Chapter-V

A new method to derive middle atmospheric temperature profiles using a combination of Rayleigh Lidar and O$_2$ Airglow temperatures measurements
A new method to derive middle atmospheric temperature profiles using a combination of Rayleigh Lidar and \( \text{O}_2 \) airglow temperatures measurements.

5.1 Introduction

At the stratosphere and lower mesosphere regions, information about gravity waves and tides is usually obtained from Rayleigh and resonance lidars. Reported periods are often >2 h owing to the large errors at higher altitudes [Batista, Clemesha, and Simonich 2009; Chandra et al. 2005; Friedman et al. 2009; Sivakumar et al. 2004; Whiteway and Carswell 1995]. While airglow measurements represent a particular altitude range, lidar measurements provide latitudinal resolution, and thus they complement each other. In Lidar research, there have been significant attempts to use resonance, Rayleigh, and rotational Raman scattering techniques simultaneously to acquire accurate temperature information at altitudes between 1 and 105 km [Alpers et al. 2004; Rauthe et al. 2006]. This is obviously highly desirable when studying the perturbation physics involved in wave propagation from the lower atmosphere to the higher, and also for global circulation models. From a convenience point of view, routine and simultaneous operation of such Lidars is difficult in the tropics. Hence, the atmospheric science community still requires a simple method that can be used for the above purpose.

In this chapter Rayleigh Lidar and mesospheric OH and \( \text{O}_2 \) temperature measurements are made near simultaneously during moonless clear sky nights. As the \( \text{O}_2 \) emission represent a layer at 95 km region with a thickness of about 5 km. Utilize the airglow data to improve the Lidar temperature estimation algorithm. This is reasonable because the present methods for Lidar temperature estimates utilize the model values [e.g. CIRA- 86] at about 100 km, which are well understood to be far from reality. The present
work demonstrates that near simultaneous O\textsubscript{2} temperature measurements can be used as an input in the Lidar temperature retrieval method instead of the model values. The significant improvement can be achieved in the altitude coverage of Rayleigh Lidar temperature estimates. The coincident space-borne measurements to crosscheck and validate the new method.

5.2. Measurement techniques

The present study used a combination of co-located measurements made with Rayleigh Lidar and the Mesosphere Lower Thermosphere Photometer (MLTP) from Gadanki (13.5\textdegree\text{N}, 79.2\textdegree\text{E}), to retrieve temperature profiles in the altitude range 35–95 km. The Rayleigh Lidar (details are given in Table 3.1) uses a Nd-YAG laser with 550 mJ energy at 532 nm with a pulse repetition frequency of 50 Hz and pulse width of 7 ns. It receives backscattering with a 75 cm diameter Newtonian telescope. The received signals are filtered through an interference filter (full width at half maxima ‘FWHM’, 1.07 nm with centre wavelength 532 nm) and are focused onto the photocathode of a photomultiplier tube (Hamamatsu R3234). Temperature retrieval follows the method as described by Hauchecorne and Chanin (1980). More details of the Lidar system and techniques have been described in chapter-III.

The MLTP (details are given in Table 2.2 of ChapterII.) is a simple, multi-wavelength airglow photometer with F/2 optics and a full field of view \(\sim 4^\circ\). It measures mesospheric OH (at 840 and 846 nm rotational lines) and O\textsubscript{2} (at 866 and 868 nm rotational lines) emissions together with thermospheric O(\(^1\)D) emission intensities with the help of seven temperature-controlled interference filters of FWHM \(\sim 0.45\) nm. The temperatures are derived from OH emissions using the ratio method and O\textsubscript{2} emissions using the slope methods described by Meriweather [1984]. The MLTP uses the Hamamatsu H7421-50 photon-counting module as a detector. The filter movement is synchronized with the counting unit C8855 of the photomultiplier tube for the operations. More details of MLTP have been described in chapter –II.

