Ionosphere as a detector of high energy space radiation

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The Earth's ionosphere is a highly dynamic region of the atmosphere, continuously influenced by perturbations originating both above and below it. In addition to its regular diurnal variations, driven primarily by changes in solar UV radiation flux, and long-term modulation due to solar cycles and cosmic ray variability, the ionosphere also responds significantly and transiently to various energetic space phenomena. High-energy photons from solar flares and charged particles associated with coronal mass ejections (CMEs) alter the plasma density of the ionosphere. Similarly, X-rays and gamma rays from celestial transients such as gamma-ray bursts (GRBs) and soft gamma repeaters (SGRs) induce short-lived but distinct modulations in ionospheric layers. Much like artificial detectors, whose electrical properties change temporarily upon receiving energetic photons or particles, the plasma properties and conductivity of the ionosphere are modified by such space radiation. These perturbations can be monitored remotely using radio waves propagating through the Earth–ionosphere waveguide. In particular, Very Low Frequency (VLF, 3–30 kHz) radio waves serve as effective probes for studying the modulation of the lower ionosphere (~50–120 km altitude). During transient events, changes in plasma density alter the absorption of VLF sky waves, thereby affecting their amplitude and phase. By analyzing these modifications, it is possible to detect and study the space events responsible for such ionospheric changes. Our approach employs a three-step modeling framework: (1) Monte Carlo simulations of ionization, (2) ion-chemical evolution of the resulting electron–ion densities, and (3) the Long Wave Propagation Capability (LWPC) code to estimate changes in VLF wave characteristics. Using this methodology, we model the modulation of the lower ionosphere and corresponding VLF signals by various ionizing space transients.