# Theory and Practice of Using Ground and Ionospheric Reflections to Determine Radio Emission Source Heights and Ionosphere Virtual Heights

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Measurement of the differential times of arrival (DTOAs) of distinct waveform features by multiple, spatially separated recording stations provides a powerful means of locating the source of the waveforms. For many decades, DTOA techniques have been utilized to determine the locations of lightning strokes in two dimensions (latitude and longitude) or three dimensions (2-D plus altitude).

A powerful extension of lightning DTOA location techniques has recently been developed and applied to the geolocation of events within a distinct class of thunderstorm electrical discharges. The discharges are singular, isolated events that occur at altitudes between 7 and 20 km and produce very powerful, very brief broadband radio emissions. In addition to receiving groundwave or line-of-sight signals from these sources, VLF/LF recording stations and HF recording stations have often recorded clear reflections of the emissions from the ionosphere and surface of the earth. The relative delays of the reflections provide a means of determining both the height of the source that produced the emissions (h) and the virtual reflection height of the ionosphere (H). The technique requires that multiple stations record one-hop reflections or that a single station record multiple-hop reflections. It is also possible to determine h and H when one-hop reflections are received by a single station and the range to the source (r) is known a priori. Some challenging aspects of the technique include the assignment of time tags to the reflected signals after their distortion by the ionosphere and distinguishing the reflections from other lightning transients.

This technique for radio emission source geolocation was utilized to analyze data acquired in 1996 by an array of electric field change meters (LF/VLF instruments) and an array of broadband HF receivers. During 1998 the technique has been refined and used to study data acquired by the Los Alamos National Laboratory sferic array, a quartet of electric field change meters that began operation in May of 1998 in New Mexico in support of the acquisition of VHF lightning emissions by the FORTE satellite.