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GLOBAL TEMPERATURE AND ENERGY IN THE IONOSPHERE THERMOSPHERE SYSTEM

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Abstract : The study aims to examine the temperature structure and energy in the Mesosphere to Lower Thermosphere region using the TIMED SABER instrument (Sounding of the Atmosphere using Broadband Emission Radiometry) onboard NASA's Thermosphere Ionosphere Mesosphere Energetic Dynamics (TIMED) satellite. A global temperature map ranging from 50 km to 110 km altitude, with a vertical resolution of 2 km, was generated using Level 2A data. The temperature shows significant spatial and altitudinal variability, with the maximum observed at 50 km, decreasing until 90 km, and then increasing again up to 110 km. The spatial temperature variability is approximately 50ºC. Radiative energy, estimated using the fundamental radiation law with an assumption of σ = 1, typically ranges from 200 Wm-2 to 600 Wm^{-2}, reaching up to ~1300 Wm-2 in the lower thermosphere of the southern hemisphere polar belt during typical Northern winter.

Index Terms : Temperature, Radiative energy, Ionosphere Thermosphere system

INTRODUCTION

The Earth's atmospheric system is primarily driven by the Sun's electromagnetic radiation. The Mesosphere to Lower Thermosphere (MLT) region is predominantly influenced by atmospheric tides, planetary waves, gravity waves, chemistry, and radiative forcing. The thermal structure of the mesopause, which connects the mesosphere below with the thermosphere-ionosphere above, experiences significant changes as waves and tides interact and propagate through this region (Smith, 2004). As these waves travel upward, their amplitude increases exponentially to compensate for the decreasing atmospheric density.

Human activities are known to affect not only the lower atmosphere but also the upper atmosphere (Roble & Dickinson, 1989; Roble, 1995). Thus, it is essential to study the natural variations in atmospheric parameters that impact climate to distinguish them from changes caused by global phenomena. A fundamental understanding of the radiative energy budget is necessary to interpret the causes of atmospheric trends.

MLT dynamical condition measurements are conducted remotely using ground-based and space-based instruments, as well as on-site with rockets. While no single instrumentation provides a complete picture, the combination of these methods offers a more comprehensive understanding of the base state and its variations. Ground-based and rocket-borne instruments, though limited in geographic coverage, deliver high vertical resolution. Continuous ground-based observations provide detailed local time variations, whereas satellite instruments offer a global or near-global view with limited local time sampling and sometimes restricted spatial resolution.

The primary dynamical fields measured include kinetic temperature, neutral density, horizontal wind vector, and small-scale wave-induced luminescence perturbations. Special measurements, such as turbulence, are also conducted. Satellite limb scans are particularly useful for achieving good vertical resolution (several km). Key data sets contributing to our understanding of MLT dynamics have come from the Solar Mesosphere Explorer (SME), the Upper Atmospheric Research Satellite (UARS; 1991–2005), the Thermosphere Ionosphere Mesosphere Energetics and Dynamics satellite (TIMED; 2002–ongoing), the Envisat satellite (2002–ongoing), and the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA; November 1994, August 1997).

Thorough examination of the spatial and temporal variation in the temperature structure of the mesosphere and lower thermosphere requires continuous data. Models frequently detail density and temperature variations over altitudes ranging from 100 km to 400 km.

Temperature measurements in the middle and upper atmosphere are vital not only for understanding temperature itself but also for deriving density and pressure profiles. This region is important as it serves as the operating environment for many satellites and is influenced by GPS and radio navigation signals. Thus, any changes in the ionospheric-thermosphere system can significantly impact these satellite-based technologies, which are increasingly critical today. Investigating the effects of solar activity on the vertical temperature structure and distinguishing these effects from global change signals is challenging due to the reliance on time-series data sets. The analysis of systematic temperature changes in the mesosphere and lower thermosphere has not been as comprehensive as in the lower atmosphere. To address this, continuous data is essential for examining the spatial and temporal variations in these regions.

The present study focuses on the equatorial belt covering the Indian region for time series analysis. The objective is to examine the spatial variation of temperature in the ionosphere and thermosphere system (Smith, 2004) and to analyze the altitude variation of temperature at each elevation, quantifying its amplitude and energy (Roble and Dickinson, 1989; Roble, 1995).

DATA AND ANALYSIS

The Sounding of the Atmosphere using Broadband Infrared Emission Radiometry (SABER) instrument on the TIMED (Thermosphere Ionosphere Mesosphere Energetic and Dynamics) satellite is a limb-scanning multichannel radiometer that provides vertical profiles of temperature and atmospheric composition from 10 to 120 km, with continuous coverage up to 50° geographic latitude towards the equator. SABER measures temperature, ozone, water vapor, carbon dioxide, nitric oxide, and emissions across a wide range of altitudes, from near the troposphere to the low thermosphere (Martin *et al.*, 2022).

