Abstract:
In the current paper, the authors use high-accuracy accelerometer sensor data from the CHAMP and GRACE satellites to study the density variation with the alternative Dst geomagnetic index. The three hour ap and the one hour Dst indices are compared during the August 2005 geomagnetic storm. The correlation of the Ap and Dst for the approximately 50 geomagnetic storms that took place from 2003-2007 is studied. The correlation coefficient between density and Dst is greater than that between density and Ap. Definitions are introduced for storm intensity and density amplitude. The correlation coefficient between the amplitude and storm intensity for Dst and ap is given for the CHAMP, and GRACE-A and GRACE-B data. The first response of density in the pole region occurs about 15 minutes after the storm occurred. The first response of density at the equator occurs about 2 – 6 hours after the storm. The density response is hemisphere asymmetric – the response in the summer hemisphere is greater than that in the winter hemisphere. The response is related to local time – the enhancement on the dayside is larger than that on the night side. The Jacchia-Bowman 2008 density model employs the Dst index to compute storm-time density.

1. Introduction
A magnetic storm is a kind of disturbance in the Earth’s magnetic field. The space physical research shows that the appearance was caused by solar activity. When several coronal mass ejection (CME) events occurred on the solar surface, many high energy particles were thrown into interplanetary space. On arriving at the Earth, some of them would inject into the atmosphere from both poles. Then many complicated physical processes happened, such as ring current, Joule heating, thermal expansion and upwelling. Some beautiful aurora often arose around the poles when a storm happened. In this study we focus on the thermosphere density enhancement during storms.

The thermosphere was disturbed in storms. For example, the consistency of various neutral gas components changed, and the total density increased distinctly. As early as 1960s, Jacchia had modeled the density response as an empirical equation in his model. However, in the past 50 years, the response had not been studied very well, some details were still vague.

The CHAMP and GRACE-A/B satellite had been launched for a gravity field study. High accuracy accelerometers were fixed on them to measure the non-gravity acceleration acting on the satellite surface. The observation of this kind of instrument could be used to study the thermosphere density, because the air drag force was the main part of measurement. In the paper, we will show how to use accelerometer data to analyze the thermosphere density response during storms.
2. Data and Method

The accelerometer data are released by ISDC in the form of level-2 ACC ASCII files. They contain much information, such as linear accelerations, corrections, calibration parameters, attitude quaternion and satellite mass values, etc. In order to calculate the instantaneous non-gravitational acceleration \(a_{acc}^{\text{STAR}}\), data stored in ACC files should be processed according to the following steps: (1) the calibration of acceleration, (2) rotation of coordinate frame, and (3) rude data eliminating [Wang and Zhao, 2008]. However, this acceleration is a total value involving solar radiation, Earth albedo, and air drag. In this paper, we are concerned with the atmospheric drag acceleration, so the solar radiation should be eliminated, while the Earth albedo has not been taken into account because of its negligible quantity. In the process of calculating solar radiation acceleration \(a_{solar}^{\text{model}}\), the Box-Wing model [Luthcke, 1992] and the satellite body Macro-Model [Lühr, 2002] are used. Considering that the air drag is mainly in an along-track direction, its composition in along-track is used to produce atmosphere densities. The formulas are:

\[
U = \left( a_{acc}^{\text{STAR}} - a_{solar}^{\text{model}} \right) \cdot \vec{v}
\]

\[
U = -\frac{1}{2} \left( \frac{C_D S}{m} \right) \rho V^2 \left\{ 1 - \frac{r \cdot k \eta_v}{v} \frac{1 + e \cos f}{\sqrt{1 + 2 e \cos f + e^2 \cos^2 i}} \right\}
\]

where \(V = |\vec{v} - \vec{\nu}|\), \(\vec{v}\) is the vector of satellite velocity, \(\vec{\nu}_a\) is the vector of atmosphere rotation velocity, \(C_D\) is aerodynamic coefficient, \(S\) is cross-sectional area which means the effective area normal to the relative velocity vector, \(\eta_v\) is the velocity of the Earth rotation, \(k\) is the rotation factor, \(m\) is the satellite total mass, and \(a, e, i, f\) are the orbit Kepler elements which can be computed from satellite orbit data supplied by RSO (for CHAMP) and GNV (for GRACE) files. More details about how to calculate cross-sectional area for drag and solar radiation pressure can be found in Sutton’s work [Sutton et. al., 2005].

For the basis of the study, the accelerometer data of CHAMP and GRACE from 2003 to 2007 have been processed to produce the densities near the orbit. Then fifty-two storms during these years are selected to be the objects of our study (see figure.1 and table 1). The intensity of the storm is expressed by a geomagnetic activity index. In this paper, the 3-hour \(Ap\) index and 1-hour Dst index are adopted.

3. The comparison between Ap and Dst index

There are many storm indices, such as Kp, 3-hours Ap and Dst. The figure 2 shows the Dst value during one storm that occurred in August 2005. Several hours before the storm onset, Dst will increase to a positive value below 50, and then suddenly decrease to its minimum. We call this process as the “main phase”; in this time, the storm happens and grows. Then Dst begins to recovery to the quiet level; this process is called the “Recovery phase”. This index is often used in
the space physical field, but hasn’t been used in density model. The resolution is an hour, and better than that of Ap. In the study, we will detect Dst and Ap. Which one is suitable to describe the density variation during the storm?