5.3. Analysis Procedure

The present experiment is somewhat similar to that of Alpers et al. [2004], whereby actual temperature measurements are used in the Lidar temperature retrieval methods rather than model temperatures. These investigators used higher-altitude,
A new method to derive middle atmospheric temperature measurements obtained by resonance Lidar methods as the seed temperatures for the Rayleigh scattered echoes and successfully obtained reliable temperature estimates at upper mesospheric altitudes. Rather than resonant Lidar temperatures (not available at location), proposed a method of using $O_2$ airglow temperature data to feed the initial conditions in temperature retrieval algorithm as expelled in following

![Flowchart of processing the retrieval temperature seed the $O_2$ from the Rayleigh Lidar data.](Figure 5.1)

The schematic for the off-line data processing is shown as a flowchart in Figure 5.1. It involves the photon count values versus range bin for each profile having 4 minute integration. The background noise is removed at this stage, by estimating the average photon counts between 100 and 105 km, which is subtracted from each bin. Range correction is then applied, and the density values are obtained from the range corrected photon count profile by equalizing them at 50 km altitude.

The retrieval of temperature assumes that the atmosphere is free from aerosols, and the signal strength is proportional to molecular number density. Using the number density obtained from the CIRA-86 model for the height where the signal-to-noise ratio is fairly high, the constant of proportionality is evaluated and thereby the density profile $\rho(z)$ is derived at altitude $\sim$100 km. In existing methods, taking the pressure (P) at the top of the
height range (100 km) from the CIRA-86 model, the pressure profile is computed using the measured densities under an assumption that the atmosphere is in hydrostatic equilibrium. Further, using the ideal gas law, the temperature at a particular height “z”, $T(z)$ is calculated using the expression:

$$T(z) = \left[ \frac{Mg(z)dz}{R \log(1 + X)} \right] = -(5.1)$$

Where

$$X = \left( \frac{\rho(z)g(z)dz}{p(z + dz/2)} \right) = -(5.2)$$

Where, $Pz$ is the pressure value at an altitude ‘z’, $R$ is the gas constant, $g$ is the earth’s gravitational force, $T$ is $O_2$ temperature, $dz$ is range resolution, and $M$ is mean molecular mass.

$$P(z) = \exp \int \frac{Mg(z)}{RT}dz = -(5.3)$$

$$\frac{\delta T(z)}{T(z)} = \frac{\delta \log(1 + X)}{\log(1 + X)} = \frac{\delta X}{(1 + X) \log(1 + X)} = -(5.4)$$

In our modified scheme, the measured temperature values are fed from the $O_2$ airglow emission measurements in Eq. (5.2) by deriving $X$ for model densities with pressure values estimated at 100 km for the measured $O_2$ temperature values.

It is important to state here that the use of known $O_2$ temperature measurements (which represent 94 km with a semi-thickness ~5 km) for 100 km is better than the CIRA/MSIS model estimates. This is supported by the results reported by [Taori, et.al, 2012], and provided the evidence that at upper mesospheric altitudes, model temperatures over Gadanki deviate from the real temperatures by 20–50 K. Therefore, the use of model temperatures itself introduces large errors at significantly lower altitudes and hence the error (or standard deviation) convergence occurs and it is clearly shown in $Figure 6.5$ in $chapter-VI$. Suggested that short-term waves can be studied, from ~95 km with standard deviation ±5 K. This is achieved when temperature profiles are averaged for 12 min in the
time domain and 5 km in the altitude domain, enhancing the signal-to-noise ratio to ~3, which is sufficient for the analysis of short-term waves (wave period >0.4 h).

5.4 Results and discussion

The middle atmosphere is dominated by a variety of dynamical features of transient nature, Rayleigh Lidar temperature profiles are derived using the traditional as well as a modified scheme for time “T” and average the profiles for ±0.25 h for a comparison. The time “T” is chosen when the SABER passes were available for a grid of 5° X 5° its’ latitudes 09°–19° N and longitudes 74°–84° E so that an instantaneous comparison can be made. Concerning the Rayleigh Lidar at Gadanki, it is important to state that the signal-to-noise ratio of the received photon statistics becomes poor above 90 km. However, it is found that the standard deviations converge at higher altitudes when the starting values are taken at ~100 km from the CIRA-86 model instead of ~90 km. Another important aspect is that the O₂ airglow layer represents 95±5 km, which is used in the temperature retrieval process as a representative temperature at ~100 km. This may vary a bit from actual values but still represents 100 km better than the model values. This approximation may also suggest that large differences of starting values from the real ones may create large changes in the observed thermal structures in terms of standard deviations and hence the precision of measurements.

