Global Nightly OH and O_2 Mesospheric Airglow: Examining a Decade of Measurements Using the NASA SABER Satellite Sensor

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Abstract

The SABER instrument aboard the TIMED satellite is a multichannel radiometer and has been continuously measuring the altitude distribution of infrared airglow intensity in the mesosphere on a global basis since 2002. While the majority of these altitude distributions are Gaussian-like, a significant portion exhibit two or more local maxima, suggesting multiple airglow layers. To better understand the cause of this phenomenon, the global and temporal distributions of infrared OH and

O_2 scans resulting in multiple peak altitude profiles are being examined.

Background

Photochemical reactions in the mesosphere fueled by sunlight produce optically excited molecules that subsequently give off infrared radiation when they relax to their ground states. Hydroxyl (OH) is formed when ozone (O_3) reacts with hydrogen (H) to form excited OH and O_2. This airglow is so bright it can be seen with night-vision goggles, which convert this light into visible wavelengths. Characteristic wavelengths of radiation in the airglow are emitted by specific molecules or atoms transitioning between specific energy states. The brightness of the airglow gives information on concentrations of chemical reactions. The mesospheric airglow forms in characteristic layers above the Earth from various emitters. Figure 1 shows an example of airglow layers, in this case from atomic oxygen emitting at visible (green and red) wavelengths.

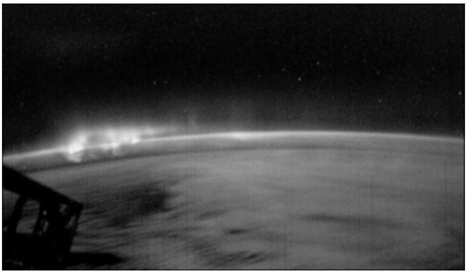

Figure 1. Airglow layers as seen from the International Space Station. This image is by NASA, 2011.

SABER Instrument

The Sounding of the Atmosphere using the Broadband Emission Radiometry (SABER) instrument aboard NASA's Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite provides 10 channels of infrared airglow measurements. This instrument, engineered by the Utah State University Space Dynamics Laboratory (SDL) for the NASA Langley Research Center, scans through the edge of the mesosphere (Figure 2) looking at the emissions of selected atmospheric molecules. The data from this type of scan, known as a limb scan, must be processed to produce vertical altitude emission profiles.

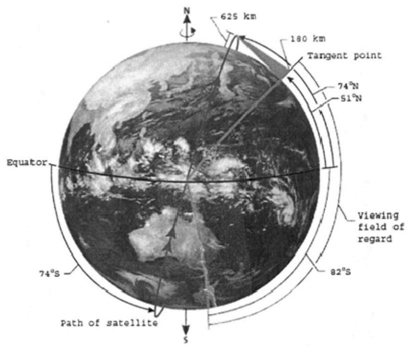

Figure 2. SABER limb scan of the atmosphere.

Two of the channels of SABER monitor the OH infrared emissions at 1.6 μm and 2.0 μm.

The SABER instrument completes an up/down limb scan approximately every 60 seconds, while the satellite makes one complete orbit of the Earth every 90 minutes covering some 70% of the globe (the polar regions are not included). The instrument has been operational since January 2002, providing data for over 12 years and producing almost 1500 vertical altitude profiles a day. To date, the SABER has generated roughly six and a half million such profiles from each channel.

Data Processing

The OH and O_2 data from SABER are processed to look at the profiles of the airglow power output (called the column emission rate, or CER) at altitudes from 75 to 100 km during the nighttime hours of the Earth as shown in Figure 3. The CER is obtained by integration of the energy per unit time over a small area. The most common type of profile is Gaussian-like with a single peak. Typically, this peak is approximately 80–90 km in altitude. Such profiles account for some 84% of the total data. Other profile types illustrated by Figure 3 include (1) multiple peak profiles with more than one peak with a valley in between, and (2) broadened profiles with a ledge leading off the slope of a peak. These two profile types are characteristic of about 15% of the data. Erroneous receptions due to satellite system effects, which are removed from further consideration, make up less than 1% of the data.

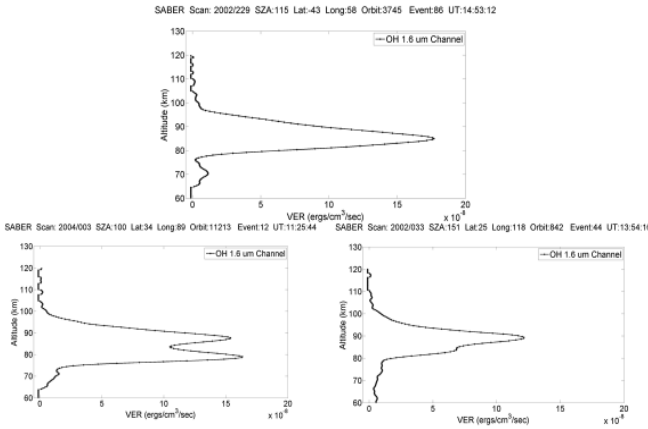

Figure 3. Example of OH airglow profiles. (Top) Single peak; (bottom left) multiple peak; (bottom right) broadened.

