitude range, 250 – 1000 km, geomagnetic storm give significant effects to atmospheric density. Atmospheric density fluctuations cause large orbital perturbations during a large geomagnetic storm [2].

Geomagnetic activity was active on September 1st -2nd, 2017 with minimum Dst index was -44 nT on September 1st, 2017. There were substorms occurred several times during the geomagnetic storm period. On September 4th-5th, 2017 the electron flux were maximum around 10000 [/cm^2/sec/sr] and the second maximum around 1000 [/cm^2/sec/sr]. This condition continued phase from a minor storm that occurred on August 31st, 2017. 2017 was minimum of solar cycle 24, but this year had extreme solar activity in early September 2017. It was rare occurred. Active Region AR2673 produced four powerful eruptions class X, including the strongest flare X9.3 of Solar Cycle 24 on September 6, 2017. It was the beginning of the intensive solar-terrestrial disturbances. After that, it followed by severe geomagnetic storm (G4) on September 7, 2017, until September 8, 2017. And then the second strongest flare of Solar Cycle 24 occurred on September 10, 2017. These phenomena were also followed by partial halo CME with angular width 268 degree and max velocity was 1488 km/s.[3,4].

The purpose of this study is to determine the relationship between atmospheric drag, orbital elements, and geomagnetic storm. We use the Dst index and TLE provided by *www.celestrak.com* [9] and *https://omniweb.gsfc.nasa.gov* [7]. We also calculate the daily drag using formula (1). LAPAN A1 was launched on January 10, 2007, into a sun-synchronous circular orbit with an inclination of 97.60°, eccentricity of 0.0014, period of 99.039 minutes and an altitude of 630 km. Comparing daily average LAPAN A1 drag, LAPAN A1 orbital elements, and geomagnetic data, we determine the effect of atmospheric drag on LAPAN A1 orbit during the geomagnetic storm [5] find that there was a correlation between drag acceleration and level of geomagnetic storm. This indicates that the orbital path of KOMPSAT-1 is significantly perturbed during the extremely geomagnetic storm because of atmospheric density increase.

2. Method

Orbital elements consist of semi-major axis (a), inclination (i), eccentricity (e), argument of perigee (ω), and right ascension of the ascending node (Ω). First, we calculate the changes of orbital elements value from day to day. Then we compare this value with daily Dst index (geomagnetic storm index). Second, we calculate satellite acceleration using the formula [6]:

$$a_{drag} = -\frac{1}{2}\rho\frac{C_D A}{m}v^2 \quad (1)$$

where m is the satellite mass, a_{drag} is the satellite acceleration in a direction opposite to the velocity vector due to air drag, C_d is the dimensionless drag coefficient, A is the satellite's cross-sectional area perpendicular to the direction of the motion, ρ is the atmospheric total mass density at the location of the satellite, and V is the orbital velocity of the satellite relative to the atmosphere. In order to find ρ and V value, we need CCMC (Community Coordinated Modeling Center) interactive model and STK (System Tool Kit). Then we compare satellite acceleration with daily Dst index (geomagnetic storm index).

3. Data and analysis

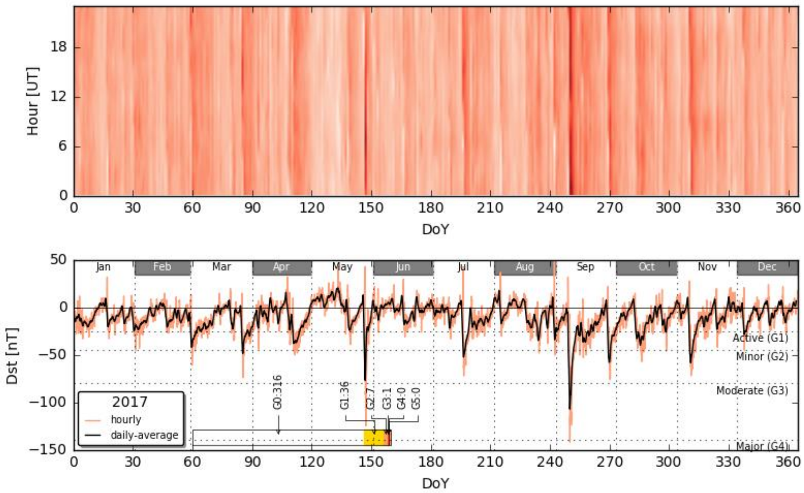

Figure 1(a). Daily Dst index (nT) in 2017.
Source: *http://wdc.kugi.kyoto-u.ac.jp*

