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Space Weather Effects on GNSS Signals at Equatorial and Low Latitudes

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An important component of space weather in dip equatorial and low geomagnetic latitude ionosphere is the post-sunset phenomenon of equatorial plasma bubble (EPB). An EPB is a region of lower plasma density compared to the background ionosphere, which extends vertically upward from the bottom-side of the equatorial F layer, when the right conditions exist in this region for a Rayleigh-Taylor (R-T) instability to grow in the plasma. The entire geomagnetic flux tube, extending from one hemisphere to the other, is involved in this instability. Hence an EPB is aligned with the geomagnetic field, extending to hundreds of kilometers in the magnetic north-south direction, while its magnetic east-west extent in the bottom-side of the equatorial F region may be tens of kilometers. As an EPB rises above the dip equator, it develops shorter scale structures or irregularities, which also extend along the geomagnetic field line to off-equatorial latitudes. The latitudinal extent of the irregularities depends on the altitude where they develop within an EPB. Also, after sunset, several EPBs may develop in quick succession on the bottom-side of the equatorial F layer in a particular longitude region, even as they generally drift eastward through the night at speeds of about 100 m/s. Thus, the equatorial and low latitude ionosphere over this region may become highly structured. Such a structured ionosphere scatters VHF and higher frequency radio signals that propagate through it, in addition to refraction caused by variations in the ionospheric refractive index. If the irregularities were stationary and the radio signals were transmitted from a geostationary satellite, a stationary diffraction pattern would be formed on the ground. However, with the movement of the irregularities across the signal path, the ground pattern drifts across a receiver, giving rise to temporal fluctuations or scintillations in the amplitude and phase of the recorded signal. Deep fades in signal strength may result in loss of signal, while rapid phase scintillations may cause loss of lock for GNSS (Global Navigation Satellite Systems) signals. Even after decades of study, it remains a challenge to understand the day-to-day variability in the characteristics of the irregularities that develop within EPBs, which may impact the performance of space-based communication and navigation systems such as the GNSS. The EPB irregularities also scatter L-band signals used in remote sensing by space-based synthetic aperture radars (SARs), and create distortions in SAR images.

After the initial demonstration of the presence of EPB irregularities using ionosonde observations many decades ago, extensive studies using coherent scatter radar observations, measurements of ionospheric scintillations on signals propagating through a structured ionosphere, and in-situ measurements by instruments on board rockets and satellites, have provided answers to several important questions, while raising new questions. Height of the equatorial F-layer, which depends on the zonal electric field in the equatorial ionosphere, has emerged as a key player in the growth of the R-T instability on the bottom-side of the post-sunset equatorial F-layer. This zonal electric field is highly variable, particularly due to magnetic storms and substorms driven by transient events on the Sun. As it is, ionospheric dynamics is influenced by forcing from the magnetosphere above and the atmosphere below it. The upper atmosphere is only partially ionized, with the number density of neutral particles far exceeding that of the charged particles in the lower regions of the equatorial ionospheric F layer. Hence, in addition to movement of ions and electrons under the combined influence of ambient electric fields and the geomagnetic field, dynamics of the ionospheric plasma is influenced by collisions of ions with the neutral particles in the thermosphere. Conditions in the coupled ionosphere-thermosphere system, created by geomagnetic activity, which is an important aspect of space weather, play a major role in the subsequent development of EPBs.

In this talk, some of the findings in recent years, particularly based on ionospheric scintillation measurements, would be discussed to identify the effects of varying conditions in the ionosphere and thermosphere on the non-linear evolution of EPBs. This determines the characteristics of the ionospheric irregularities, such as their spatial spectrum, and their latitudinal extent, which are important for forecasting the effects of EPB irregularities on GNSS signals recorded at equatorial and low latitudes. Recent developments would be presented, especially in the context of the present status of three-dimensional numerical simulation of the non-linear evolution of EPBs, and new observations provided by satellite missions such as GOLD (Global–scale Observations of Limb and Disk).