The temperature profiles from the Rayleigh backscatter signals with traditional (black solid lines with purple standard deviations) and modified (dark blue lines with yellow standard deviations) as shown in Figure 5.2 retrieval methods for 6 January 2011 data. Solid red line shows the average of two SABER profiles as shown in Figure 5.3 available in the above-mentioned grid for a comparison.

Note that Lidar temperature profiles that use existing traditional method start deviating from SABER values from 70 km. On the other hand, the profiles that use the O₂ temperature (averaged over the corresponding time, i.e. ±0.25 h) provide a good comparison to the SABER values till 95 km altitudes. It is worth mentioning that the profiles obtained with the traditional method above 90 km are not shown because of their large differences from SABER and very large standard deviations. As mentioned earlier, the use of the CIRA-86 model values at ~95 km at starting altitude also do not bring improvements. However, note much smaller standard deviations when O₂ temperatures are used as starting temperatures at ~100 km. In fact, it is only an approximate value for 100
A new method to derive middle atmospheric temperature

km. Also noteworthy are the differences between SABER values and the temperatures (obtained with the modified method) at 80–95 km regions where both show large wave-like oscillatory features.

Figure 5.2 Rayleigh Lidar temperature profiles and associated standard deviations deduced with the help of CIRA-86 model temperatures (solid black lines with purple standard deviations) and O\textsubscript{2} airglow temperatures (dark blue lines with yellow standard deviations) for the backscatter data of 6 January 2011. Shown in red lines are the SABER estimates for a grid of 9\textdegree-19\textdegree N and 74\textdegree-84\textdegree E for instantaneous comparison.

Figure 5.3 The individual SABER profiles in the used grid. It is evident that large amplitudes of wave structures make a significant difference in a narrow latitude-longitude separation.
This is because (i) the gravity wave fields are highly variable and transient in nature so change of gravity wave phases within 1–2° locations may provide an apparent difference as noted in this study; and (ii) that SABER pass is not having exact coincidences, which is evident in Figure 5.3. One may note that near coincident SABER profiles show large oscillatory features in data with somewhat opposite phase within a short spatial difference. In the light of above, trusted that agreement between the modified Rayleigh Lidar profiles and SABER values are very good till 95 km altitudes.

Performed a similar analysis on 27 January 2011, data and results are shown in Figure 5.4. Similar to the earlier case, on this night also, data reveal large oscillatory features. The results of traditional method for Rayleigh Lidar temperature estimation show a good comparison with average SABER values till 65 km, while the modified method results in a better temperature profile and good agreement with SABER values up to about 95 km altitude. In comparison to SABER data, which show large oscillatory features, the modified method temperature profiles reveal a large temperature inversion to occur at 80–90 km altitudes.

Figure 5.4 Rayleigh Lidar temperature profiles and associated standard deviations deduced with the help of CIRA-86 model temperatures (solid black lines with purple standard deviations) and O2 airglow temperatures (dark blue lines with yellow standard deviations) for the backscatter data of 27 January 2011. Shown in red lines are the SABER estimates for a grid of 9°–19° N and 74°–84° E for instantaneous comparison.
The individual SABER temperature profiles for the chosen grid are shown in Figure 5.5. Note that no SABER pass was coincident over the Gadanki location, which possibly is because the observed differences in the variability noted in upper mesospheric temperatures. To believe that such a comparison is very good considering a highly dynamic condition owing to the non-linear interaction and dissipation of gravity waves at upper mesospheric altitudes.

