

Study of solar and geomagnetic activity effects on the neutral upper atmosphere

A thesis submitted to the faculty of science, Astronomy and
Meteorology Department,
As required for the degree of
Master in Science
Cairo University

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2009

دراسة تأثير النشاط الشمسي والنشاط المغناطيسي للأرض علي الطبقات العليا للغلاف الجوي الأرضي الغير متأين

رسالة مقدمة الي كلية العلوم
قسم الفلك والأرصاد الجوية
كما هو مطلوب للحصول علي درجة
ماجستير في العلوم
جامعة القاهرة

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۲۰۰۹

ACKNOWLEDGMENT

All gratitude is due to almighty Allah who aided me to bring forth this thesis to light. I thank Allah

I would like to thank my family, particularly my father, my mother and my wife for the continuous encouragement and help.

My deep appreciation and sincere gratitude are presented to my supervisors, Prof. Dr. Mohamed Saleh Elnawawy and Prof. Dr. Mohamed Magdy Abdelwahab for supervision and following the progress of the work with keen interest.

I would like to acknowledge Prof. Dr. Magdy Yousef Amin for his helping me in operating the model program and this acknowledgement is not enough for appreciating his spending much time with me to finish this work.

Finally, I would like to express my sincere appreciation for every body who contributed directly or indirectly in this study, especially my wife that was behind me in finishing this work and tried to introduce any help that I need.

Abstract

This work provides a review to models used to simulate temperature and density for upper atmosphere. This work will focus only on the neutral case of the upper atmosphere which remains to be the major one. The proposed analysis carried out in this work depends upon extensive review to models and analysis to the subject. The proposed computational model (EGY-2009) is based on Jacchia atmosphere equations and benefits of the most recent efforts carried out in the field to model the upper atmosphere in order to determine altitude profiles of some atmospheric physical parameters like the temperature, density, pressure, and scale height. We studied two cases, one for the past time and the other for prediction of the future. In our model we have followed Bowman et al in their model (JB2008) in using new modified equations for the exospheric temperature, the semiannual density variation and new solar indices based on recent efforts to include the effect of EUV radiation on heating the upper atmosphere. Our results can give detailed analysis of the different physical parameters of the neutral upper

atmosphere. Our model is focused to study the atmosphere up to altitudes of 1000 km. Predictions of the density variation are also given for more than ten future years.

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Aim of the present work

In this work we will follow the past Jacchia atmosphere models in using the past equations for the exospheric temperature and semiannual density variation then (Bowman et al, 2008) model in using the modified equations for the temperature and semiannual density variation also. In addition the new solar indices will be employed to express the effect of EUV radiation on heating the upper atmosphere. Results of the temperature, density, pressure, and scale height values and their variability with height will be provided.

CHAPTER (1)

INTRODUCTION

1.1 Overview on the neutral upper atmosphere

1.1.1 What is the upper atmosphere?

The upper atmosphere is the upper part of the atmospheric layer that surrounds the Earth. This atmospheric layer is divided into several regions or layers, based on the temperature or composition profiles or the physical processes operative in the region (Daniel and Henry, 1996). We will present briefly the main features of these layers in the next section concentrating on the thermosphere, ionosphere and the magnetosphere layers which are important for modeling the upper atmosphere. According to (King-Hele, 1987) the thermosphere layer marks the beginning of increased ultraviolet (UV) radiation absorption and a rapid increase in temperature. In the thermosphere we transition from the lower atmosphere to the upper atmosphere. This layer ranges from about 100 km to about 500 km height. The upper atmosphere is characterized by roughly an exponentially varying model for some physical parameters such as the densities and the concentrations. Also in the thermosphere the temperature increases with altitude (Ross and Darren, 1993). The ambient neutral upper atmosphere is an important environment at low earth orbit (LEO) and polar orbits (PEO) altitudes. Values of the three basic neutral atmosphere parameters: concentration, temperature and composition vary in response to many factors, including local time, latitude, altitude, and solar and geomagnetic activity (Daniel and Henry, 1996). And we will discuss these activities and their indices in the next section.

1.1.2 Why we study the upper atmosphere?

An understanding of the thermosphere and the ionosphere, two tightly coupled, overlapping regions of the atmosphere, is important for a number of research and space weather applications (A.J. Ridley et al, 2006), for example:

- (1) Examining increased satellite drag due to heating of the atmosphere.
- (2) Examining where and when strong gradients of total electron content will occur for GPS signal degradation analysis
- (3) Determining when and where high frequency signals will be strongly scattered or lost due to ionospheric scintillation.
- (4) Examining the role of ionosphere and thermospheric dynamics on the climatology of the lower atmosphere.
- (5) Determining how the ionosphere influences the magnetosphere through ionospheric conductance and outflow.

