The changes in the ionosphere during the recent deep solar minimum

LIU, Libo\textsuperscript{1*}, Yiding Chen\textsuperscript{1}, Huijun Le\textsuperscript{1}, Weixing Wan\textsuperscript{1}

\textsuperscript{1}Institute of Geology and Geophysics, Chinese Academy of Sciences

The solar activity is low and extremely extended in 2007-2009, with a highest record of spotless days in 2008 since the finding of the ionosphere. It is a critical issue that whether or not this deep solar minimum brought serious influences on the Earth’s space environment.

To explore what happened in the ionosphere during the deep minimum, we analyzed the historical records of ionospheric parameters (the F2 layer critical frequency $f_{oF2}$, E-layer critical frequency $f_{oE}$ and F-layer virtual height $h'F$) observed by global ionosondes. A comparative study is performed to evaluate the difference in the ionosphere between recent deep minimum (2008-2009) and past solar minima. The analysis indicates that the moving 1-year mean $f_{oF2}$ at most ionosonde stations went to the lowest during cycle 23/24 minimum. The solar cycle differences in $f_{oF2}$ minima display local time dependence, being more negative during the daytime than at night. In contrast, a complex picture presents in global $h'F$ and $f_{oE}$. Evident reduction exists prevalingly in moving 1-year mean $h'F$ at most stations, while no huge differences are detected at several stations. A compelling feature is the increase in $f_{oE}$ at some stations, which requires independent data for further validation.

In addition, the ionograms recorded by a DPS ionosonde at Jicamarca (12.0° S, 283.2° E) are also collected and manually scaled these data to retrieve F-layer parameters and electron density profiles. Compared to 1996-1997, the seasonal median values of $f_{oF2}$ were identified to be remarkably reduced during the deep solar minimum. It is the first time to find that lower values prevail at most times in 2008-2009 in the F2-layer peak height ($h_{mF2}$) and Chapman scale height ($H_m$). In contrast, the bottom-side profile thickness ($B_0$) in 2008-2009 shows higher values than that in 1996-1997 at some daytime intervals, although it is also smaller during the rest times. Furthermore, the ionogram-retrieved electron density profiles demonstrate that the ionosphere in 2008-2009 is contracted strongly at altitudes above $h_{mF2}$ and more perceptible in the afternoon hours. The decrease in Ne is strongest in September equinox and weakest in June solstice.

Quantitative analysis indicates that record-low $f_{oF2}$ can be explained principally in terms of the decline in solar extreme ultraviolet (EUV) irradiance recorded by SOHO/SEM, which suggests low solar EUV being the prevailing contributor to the unusual low electron density in the ionosphere during cycle 23/24 minimum. It also verifies that a quadratic fitting still reasonably captures the solar variability of $f_{oF2}$ at such low solar activity levels. The reduction in solar EUV input from solar minimum to minimum mainly contributes to the ionospheric responses, but the involved ionospheric processes are competed and variable in different time scales and played roles in the complicated variations in different seasons and altitudes.

Acknowledgments. The authors would like to thank B. W. Reinisch of the Center for Atmospheric Research, University of Massachusetts Lowell for the ionogram data of DIDBase. Ionosonde data are provided from National Institute of Information and Communications Technology, Institute of Solar-Terrestrial Physics of Russia, and from SPIDR. The F10.7 index is also downloaded from the SPIDR website. The SEM/SOHO EUV data is downloaded from the web site: http://www.usc.edu/dept/space_science/. The CELIAS/SEM experiment on the Solar Heliospheric Observatory (SOHO) spacecraft (SOHO is a joint European Space Agency and US NASA mission). This research was supported by National Natural Science Foundation of China (41074112, 41174137) and National Key Basic Research Program of China (2012CB825604).

Keywords: ionosphere, solar activity, solar cycle, critical frequency, deep solar minimum