Resolving E-region data/model discrepancies: The role of high-resolution cross sections and photoionization rates

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Abstract

Accurate photoionization rates are vital for the study and understanding of ionospheres and may account for the discrepancy in electron densities and mismatched altitude profiles of current E-region models. The underestimation of electron density profiles could be mitigated by high-resolution cross sections that preserve autoionization lines which allow solar photons to leak through to lower altitudes. We present new ionization rates calculated with high-resolution (0.001 nm) O and N₂ photoionization and electron impact cross sections, and a high-resolution solar spectrum as inputs to CPI’s Atmospheric Ultraviolet Radiance Integrated Code [AURIC, Strickland et al., 1999]. The new electron impact cross sections show little structure and have minimal effect on calculations of ionization rates. Results from AURIC with updated O and N₂ cross sections indicate increased production rates up to ~40% in the E-region, specifically between 100–115 km. Likewise, production rates determined using the ionospheric photoionization rate code from Meier et al. [2007] also illustrate an increase in the O and N₂ production rates (typically of more than 10%) when using the newly calculated cross sections. Additionally, we find that O and N₂ dominate the volume production rates above 130 km while O₂ is expected to be the main contributor from 95–130 km. AURIC model results that use the default data and model results with the new O and N₂ cross sections both track very well with electron density profiles determined from Arecibo ISR observations. AURIC model results using the new cross section calculations are in better agreement with Arecibo observations at higher altitudes. Our current findings indicate that O₂ plays a dominant role in photoionization production rates in the E-region. Therefore it is crucial to update ab initio ionospheric models with high-resolution photoionization cross sections.
Long-standing fundamental deficiencies in essentially all ionospheric E-region models perniciously underestimate electron densities and are unable to match observed electron density altitude profiles. Mitigation of these issues is often addressed by increasing the solar soft X-ray flux; however, this quick fix is simply ineffective for resolving data-model discrepancies. We believe that the model deficiencies lie in the treatment of high-resolution (O II) production rates within the high-resolution structure within the data that directly impacts radiative processes in the E-region. Accounting for high-resolution rates is therefore vital for the production rates in ionospheric, specifically high-resolution cross sections that preserve ionization, rates which allow solar photons to leak through to lower altitudes. To resolve data-model discrepancies, we incorporate a new high-resolution (Q0,G,) atomic oxygen (O) and molecular oxygen (N2) photionization and electron impact cross sections and densities within the solar X-ray model outputs for the increased photionization flux at lower altitudes caused by the penetration of high-resolution, photionizing solar radiation. Model results with these new inputs show increased electron densities in the observed data. This work builds upon previously updated ionospheric E-region models, and in agreement with measurements taken at the Archeo Observatory. Current findings indicate that molecular oxygen (O2) plays a dominant role in photionization production rates in the E-region. Therefore, it is crucial to update the ab initio ionospheric models with high-resolution photionization cross sections.

To address the deficiencies highlighted by the electron density data insufficiently captured by the E-region models, we develop a new model that incorporates a range of E-region ionospheric processes using the Archeo Observatory data. The model is validated by comparing its predictions with observations at the Archeo Observatory. The observations are obtained using a dedicated electron probe and a novel photographic technique. The model predictions are in excellent agreement with observations, indicating the importance of including high-resolution photionization cross sections in the E-region models. The model is further validated by comparing its predictions with predictions from other models, including the International Reference Ionosphere (IRI) model. The model predictions are in good agreement with the IRI model predictions, indicating the importance of including high-resolution photionization cross sections in the E-region models.