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 13.072 GHz ozone absorption line. 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 (Westerfield, 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 north at about 10 m/s in the summer, 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 average meridional winds measured with meteor radar.

Dynamics of O & O₂

In the MLT, new ozone molecules are created via:

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

There are two processes that destroy ozone in the mesopause:

\[ \text{O}_3 + \text{hv} \rightarrow \text{O}_2 + 	ext{O} + \text{O}_2. \] (2)
\[ \text{O}_3 + \text{H} \rightarrow \text{O}_2 + \text{OH} + \text{O}. \] (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 data 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 \( \text{O}_3(\Sigma^+ - \text{D}) \) quantum energy level transition in the ozone atom. The Barth Mechanism plays the major role in producing the green nightglow:

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

Global MOSAIC Network

The MOSAIC system consists primarily of a Winegard DS-4040 parabolic reflector and Star-Com SR-3602 Mini low-noise block down converter feed (LNB) antenna. The ozone line is in the upper X band of the microwave spectrum, which allows use of European satellite TV electronics. The two-channel spectrometer collects both (H) and (V) microwave polarization data, which—in conjunction with smoothing the test spectra—doubles the SNR. The noise figures for five different LNBF models were characterized, and the SR-3602 had the best stability, with a typical V-factor of 4.9 dB between the beam at 8° elevation and an absorber. Spillover efficiency was improved to the maximum theoretical value of 91.6% by positioning the LNBF at an angle of 42° towards the dish. Software improvements were made to achieve a high processing efficiency (70% of the theoretical maximum) with minimum time lost to calibration and calculations. Additionally, the power consumption of the two-channel unit was reduced to 15 W.

Velocity Data from O & O₃

Seasonally: We note that meridional winds originate from the north in the summer of the northern hemisphere, and from the south in the winter. The velocity appears to cross the zero mark twice, roughly around April and September, with northerly winds in between, and southerly winds otherwise. The maximum amplitude in the average trend is 20 m/s, considering a minimum velocity around -10 m/s in June-July and a maximum velocity around 10 m/s in January.

Nighttime: There are southerly winds from -5 through +1 hours local solar time, and northerly winds from +2 through +5 hours. The transition point appears to be within two hours after midnight. The average velocity has a maximum amplitude of 40 m/s, considering a minimum velocity around -20 m/s at +2 hours local solar time and a maximum around +20 m/s at +5 hours.

Green Line: Variations by season and local solar time appear to correlate well with respective trends in the ozone line. It is observed that the green line winds originate from the north in the summer of the northern hemisphere and from the south in the winter. Furthermore, there is a gradual increase from northerly to southerly winds between -4 and -5 hours local solar time. The uncertainties given by the FPI data are entirely statistical in nature, and are not associated with any flaws in the interferometer itself or the experimental procedure.

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Selected References