Mesospheric Temperature Observation Using a Michelson Interferometer

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Abstract
A Michelson interferometer was used to record spectral data of nightglow emissions, and software was written to process the data. The upper mesosphere/lower thermosphere (MLT), approximately 80-105 km above Earth, is a dynamic region of the atmosphere where processes and forces from two layers interact. The MLT is affected by periodic tides, the effects of which can be seen through study of the temperature of the region over time. Due to the altitude of the layer, measurement by long-lived satellite and balloon are impossible, and sounding rockets yield only an instantaneous snapshot. However, with spectral analysis of hydroxyl emissions, remote sensing of temperature over the course of a night is possible. Hydroxyl, found most abundance in this region, exists in a vibrationally excited state (OH⁺) as well as a ground state (OH). The process which de-excite the OH⁺ to OH results in infrared photon emission. The molecules are in thermodynamic equilibrium with the surrounding atmosphere, so rotational temperature is a reliable measurement of atmospheric temperature. Rotational temperature is calculated using the relationship of photon emission intensity to total upper state angular momentum for a Boltzmann distribution of multiole rotational levels. To remove noisy data, the spectral data sets are passed through a series of filters before a time vs. temperature graph is created with only valid data. Observations at the 3-⁸/₄-Meigar bands were made in J when during July 2012 at Center Green Building 1, Boulder, CO in an effort to investigate terrestrial (23-57 day) tides at mid-latitudes. An interferometer was used with a Hamamatsu spectrometer containing a Michelson interferometer and a grating. An InGaAs detector was used with a Nicolet 6700 spectrometer to investigate terdiurnal (thrice-daily) tides at mid-latitudes. An example graph; 1:15am, July 13

The Interferometer
Sky-light is reflected into the instrument from the scope. The beam splitter directs half of the beam a fixed mirror and the other half to the scanning mirror. The scanning mirror moves back and forth at a constant rate; one cycle of the mirror is called a scan. The beams recombine and interfere with each other due to the different path lengths. The recombined beam is reflected by the parabolic mirror by the detector onto the detector, which records the interference pattern (known as interferograms). The relative intensity of each interferogram at different path lengths is related the relative intensity of input light at respective wavelengths. The spectrometer software interprets the interferograms, and calculates relative intensity vs. wavelength.

Data Collection
Collected on 5 nights in July 2012:
• 19/20, 11/12, 13/14, 18/19, 19/20
(Time 6pm-7am co-added per data set)
• Approximately every 5 minutes
• Data was taken from 10pm to 5am to mitigate solar radiation influence
• Looking for evidence of diurnal (once daily) tides
• Approximately every 5 minutes
• Data was taken from 10pm to 5am to mitigate solar radiation influence

Data Filtering
• Most spectral data sets collected weren’t accurate due to noise attributed to alignment errors and clouds
• Data was filtered by passing it through a series of tests:
  • Peak intensity must be greater than 0
  • Peak intensity must be greater than 10x average intensity
  • ln(Peak 1)/ln(Peak 2)>ln(Peak 3) must be true for F(J') graph
  • Chi square goodness of fit value for linear fit must be less than .05
• Only valid data was displayed on final graph

Results and Conclusions

<table>
<thead>
<tr>
<th>Date</th>
<th>Delta T (K)</th>
<th>Average (K)</th>
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<tbody>
<tr>
<td>Jul 09-10</td>
<td>93.40968</td>
<td>350.4082</td>
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<tr>
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<td>172.7274</td>
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<td>Jul 13-14</td>
<td>161.4956</td>
<td>403.7898</td>
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<td>Jul 18-19</td>
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<tr>
<td>Jul 19-20</td>
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<td>235.9299</td>
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<tr>
<td>Average</td>
<td>189.8138</td>
<td>271.1458</td>
</tr>
</tbody>
</table>

Theoretical Fundamentals of Atmospheric Optics

Hydroxyl
• Appears in most abundance in MLT due to thermodynamic equilibrium with atmosphere
• Temperature affected by tides and waves
• Excited state from displacement reaction:
  \[ \text{H}_2\text{O}^+ + \text{e}^- \rightarrow \text{H}_2\text{O} + \text{H}^+ \]
  \[ \text{H}_2\text{O}^+ \rightarrow \text{H}_2\text{O} + \text{H}^+ \]
• Radiation known as ‘Meinel Bands’ as de-excitation process allows for emission
• Ratio of molecules in different states compared to temperature
• Studied the P1 band

Future Study
Select on more nights in hopes of clear skies
Improve alignment of detector optics
Tidal setup was very stable and prone to de-aligning
Clouds were seen in hopes of less noise
Should result in decreased time resolution

Temperature Calculation
• Equations are derived from relationship of photon emission intensity to upper state angular momentum for a Boltzmann distribution of rotational energy levels.

\[ \text{F(J')} = \frac{\text{A(J')} \times 
\text{e}^{-
\text{B(J')}}}{\text{J'} \times \text{C} \times \text{H} \times \text{T}^{-1}} \]

\[ \text{F(J')} = \text{A(J')} \times \text{e}^{-
\text{B(J')}} \times \text{J'} \times \text{C} \times \text{H} \times \text{T}^{-1} \]

\[ \text{T} = -\frac{100 \times \text{h} \times \text{c}}{\text{k} \times \text{slope}} \]

\[ \text{T} = -\frac{100 \times \text{h} \times \text{c}}{\text{k} \times \text{slope}} \]

\[ \text{A(J')} = \text{Einstein Constants} (16.74, 20.37, 21.82 \text{s}^{-1}) \]

\[ \text{J'} = \text{Total Upper Angular Momentum} (1.5, 2.5, 3.5) \]

\[ \text{C} = \text{Speed of Light} \]

\[ \text{H} = \text{Planck’s Constant} \]

\[ \text{T} = \text{Mesospheric Temperature} \]

References and Image Credits


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