1.1.3 Interactions between the neutral gas environment and a spacecraft

For spacecrafts in low earth orbits LEO, and polar orbit PEO, the dominant environment is the ambient neutral atmosphere. The neutral gases that make up the atmosphere in this environment form a distinctive structure around the spacecraft and give rise to atmospheric drag, surface erosion and spacecraft glow. The neutral gas emitted by the spacecraft itself gives rise to contamination on other parts the spacecraft (Daniel and Henry, 1996).

We will discuss now shortly these different interactions:

a - Atmospheric drag

At the typical operational altitude for spacecrafts, including the space shuttle in LEO, the neutral atmospheric density is much less than that at sea level, which is about 10 orders of magnitude less. However, it's still large enough that, for instance, a 1-m² spacecraft orbiting at 8 km/s would suffer about 3×10^{22} collisions with ambient atoms every hour (Tribble AC, 1993).

Undergoing such collisions, which cause the transfer of momentum to the spacecraft, the spacecraft would experience a sizable amount of drag force during operation. This may result in its early entry to the atmosphere and require a large amount of fuel for thrusting (Joo-Hyun and Chun-Gon, 2004)

For LEO, the aerodynamic drag will eventually de-orbit the spacecraft, if it is not countered by periodic re-boosting of the spacecraft. For example, the space station will require one logistics shuttle flight a year to replace the propulsion modules and keep the station in orbit (Daniel and Henry, 1996).

b - Surface erosion

Spacecraft or space structure experiences bombardment of atomic oxygen, which is the predominant component of the atmosphere in LOE. In long missions, the structural materials of spacecraft, especially organic materials may suffer from serious degradation damages caused by the impact of atomic oxygen with typically 8 km/s relative velocity or with the kinetic energy of 5ev (Koji et al, 2003), and the nominal of atomic oxygen flux ranging approximately from 10^{14} to 10^{15} atom /cm² (Cvelbar et al, 2003)

Although generally this is not energetic enough to physically remove materials from the surface, it's energetic enough to initiate chemical reactions on certain materials at the spacecraft surface that can lead to material loss such as Kapton or Silver (Daniel and Henry, 1996). (Raja Reddy, 1995) reviewed actual flight experiments in LEO conducted for a large number of materials on several space shuttles and the long duration exposure facility (LDEF). For example unprotected Kapton, a material often used as an external thermal control surface, was completely eroded from exposed surface on LDEF spacecraft. The LDEF was placed in LEO orbit by the shuttle and orbited for six years before being retrieved. Even on the short shuttle missions, exposed Kapton samples have been found to erode measurably in a few days.

Even if the flux of atomic oxygen doesn't erode the surface, oxidation of the surface may change the thermal properties of the surface layer. This must be considered in the design of the spacecraft thermal control system. (Daniel and Henry, 1996)

c - Spacecraft glow

The LEO ambient neutral component is also a direct contributor to the diffuse UV-visible-IR glows that have been observed to occur above surfaces oriented toward the spacecraft ram direction (Daniel and Henry, 1996). These complex glow phenomena, which include surface-catalyzed, excited recombination, appear to be functions of the spacecraft altitude, attitude, materials, surface temperature, time in orbit, nature of the orbit, and vehicle size.

d - The contamination

Many materials are known to release absorbed gas on exposure to the space environment because the ambient neutral gas pressure in space is so low relative to that of the earth. Additionally materials may release gas through decomposition or sublimation. Neutral gas is generated through backflow from thruster firings, incomplete ionization of ion thruster gases, and effluent dumps. Overtime, these gaseous products can coat and contaminate sensitive sensors and surfaces, seriously degrading their performance or rendering them useless. (Daniel and Henry, 1996)

