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Characterization of the semi-annual-oscillation in mesospheric temperatures at low-latitudes

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Abstract

Novel measurements of the seasonal variability in mesospheric temperature at low-latitudes have been obtained from Maui, Hawaii (20.8°N, 156.2°W) during a 25-month period from October 2001 to January 2004. Independent observations of the OH (6, 2) Meinel band (peak height ∼87 km) and the O_2 (0–1) atmospheric band emission (∼94 km) were made using the CEDAR Mesospheric Temperature Mapper. The data revealed a coherent oscillation in emission intensity and rotational temperature with a well-defined periodicity of 181 ± 7 days. The amplitude of this oscillation was determined to be ∼5–6 K in temperature and ∼8–9% in intensity for both the OH and O_2 data sets. In addition, a strong asymmetry in the shape of the oscillation was also observed with the spring maximum significantly larger than the fall peak. These data provide new evidence in support of a semi-annual-oscillation in mesospheric temperature (and airglow emission intensities) and help quantify its seasonal characteristics.

Keywords: Airglow; Mesospheric temperature; Atmospheric oscillations; Seasonal variations

1. Introduction

It is our growing understanding that planetary waves, gravity waves and tides dominate the structure and dynamics of the mesosphere and lower thermosphere (MLT) region. Long-term observations are therefore important for quantifying seasonal variability of this region as a function of latitude, and for investigating the primary causes of the variability. Satellite measurements provide excellent geographic coverage usually over a several year period, but, due to orbital constraints, the measurements are naturally limited to sampling at certain local times (e.g., Clancy and Rusch, 1989; Shepherd et al., 1998). On the other hand, rocket-borne sampling of the MLT region can be made from any latitude (providing there is a suitable launch facility available), but the data are of very limited duration. In contrast, ground-based observations offer an economical and very important method for routine remote sensing studies of the upper atmosphere. Although these measurements are subject to changes in the viewing conditions (due to adverse weather), long-term observations from a well chosen mountain site provide an excellent opportunity for seasonal studies of the MLT region.

As early as the International Geophysical Year (IGY) ground-based investigations have been carried out to study the seasonal variability in the mesospheric nightglow emissions. Initial investigations revealed strong latitudinal and seasonal variations in the mesospheric OI (557.7 nm), Na (589.3 nm), and the near infrared OH Meinel nightglow emission intensities which originate from well defined layers in the upper mesosphere (e.g.,

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Roach and Smith, 1967; Wiens and Weill, 1973; Fukuyama, 1977). Longer-term observations have also revealed semi-annual, annual and quasi-biennial oscillations in these data sets, the characteristics of which alter significantly with latitude. Furthermore, modeling and observational studies of the seasonal variability of the OH Meinel band emission intensity have shown that at low- and mid-latitudes vertical diffusion (due primarily to small-scale gravity wave breaking) can be large, leading to a semi-annual-type oscillation while, at higher latitudes much stronger vertical advection leads to an annual-type oscillation (e.g., Le Texier et al., 1987). Variations of the vertical diffusion and residual circulation in the MLT region, both induced by gravity wave breaking, are also likely causes of mesospheric OI (557.7 nm) seasonal variations at mid-high latitudes (e.g., Garcia and Solomon, 1985; Liu and Roble, 2004).

In addition to measuring the mesospheric emission intensities it is also possible to use optical techniques to determine the temperature of the mesosphere at the height of the emission layers. Long-term investigations of mesospheric temperature using a variety of optical instrumentation ranging from simple photometry to interferometry and nowadays CCD imaging and resonant lidar sounding techniques continue to be conducted (e.g., Niciejewski and Killeen, 1995; She et al., 2000; States and Gardner, 2000; Bittner et al., 2000; Espy and Stegman, 2002). The majority of these measurements have been made from mid- and high latitude sites and have revealed a strong annual-oscillation in middle atmosphere temperatures with some evidence for an additional, but small, semi-annual component at mid-latitudes. In contrast, long-term, ground-based measurements of mesospheric temperature at low- and equatorial latitudes are exceedingly few (e.g., Takahashi et al., 1995; Friedman, 2003) and the seasonal structure and variability of the MLT region has yet to be fully quantified.

This paper utilizes ground-based observations of the nightglow emissions from the US Air Force AEOS high altitude facility located at the summit of Haleakala Crater, Maui, Hawaii (20.8°N, 156.2°W, 2970 m), which affords excellent seeing conditions throughout the year. The present work focuses on long-term observations of the mesospheric OH M (6,2) and O_2 (0,1) atmospheric band temperature and their variability over a 25-month (encompassing 2002–2003). The measurements were made using the CEDAR Mesospheric Temperature Mapper (MTM) and show a clear semi-annual-oscillation in the nocturnal temperatures in both data sets.

2. Instrumentation and observations

The Mesospheric Temperature Mapper (MTM) was developed at Utah State University (USU) in 1997 with support from the National Science Foundation (NSF) Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) program. The MTM is a high performance, solid state imaging system capable of determining variations in the intensity and rotational temperatures of two upper mesospheric near infrared nightglow emissions: the OH M (6,2) band (peak altitude ~87 km), and the O_2 (0,1) atmospheric band emission (peak altitude ~94 km), both of which exhibit well defined half-widths of ~8–10 km (e.g., Donahue et al., 1973; Baker and Stair, 1988). The MTM utilizes a large format 1024×1024 pixel CCD array coupled to a 90° circular field of view telecentric lens system. The detector is cooled to -50 °C using a two-stage Peltier system assisted by a closed cycle liquid refrigeration unit providing very low noise operational characteristics (dark current ~0.1 e^-/pixel/s). Sequential observations are made using narrow band ($\Delta\lambda \sim 1.2$ nm) interferences filters centered at 840 and 846.5 nm for the OH M (6,2) band and 866 and 868 nm for the O_2 (0,1) atmospheric band measurements followed by a background sky measurement at 857 nm. Each filter is exposed for 60 s duration resulting in a cadence of ~5.5 min. To optimize the temperature determinations the CCD data are binned 8×8 on the chip to form a 128×128 super-pixel image with a resultant zenithal foot print of $\sim 0.9 \times 0.9$ km per super-pixel. Rotational temperatures are then computed separately using the ratio method as described eloquently by Meriwether (1984). The precision of the emission intensity measurements is better than 0.5% (for an individual image) and the derived rotational temperatures are better than 1–2 K (in 3 min) or 0.5 K in 1 h (Pendleton et al., 2000). Recent comparisons of the MTM temperature data with coincident Na lidar and satellite borne temperature measurements indicates that the MTM results are accurate to about ±5 K for both the OH and the O_2 data when referenced to their nominal emission altitudes of 87 and 94 km, respectively (e.g., Pendleton et al., 2000; von Savigny et al., 2004; Zhao et al., 2005). Of key importance to this investigation is the inherent linearity and stability of the MTM which provides an additional capability for high-precision seasonal investigations of mesospheric temperature variability (Taylor et al., 2001).

Since November 2001 the MTM has operated near-continuously at Maui, HI as part of the Maui-MALT program which is a jointly sponsored initiative between the US Air Force Office of Scientific Research (AFOSR) and the National Science Foundation (NSF). Autonomous observations are made on a routine basis centered on the new moon period (for ~22 nights per month) in coordination with a suite of optical and radar measurements to investigate the dynamics of the mesosphere and lower thermosphere (MLT) region at low-latitudes over the central Pacific Ocean. Recent related results describing coordinated measurements using the MTM with a co-located meteor radar and an Na wind temperature