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# On the use and calculation of MUF(3000)F2 for 3D ionospheric model validation

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MUF(3000)F2, the Maximum Usable Frequency (MUF) at 3000km range at High Frequency (HF) sustained by the F2-layer of the ionosphere, remains a popular and important parameter used in the characterization of the ionosphere and High Frequency (HF) radio propagation. This parameter can be directly acquired from transmission curve methods in ionogram processing; however, there remains no clear convention on how one should calculate it from a model of electron density for comparison to these ionosonde measurements. Instead, modelers will often resort to the use of empirical relationships, such as the Shimizaki [1955] relationship (given by Equation 1), rearranged to calculate MUF(3000)F2.

$$hmF2 = \frac{1490 \cdot foF2}{MUF(3000)F2} - 176 \tag{1}$$

For example, this method is currently used to provide an operational MUF(3000)F2 product for NOAA WAM-IPE. The Shimizaki [1955] relationship remains the most popular in the determination of MUF(3000)F2, as it does not require an assessment of foE or other parameters, which can be ambiguous to determine from gridded electron density model output; however, this relationship is also the most simple and is known to carry with it considerable systematic errors. This relationship is also intended for the calculation of hmF2 from MUF(3000)F2, not the other way around; as such, its error behaviour in this inverted context has not been well characterized.

With MUF(3000)F2 still being a core parameter in the International Civil Aviation Organization (ICAO) Space Weather Advisories framework, there is an established need to understand the accuracy of ionospheric models in the context of MUF and there is subsequent need to establish standards for its calculation from 3D ionospheric electron density model output.

In this study, using incoherent scatter radar and other measurements, we will examine the performance of standard MUF(3000)F2 calculation methods that are currently being employed as operational products. We will furthermore provide an overview of how to calculate MUF(3000)F2 from gridded electron density model output in a manner that is self-consistent, does not rely on empirical relationships, and can be directly compared to the MUF(3000)F2 derived from ionosonde measurements.

## References

Shimazaki, T. (1955), World-wide variations in the height of the maximum electron density of the ionospheric F2 layer, *J. Radio Res. Lab. Jpn.*, 2(7), 85–97.