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# Long-term variation in the upper atmosphere as seen in the geomagnetic solar quiet (Sq) daily variation

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It has been well-known that geomagnetic solar quiet (Sq) daily variation is produced by the global ionospheric currents flowing in the E-region from middle latitudes to the magnetic equator. These currents are generated by dynamo process via interaction between the neutral wind and ionospheric plasma in a region of the lower thermosphere and ionosphere. The motion of the neutral particles is driven by heat convection due to solar irradiance and by tidal force of the sun and moon. According to the Ohm's equation, the ionospheric currents strongly depend on ionospheric conductivity, polarization electric field and neutral wind. Then, the long-term variations in the ionospheric conductivity and neutral wind in the lower thermosphere and ionosphere can be detected by investigating the long-term variation in the Sq amplitude. Recently, Elias et al. [2010] reported that the Sq amplitude tends to increase by 5.4-9.9 % in the middle latitudes in a period of 1961-2001. They mentioned that the long-term variation of ionospheric conductivity associated with geomagnetic secular variation mainly determines the Sq trend, but that the rest component is due to ionospheric conductivity enhancement associated with cooling effect in the thermosphere due to increasing greenhouse gas. In the present study, we try to clarify the characteristics of the long-term variation in the Sq amplitude using the long-term observation data of geomagnetic field and neutral wind. These observation data have been provided by Japanese institutes participating in the IUGONET (Inter-university Upper atmosphere Global Observation NETwork) project which started in FY 2009. In the present analysis, we used the F10.7 solar flux as a good indicator of the variation in the solar irradiance in the EUV and UV range as well as geomagnetic field data with time resolution of 1 hour observed at 184 geomagnetic stations. The definition of the Sq amplitude is the difference of the H-component between the maximum and minimum every day when the Kp index is less than 4. As a result, the long-term variation in the Sq amplitude at all the geomagnetic stations shows a strong correlation with the solar F10.7 flux which depends on 11-year solar activity. The relationship between the Sq amplitude and F10.7 flux was not linear but nonlinear. This nonlinearity could be interpreted as the decrease of production rate of electrons and ions in the ionosphere for the strong EUV and UV fluxes as already reported by Balan et al. [1993]. In order to minimize the solar activity dependence on the Sq amplitude, we calculated second orders of fitting curve between the F10.7 flux and Sq amplitude during 1950-2011, and examined the residual Sq amplitude defined as the deviation from the fitting curve. The residual Sq amplitude clearly shows increase and decrease trends with the periods of 20 years. It should be noted that the residual Sq amplitude around 2010 is almost the same level as that around 1970. On the other hand, the similar tendency can be seen in the diurnal variation of geomagnetic field in the auroral zone and polar cap (Sqp field) driven by the twin vortex of ionospheric currents associated with energy inputs from the solar wind into the ionosphere. Then, it seems that the trends in the residual Sq and Sqp fields are related to the long-term variation in the ionospheric conductivities associated with the secular variation of the ambient magnetic field and the upper atmosphere (for example, plasma and neutral densities). In order to verify qualitatively the above signatures, we need to investigate the long-term variation in the ionospheric conductivities using a calculation tool developed by the IUGONET project.

Keywords: Geomagnetic solar quiet (Sq) daily variation, Solar activity, Upper atmosphere, Neutral wind, Ionosphere, Thermosphere