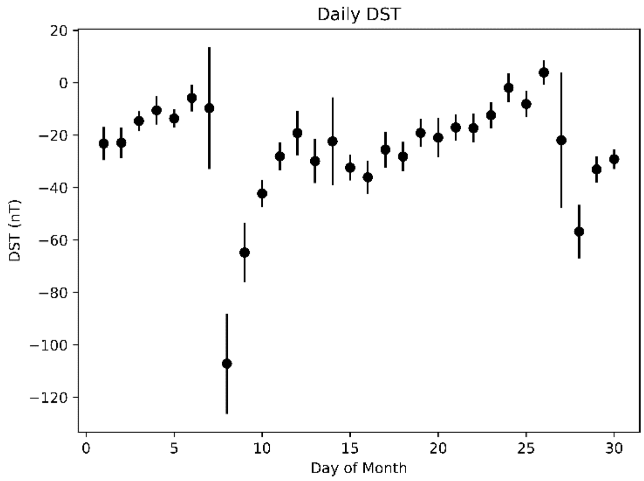

Figure 1(b). Daily Dst index (nT) on September 1st-30th, 2017.

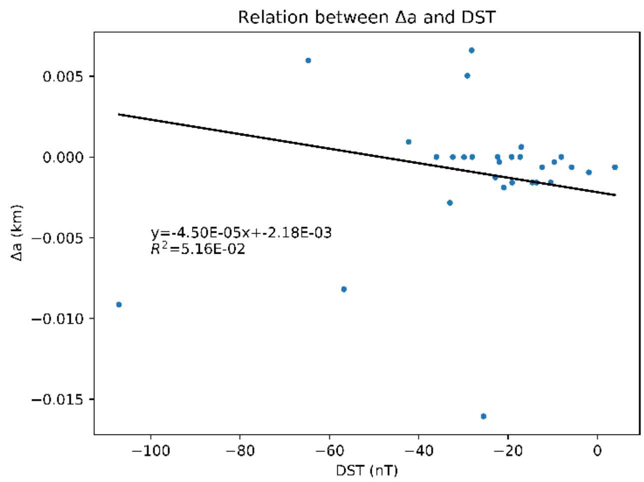

Figure 2. Comparison between *Δ*a (km) and Dst (nT) during September 2017.

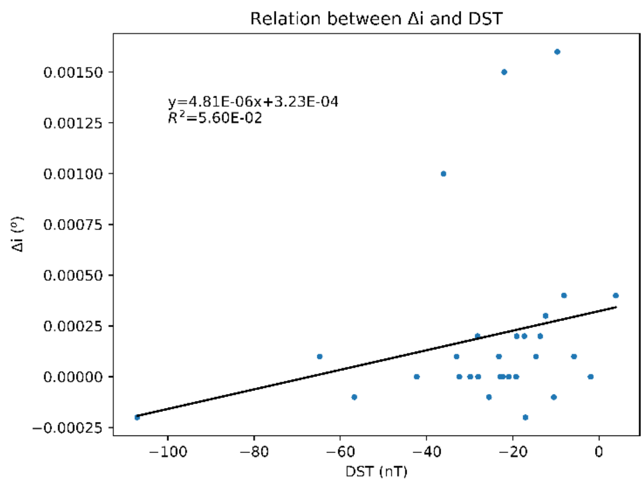

Figure 3. Comparison between *Δ*i (°) and Dst (nT) during September 2017.

