Geophysical Research Abstracts
Vol. 18, EGU2016-2529-1, 2016
EGU General Assembly 2016

Lightning location with variable radio wave propagation velocity

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Lightning discharges can be located by triangulation of their broadband electromagnetic pulses in long-baseline (∼500 km) radio receiver networks. Here we apply the time of arrival difference (TOA) method to electric field recordings with a low frequency radio receiver array consisting of four stations in western Europe. The electromagnetic wave propagation velocity at low radio frequencies is an important input parameter for the TOA calculation and it is normally assumed to be equal to the speed of light. However, the radio wave propagation depends for example on the frequency, ground conductivity and the ionospheric height and small variations can cause location differences from hundreds to thousands of meters, as demonstrated in this study. The radio wave propagation from two VLF transmissions at 20.9 kHz and 23.4 kHz are compared. The results show that the apparent phase velocities are 0.6% slower and 0.5% faster than the speed of light respectively. As a result, a variable velocity is implemented in the TOA method using continuously recorded data on the 8th August 2014, when a mesoscale convective system developed over central France. The lightning locations inferred with a variable wave propagation velocity are more clustered than those using a fixed velocity. The distribution of the lightning velocities in a given geographic area fits a normal distribution that is not centred at the speed of light. As a result, representative velocities can be calculated for smaller regions to generate a velocity map over a larger area of enhanced lightning activity. These results suggest a connection with the ground elevation and/or surface conductivity that might have an impact on the observed wave propagation velocities.