SIMULTANEOUS HIGH-RESOLUTION OBSERVATION OF SCATTERING LAYERS WITH A RAMAN/MIE LIDAR AND THE MU RADAR/FREQUENCY INTERFEROMETIC IMAGING TECHNIQUE

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Abstract

We have carried out simultaneous MST (Mesosphere, Stratosphere, Troposphere) radar (MU radar of RISH, Kyoto University) and Raman-Mie-Rayleigh lidar observations at Shigaraki, Japan. High altitude resolution using a radar imaging technique has been achieved for comparisons with lidar observations. Time - height variations of backscattering layers' echo intensities observed by both techniques have been compared in detail. An example of scattering layers and the variations around 8-9 km altitude are focused. Although both radar and lidar signals showed short-period fluctuations (5-10 min), cross-correlations show complex structures.

1. Introduction

Although both atmospheric radar (such as wind profiler, MST radar) and lidar techniques are used for profiling atmospheric parameters such as wind, temperature, humidity and layered phenomena in the troposphere up to mesosphere/lower thermosphere, the scattering mechanisms of the two techniques are quite different. Radar echoes dominantly result from Bragg scattering from fluctuations of refractive index which are related to fluctuations of partial pressure of water vapor, and absolute temperature. Intense clear air radar echoes are mainly due to scattering from turbulent motions in a stable refractive index gradient background and partial reflection from thin laminar and horizontally stratified gradients (sheets) at VHF. In contract, a lidar measures the backscatter by atmospheric molecules or particles, such as aerosols and clouds. The power of scattered signal is related to the density of scattering molecules/particles as well as the distribution of scattering cross-section, i.e. particle size distribution.

In this study, we have simultaneously operated the upgraded MU radar system and a Raman/Mie/Rayleigh lidar, both belonging to RISH, Kyoto University, at Shigaraki, Japan. Both observation techniques have a high altitude - time resolution of about ten meters and tens of seconds typically. We focused on the comparison of height and temporal variations of scattering layers detected within the troposphere by the two instruments.

2. Experimental setup

2.1 Raman/Mie/Rayleigh lidar

The lidar system in the Shigaraki MU observatory uses frequency-doubled Nd:YAG laser (532 nm, 600mJ, 50Hz) as a light source. Backscattered light is received by a telescope with a diameter of 82 cm, and then separated into five channels of the two rotational Raman, water vapor Raman, Mie/Rayleigh (high and low sensitivity) channels. The received light is detected by photo -multiplier tubes (PMTs) and recorded by photon counting and analog detection modes [1]. From the five channel signals, we derive the atmospheric temperature (rotational Raman technique and integration technique), the water vapor mixing ratio, the backscatter ratio, the extinction and backscatter coefficients, and the lidar ratio. The height resolution (dwell time) is usually set to be 72 m, but for the current experiment we adopted a 9 m height resolution in order to detect detailed structure of backscattering ratio with the elastic channel. The time resolution is set to be 30 sec.

2.2 The MU radar

The MU radar is a large MST (Mesosphere Stratosphere Troposphere) radar operating at 46.5 MHz VHF with an active phased array antenna, which consists of 475 crossed Yagi antennas. The antenna aperture is 8330 m^2, and the peak output power is 1 MW. Minimum pulse length is 1 μ sec, corresponding to a height resolution of 150 m. The characteristics of the MU radar is fast beam-steering (pulse by pulse) and a computer controlled flexible system design for miscellaneous experimental setup. In 2004, a MU radar system was upgraded for operating in various interferometric imaging modes. In this study, we used the MU radar in range imaging mode devoted to detailed measurements of atmospheric clear-air turbulence and stable gradient sheets. This interferometric mode, called FII (Frequency domain Interferometric Imaging), is based on frequency diversity [2]. During the experiment described in this paper, a vertical beam was used and FII data were collected at an initial height resolution of 150 m. Five equally-spaced frequencies between 46.0 MHz and 47.0 MHz were selected and steered after each coded pulse. From the (5×5) covariance matrix of the received signals, the brightness (reflectivity) distribution in each 150 m range gate is estimated with the Capon method [3]. Vertical profiles of MU radar observations were obtained from 1.25 km to 20.30 km above sea level, and the time resolution was 16.5 s.

Simultaneous observations with the Raman, Mie lidar and MU radar were conducted on November 14-16, 2005. The radar observations started at 21:30 LT on November 13, 2005, and ended at 12:00 LT on November 16, 2005. The lidar observations were carried out between 21:34 - 28:44 LT on November 14 and between 20:21 - 29:32 on November 15, 2005.