![SABER Data Jan 27, 2011](image)

Figure 5.5 The individual SABER profiles in the used grid. It is evident that large amplitudes of wave structures make a significant difference within a narrow latitude-longitude separation.

Similar to other two cases, on this night also the Rayleigh Lidar temperature profiles with modified method provide a better comparison with SABER values. The improved altitude coverage of Rayleigh Lidar by using the new method is understandable due to the fact that a recent study based on two years of mesospheric temperature observations of OH (~85) and O$_2$ (~95 km) emissions show large differences from model values [Taori et al., 2012b], and hence an improper starting value in the Lidar temperature retrieval algorithm.

This may be due to the fact stated in the previous paragraph that if the starting temperature has a large difference from the actual temperatures, the downward propagation of error will affect the observed variability. Hence, the variability may be masked by large standard deviations. The standard deviations for one hour average profiles are shown in Figure 5.6, where modified temperature retrieval method gives acceptable standard deviations in the temperature estimates up to ~95 km altitudes. It is evident that at
~90 km, to study the short period wave features, the standard deviations arising from photon statistics are very large in the case of the traditional methods.

![Figure 5.6](image)

*Figure 5.6 The standard deviations for hourly averaged temperature profiles (on 6 January 2011) with improved (red lines) and traditional (black lines) methods.*

### 5.4.1 The propagation characteristics of short-term waves

To investigate the propagation characteristics of short-term waves, selected 6 January and 27 January 2011, when more than 6 h of continuous measurements were made with both Rayleigh Lidar and MLTP over Gadanki.

#### 5.4.1.1 January 6, 2011

To note that on this night, temperatures at O$_2$ altitudes show peak-to-peak variations of ~100 K. The O$_2$ temperature data as seed to derive each temperature profile with Rayleigh Lidar backscattered data, and the results are shown in *Figure 5.7*, Where temperature profiles are shown in altitude range 35–95 km for every 12 min from 22.5 h IST to 04.5 h IST (i.e. 28.5 h in plot) with the temperature scale ranging from 180 to 260 K. Each profile is separated by 20 K from its previous profile. A large variability from one profile to another will be noted.

It is evident from the profiles that short-scale perturbations at lower altitudes have significantly smaller (~1–3 K) amplitudes compared with that observed at mesospheric altitudes (~8–10 K). Note that, at times, data show upward wave propagation characteristics. For example, from 23.0 to 24.5 h, quasi sinusoidal short-scale perturbations showing a downward phase progression from 80 to 75 km are notable. Further, a wave with slow downward phase propagation in the phase of temperature minima, which occurred at ~70 km, is evident since the beginning of the observations.
The procedure used to investigate the fluctuations caused by short-term waves in temperature is as follows. First, add all the profiles to acquire a mean nocturnal temperature profile. This mean profile was subtracted from every profile to obtain the perturbation profiles (anomalies from the mean), which were further normalized to their mean values. Thus, obtained the percentage temperature perturbation profiles, which are plotted in Figure 5.8. The plot reveals that the percentage variations in temperature are negligible at around altitude 40–50 km (~1–2 K amplitude). These perturbations increase after 60 km, from which point one clearly notices a downward propagation of waves, which is in agreement with existing reports (e.g. Batista, Clemesha, and Simonich 2009; Sivakumar, Rao, and Krishnaiah 2003). The perturbation amplitude throughout the observations varies from –12% to 14%, which is very significant from the atmospheric stability point of view as also reported by Wilson, Hauchecorne, and Chanin (1991). Maximum perturbations occurred around altitude 85–90 km. Note that for a limited time interval, a clear phase propagation is observed around 90 km, possibly because the data are dominated by the superposition of multiple wave events, with several achieving large amplitudes in this region. In particular, at the 80–95 km altitude region, the periodic nature of temperature perturbations is conspicuous.

