# Electron density changes in the night time lower ionosphere associated with lightning-electromagnetic pulse

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Transient and localized electron density changes in the night time lower ionosphere (D-region) associated with lightning induced transient luminous events (TLEs) are investigated with observations of phase and amplitude variations in standard radio signals in the low frequency (LF) range. The LF standard signals which are transmitted from Japan (JJY: 40 and 60 kHz) and China (BPC: 67.5 kHz) are received at the Rikubetsu observatory (Hokkaido, Japan), the Zao observatory (Miyagi, Japan), and the Tainan Municipal Cingcao elementary school (Taiwan, corporation with NCKU) with 0.1 sec interval. Because the LF waves propagate between the earth's surface and the lower ionosphere, the received radio signal suffers phase and amplitude modulations when the ionization changes occur on the radio propagation path. Previous modeling studies showed that lightning-electromagnetic pulses (EMPs) could lead significant increase or decrease in the electron density in the night time D-region depending on their intensity and predicted to cause measurable changes in the standard wave signal although these predictions are still not well confirmed by observations. We identified a number of sudden changes of the LF signals and the subsequent recoveries with a time scale from a few tens of seconds to tens of minutes. The long recovery (more than several minutes) implies a significant effect of TLE on electron density in the lower ionosphere. We compared the LF event with lightning location and time which are provided from the world wide lightning location network (WWLLN) to identify the causal lightning and with observations of elves and the extreme low frequency (ELF) wave to investigate the relation of the LF event with TLE. Two main results are as follows. (1) The sudden changes in the LF signal occurs within 0.1 seconds after the causal lightning, which indicates direct ionization change in the D-region associated with TLE. (2) 13 elves which were observed by the FORMSAT-II/ISUAL (5 events from 2006 to 2009) and the Japanese super science high school (SSH) network (8 events from Nov 2009 to Jan 2010) were identified to be accompanied by the LF events. The recovery time is distributed from a few tens of seconds to more than 9 minutes. This is the first time to show that not only the short recovery events but long ones occur associated with elves, which imply that the EMPs cause long-duration electron density change in the night time D-region. A question still remained is what controls the recovery time of the LF event. We plan to compare the peak current of the causal lightning with the LF event to investigate dependence of the recovery time on the strength of EMP.