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Observations of sporadic E using aeronautical navigation radio waves

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The sporadic E (Es) layer is a thin layer in the ionospheric E region (at ~100 km altitude) characterized by a dense electron density. Es is typically observed during the summer months, from May to August, with higher occurrences during daytime. It has long been known that the Es layer can cause anomalous propagation of VHF radio waves, such as those used for FM radio and analogue TV, by reflecting waves that would normally penetrate through the ionosphere. The International Civil Aviation Organization (ICAO) has noted that the Es layer has the potential to introduce anomalous propagation in VHF signals used for aeronautical navigation (NAV) systems, such as VHF omnidirectional radio range (VOR), instrument landing system localizer (ILS LOC), and ground-based augmentation system VHF data broadcast (GBAS VDB), which utilize frequencies in the band from 108 to 118 MHz. However, the number of ground-based monitoring stations for aeronautical VHF signals has been limited, making it difficult to evaluate and monitor the potential impact of Es on VHF NAV signals.

To address this, we initiated a network observation of VHF NAV signals in May 2019 at six stations in Japan, extending from the southernmost station in Okinawa to the northernmost station in Hokkaido [1]. By 2022, we had deployed three additional receivers in Kyoto, Sendai and Kagoshima, bringing the total number of stations to nine. The receiver consists of a log-periodic antenna, air-band filter, software-defined radio, and a small computer, which is capable of recording the strength of radio signals in the frequency band from 98 to 118 MHz with a temporal resolution of 2 seconds. The receiver covers not only the NAV band, including VOR, ILS LOC, and GBAS VDB from 108 to 118 MHz, but also broadcasting channels from 98 to 108 MHz.

The statistics, derived from the past observation data, demonstrated that the occurrence pattern of anomalous propagation due to Es is generally consistent with ionosonde observations of the Es layer. Most Es layers appear during summer, with a primary peak during daytime, and a secondary peak in the evening. These statistical characteristics further confirm that the origin of anomalous propagation is the reflection caused by Es [2]. During an extreme event, an anomalous propagation signal was superposed on a ground wave signal, resulting in a fluctuation of the ground wave signal by more than ±10 dB. Our statistical results suggest that the Es layer has a potential to impact VHF NAV applications.

Continuous multi-point observations of anomalous propagation signals, from widely distributed VOR, ILS LOC, and GBAS VDB stations, also allow us to map the two-dimensional spatial distribution of Es [3]. We have introduced a method for mapping the structure of Es in a wide area by combining VHF radio observations with GPS-TEC ROTI data. The mapping results indicate that the Es showed an east–west extension with a spatial scale of approximately 730 km in east–west and 110 km in north–south directions, respectively. Sequential mapping of images demonstrated that the entire Es structure was moving northward with a speed of approximately 63 m/s. The current results indicate that the combination of ROTI with VHF anomalous propagation data from nine receiving stations in Japan enables us to visualize the two-dimensional structure of Es over a wide area, including the sea area, with a time resolution of at least 5 minutes.

References

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