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Thermospheric mass density: A review

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Abstract

The mass density of Earth's thermosphere (∼90–600 km altitude) is a critical parameter for low Earth orbit prediction because of the atmospheric drag on satellites in this region. In this review, we first survey techniques for measuring thermospheric density, empirical models that provide a synthesis of historical data, and physical models that simulate the environment by solving fluid equations. We then review the climate and weather features that are observed in thermospheric density (including its response to solar forcing) and summarize recent studies of these features. The review is focused on results published between 2000 and 2014, which coincides with a period of extensive accelerometer measurements of density and accompanying research; some historical context is also provided.
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Keywords: Thermosphere; Mass density

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1. Introduction

The thermosphere (∼90–600 km altitude) and exosphere (>600 km) are a hot, partially ionized gas consisting primarily of N_2, O_2, O, He, and H. The mass density of this gas falls off exponentially with increasing altitude, with scale heights of 25–75 km in the upper thermosphere. At an altitude of 400 km, where many active satellites orbit, including the International Space Station, the density is typically only 2 g per cubic kilometer, but this is large enough to measurably impede the motion of orbiting objects and is a critical consideration in the planning of satellite missions and lifetimes, orbit and reentry prediction, and collision avoidance.

Thermospheric density variations are driven in large part by variations in solar ultraviolet (UV) irradiance, which is the thermosphere's primary heating source. Changes in UV irradiance cause the thermosphere to expand (more UV) or contract (less UV), so that density at a given altitude increases or decreases, respectively. Other major drivers of density variations are electrical energy and energetic particles from the magnetosphere and solar wind, and waves originating in the lower atmosphere that propagate upward into the thermosphere. In addition to the exponential vertical dependence, density varies horizontally (latitude and longitude) and with local time and day of year.

In this paper, we review our understanding of the behavior of thermospheric mass density, including its climate, short-term variations, and long-term changes. Many upper atmospheric density measurements extend well into the exosphere, as does satellite drag. Accordingly, we consider both the thermosphere and exosphere in this review, although the main focus is on the upper thermosphere (∼200–600 km). For simplicity, we use "thermosphere" to refer to both the thermosphere and exosphere. We also use "density" to refer to mass density (in contrast to number density), unless otherwise noted.

Review papers generally aim toward one or more of the following objectives: (1) a comprehensive summary of the literature during a selected time interval; (2) a critical synthesis of existing knowledge; (3) a historical account of the development of the knowledge; or (4) a tutorial for newcomers to the field. Thermospheric density is a rather broad topic, being a property of the environment driven by many mechanisms and closely connected to other properties. This makes it very difficult to achieve a critical synthesis or historical account in a single paper. The primary aim of this review is a comprehensive summary of the literature between 2000 and 2014. However, for each subtopic, brief syntheses are attempted, and seminal contributions are cited to provide historical context. Some tutorial content is also provided for orientation.

Although temperature and density are closely related, in our survey we mainly consider papers that deal explicitly with mass density. The 2000–2014 period that we focus on coincides with the extensive measurements made by

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