Introduction

• Solar EUV and XUV radiation (0.1-120 nm) are the dominant global energy sources for heating of the thermosphere, creating the ionosphere, and driving the diurnal cycles of wind and chemistry.
• The effects of solar variability on the ionosphere are often most clearly seen in the topside ionosphere, the region which extends from the F peak up to the plasmasphere. Previous studies found strong 27-day fluctuations in ion density by DMSP spacecraft at ~840 km altitude [Rich et al. 2003] and the CNOFS spacecraft (~450 to 830 km) [Coley and Heelis 2012] in response to the 27-day solar rotation.
• A lack of simultaneous ionospheric satellite and solar EUV measurements means most of the current understanding of the response of the ionosphere to solar variability has come from modeling studies.
• The composition of and scale height (H+Kr/mg) in the topside ionosphere depends on many parameters such as the solar EUV flux, the neutral composition and winds, and the electric fields.
• O+ dominates the ionosphere below the O+He transition height where the ionosphere transitions from an O+ dominated plasma to an H+ dominated plasma. This transition height can vary significantly during the solar cycle, seasonally, and during geomagnetic storms due to thermospheric heating and winds, and electric fields. The other major constituent in the topside ionosphere is H+.

Spacecraft and Instrumentation

• DMSP spacecraft fly in sun-synchronous, dawn-to-dusk and pre-midnight-to-pre-moon orbits at ~800 km.
• SSSES includes a Langmuir probe, a retarding potential analyzer (RPA), a total ion density trap, and an ion drift meter (IDM).
• CNOFS was launched in April 2008 into an elliptical orbit (450 to 850 km, 13 degree inclination) and includes an RPA as part of CINDI.
• SDO was launched in February 2010 into geosynchronous orbit. The Extreme ultraviolet Variability Experiment (EVE) measures radiation in the 0.1-105 nm range [Woods et al. 2010].
• TIMED orbits at a 625 km altitude. The SEE instrument measures solar EUV in the 0.1-195 nm range since Jan 22, 2002. [Woods et al. 2005]

Data

We present an analysis of measurements of ionospheric density, composition, and temperature in the topside ionosphere by the DMSP spacecraft near 800 km for two full solar cycles. These measurements provide a unique opportunity to examine the influence of solar EUV variability on the topside ionosphere over a period of time never accomplished before. The observed variations are interpreted in terms of the variability in solar EUV using the E10.7 solar EUV flux proxy as well as high-resolution solar EUV measurements from the TIMED SEE and SDO EVE instruments.

EOF Analysis

Empirical Orthogonal Function analysis, closely related to Principal Components Analysis and dimensionality reduction in the signal processing literature, is based on the singular value decomposition of a matrix. For any real m-by-n matrix A of rank r.

\[
A = \sum_{k=1}^{r} \sigma_k u_k v_k^T = U \Sigma V^T
\]

where the columns of U and V are eigenvectors, and \(\Sigma\) a diagonal matrix of eigenvalue-square roots:

\[
\sigma_k = \| u_k \| V_k = \frac{u_k^T A v_k}{\| u_k \| \| v_k \|}
\]

Since \(A^H A\) and \(A A^H\) are each Hermitian matrices, their eigenvectors are orthogonal. Thus SVD is a series expansion of the matrix A in terms of orthogonal vectors ordered by convention from largest to smallest, so the first term in the series represents the largest variation in a data set A. In the present study, A is a unit-normalized, zero-meaned matrix of daily averages of total ion density measured by DMSP spacecraft as a function of geographic latitude and time.

The first term in the equation is the dominant eigenvector which corresponds to the largest eigenvalue. These eigenvectors represent sample functions of the input data and are called the empirical orthogonal functions (EOFs) or principal components (PCs).

1. Figures 1a and 2a show examples of the daily averaged (a) ionospheric density, (b) H+O+ ratio, and (c) ion temperature along the (d) solar zenith angle in the dawn sector for two complete solar cycles from 1992 through 2014. The data are from three spacecraft - DMSP F11 (blue), F13 (red), and F17 (green). The E10.7 solar EUV proxy is shown in black in (a).

2. Figure 2a shows the effect of solar EUV on the ionosphere and the ion-temperature. The ionosphere is H+ dominated as the ion is more strongly affected by solar wind and other variables. The ion-temperature increases as the solar EUV increases.

3. Figure 3a shows the seasonal oscillations in ion density and composition in the topside ionosphere. The ionosphere is H+ dominated as the ion is more strongly affected by solar wind and other variables. The ion-temperature increases as the solar EUV increases.

4. Figure 4a and 5a show the effect of solar EUV on the ionosphere and the ion-temperature. The ionosphere is H+ dominated as the ion is more strongly affected by solar wind and other variables. The ion-temperature increases as the solar EUV increases.

5. Figure 6a shows the effect of solar EUV on the ionosphere and the ion-temperature. The ionosphere is H+ dominated as the ion is more strongly affected by solar wind and other variables. The ion-temperature increases as the solar EUV increases.

Conclusions

• The solar cycle variations of the daily averaged densities, temperatures, and H+/O+ ratios show a strong relationship to the solar EUV as described by the E10.7 solar EUV proxy. The densities near the equator show a very strong dependence on solar EUV, with E10.7 producing CCCs consistent with GLAT and GLA.
• During solar minimum the topside ionosphere at DMSP is E10 dominated while it is O+ dominated during solar maximum. These ionospheric parameters also vary strongly with season, particularly at latitudes well away from the equator where the SZA varies greatly with season.
• The response of the topside ionosphere to solar EUV variability is closely related to the composition.
• CCCs between the density and E10.7 and PC1 are greater than during solar maximum, when the topside ionosphere at DMSP is O+ dominated than during solar minimum when it is H+ dominated.
• The response of the ionosphere to the SZA changes is much stronger during solar maximum than during solar minimum.
• This is interpreted as the result of the effect of composition on the scale height (H+Kr/mg) in the topside ionosphere and the "pivot effect" in which the variation in density near the F2 peak is expected to be amplified by a factor of e at an altitude a scale height above the F2 peak. [Rich et al. 2003]
• When the topside ionosphere is H+ dominated, DMSP may be much less than a scale height above the F2 peak while when it is O+ dominated, DMSP may be several scale heights above the F2 peak.

References and Acknowledgements