First, we are concerned with the relationship between the density variation and storm indices. We know, during one certain storm, the density would increase or decrease with the storm index. We estimate the correlation relationship between them, such as Dst and Ap. The results show that the Dst has a higher correlation coefficient than Ap does. For example, the coefficient of Dst is 0.9 (Figure 3), while that of Ap is only zero point seven four (0.74) (Figure 3). It implies that Dst might be more suitable than Ap to describe the density variation during the storm. In detail, we found, the secondary disturbance of magnetic field had made the density increase again, but its max value is smaller than that of the first disturbance. The Dst index curve had the same character, while the Ap lost this character; the Ap value of both disturbances are the same.

Second, We also verified the relationship between the density amplitude and storm intensity. As we all know, the more intense the storm is, the greater the density increase. With regard to amplitude, there are two kinds of definition, such as absolute amplitude and relative amplitude. About the definitions of amplitude, many authors have their own choices, a different choice would have different results. We detect and compare both definitions. Then the correlation coefficient between amplitude and storm intensity was estimated. In table 1, we can see the result of the group Dst, and the absolute item is the largest of all. It implies that Dst is better than Ap for depicting the density enhancement. On the other hand, the figure 4 indicates the relationship between absolute amplitude and Dst; it agrees well with linear correlation.

Based on the up two aspect comparison, we believed that Dst might be more suitable than Ap for describing density variation during a storm.

![Figure 1](image1.png)

**Figure 1.** The index Ap during the storm on August, 2005
Figure 2. The index Dst during the storm on August, 2005

Figure 3. The density variation via index Ap and Dst during the storm on April 2004

Table 1. The correlation between amplitude and index

<table>
<thead>
<tr>
<th>index</th>
<th>amplitude</th>
<th>CHAMP</th>
<th>GRACE-A</th>
<th>GRACE-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[-Dst]_{max}$</td>
<td>Relative</td>
<td>0.66</td>
<td>0.72</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Absolute</td>
<td>0.92</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>$A_p_{\text{max}}$</td>
<td>Relative</td>
<td>0.63</td>
<td>0.67</td>
<td>0.61</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Absolute</td>
<td>0.85</td>
<td>0.82</td>
<td>0.81</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The linear relationship between Dst and absolute amplitude of density

4. The density response to the storms

4.1 First response in high-latitude region

This figure 5 indicates that the first response is in high-latitude region during a storm. When the storm occurred, GRACE-A was on the north-pole, there was not any density disturbance around. About 40 minutes later, GRACE-A arrived at the south-pole and observed the density had increased for about 50%. That is to say, the density would respond about 40 minutes after the storm happened. Similarly, when the storm happened, CHAMP was located on the 45 degree in north hemisphere. 15 minutes later, CHAMP arrived at the north-pole and found the density had increased for about 40%. So we can deduced that the density responds to the storm very quickly, for about 15 minutes.
4.2 First response in equator region

As we all know, after the density around poles was disturbed by storms, the disturbance would travel to the equator in the form of waves. Taking advantage of the high time-resolution of accelerometers, we inspect how much time the disturbance takes to propagate to the equator. The statistic analysis shows this process would take 2-6 hours. The lag time varies with different events. It might relate to the storm intensity and complex physical process.

Figure 6. The lag time of the dayside-density-response at equator observed by GRACE-A
4.3 Hemisphere asymmetry of response

Figure 8 shows that the responses in both hemispheres are different. The response in the summer hemisphere is greater than that in winter one. Figure 8 indicates that two storms occurred at summer solstice and winter solstice. If the solar latitude was in north hemisphere, the response in north is more obvious. Contrarily, if the solar latitude was in south hemisphere, the response in south is greater. The result was verified in most of events. Forbes thought that it might be related to “summer-winter” circulation of atmosphere. In summer hemisphere, the direction of disturbance is same with this circulation, its energy is easy to be spread to the equator. While in winter hemisphere, both directions are reverse, and then the energy was restricted around the high-latitude.
4.4 Day-night difference of response

On the other hand, the response was found to be related to local time. The absolute enhancement of the density in the dayside is greater than that in the night side. The result based on CHAMP and GRACE is consistent.

5. Conclusion

Dst might be more suitable than Ap for describing density variation during a storm. JB2008 had built the empirical equation based on Dst to compute storm-time density. [Bowman, 2008]. The first response of density in the polar region lags by about 15 minutes after the storm occurred, while that at the equator lags by about 2-6 hours. The density response is hemisphere asymmetric, which in the summer hemisphere is greater than that in winter one. The response is related to local time. The enhancement in dayside is larger than that in night side.

References


Wang Hongbo, ZHAO Changyin (2008), Use CHAMP/STAR Accelerometer Data to Evaluate Atmospheric Density Models during Solar Maximum Year, Chinese Astronomy and Astrophysics, Volume 32(4)