An observational study of mesoscale phenomena with UHF wind profilers

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The understanding of the structure of the mesoscale phenomena is essential for weather forecasting since the mesoscale phenomena often dominate local weather in the region where they occur to the synoptic scale phenomena and sometimes produce severe storms. Recent progress in developing remote sensing tools like the Doppler radar has been leading to a rapid advancement of our understanding of mesoscale processes. The observational studies, however, always depend strongly on the available measuring equipment. Generally, the Doppler radar is available only for the phenomena that are accompanied by precipitation, conversely, other remote sensing tools like sodar and lidar are not available in precipitation. Wind profilers are one of the best tools for studying mesoscale phenomena, because they can observe the wind profile in all weather conditions. Moreover, the wind profilers provide the temperature profile when they are equipped with Radio Acoustic Sounding System (RASS). These observational capabilities of wind profilers assist to understand the dynamics of mesoscale meteorological phenomena. The aim of this thesis is to study the structures of mesoscale phenomena by use of the UHF L-band (about 1 GHz) wind profilers.

The L-band wind profiler was originally developed at NOAA [1,2] to provide high-vertical resolution wind measurements in the first few kilometers of the atmosphere from a few hundred meters above ground level. This lowest range gate is low enough to be supported by another measurement like a tower to the ground. In addition, recent progress of technology enables RISH to develop new L-band profilers to obtain continuous wind profiles in clear air up to 5 km on average [3]. This means that the L-band wind profiler could obtain whole structure of the mesoscale phenomena. Moreover, the L-band profiler is generally small enough to move to places where the mesoscale phenomena are expected to occur.

Even for the L-band wind profilers, observations at altitudes of a few hundred meters is, however, difficult because of hardware limitations and noise from both inside and outside of the system. In addition, the quality of the profiler data in clear air depends strongly on atmospheric conditions because of the small power aperture of the radar, since the clear-air echo becomes weak in cold and/or dry atmosphere. Moreover, the sensitivity of the L-band wind profilers to hydrometeors is different from those profilers operating at other frequencies. In this thesis, thus, the performance of L-band wind profilers is evaluated especially in observing the atmosphere from low altitudes, and their observational capabilities to facilitate understanding the dynamics of mesoscale meteorological phenomena are demonstrated.

A special focus of this thesis is the validation of the horizontal and vertical motion fields obtained from the profiler observations. In this thesis a five-beam wind profiler and a collocated meteorological tower are used to estimate the accuracy of four-beam and three-beam wind profiler techniques in measuring horizontal components of the wind at as low as 200 m in altitude. In the traditional three-beam wind profiler techniques, the horizontal components of wind are derived from two orthogonal oblique beams and the vertical beam. In the less used four-beam method, the horizontal winds are found from the radial velocities measured with two orthogonal sets of opposing coplanar beams. In this thesis the observations derived from the two wind profiler techniques are compared with the tower measurements. Results show that, while the winds measured using both methods are in overall agreement with the tower measurements, some of the horizontal components of the three-beam-derived winds are clearly spurious when compared with the tower-measured winds or the winds derived from the four oblique beams. These outliers are partially responsible for a larger 30-min, three-beam standard deviation of the profiler/tower wind speed differences (2.2 m s^{-1}), as opposed to that from the four-beam method (1.2 m s^{-1}). It was also found that the spatial variability of the vertical airflow in nonrainy periods or hydrometeor fall velocities in rainy periods makes the vertical beam velocities significantly less representative over the area across the three beams, and decreases the precision of the three-beam method. It is concluded that profilers utilizing the four-beam wind profiler technique have better reliability than wind profilers that rely on the three-beam wind profiler technique. Based on this result, the four-beam method is applied for the analyses of mesoscale phenomena in this thesis.

One of the unique capabilities of the wind profiler is to be able to rapidly sample the vertical velocity. Vertical airflow measurements are essential for understanding the structure of mesoscale phenomena because vertical airflow could initiate and maintain clouds that produce mesoscale phenomena. However, there are few studies on estimating the accuracy of profilers in measuring the vertical velocity, although it has a significant influence on the estimation of horizontal wind [4, 5]. One of the reasons is that the vertical airflow has spatial and temporal variability due to convection [6], which makes the comparison difficult. The mesoscale events discussed in this thesis provide opportunities to observe mesoscale features with *in situ* and remote sensors simultaneously and enable to estimate the accuracy of profilers in measuring the vertical component of the wind. The results show that the vertical velocities derived from the wind profiler agree well with *in situ* vertical velocities measured by a sonic anemometer on the tower.

Three kinds of mesoscale phenomena with different weather conditions are analyzed with the wind profilers along with other observational equipments in this thesis. They are, a line-shaped convective system (LCS) with strong clear-air echoes in summer, a shallow gravity current with weak clear-air echoes in winter, and gusty winds within a typhoon with heavy precipitation.

The LCS is one of the mesoscale phenomena, which produces heavy rainfall in a local region where it occurs. The formation mechanism of the LCS is currently in dispute. One of the difficulties arises from the lack of observation in the clear-air region ahead of the LCS where conventional Doppler radar has not observed because of less hydrometeors. In this thesis, wind profiler data ahead of the LCS are analyzed to understand the formation of the LCS. The analysis revealed a horizontal convergence layer above a divergence layer in the clear-air region upwind of the LCS. The profiler observed upward airflow in the convergence layer and downward airflow in the divergence layer underneath. It is concluded that the upward airflow in the convergence layer and terrain effects forms the LCS from the analysis.

Observations from a wind profiler and a meteorological tower are utilized to study the evolution of a gravity current that passed over the MRI field site. Observations from the profiler/RASS and the tower-mounted instruments illustrate the structure of the gravity current in both wind and temperature fields. The profiler data reveal that there were three regions of waves in the vertical velocity field: KH waves above the feeder flow, lee-type waves in the head region of the gravity current, and the solitary wave formed from the elevated head of the gravity current. Profiler vertical-motion observations resolve this wave and enable to classify it as a Benjamin-Davis-Ono (BDO) type solitary wave. The ducting mechanism that enabled the solitary wave to propagate is also revealed from the wind profiler/RASS measurements.

Observations from the wind profiler and a Doppler radar were used to study the evolution of two thin-line echoes that occurred over the Kanto Plain as a typhoon (T0221) passed. The first thin-line echo formed on the edge of a region of low clouds between the typhoon center and a trailing outer rainband. The second thin-line echo developed ahead of an outer rainband of the typhoon in the area where the first thin-line echo had propagated. Both thin-line echoes were accompanied by gusty winds and followed by cold airflows, and both passed the MRI field site. Surface instruments at the MRI site recorded a peak wind gust of 31.6 m s^{-1} as the first thin-echo passed. The wind profiler indicated that the cold airflow behind the first boundary had characteristics unique to gravity currents, and the second boundary was associated first with strong updrafts and then with strong downdrafts. These results suggest that the first thin-line echo was caused by a gust front, and the second thin-line echo was caused by a solitary wave. In summary, it is confirmed that the use of wind profiler/RASS is invaluable in the study of mesoscale phenomena.

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