3. Results

Fig. 1 shows time-height cross-section of lidar backscatter ratio between 01:40 and 03:00 LT on November 15. Two well-defined scattering layers can be recognized around 2 km and 8-9 km altitude, respectively. The backscatter ratio around 8-9 km shows significant time height variations with a period of between 5-10 min, and a maximum value of 20-25 dB at 9 km. On the other hand, the corresponding time-height radar echo intensity plot shown in Fig.2 indicates more numerous and thinner layered structures much more complicated with smaller height scales. However, there is an echoing structure between 8 and 9 km, especially for the latter half of the period (02:10 – 2:57 LT), in the same time height region as the intense layer detected by the lidar . The structure seems to be characteristic of convection in a cloud. The radar echo intensity in this region also shows significant time height variations with a period of 5 – 10 min. Fig.3 displays specific humidity profiles observed with the lidar at 01:50 – 02:21 (dashed) and 02:26 – 02:57 LT (dotted). The altitude of this humidity gradient corresponds well with the altitude of the radar echoing layer.

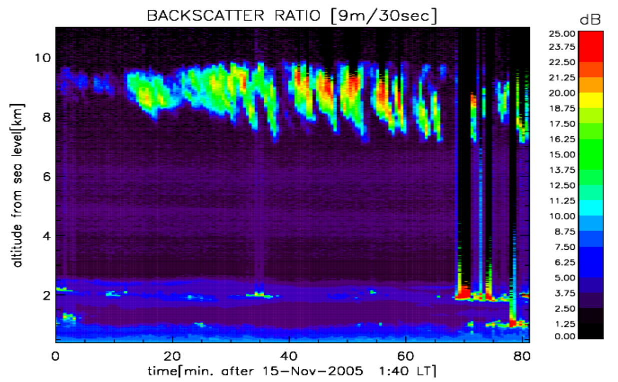


Fig.1. Lidar backscatter ratio between 01:40 to 03:00 LT. The height and time resolution are 9 m and 30 s, respectively.

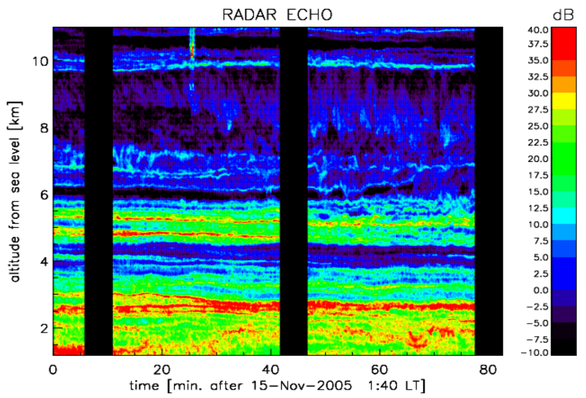


Fig.2. Radar echo intensity after FII Capon processing between 01:40 to 03:00 LT on November 15. The time resolution is 16.5 second.

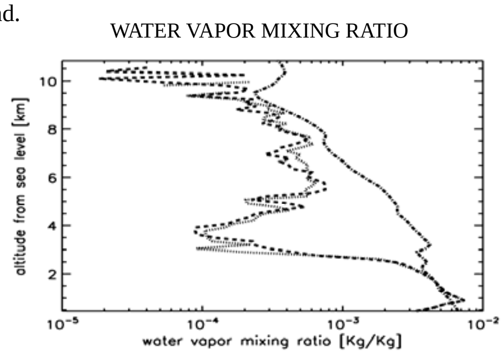
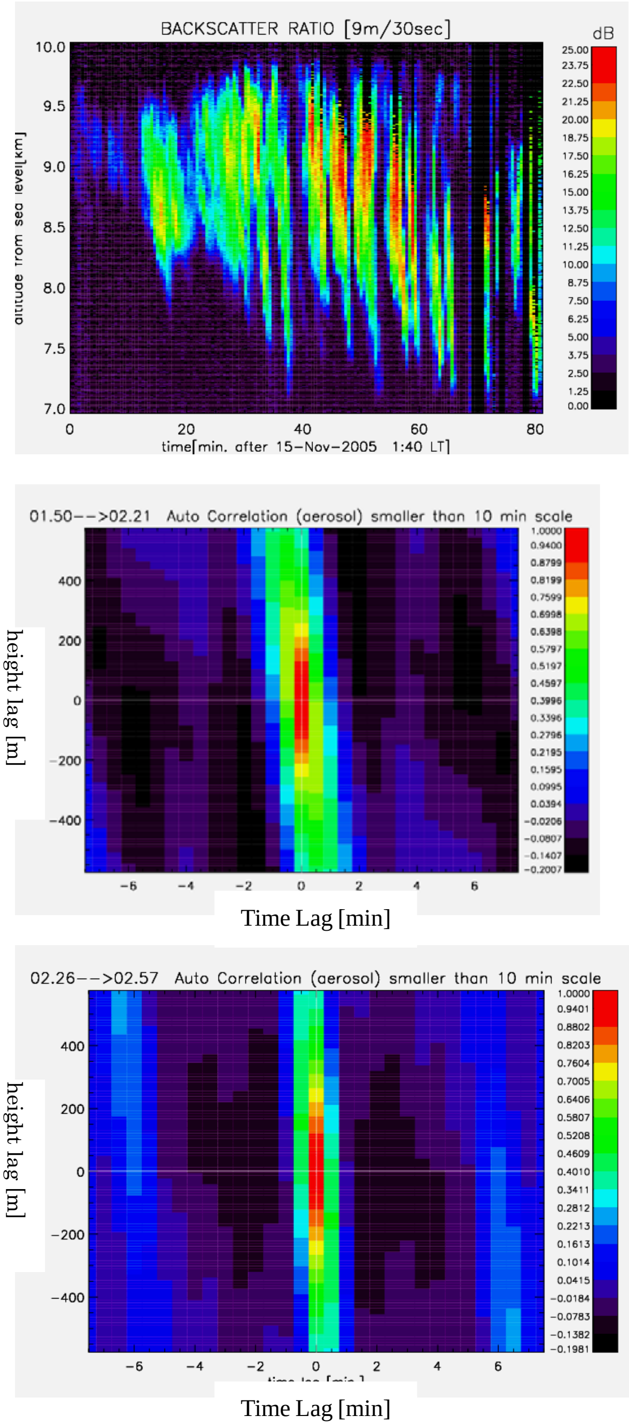