To investigate the characteristic oscillation presented in the data, carried out a discrete Fourier analysis of temperature perturbations at 85 km, which revealed the
presence of oscillations with periodicity ranging from 0.4 to 5.0 h. Of these, investigations are done for 0.5, 0.6, 0.7, 0.9, 1.2, and 2.0 h wave periods in data by doing a best-fit analysis every 10 km from 40 to 90 km. The bandwidth tolerance used in these wave fits was 10%. Figure 5.2 shows the perturbation amplitude as a percentage from 40 to 90 km at every 10 km altitude. As already noted in Figure 5.8, in this plot also one can see that the amplitude of different wave packets is very small at lower altitudes and increases as waves ascend to the higher altitudes.

![Figure 5.8 Two-dimensional plot showing percentage temperature perturbations on 6 January 2011.](image)

The amplitudes of periodicity waves 0.5–2.0 h are <0.2% at 40–50 km. The gray shaded area in the plot shows the percentage errors in the improved Lidar temperature retrieval method. After 60 km, amplitudes of different wave packets began to show a dispersive behaviour. This is understandable from the wave–wind interaction point of view, as often it is stratospheric filtering that blocks most of the upward propagating waves and thus determines upward propagation [Lindzen 1984].

In particular, a 0.6 h wave shows the lowest growth in amplitude from 40 to 60 km while the 1.2 h wave exhibits the largest amplitude increase. After 70 km, 0.9 and 1.2 h waves show significantly decreased amplitude while the 0.6 h wave shows reduced amplitude after 80 km. The 1.2 h wave amplitude, surprisingly, again starts to increase
after 80 km. Of particular interest is the finding that amplitudes of 0.5, 0.7, and 2.0 h waves grow continuously from 40 to 90 km. The 0.7, 1.2, and 2.0 h waves show sharp asymptotic growth whereas the 0.5 h wave shows a slow growth in amplitude. This is important while considering the penetration of these upward propagating waves into the thermosphere–ionosphere system because it is commonly understood that most of these waves reach their saturation levels at mesospheric altitudes [Fritts and Alexander 2003]. After reaching their saturation, secondary waves propagate higher [Vadas and Crowley 2010].

![Diagram showing wave amplitudes and phases](image)

Figure 5.9 Results of best-fit analysis of amplitudes (a) and phases (b) of different wave packets at altitude 40–95 km. The gray shaded region is the percentage error in the improved Rayleigh Lidar temperature algorithm.

The phase variation of these waves with altitude is plotted in Figure 5.9 (b). One may note that the 2 h wave shows fast vertical propagation to 60 km from where it shows a slow upward propagation. This indicates the possibility that this wave was reaching its saturation/critical levels. Up to 60 km, the 0.9 h wave showed a slow propagation that, after 70 km, exhibited a fast upward propagation. The 1.2 h wave, on the other hand,
showed a slow vertical propagation throughout the altitude range. Although the 0.6 h wave shows upward propagation, no systematic phase propagation is evident. The 0.5 h wave shows a very clear upward propagation and an approximately vertical wavelength of 20 km. Concerning the variation in phase speeds of waves at different altitudes, Rauthe et al. (2006) also reported somewhat similar observations, which they attributed to decreasing densities at higher altitudes. From the observed phase variations, vertical wavelengths of different wave packets were calculated and found that these varied from 9 to 42 km.

<table>
<thead>
<tr>
<th>Wave period (h)</th>
<th>Vertical wavelength (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10.2 6 January 2011</td>
</tr>
<tr>
<td>0.6</td>
<td>9.3 6 January 2011</td>
</tr>
<tr>
<td>0.7</td>
<td>14.1 6 January 2011</td>
</tr>
<tr>
<td>0.9</td>
<td>9.6 6 January 2011</td>
</tr>
<tr>
<td>1.2</td>
<td>20.5 6 January 2011</td>
</tr>
<tr>
<td>2.0</td>
<td>42.8 6 January 2011</td>
</tr>
</tbody>
</table>

