Enhancing Low-Cost Ozone Spectrometers to Measure Mesospheric Winds and Tides

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Abstract

Ground-based spectrometers have been developed to measure the concentration, velocity, and temperature of ozone in the mesosphere and lower thermosphere (MLT) using low-cost satellite television electronics to observe the 107.7 GHz (N2O) band. A two-channel spectrometer has been engineered to yield various performance improvements, including a doubling of the signal-to-noise ratio, improved data processing efficiency, and lower power consumption at 15 W. Following 2009 and 2012 observations of the seasonal and diurnal variations in ozone concentration near the mesopause, the ozone line was observed at an altitude near 95 km and latitude of 38 degrees north using three single-channel spectrometers located at the MIT Haystack Observatory (Westford, MA), Chelmsford High School (Chelmsford, MA), and Union College (Schenectady, NY) pointed south at 8 degrees. Observations from 2009 through 2014 are used to derive the nightly-averaged seasonal variation in meridional velocity, as well as the seasonally-averaged variation with local solar time. The results indicate a seasonal trend in which the winds at 95 km come from the south at about 10 m/s in the summer of the northern hemisphere, and from the south at about 10 m/s in the winter. Nighttime data from -5 to +5 hours local solar time show a gradual transition of the meridional wind velocity from about –20 m/s to +20 m/s. These two trends correlate with nighttime wind measurements from the Millstone Hill High-Resolution Fabry–Perot Interferometer (FPI) in Westford, MA, which uses the 597.7 nm green line nightglow from atomic oxygen centered at 95 km. The results have also been compared with averaged meridional winds measured with meteor radar.

Dynamics of O & O3

In the MLT, new ozone molecules are created via:

\[ \text{O} + \text{O}_3 + \text{M} \rightarrow \text{O}_2 + \text{M}. \]  (1)

There are two processes that destroy ozone in the mesopause:

\[ \text{O}_3 + \text{h}_\text{v} \rightarrow \text{O}_2 + \text{O} + \text{M}. \]  (2)
\[ \text{O}_3 + \text{H} \rightarrow \text{OH} + \text{O}_2. \]  (3)

which involve physical collisions with ultraviolet photons and atomic hydrogen, respectively. During the daytime, almost all of the ozone in the mesopause is destroyed by ultraviolet photon collisions. This is why daytime wind is not considered.

We also analyze experimental observations of the spectral line at 597.7 nm, or green line, which is the physical result of the $\text{O}_3(\text{S}^\text{2}P^\text{0})$ quantum energy level transition in the ozone atom. The Barth Mechanism plays the major role in producing the green nighttime:

\[ \text{O}_3(\text{P})^0 + \text{O}_3(\text{P})^0 + \text{M} \rightarrow \text{O}_3(\text{S})^0 + \text{M}. \]  (4)
\[ \text{O}_3(\text{P})^0 + \text{O}_3(\text{S})^0 \rightarrow \text{O}_3(\text{S})^0 + \text{O}_2. \]  (5)

It is a two-step process, first involving a three-body collision between two oxygen atoms and an atmospheric chemical M to produce excited state of atomic oxygen and then a two-body collision to produce the excited state of atomic oxygen.

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Selected References