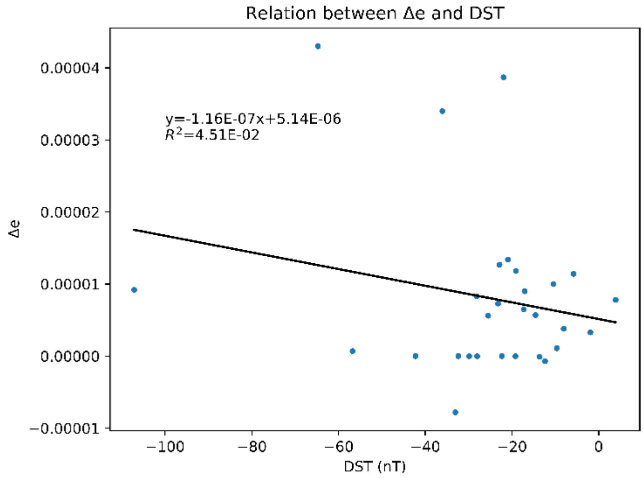

Figure 4. Comparison between *Δ*e and Dst (nT) during September 2017.

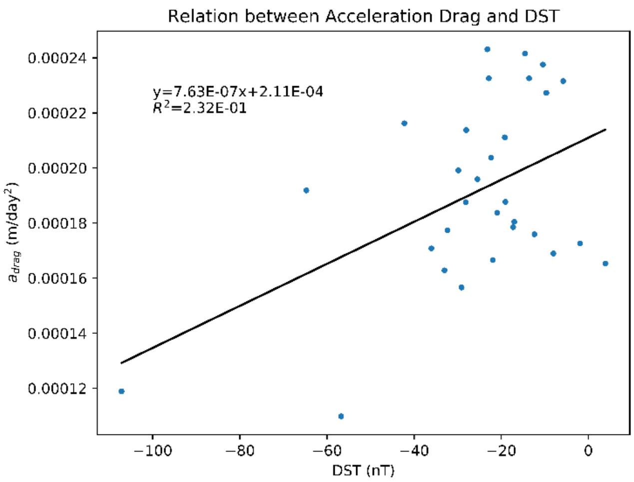

Figure 5. Relationship between drag acceleration (m/day^2) and Dst index (nT) during September 2017.

Figure 1(a) shows the daily Dst index in 2017 and figure 1(b) shows the daily Dst index on September 1st-30th, 2017. The daily Dst index data are provided at *http://wdc.kugi.kyoto-u.ac.jp* [8]. Based on hourly Dst index, severe geomagnetic disturbances occurred on September 7–8 with Dst minimum of -142 nT. Based on the daily-average Dst index, a minimum value of Dst is -107.125 nT. Actually, 2017 was minimum of solar cycle 24, but this year had extreme solar activity in early September 2017. It's rare occurred. In early September 2017, a group of sunspots and flares in the X-ray spectrum, and a series of Coronal Mass Ejections (CME) were appeared and developed rapidly. CME produced by the X9.3 solar flare on September 6, 2017. It spreads forward to the Earth and reaches Earth's magnetosphere at 23:04 UTC on September 7th, 2017 [3].

The changes of orbital elements include a semi-major axis, inclination, and eccentricity (Δa, Δi, Δe) are plotted in Fig. 2 - 4. In the plot, we include the slope determined by least squares fitting and linear correlation coefficient (cc). There is a linear relationship between the two parameters for each orbital element, with a correlation coefficient of 0.051 (Δa), 0.279 (Δi), and 0.045 (Δe). The relationship between drag acceleration and Dst index during geomagnetic storm period is plotted in Fig. 5. The daily drag acceleration is calculated using formula 1 [6]. Figure 5 shows that the drag acceleration increase by geomagnetic activity (Dst). Using linear regression, there is a linear relationship between the two parameters, with a correlation coefficient of 0.2323.

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4. Discussion and conclusion

We already studied a similar case for LAPAN A1 during the geomagnetic storm in 2015 and we got a result that geomagnetic storm influenced drag acceleration and orbital elements significantly. Because when the strong geomagnetic storm occurred, Sun ejected a big portion of mass and energetic particles with high velocity. This mass and particles affected the upper part of the Earth atmosphere and made the atmosphere denser. The denser the atmosphere, the bigger the drag acceleration. But in this case, the storm is not as strong as 2015's storm. So we had difficulty to observe the effect of the storm.

In this study, we have determined the relationship between LAPAN A1 drag acceleration and geomagnetic storm in 2017. Our analysis can be summarized as follows: (1) The geomagnetic storm in 2017 didn't influence significantly to drag acceleration of LAPAN A1; (2) During the severe geomagnetic storm, the changes of orbital elements were really small and the data is too scattered to be concluded as the effect of the geomagnetic storm.

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