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Probing equatorial ionosphere using GMRT at sub-GHz frequencies

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Radio Interferometer is an array of elements that are simultaneously working together to measure spatial coherence function to provide images of astronomical sources with unmatched resolving power. The effect of the ionosphere limits our ability to explore the sky at sub-GHz frequencies by introducing an extra phase term, which is particularly hard to calibrate in the low signal-to-noise ratio (S/N) regime. Interferometers like Very Large Array (VLA), LOw-Frequency ARray (LOFAR), Murchison Widefield Array (MWA), Giant Meterwave Radio Telescope (GMRT), and future instruments such as Square Kilometre Array (SKA) are all affected in the same way.

Here, our motivation is to study the Equatorial Ionization Anomaly (EIA) region, which has prominent plasma turbulence effect. In this region, which extends up to $\pm 20^\circ$ magnetic latitudes, Earth's ionosphere continues to vary at dawn and has unanticipated changes during night-time. These activities in the EIA region can often lead to disruption in communication and navigation such as GPS. Various telescopes like LOFAR ($\sim 53^\circ$ N), MWA ($\sim 26^\circ$ S), VLA ($\sim 34^\circ$ N), have also studied the ionosphere. But due to their location constraints, their studies were limited to their local ionospheric region. The location and array configuration (centre square and arms antennas) of the GMRT ($\sim 19^\circ$ N) array are well suited to study geophysically sensitive regions between the northern crest of the EIA and the magnetic equator because this region comes under the highest concentration of electron-ion density. We have taken the data from GMRT, which is an excellent candidate due to its positional advantage, to study this EIA region.

The observational data has been taken from a bright radio galaxy ($3C68.2$) at the sub-GHz frequencies to demonstrate the capability of GMRT to detect small-scale ionospheric variability around the EIA region. Phase correction from the calibration has been obtained using standard Common Astronomy Software Applications (CASA). Several steps have been performed to extract ionospheric information from the phase data. The observed ionospheric phase for the pair of antennas is found to be proportional to the difference in the total electron content (TEC), which is called the differential phase observed along the line of sight. As the phase contains several effects, the ionospheric effect is one of largest at lower frequencies, irrespective of the instrumental effects. After obtaining the ionospheric differential TEC data, geometrical corrections have been performed to make the observed TEC gradient comparable to vertical TEC gradients as closely as possible. Then, the data have been fitted with the proposed models to explain the small-scale variation. Also, spectral studies have been conducted on the computed TEC gradient, which were calculated using the proposed models. The first model track waves associated with medium scale travelling ionospheric disturbances (MSTIDs). The second method detect fine-scale fluctuations and also provide the statistical description of the group of waves moving in the same direction.

Our study reveals for the first time, that the GMRT is capable of measuring the differential TEC between two antenna elements with precision about the order of a few mTECU, which is more sensitive than current GPS-based TEC measurements. Furthermore, the measurement of the TEC gradient has been computed for the GMRT array, and small-scale fluctuations in the 2-D TEC values have been observed. These fluctuations are useful for measuring the micro-scale variation in the ionospheric plasma. Also, spectral analysis effectively track and characterises the TIDs and small-scale fluctuations on the basis of wavelength and speed associated with individual waves. From the obtained results, it is evident that a sensitive instrument like GMRT can be a perfect probe for ionospheric fluctuations and to study the EIA region.

Upcoming SKA-low ($\sim 26^\circ$ S) in Australia and SKA-mid ($\sim 30^\circ$ S) in South-Africa having different array configuration, will be able to conduct similar research to probe ionosphere and can provide precise information to study various space weather phenomena.

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