*Table 5.1 Summary of observed wave periods and their vertical wavelengths.*

Concerning the variation in phase speeds of waves at different altitudes, Rauthe et al. (2006) also reported somewhat similar observations, which they attributed to decreasing densities at higher altitudes. From the observed phase variations, the vertical wavelengths of different wave packets were calculated and found that these varies from 9 to 42 km. These values are summarized in *Table 5.1*. Also noted that on some occasions, phase variations do not show a clear downward propagation. This may be due to the sharp dynamical variations occurring at those altitudes. As it is not having simultaneous wind data, it is unable to comment on this issue. It is important to note that phase variations of most waves show the largest dispersion at higher altitudes owing to the increasing importance of non-linear processes, such as selective filtering of particular waves, which further emphasize the need for such systematic variations [Fritts and Alexander 2003; Lindzen 1984].
5.4.1.2 January 27, 2011

The 12 min temperature profiles corresponding to the observations of 27 January 2011 in the altitude range 40–95 km are shown in Figure 5.10. On this night, variability was significantly higher than in the previous case; the temperature range on this night was 170–280 K, with each profile separated from the preceding by 20 K. Small-scale perturbations of large amplitude at altitude 70–95 km were clearly noted. Also, the downward phase progression throughout the duration of observation is evident in this plot at various altitudes and times.

![Figure 5.10](image)

*Figure 5.10 Individual temperature profiles (every 12 min) obtained by improved Rayleigh Lidar temperature retrieval method using the combination of Lidar and airglow temperature measurements on 27 January 2011. Each profile is averaged for 5 km in altitude domain to enhance the signal to noise ratio.*

To investigate the temperature fluctuations caused by short-term features on this night, percentage perturbation profiles are calculated using the same method as in the previous case, and the results are shown in Figure 5.11. The temperature fluctuated from –9 to 10 K on this night with maximum variability noted at altitude 70–95 km. Temperature variations were noted to be very low at 40–60 km, which is consistent with earlier reports [Batista, Clemesha, and Simonich 2009; Chang, Yang, and Gong 2005; Rauthe et al. 2006; Sivakumar, Rao, and Krishnaiah 2003]. One may note a clear difference in the observed altitude range of maximum perturbation and amplitude of dominant short-term wave features, which is evident in Figures 5.7 and 5.11 on 6 January 2011, the maximum in amplitude of short-term features occurred at about 90 km while on 27 January 2011 was at 85 km.
This demonstrates a high degree of day-to-day variability in upper mesospheric processes. In the present case, beyond 85 km we note several instances of the downward phase propagation of waves. The upward wave propagation of waves in the altitude range 40–70 km is obvious in the plot, although the amplitude of perturbations is small.

Figure 5.11 Two-dimensional plot showing percentage temperature perturbations on 27 January 2011. Note the downward propagation of waves and the maximum perturbation occurrence at around 85 km.

To identify amplitude and phase variation in short-term gravity waves at altitude 40–90 km in the data, following discrete Fourier analysis a best-fit analysis was carried out (Figure 5.12). The amplitude variation for different wave packets is shown in Figure 5.12 (a), while Figure 5.12 (b) plots the phase variability of these waves.

The percentage errors in temperature estimates are shown as the shaded gray area in Figure 5.12 (a). For amplitude variations, it is clear that other than the 0.6 and 2.0 h waves, these show a decrease in amplitude beyond 80 km. It is interesting that unlike the previous case, on this night no single wave shows continuous amplitude growth, which suggests that most reached their critical levels. This may be because of strong wind shear, which would have blocked the upward propagation of gravity waves coming from different directions [Fritts and Alexander 2003]. This is only a hypothesis, as it does not have any horizontal directional information for these waves and wind data to emphasize.
the wind–wave interaction. In the phase propagation plot, please note that the 2.0, 0.9, and 0.5 h waves show a clear upward propagation throughout the altitude range.

![Phase propagation plot](image)

**Figure 5.12** Results of best-fit analysis of amplitudes (a) and phases (b) of different wave packets at altitude 40–95 km. The grey shaded region is the percentage error in the improved Rayleigh Lidar temperature algorithm.