Data Analysis

The composite CER outputs from summing all profiles are calculated from the SABER limb data. The resulting data provide a global view of the OH airglow as illustrated in Figure 4. One interesting feature observed in these plots is the higher energy in the equatorial regions as well as in an area over Scandinavia. Both the OH 1.6 μm and OH 2.0 μm channels exhibit similar global distributions.

Interest in the study of the multiple peak and broadened profiles stems from the early expectation that the OH airglow should be in a uniform layer as reported in the standard single peak profiles. A hypothesis on the causes of the multiple peak phenomena includes

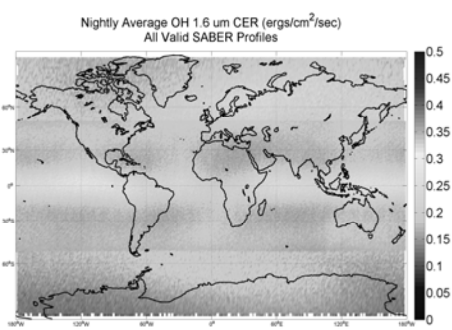

Figure 4. Average nighttime global energy distribution using all profiles.

internal buoyancy (gravity) waves in the atmosphere resulting in wave-like motion. Analysis of data near mountain ranges, where the wind causes such buoyancy waves, may provide insight into this phenomenon.

Using the data averaged over a 12-year period, a Fast Fourier Transform (FFT) provides a frequency domain spectrum that is converted and plotted to show periodic behavior. SABER data facilitate the investigation of these possible trends or periodicities in the global behavior of the airglow. For example, well-defined temporal periods appear at 180 days and 360 days (Figure 5), likely because of annual and semi-annual variations in the Earth's atmosphere. Other periodicities result from lunar and solar effects. The SABER instrument with its 10 channels has scanned the Earth limb for over a 12-year period making possible contributing analyses of solar cycle impacts on the Earth's atmosphere.

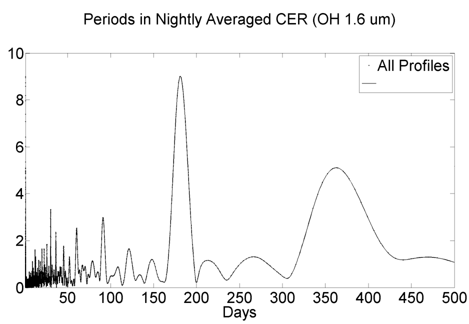

Figure 5. Periodic behavior in OH airglow.

Future Research Interests

Additional interesting research topics include the correlations of the OH airglow data with the O_2 airglow data from SABER's limb scans. These two profile sets, along with the corresponding global averages, will be studied. Multiple peak profiles within the OH and O_2 channels can be analyzed for both temporal and spatial correlations (Figure 6). It is expected that if buoyancy waves are one of the sources of the observed multiple peaks, the different molecular emissions will exhibit correlated behaviors. Geometrical observation factors must also be carefully studied. Study of these subjects will be looked at during nighttime and twilight hours.

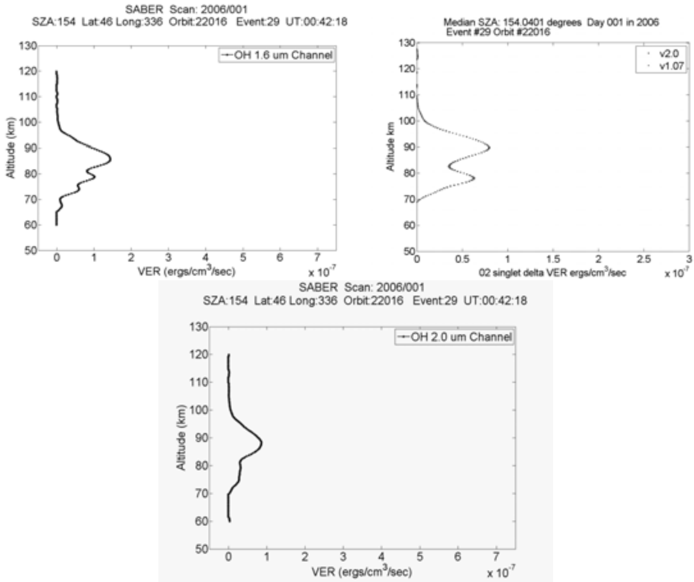

Figure 6. Multiple peak profiles from the same time and location. (Top left) O_2 data; (top right) OH 1.6 data; (bottom) OH 2.0 data.

Conclusion

Hydroxyl data from the SABER instrument are integrated over one degree square in latitude and longitude. These geographical energy data cells are then summed over the entire SABER data set in a geographical global view of the mesospheric nightly airglow distribution. High CER values have been observed over the equator as well as an area over Scandinavia. By averaging these data over the 12 years SABER has been scanning and using the FFT, periodic trends are observed. Prominent periodicities appear at 180 days and 360 days. Radiometric observations of atmosphere airglow emissions in the nighttime have revealed altitude emission profiles that depart from the expected profile shape. About 15% of the emission profiles contain multiple maxima. The effect has been observed in both the OH and O_2 emission profiles. Future research is needed to reveal the origin of these phenomena.

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