博士学位论文摘要选登

星载加速仪数据在高层大气研究中的应用

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地球高层大气是影响近地卫星运动的主要因素之一. 自 1957 年前苏联发射第 1 颗人造卫星以来，人类一直开展高层大气的研究，建立了一些著名的经验大气模型，在卫星的轨道预报和定轨中发挥了重要作用. 但是由于高层大气变化非常复杂，加上早期的资料精度有限，高层大气的一些基础问题尚未完全解决.

论文以 CHAMP 、 GRACE-A/B 双星加速仪资料 (Reigber et al. 2001, Tapley et al. 2004) 为基础，对高层大气的一些问题进行了系统研究. 首先给出了加速仪数据的处理方法，大气点密度计算方法，处理得到了 2002—2008 年高层大气的密度资料. 利用这些资料校验了 CIRA72 、 DTM94 和 NRLMSISE00 模型的精度，结果显示 CIRA72 平均误差约 22%, DTM94 约 26%, NRLMSISE00 约 27%, 3 个模型均低估了大气密度. 误差受太阳辐射的影响很大，太阳活动峰年时 (2002—2003), 3 个模型的误差均超过 30%, 而在太阳活动谷年 (2007—2008), 模型误差小于 15%.

深入研究了高层密度 3 种变化特征：周日效应、季节效应和半年效应. 结果显示： (1) 周日效应与纬度和高度都有关. 具体地，低纬地区比高纬地区周日效应更明显，高度越高周日效应越明显；若定义最大和最小密度的相对差异为周日变幅，那么 470 km 周日变幅约 1.3, 370 km 周日变幅为 0.8; (2) 季节效应与纬度有关，季节变幅在 60° 地区为 0.6, 而在 30° 附近为 0.3; (3) 半年效应与太阳辐射有关，辐射越强半年效应越明显，半年变幅在强太阳辐射时约 0.32, 弱太阳辐射时为 0.20.

从太阳活动长期趋势与短期变化两个角度证实了太阳辐射与大气密度的强相关性. 随着辐射流量的增大，日照区密度的绝对增幅是阴影区的 2 倍. 研究了几种新型辐射指数对大气模型精度的影响，结果表明 $E_{10.7}$ 能使模型平均误差减小 20%, 与 S_{10} 、 Mg_{10} 和 Y_{10} 联合建模时，能使模型中误差降低 5%.

我们研究了 2003—2007 年间 52 次磁暴 (ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP), 分析了磁暴对大气密度的影响. 结果表明 Dst 指数比 A_p 指数更能刻画大气密度在磁暴中的变化，因此今后在大气建模中应当加以考虑. 大气对磁暴的初始响应很快，在磁暴发生后 15 min 内，磁极附近的大气就会明显增大 40%∼70%, 但这种响应传播到低纬地区一般需要 2∼6 h. 而且大气响应呈现出季节差异和昼夜差异，具体地：夏季半球的响应要比冬季半球更剧烈，白天半球的响应比夜间半球更剧烈. 磁暴结束后，大气密度需要经历大约 12∼36 h 才能恢复到爆发前的水平.

用 King-Hele 方法研究了 CHAMP 卫星轨道倾角的长期变化，估计 370 km 附近的大气旋转速度是地球自转速度的 1.9 倍. 然后给出了一种用加速仪轨道面法向资料计算大气旋转速度的方法. 结果显示：以地球自转速度为单位，大气旋转角速度在 370 km 附近 (CHAMP 高度) 约 1.8, 470 km 附近 (GRACE 高度) 约 1.0, 比早期 King-Hele 的研究结果 (King-Hele 1971) 略大. 还发现大气旋转角速度具有长周期变化的特征，周期约 130∼160 d, 具体原因有待进一步研究.

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The Application of Satellite Borne Accelerometer Data to the Study of Upper Atmosphere

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The thesis studies some issues on the upper atmosphere based on the accelerometer data of CHAMP and GRACE-A/B satellites (Reigber et al. 2001, Tapley et al. 2004). The total atmospheric densities from 2002 to 2008 are computed from accelerometer measurements. Then the accuracies of three empirical density models such as CIRA72, DTM94 and NRLMSISE00 are evaluated. It shows that the mean errors of these models are about 22%, 26% and 27%, respectively. All of them underestimated the densities. For the years of Solar maximum (2002—2003), the models' errors exceed 30%, while for the years of Solar minimum (2007—2008), the errors are less than 15%.

Three characteristics of density variation are studied, such as diurnal variation, seasonal variation and semi-annual variation. The results are: (1) The diurnal-amplitude in low-latitude region is about 1.3 at 470 km and 0.8 at 370 km. (2) The seasonal-amplitude is about 0.6 in the 60 degree region and 0.3 in the 30 degree region. (3) The semi-annual variation is related to the solar radiation. The stronger the radiation is, the greater the semi-annual-amplitude is. For example, it is about 0.32 with strong solar radiation and 0.20 with weak solar radiation.

The effects of various solar indices on the model accuracy are also studied. It is shown that $E_{10.7}$ could reduce the mean errors of models about 20%, and S_{10}, Mg_{10}, Y_{10} could reduce the standard deviations of models about 5%.

To study the density response to magnetic storms, 52 storm events from 2003 to 2007 (ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP) are chosen as examples. It is deduced that the index Dst is more suitable to describe the density variation than index A_p. The first response of density during the storm is very fast. In about 15 minutes after the storm onset, the density around the north and south poles would enhance about 40%~70%. However, the disturbance would take 2~6 hours to travel to the equator region. It is also found that the density response has seasonal difference and day-night difference. Concretely, the response in the summer hemisphere is stronger than that in the winter hemisphere, while the response in the dayside is greater than that in nightside. After the storm ends, the density would take 12~36 hours to recover to the level during the quiet time.

The King-Hele method is applied to study the long-term variation of CHAMP inclination and estimate the angular velocity of atmosphere rotation. It is about 1.9 at CHAMP's height (the unit is the velocity of the earth rotation). On the other hand, the cross-track measurement of the accelerometer is used to study rotation velocity in detail. It is deduced that the velocity is about 1.8 at 370 km and 1.0 at 470 km, which is a little larger than the result in King-Hele (1971). A periodic variation of the velocity, which is about 130~160 days, is also found. The reason has not been discovered so far.