Effects of Space weather on the ionosphere and LEO satellites' orbital trajectory in equatorial, low and middle latitude

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1. Introduction

We study the effects of space weather on the ionosphere and LEO satellites' orbital trajectory in equatorial, low- and mid-latitude (EQL, LLT and MLT) regions during (and around) the notable storms of October/November, 2003. We briefly review space weather effects on the thermosphere and ionosphere to demonstrate that such effects are also latitude-dependent, and well established in the literature. Following the review we simulate the trend in variation of satellite's orbital radius *r*, mean height *h* and orbit decay rate *ODR* during 15 October - 14 November 2003 in EQL, LLT and MLT. Nominal atmospheric drag on LEO satellite is usually enhanced by space weather or solar-induced variation in thermospheric temperature and density profile. To separate nominal orbit decay from solar-induced accelerated orbit decay, we compute *r*, *h* and *ODR* in three regimes viz. (i) excluding solar indices (or effect), where $h=h_0$ and $ODR=ODR_0$ (ii) with mean value of solar indices for the interval, where $h=h_m$ and $ODR=ODR_m$ and (iii) with actual daily values of solar parameters for the interval (*h* and *ODR*).

2. Data, scope and method

Data include daily variation in solar wind speed (V_{sw}) and associated particle density (PD), solar radio flux ($F_{10.7}$), geomagnetic (Ap), disturbance storm time (Dst) index and auroral electrojet (AE) during 15 October - 14 November 2003. We complement and/or update the data using NOAA's list of 'proton events that affected the Earth's environment', archival solar data (DSD) and SOHO/LASCO's CME catalog. Variations in V_{sw} and associated PD, $F_{10.7}$, A p , Dst index, AE during 15 October - 14 November 2003 is shown in figure 1. We simulate trend in variation of satellite's *r*, *h* and *ODR* at 450 km as it traverse the middle (around 60°), Low (around 30°) and equatorial (around 0°) latitudes. We also analyse the density (ρ) and temperature (T) of the thermosphere, because atmospheric drag force on LEOSs and consequent orbital decay strongly depends on the condition of the atmosphere (defined by ρ and T) through which they traverse.

1. **Figure**

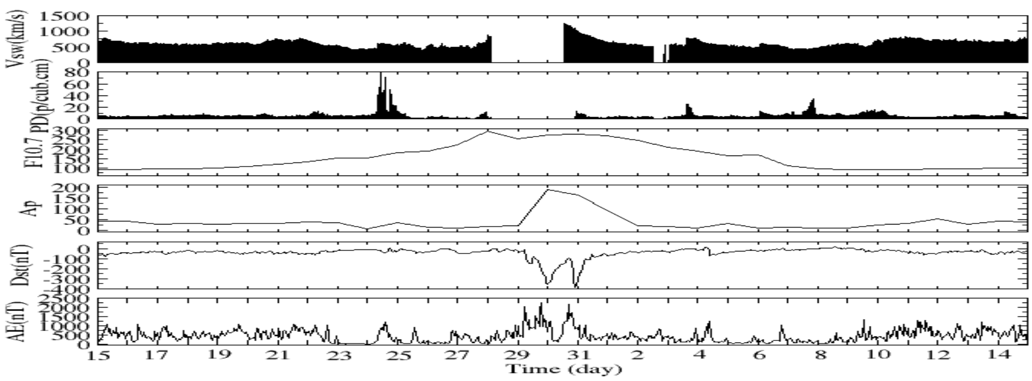

Figure 1: Daily variation of solar wind speed (V_{sw}) and associated particle density (PD), solar radio flux ($F_{10.7}$), geomagnetic Ap , disturbance storm time Dst index and auroral electrojet (AE) during 15 October - 14 November 2003.

3. Equations

We compute r, h and ODR from the following coupled equations [1],[2],[3].

$$\dot{v}_r = -\phi r^2 (A_s C_d / m_s), \quad (1)$$

$$\dot{r} = v_r,$$

$$\ddot{\phi} = -\frac{1}{2} r \rho \dot{\phi}^2 \frac{A_s C_d}{m_s},$$

$$\dot{\phi} = v_\phi / r,$$

where v_r and v_φ are the radial and tangential velocity components respectively, r (sum of Earth's Radius (R_e) and h) is the radius of the orbit, A_s (1.1 m 2 is used here) is the satellite projected area with respect to the direction of motion, ρ is atmospheric density, m s (1100 kg in this case) is the mass of the satellite and C_d (3.7 in this case) is the dimensionless drag coefficient of the satellite.

4. Summary

For a typical LEO satellite at *h*=450 km, we show that the total decay in *r* with respect to EQL, LLT and MLT during the period is about 4.2 km, 3.9 km and 3.2 km respectively. While the respective nominal decay (r_0) is 0.4 km, 0.34 km and 0.22 km, solar-induced orbital decay (r_m) is about 3.8 km, 3.55 km and 2.95 km. Similarly, the respective nominal ODR_0 is about 13.5 m/day, 11.2 m/day and 7.2 m/day, while mean solar-induced ODR_m is about 124.3 m/day, 116.9 m/day and 97.3 m/day. We also show that severe geomagnetic storms can increase *ODR* (from daily mean value) by about 117%.

5. References

[1] Nwankwo V. U. J., Sandip K. Chakrabarti and Weigel R. S.: Effects of plasma drag on low Earth orbiting Satellites due to solar forcing induced perturbations and heating. Adv. Space Res. 56, 47-56, 2015

[2] Nwankwo, V. U. J. and Chakrabarti K. S.: Analysis of planetary and solar-induced perturbations on trans-Martian trajectory of Mars missions before and after Mars orbit insertion. Indian J. Phys. 89, 1235-1245, 2015

[3] Nwankwo V. U. J and Chakrabarti K. S.: Theoretical modeling of drag force impact on a model international space station (ISS) during variation of solar activity. Trans. JSASS Aerosp. Technol. Jpn. 12, 47-53, 2014.

Short Summary

We study the effects of space weather on the ionosphere and simulate the trend in variation of LEO satellite's orbital radius r, mean height h and orbit decay rate ODR in equatorial, low- and mid-latitude (EQL, LLT and MLT) regions during the notable storms of October/November, 2003.