On the other hand, 0.6 and 0.7 h waves show no clear signatures of propagation. The calculated vertical wavelengths of the observed waves vary from 6 to 26 km and are shown in *Table 5.2*. Compared the observed wave amplitudes with that of reported in selected key investigations in *Table 5.4*. It is noteworthy that most investigators reported an increase in gravity wave amplitude with altitude from 2 to 15 K at around 80 km. Our investigation is unique in reporting amplitude variations of different short-term wave packets in altitudes ranging from 40 to 90 km.
Avoided direct comparison with earlier reports because gravity waves are known to be highly variable both temporally and spatially, and also due to the lack of sufficient statistics and simultaneous measurements. Having acquired data using enhanced Rayleigh Lidar capability for two different nights, it was demonstrated that short-term upper mesospheric waves can be studied using a combination of Rayleigh Lidar and airglow photometry. It is showed that the propagation characteristics of short-term waves can be retrieved for building meaningful statistics.

<table>
<thead>
<tr>
<th>S No</th>
<th>Reference</th>
<th>Wave period range (h)</th>
<th>Amplitude (K)</th>
<th>Altitude range (km)</th>
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<tr>
<td>1</td>
<td>Deepa, Ramkumar, and Krishna Murthy (2006)</td>
<td>0.5-3.0</td>
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<td>5-10</td>
<td>~89</td>
</tr>
<tr>
<td>3</td>
<td>Rauthe, Gerding, and Lubken (2008)</td>
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<td>2.5(summer)</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.5(winter)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Sarah, Hauchecorne, and Chanin (1991)</td>
<td>2-5</td>
<td>2-12</td>
<td>30-80</td>
</tr>
<tr>
<td>5</td>
<td>Shepherd and Fricke-Begemann (2004)</td>
<td>~8</td>
<td>5.2</td>
<td>~89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5-10</td>
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<td>7</td>
<td>Present study</td>
<td>0.5–2.0</td>
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<td></td>
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<td>3</td>
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<td></td>
<td></td>
<td></td>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 5.2 Comparison of wave amplitudes in the present study with those of other reports.

As the statistical data on these waves are valuable for the modeling of global circulation in the middle atmosphere, such simple technological improvement is desirable in the acquisition of altitude and time resolution. Together with temperature data, wind data are also important in understanding the physics of the propagation of perturbations from lower to the upper atmosphere. A combination of such data with information on wave directions would possibly provide a wide-ranging insight into the various physical processes occurring in the middle and upper atmosphere. It should also mention that although similar or better altitude coverage can be obtained using a combination of
resonance and Rayleigh Lidar [Alpers et al. 2004; Gerding et al. 2008], the simplicity and cost effectiveness of methods presented in this report are important aspects that need to be investigated for optimization of resources.

5.5 Summary

In this chapter, it was shown “for the first time” that by using O₂ temperatures derived from airglow measurements as input to Rayleigh Lidar temperature retrieval algorithm, one can derive temperature information till 95 km. The standard deviations in photon statistics are found to be improved when modified method is utilized. This improvisation enables the study of short period wave features at upper mesospheric altitudes with high temporal resolution.

(1) Short-term (0.5–2.0 h) gravity wave features in mesospheric temperature fields and their propagation can be studied in the altitude range 40–95 km when real-time airglow temperatures are integrated with the Rayleigh Lidar temperature retrieval algorithm as the seed temperatures.

(2) The waves show a significantly different behaviour in the cases presented, and also show dissipation of energy by a large part of the short-term wave spectrum around altitude 75–80 km.

(3) Consistent propagation of 0.7, 1.2, and 2.0 h waves was noted in both cases, with increased amplitude of 2.0 h waves.

Finally, concluding that a significant improvement in Rayleigh Lidar can be made to cover upper mesospheric altitudes with cost-effective airglow monitoring tool. A systematic and simultaneous airglow and Rayleigh Lidar temperature measurements will provide good statistics that will be helpful in answering key issues related to the mesospheric heat budget and circulation.