In this study, we use SABER Level 2A temperature observations (http://saber.gats-inc.com) to determine the spatial and longitudinal structure, utilizing a 5º × 5º grid over the globe. The method for retrieving SABER temperatures is described by Mertens *et al.* (2001), and the validation of kinetic temperature and other species, using lidar observations, is detailed by Dawkins et al. (2018).

OBSERVATIONS

Figure 1 presents the average monthly mean global temperature from 50 km to 110 km altitude, with a vertical resolution of 2 km, for December 2014. The temperatures display both spatial and altitudinal variations, clearly illustrating the differences in thermal structure between the hemispheres.

At altitudes of 50-52 km, observed temperatures range from approximately 230 K to 270 K, with a spatial variation of about 30 K to 40 K. With the sun in the southern hemisphere (SH) during this period, maximum temperatures, particularly in the polar regions, exceed 270 K, while northern latitudes display a significant spatial temperature gradient. In the Northern Hemisphere (NH), mid-latitudes experience considerable variation, ranging from around 220 K to 230 K. The temperature continues to decrease, reaching its lowest point at the mesopause, located between 92 km and 94 km, where it ranges from 170 K to 210 K, with a variation of approximately 40 K.

At 102 km, in the lower thermosphere, the maximum observed temperature gradient is approximately 100 K, ranging from 170 K to 270 K. The polar thermosphere has started to warm, and significant latitudinal heating is observed in the lower thermosphere at around 110 km.

Figure 2 illustrates the average monthly radiant energy estimated using the temperature observed for December 2014. The estimated energy in the lower thermosphere is shown in Figure 2. The energy estimated using fundamental radiation theory stated as Stefan-Boltzmann law $E = \sigma T^4$, where σ = Stefan-Boltzmann constant and T = Absolute temperature in (ºK). The estimated energy in the lower thermosphere shown in Figure 2. The magnitude of the variation ranges from 200 Wm^{-2} - 1300 Wm^{-2} in the lower thermosphere.

CONCLUSIONS

The objective of the study is to examine the temperature structure and energy in the ionosphere-thermosphere system using global observations. Temperature from the TIMED/SABER satellite observations was used for the study and it summarized the following points.

1. Global temperatures from an altitude of 50 -110 km have created a spatial temperature gradient of about ~ 40º K in the stratosphere to the mesosphere and about ~100º K in the lower thermosphere.
2. The estimated global energy using fundamental radiation theory is between 200 Wm^{-2}-1300 Wm^{-2}in the lower thermosphere.

ACKNOWLEDGEMENTS

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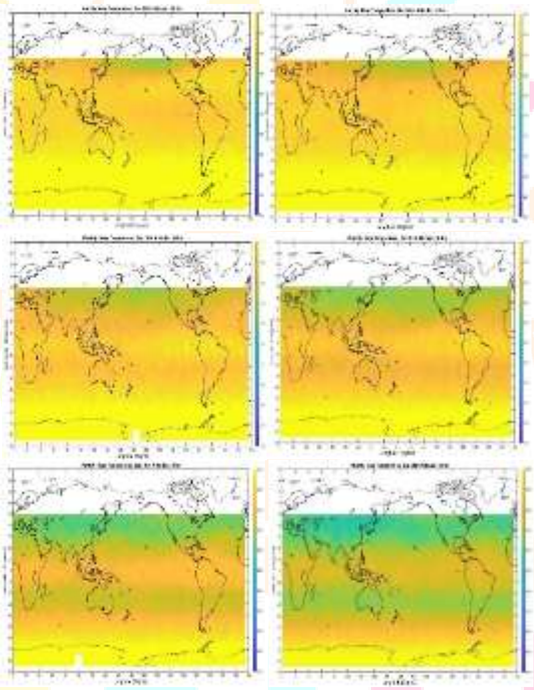
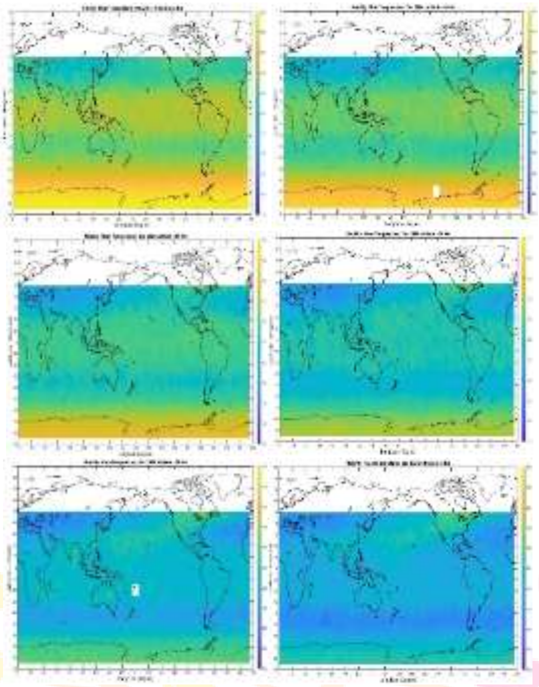


Figure1: Monthly mean global temperature from 50 km -110 km altitude with a vertical resolution of 2 km derived using TIMED SABER satellite data.