Fig.3. Water vapor mixing ratio measured by Raman lidar. Dashed and dotted lines correspond to the time between 01:50 – 02:21 and 02:26 – 02:57, respectively. Dash-dotted line shows saturation water vapor mixing ratio, derived from a local radiosonde of the following day . The height resolution is 144 m.

Fig. 4 (top) shows the detailed structure of the lidar backsatter ratio between 7 and 10 km altitude. The below two panels show two-dimensional auto-correlation function of the backscatter ratio, after a high-pass filter with a cut-off period of 10 min was applied. Similarly, radar signal intensity is indicated in Fig. 5. It is found that radar and lidar signals show similar periodicity of about 10 min, but the height structure is different. The lidar backscatter ratio has a larger height correlation than the radar signal intensity, as seen from the autocorrelation function.



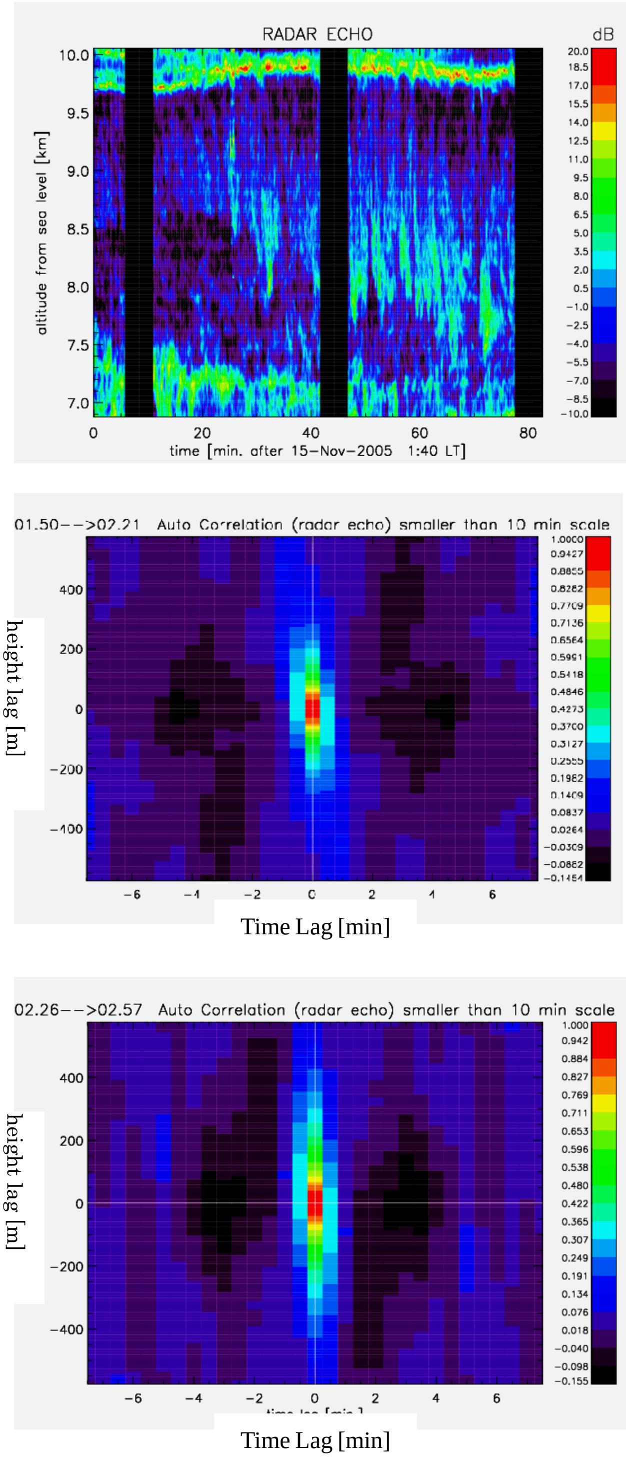


Fig.4. Detailed structure of the lidar backsatter ratio between 7 and 10 km altitude (top), auto-correlation function of the backscatter ratio between 01:50 – 02:21 LT on November 15 and 7.4 – 9.7 km above sea level (center) and simultaneously between 02:26 – 02:57 LT (bottom), after a high-pass filter with a cut-off period of 10 min was applied.

Fig.5. Detailed structure of the radar echo intensity between 7 and 10 km altitude (top), auto-correlation function of the radar echo between 01:50 – 02:21 LT on November 15 and 7.4 – 9.7 km above sea level (center) and simultaneously between 02:26 – 02:57 LT (bottom), after a high-pass filter with a cut-off period of 10 min was applied.

