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Atmospheric drag force on LAPAN-TUBSAT during geomagnetic storm 2015

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Abstract. The purposes of this research are (1) determine the relationship between LAPAN-TUBSAT orbital elements and geomagnetic activity; (2) estimate daily drag acceleration; (3) determine the relationship between drag acceleration and geomagnetic activity. We used STK (System Tool Kit), python, and CCMC (Community Coordinated Modeling Center) interactive model to process the data. To calculate the drag acceleration, it takes data of satellite's velocity that obtained from STK and atmospheric density. To generate atmospheric density, we used CCMC with MSISE-90 (Mass Spectrometer – Incoherent Scatter Extended 1990) and IRI (International Reference Ionosphere) atmospheric model. In addition, it takes the satellite's position (latitude, longitude, and height – taken from STK) as input. On March 2015, geomagnetic storm index (daily Dst) had a minimum value of -105 nT on March 18, 2015. According to hourly Dst data, the minimum value of Dst reached -223 nT at 23:00 UT on March 17, 2015. Changes of orbital elements were influenced by geomagnetic storms through the Dst index. Maximum changes of semi-major axis, inclination, argument of perigee, and longitude of ascending node occurred on March 17-21, 2015 (geomagnetic storm period). Minimum change of eccentricity occurred on March 15-16, 2015 when Dst reached a maximum value. Atmospheric model is influenced most by solar conditions both during periods of calm or storm. Atmospheric density generated by MSISE-90 and IRI, both of them has 10^{-6} order difference. MSISE-90 is 10^{-16} while IRI 10^{-22}. For MSISE-90, maximum drag acceleration reached 451,4416 m/hari^2 occurred on March 17, 2015, along with a strong geomagnetic storm phenomenon. For IRI, the value of drag acceleration during peak geomagnetic storm (March 18, 2015) reached 0,000373 m/hari^2 (close to the minimum value in March 2015). Drag acceleration of LAPAN-TUBSAT is linear to the Dst index with a correlation coefficient of -0,51.

***Keyword** : satellite, orbital elements, drag atmosphere, geomagnetic storm*

1. Introduction

Drag force is a force which happens on the satellite's body in the opposite direction of satellite movement. It is the biggest non-gravitational perturbation on low earth orbit satellites. Satellites move through an atmosphere that has a total mass density of all components (proton, electron, and ion). Atmospheric ionization process increases extremely when a geomagnetic storm occurred. During extreme condition like an intensive geomagnetic storm, there were significant atmospheric density fluctuations that caused orbital perturbations. Perturbations of orbit caused changes of satellite's orbital elements [1]. First intensive geomagnetic storm of Solar Cycle 24 occurred on March 17, 2015. SOHO/LASCO C3 recorded partial halo Corona Mass Ejection (CME) that followed by C9.1/1F (S22W25) flare at 02:10 UT on March 15, 2015. The velocity of CME reached ~668 km/s. Interplanetary shockwave controlled by CME, arrived in the Earth at 04:45 UT on March 17, 2015. It caused a sudden geomagnetic storm, and then became a strong geomagnetic storm until Dst decreased to -73 nT at 10:00 UT. It caused by CME sheath crossing. After that, Dst of the storm increased to -44 nT because of Interplanetary Magnetic Field. On March 17, 2015, the storm became stronger than previous, at 23:00 UT Dst reached -223 nT. Geomagnetic storm power measured using Dst (Disturbance storm time) index. Dst is an hourly average value of horizontal magnetic field and expressed in nT [2]. Determining the relationship between atmospheric drag, orbital elements, and geomagnetic storm are purposes of this research. We used the Dst index and TLE (Two Line Elements) provided by *www.celestrak.com* and *https://omniweb.gsfc.nasa.gov*. Daily drag acceleration is calculated by using formula (1). LAPAN-TUBSAT was launched on January 10, 2007, from Satish Dhawan Space Center, India. Its orbit is 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. Kim *et al.* [3] found that the orbital path of KOMPSAT-1 was significantly perturbed during an extremely geomagnetic storm.

