A Detailed Error Analysis for Meteor Radar Systems: Evaluation of COBRA Meteor Radar Observations on 2005 and 2006

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Meteor wind radar systems are typically designed to study the horizontal wind field in the mesosphere and lower thermosphere (MLT). While such systems have operated for many years, a comprehensive error analysis is not available in the literature. In this work a detailed analysis of the uncertainty for the parameters derived from meteor radar measurements is presented. The parameters of interest include range, diffusion coefficient, Doppler shift, and angle of arrival (AOA), among which the range uncertainty is completely determined by the radar sampling rate and can be very precise, e.g. 333.3KHz sampling rate corresponds to 450m uncertainty. Uncertainties of diffusion coefficient, Doppler shift and AOA are demonstrated to be sensitive to the signal-to-noise ratio (SNR) and the true value of the diffusion coefficient. Echoes with high SNR and small diffusion coefficient always have higher precision.

Based on this analysis a 10dB SNR threshold is suggested for echo processing and error analysis, since the parameters estimated for echoes above this threshold are unbiased for most parameter estimation algorithms. The uncertainties of any unknown parameters can be completely determined by the Cramer-Rao bound (CRB), which is the minimum mean-square-error (MSE) that any unbiased estimator can achieve.

In this work, the CRB of the diffusion coefficient, Doppler shift and AOA are derived. Based on these measurements, the horizontal wind velocity and the height of the echoes can be determined. The errors in the measurements of the diffusion coefficient, Doppler shift and AOA propagate through the calculations to form the uncertainty of the height and horizontal wind measurements. The horizontal wind velocity is computed by neglecting the vertical component of the vector wind field, which is believed to be more than 10 times smaller than the horizontal wind in amplitude. While the vertical fluctuation is small, neglecting this component increases the bias of the derived horizontal wind especially at high elevation angles, and it becomes the dominant error source above 50 degrees elevation. Below 50 degrees elevation the uncertainty of the horizontal wind velocity is dominated by the uncertainty of the measured radial velocity. The uncertainty is demonstrated to be invariant to the magnitude of the actual wind velocity and minimum uncertainties occur between 30-50 (degree) elevation angles. The height uncertainty decreases as the elevation angle of the echo increases.

These results provide more confidence in the meter radar derived parameters and a better understanding of the statistical characteristics associated with meteor echoes. Meteors echoes collected by the South Pole COBRA meteor radar on 2005 and 2006 have been processed, and the resutls indicate that the COBRA system can measure the horizontal wind with a standard deviation less than 1m/s, and provide height measurements with about 0.5km standard deviation. Additionally, the error analysis also provides a tool for radar system optimization. For example, if directive transmitting antennas are used, such as the COBRA meteor radar system, an antenna beam elevation of 40 degrees will provide more precise measurements than at the current elevation of 30 degrees.