Various radio techniques are employed for remote sounding of the ionospheric plasma. The most powerful by far is based on the Thomson scattering of EM waves by the electrons in the ionospheric plasma, commonly known as incoherent scattering. The same technique is employed to study laboratory plasmas using a laser instead of a radar. In this review we will describe the physical basis of incoherent scattering, show a few illustrative discoveries made using the technique at auroral latitudes, in particular employing the EISCAT radars in northern Scandinavia, and briefly describe the state of the art.

William E Gordon came up in 1958 with the idea of using radio signals backscattered from individual electrons in the ionosphere to study the ionosphere above 50 km. This scatter is exceedingly weak, it is equivalent to trying to detect a one-millimetre sphere at a range of 300 km. Gordon showed that this could be done with existing 1958 radar technology using a 300-metre-diameter antenna and a one or two megawatt transmitter. Gordon built in 1960-1963 the Arecibo Observatory with precisely these specifications. Parallel with the construction of the Observatory, several prominent plasma physicists discovered that the technique was far more powerful than Gordon had realised.

The theory of incoherent scatter is one of the most successful triumphs of linear kinetic plasma theory. The reason is that the signal spectrum depends directly on the spectrum of electron density fluctuations of the plasma which is in most cases in thermal equilibrium and therefore intrinsically weak. Even in non-equilibrium, the fluctuations remain relatively weak due to nonlinear saturation processes. From the power and shape of the Doppler spectrum of the incoherent scatter signal it is possible to determine most of the properties of the ionosphere to altitudes beyond 1,000 km. The problem of deducing the spectrum of the scattered radar signal leads to calculating the plasma susceptibilities which depend only on the particles's velocity distributions. The susceptibilities are obtained from linearised solutions of the Vlasov equation (the single-particle kinetic equation) and the fluctuation spectrum by application of the particle test method which bypasses the need to solve the (very unyieldy) two-particle kinetic equations. The test particle method (akin to renormalisation techniques used in particle physics) is mathematically extremely efficient and illuminates strikingly the underlying physical processes making them easier to understand intuitively.

Gordon's initiative was repeated in parallel with his in Lima, Peru, resulting in the Jicamarca Observatory which started operations even before Arecibo, in 1961, and some years later in Europe (in the UK and France), Russia and Japan. Since then, three generations of observatories have been built with investments of several tens of million dollars each. A testament to the usefulness and success of the technique is the ongoing initiative to construct the first fourth generation radar, EISCAT_3D with 3-dimensional vector imaging capabilities. EISCAT_3D is at the fund raising phase with support from the European Union and has a cost estimate of 130 million euros.