2. Method

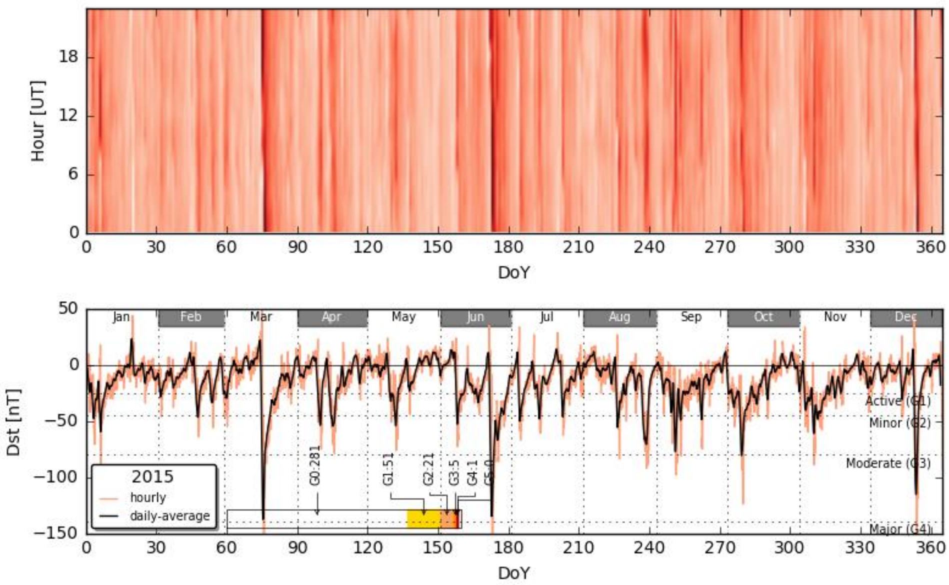
Two Line Elements consist of semi-major axis (a), inclination (i), eccentricity (e), argument of perigee (ω), and right ascension of the ascending node (Ω). To determine the relationship between LAPAN-TUBSAT orbital elements and geomagnetic activity, we calculate the daily changes of orbital elements value. Next, we compare this value with daily Dst index (geomagnetic storm index). After that, we calculate satellite acceleration using this formula [4]:

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

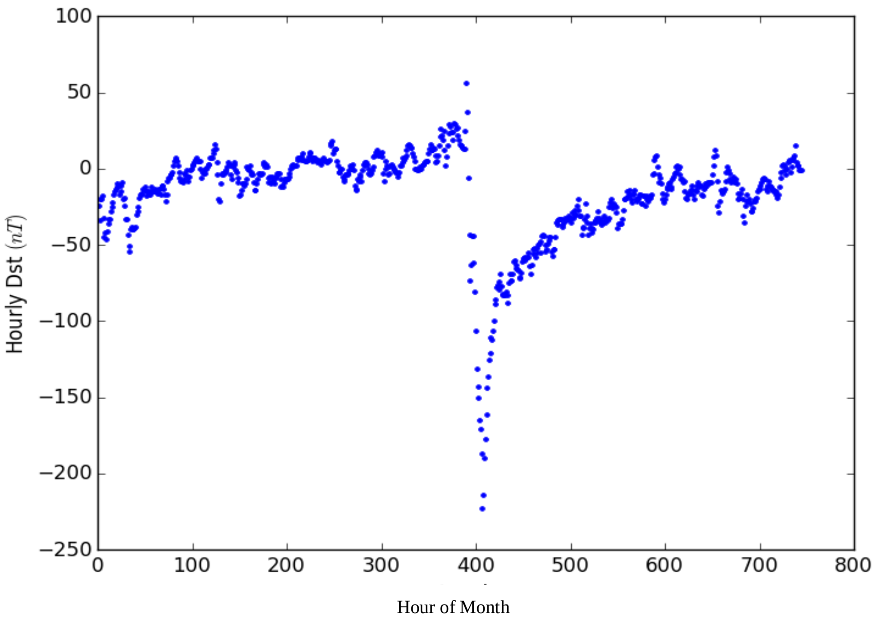
a_{drag} is the satellite acceleration, ρ is the local atmospheric total mass density, C_d is the dimensionless drag coefficient, A is the satellite's cross-sectional area perpendicular to the direction of the motion, m is the satellite mass, and V is the satellite's orbital velocity. We used CCMC (Community Coordinated Modeling Center) and STK (System Tool Kit) to calculate ρ and V value. Finally, we compared drag acceleration and daily Dst index.

3. Results and analysis

Figure 1(a) shows the daily Dst index in 2015 and figure 1(b) shows the daily Dst index on March 1st-31th, 2015. The daily Dst index data are provided at *http://wdc.kugi.kyoto-u.ac.jp*. Based on hourly Dst index, severe geomagnetic disturbances occurred on March 17 with a minimum value of Dst is -223 nT. The first intensive geomagnetic storm of Solar Cycle 24 occurred on March 17, 2015. The source of this storm could be traced back to solar phenomena in the middle of March 2015 [2]. Figure 2 (a)-(c) are the changes of semi-major axis, inclination, and eccentricity (Δa, Δi, Δe). In the plot, we include the slope determined by least squares fitting and linear correlation coefficient (cc). There is a linear relationship between Δa and Dst, with a correlation coefficient of 0.0206. During the geomagnetic storm period, inclination value decreased significantly, it means that the orbital plane becomes so close to the equator plane. There is a linear relationship between Δi and Dst, with a correlation coefficient of 0.186. For eccentricity, the value was relatively small almost zero, which means the orbit is nearly circular. The change of eccentricity decreased on 15-16 but increased on 17-18 (the geomagnetic storm period). The relation between drag acceleration and Dst index during geomagnetic storm period is plotted in Figure 3. The maximum value of drag acceleration was 451,44 m/day^2 on March 17, 2015, when the severe geomagnetic storm happened. The drag acceleration increased well correlated with geomagnetic activity (Dst). There is a clear linear relationship between drag acceleration and Dst index, with a correlation coefficient of -0,51.