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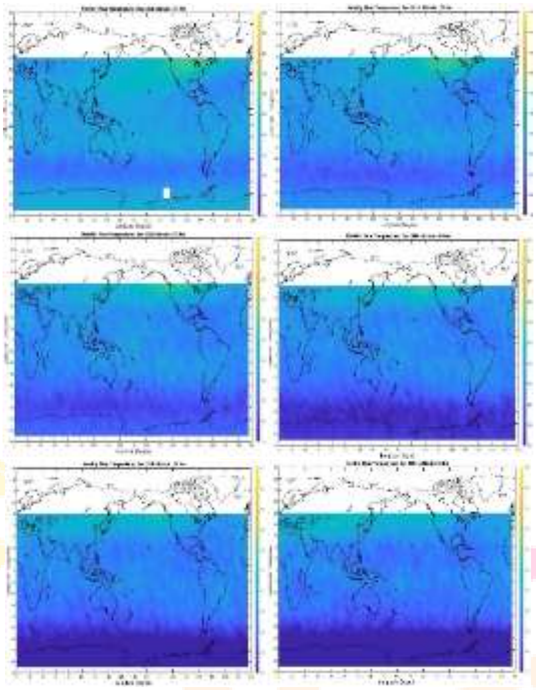

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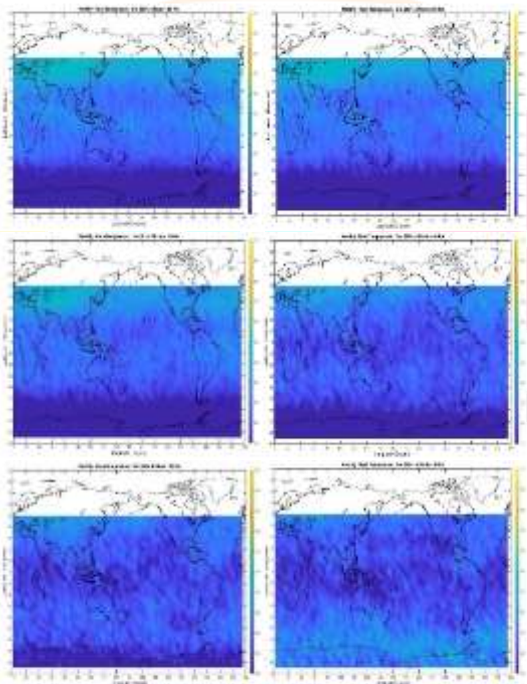

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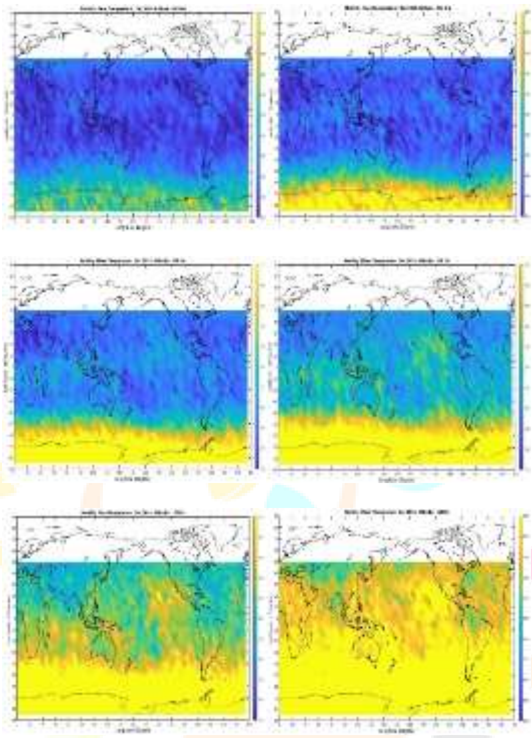

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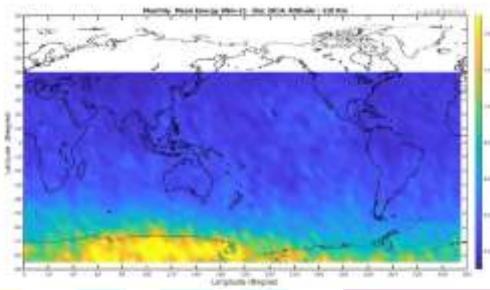

Figure 2: Monthly mean energy on December 2014 at altitude of 110 km