Abstract

Radars operated at VHF (30 – 300 MHz) or UHF (300 – 3000 MHz) frequency bands (atmospheric radars; ARs) are sensitive to refractive index perturbations caused by atmospheric turbulence. From a Doppler spectrum collected by a AR, echo power (P), Doppler velocity (V_{d}), and spectrum width ($\sigma_{3\mathrm{dB}}$) of echoes scattered by the refractive index perturbations (clear-air echo) can be measured. Hereafter, these parameters are referred to as spectral parameters. Because the refractive index irregularities can be produced by temperature and humidity perturbations caused by atmospheric turbulence, ARs can be used to measure turbulence parameters (e.g., dissipation rate and diffusivity).

In order to improve angular resolution or range resolution, spaced receiver antennas or multiple carrier frequencies are used. The former is referred to as coherent radar imaging (CRI) or spatial domain interferometric imaging (SDI). The latter is referred to as range imaging (RIM) or frequency interferometric imaging (FII). In this study, we developed a new radar digital receiver which can perform both RIM and oversampling (OS) on a 1.3-GHz AR (RIM LQ-7). The new radar digital receiver contains a general-purpose software-defined radio receiver referred to as Universal Software Radio Peripheral 2 (USRP2) and a commercial personal computer. Software developed for the digital receiver was written in the C++ language and that developed for signal processing was written in the Python language.

Because high-resolution ARs collect a huge amount of Doppler spectra, methods for calculating the spectral parameters must be simple and fast. Using numerical simulations, we investigated a method for calculating the spectral parameters from Doppler spectra collected in the clear air region. The proposed method has two steps in general. In the first step, the echo range (R_{echo}), in which the Doppler spectrum point with peak intensity is contained and all the smoothed Doppler spectrum points have intensities that are greater than the noise intensity, was determined. For producing the smoothed Doppler spectrum, a running average with equal weight (RA) or multi-taper method (MTM) was used. In the second step, the spectral parameters were calculated using the Doppler spectrum points within R_{echo}. By

comparing the performance of the computation method using RA and that of the computation method using MTM, we concluded that the computation method using RA is more suitable because it has better estimation performance for small spectrum widths and the calculations are faster.

Estimation error of the spectral parameters depends on the determination accuracy of the Doppler spectrum peak and R_{echo}. Furthermore, for the case of a 512-point Doppler spectrum and 13-point RA, the estimation errors tend to be independent of the signal-to-noise ratio (SNR) when the detectability (D) is $\sim$6 or more larger. For a D range of $< \sim$2.5, the estimation errors are significantly large. The results indicate that the estimation accuracy is affected by D. It is recommended that number of incoherent integration times is determined by considering both D and the SNR.

By using the method we proposed, data collected by the vertical beam of the RIM LQ-7 was processed. Measurement using a 1-μs subpulse width, a 8-bit optimum binary code, five frequencies (1357.00, 1357.25, 1357.50, 1357.75, and 1358.00 MHz), 10-MS s^{-1} sampling in the range direction, and the vertical beam was carried out at Shigaraki MU Observatory (34°51′ N, 136°06′ E). Measurement results indicate that RIM in combination with OS achieves unambiguous RIM measurement in the range direction, and hence is useful for improving the accuracy of RIM measurement. Further, measurement results indicate that the high range and time resolution of the RIM LQ-7 are useful for observing the boundary layer.

In the precipitation region, ARs can receive clear-air echoes and Rayleigh scatterings from hydrometeors (hydrometeor echoes) simultaneously. In order to calculate the spectral parameters of the clear-air echo accurately, the clear-air echo must be separated from the hydrometeor echo well. Therefore, we proposed methods (top method and two-echo method) for calculating the spectral parameters in precipitation region. The top method is used when raindrops or solid hydrometeors with small echo intensities exist. The top method sets an echo cut level by using the peak intensity of a clear-air echo. The echo cut level is used for separating clear-air echoes from hydrometeor echoes. The two-echo method is used when solid hydrometeors with large echo intensities exist. The two-echo method sets the echo cut level by using the local minimum of echo intensity between the clear-air echo and the hydrometeor echo.

In order to determine the optimum echo cut levels for the top method and two-echo method, numerical simulations with different simulation conditions were carried out. The simulation results indicate that the top method with L of 10 dB shows the best performance and that L down to 5 dB also can be used. For the two-echo method, the simulation results indicate that an echo cut level which is 1 dB greater than the minimum echo intensity has good performance.

Measurement results obtained by the vertical beam of the MU radar at Shigaraki MU Observatory during a precipitation event on 26 October 2009 were used for evaluating the performance of the top and two-echo methods. The measurement results demonstrate that the top method and two-echo method are useful for reducing the errors of spectral parameters.

We believe that the high range and time resolution of RIM LQ-7 are useful for observing the boundary layer. Further, the top and two-echo methods are useful for measuring the vertical wind in precipitation for 50-MHz band ARs.