(a)



(b)

Figure 1(a). Daily Dst index (nT) in 2015. Source: *http://wdc.kugi.kyoto-u.ac.jp* **(b).** Daily Dst index (nT) on March 1st-31th, 2015

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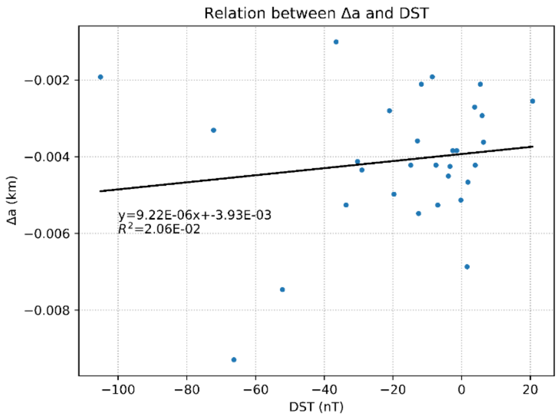
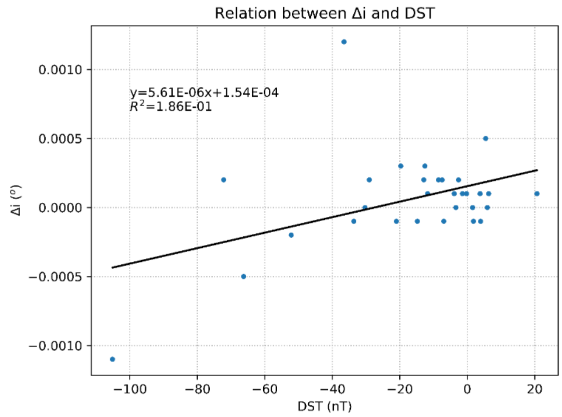
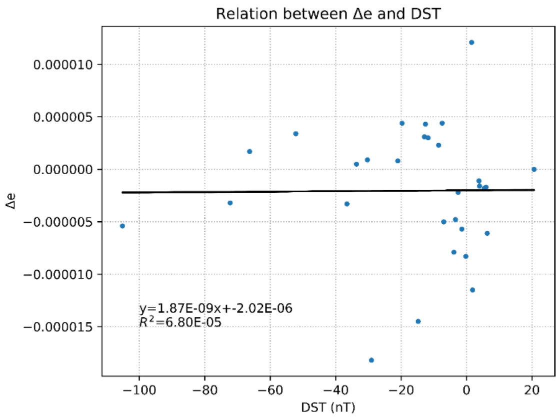


(a)



(b)



(c)

Figure 2(a). Comparison between Δa (km) and Dst (nT) during March 2015. **(b).** Comparison between Δi (°) and Dst (nT) during March 2015. **(c).** Comparison between Δe and Dst (nT) during March 2015.

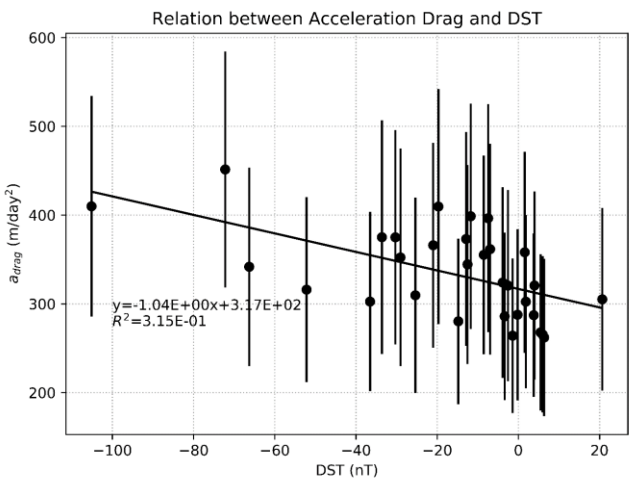


Figure 3. Relation between drag acceleration (m/day^2) and Dst index (nT) during March 2015.

4. Conclusion
We had determined the relationship between LAPAN-TUBSAT drag acceleration and geomagnetic storm in 2015. Our conclusion can be summarized as follows: (1) LAPAN-TUBSAT drag acceleration correlated strongly with the strength of geomagnetic disturbance. Drag acceleration of LAPAN-TUBSAT is linear to geomagnetic activity; (2) During severe geomagnetic storm period, the change of orbital elements were influenced most by geomagnetic storm through the Dst index. The change of orbital elements is linear to the Dst index.

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