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Observations of meteors using VHF atmospheric radar

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Radars at lower VHF band between 40 and 60 MHz for the atmosphere can collect not only the echoes from clear-air turbulence, atmospheric stable layers, and plasma irregularities, but also the returns from aircrafts, meteors (meteoroids and meteor trails), precipitation, and so on. In this study, we examined the meteor echoes using adaptive constrained methods such as Capon's method and its modified version, norm-constrained Capon method. The radar data were collected by the middle and upper atmosphere radar (MUR), operated by the Kyoto University, Japan. Twenty receivers and five frequencies (46.25, 46.375, 46.5, 46.625, 46.75 MHz) were utilized in observation. Because of multi-channel reception, angular and range distributions of the meteor heads and trails in the radar volume can be resolved by the conventional or modified Capon methods. Some initial results will be shown. For example, fragmentation of the meteoroids can be disclosed from the range distribution of the meteor trails with conventional Capon method, and the meteor heads are possible to be identified from the angular distribution of the echoes resolved by the modified Capon method.

The basic Capon equations for angular distribution is expressed as

$$\min\ (B(\mathbf{k}) = \mathbf{w}_c^{+}\mathbf{R}\mathbf{w}_c) \text{ subject to } \mathbf{e}^{+}\mathbf{w}_c = N, \tag{1}$$

$$\mathbf{e} = [e^{j\mathbf{k}\cdot\mathbf{D}_1}\ e^{j\mathbf{k}\cdot\mathbf{D}_2} \ldots e^{j\mathbf{k}\cdot\mathbf{D}n}]^T, \tag{2}$$

and $\mathbf{w}_c$ is the optimal weighting function adaptive to the echoes themselves, and is derived as

$$\mathbf{w}_c = \frac{\mathbf{R}^{-1}\mathbf{e}}{\mathbf{e}^{+}\mathbf{R}^{-1}\mathbf{e}}N, \tag{3}$$

where B is the retrieved power (brightness distribution) at the looking direction **k. k**=$(2\pi/\lambda)$ [sinθsinϕ, sinθcosϕ, cosθ], λ is the radar wavelength, θ and ϕ are zenithal and azimuthal angles, respectively. **R** is the covariance matrix of the echoes. $\mathbf{D}_n$ indicates the coordinates of receiver antennas, and the upperscripts, T, + and -1, denote the transpose, Hermitian and inverse operations of matrix, respectively. N is the number of receivers. Substituting (3) into (1) gives

$$B(\mathbf{k}) = \frac{N}{\mathbf{e}^{+}\mathbf{R}^{-1}\mathbf{e}}. \tag{4}$$

The modified Capon method is described briefly below:

$$\min(\mathrm{B}(\mathbf{k}) = \mathbf{w}^{+}\mathbf{R}\mathbf{w}) \text{ subject to } \mathbf{e}^{+}\mathbf{w} = \mathrm{N} \text{ and } |\mathbf{w}^{+}\mathbf{w}| \leq \delta\mathrm{N}, \tag{5}$$

where δ is an adjustable value (approximately between 1.2 and 1.4 for the MUR), and **w** is modified as

$$\mathbf{w} = \frac{(\mathbf{R}+\sigma\mathbf{I})^{-1}\mathbf{e}}{\mathbf{e}^{+}(\mathbf{R}+\sigma\mathbf{I})^{-1}\mathbf{e}}N, \tag{6}$$

where σ is a variable and **I** is the identity matrix; therefore it is basically a diagonal-loading technique. The optimal **w** can be obtained by changing the value of σ, if δ is given. Finally, $B(\mathbf{k})$ is computed from (5) with the optimal **w**. For the range distribution, the echoes at different carrier frequencies are used instead of those of receivers.