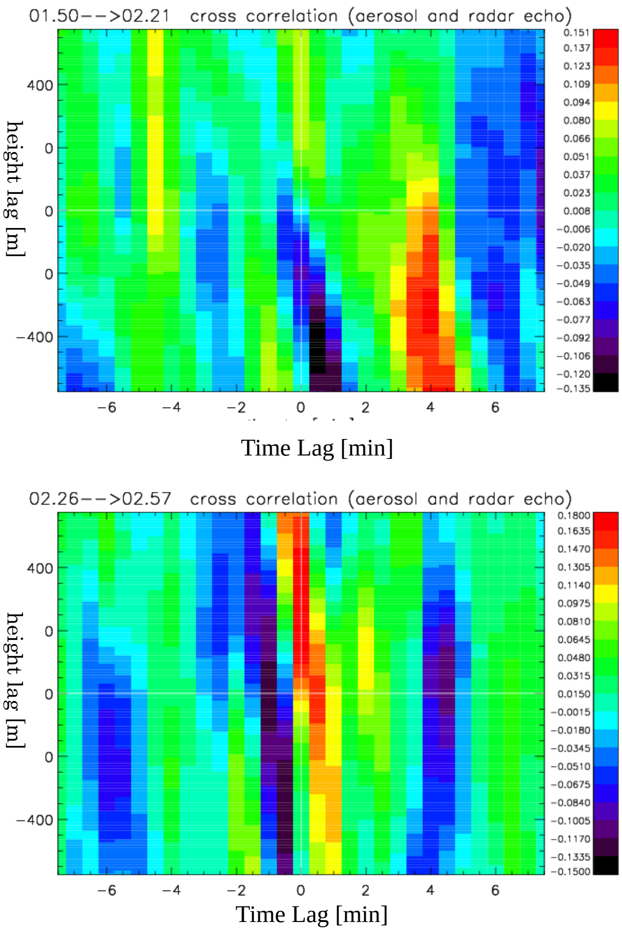


Fig.6. Cross-correlation functions between the lidar and radar signals. The top and bottom panels correspond to the time of 01:50 – 02:21 and 02:26 – 02:57 LT. A high-pass filter is applied before the correlation calculation.

Cross-correlation functions between the lidar and radar signals are plotted in Fig. 6. The left and right panels correspond to the time of 01:50 – 02:21 and 02:26 – 02:57 LT. A high-pass filter is also applied before the correlation calculation. For both periods, maximum correlation was around 0.1-0.2, which was not large. Also, the time height lags giving the maximum correlation coefficient are different between the two periods. This suggests that the the short period fluctuations (5 – 10 min) between the radar and lidar echoes are not so directly linked with a simple physical characteristics.

The radar echo intensity is related to the vertical gradient of refractive index, whereas the lidar backscatter ratio is considered to be more correlated with local refractive index. This could be the reason of a poor correlation between the two parameters. We plan to expand our analysis including vertical gradients of the backscatter ratio observed by the lidar. The radar echoing layer corresponded to gradients in the humidity profile. We plan to analyze temperature, and wind velocities derived from lidar and radar, in order to clarify the possible relationships between lidar and radar signals in more detail.

References

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