1.1.4 The previous efforts in modeling the upper atmosphere**1.1.4.1 Introduction**

Of the many perturbations affecting the orbit of a near-earth satellite, those caused by the atmosphere have attracted the most attention. This is due not only to the dominance of air drag at low altitudes but also to the important difficulties and uncertainties associated with atmospheric modeling (Lafontaine and Hughes, 1983). Accurate trajectory determination and prediction are limited by one's ability to model the atmosphere mathematically, at least the height, geographical and time distributions of the electron concentration and the neutral densities (C.Lathuillère. et al 2002). The modeling effort has started a long time ago, due to the development of our technological society. However, there is no model able to reproduce in a satisfactory way both the climate and the weather of the earth's ionosphere-thermosphere. In addition, there is no well established experimental database that can be used to verify and test the existing models; in order to generate the improvements needed (C.Lathuillère. et al 2002). For many years a number of satellites have been supplied with accelerometers to measure the thermospheric densities, as well as with neutral and ion mass spectrometers to measure the number densities of the neutral and ionized components in the upper atmosphere. In addition the atmospheric densities have also been derived from the tracking of satellites and a careful analysis of orbital – parameters changes with time. All of these data sets have led to the development of composite thermospheric density and temperature models which were used in orbital prediction studies; as well as for a number of scientific purposes (Šegan and Šurlan, 2005). Above 200 km the upper atmosphere's structure is determined by

solar activity (King-Hele, 1987). There are five different measurable effects which make the atmosphere vary from the static model (Jacchia, 1977):

- 1-Variation with solar cycle
- 2-Daily, or diurnal, variation
- 3-Variation with geomagnetic activity
- 4-Seasonal-latitudinal variations
- 5-Rapid density fluctuations, probably connected with gravity waves

Thermospheric semiannual-empirical models are based on the hypothesis of independent static diffusive equilibrium of the different thermospheric constituents above 120 km altitude. The density of each constituent decreases exponentially with altitude, according to its own scale height that depends on its mass and on the temperature. The temperature variation is described by the Bates profile that is a function of the exospheric temperature, and the temperature and its gradient at the lower limit. The temperature and the gas concentration evolve depending on season and solar local time, latitude, solar flux represented by the F10.7 index, and geomagnetic activity represented by Ap or Kp indices. Periodic functions are used to represent the diurnal and seasonal variations. Latitudinal, solar activity and geomagnetic activity variations are represented by non-periodic functions that may differ from one model to another (C.Lathuillère. et al 2002)

1.1.4.2 Previous models review

(Šegan and Šurlan, 2005) described the atmospheric models as three lines. The first line basis is a numerical quadrature of the species wise diffusion equations. Examples of the models that describe this line are Jacchia model series and other models that depend on Jacchia models in their basis.

Jacchia has derived multi-parameter models based on satellite drag data (for total density estimation) and on composition and temperature measurements of the atmosphere. These models give density, temperature, pressure, mean molecular mass, density scale height and composition as function of the parameters like (altitude, solar activity,.....etc) as mentioned before (Lafontaine and Hughes, 1983).

Early models of the thermosphere emerged about 1965 (e.g. Harris- Priester and Jacchia-65) (Šegan and Šurlan, 2005)

Jacchia-70 model (Jacchia, 1970) is based on satellite drag data derived from ground- based tracking of selected satellites. An earlier model by Jacchia (1965) was used as the basis for this successor model. All the available observational material up to that time, including the then measurements of density and composition, has been taken into account in the construction of this model. It should be understood that no good observational data existed above 1100 km at the time this model was prepared (American National Standard, 2009), so that all of the model data output above that height must be considered as unconfirmed extrapolation

Jacchia-71 model (Jacchia, 1971) is a revision of the Jacchia-70 model. Although an effort has been made in the Jacchia-70 model to increase the $n(O)/n(O_2)$ ratios, new observational evidence showed that the increase had not been large enough. The Jacchia-71 models attempt to meet, as closely as possible; the composition and density data derived for a height of 150 km on the basis of an available mass spectrometric and EUV- absorption data. All recognized variations of model parameters are represented by empirical equations. Some of these equations were revised in the Jacchia-71 model, not only in their numerical coefficient, but also in their form, as result of new analyses (American National Standard, 2009). (Marcos et al, 2006) provides a comparison of the Jacchia-71 model with several other thermospheric models versus altitude, latitude, local time, day of year, and solar and geomagnetic conditions.

Jacchia-77 model (Jacchia, 1977) is a revision and updating of the Jacchia-71 model. This new model consists of two parts: (1) the basic static models, which give temperature and density profiles for the relevant atmospheric constituents for any specified exospheric temperature, and (2) a set of formulas to compute the exospheric temperature and the expected deviation from the static models resulting from all of the recognized types of thermospheric variation (American National Standard, 2009). All temperature profiles start at a constant value or $T_0 = 188$ K at a height of $Z_0 = 90$ km. A condition of complete atmospheric mixing is assumed up to 100 km and diffusive separation above this altitude. The Jacchia-77