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Studying the powerful lightning discharges from the Antarctic and the Arctic stations using synchronous ELF and VLF data

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This paper presents results of mapping the powerful lightning discharges using ELF transients recorded simultaneously at two widely spaced sub-polar stations located in the Antarctic (Ukrainian Antarctic station (UAS), “Akademik Vernadsky”; 65.25°S, 64.25°W) and in the Arctic (“SOUSY”, Svalbard; 78.15°N, 16.05°E). Both stations are equipped with identical induction-coil magnetometers operating in the frequency range 0.001-80 Hz. They record horizontal magnetic field components synchronized with UTC by the GPS time stamps. Discharges mapping is performed in several steps. At the first one we select all ELF transients simultaneously detected at both stations whose amplitude exceeds an empirically chosen threshold. Then, we estimate the source bearings from observatories using the amplitude and polarization technique and correspondingly rotate the coordinate systems. We assume that location of lightning stroke corresponds to one of the intersections of the deduced bearing lines. To choose the correct position, we use the difference in arrival times of the pulses to the observer by comparing the transverse components of the transients. We implemented this algorithm into the computer code, which was used for mapping the powerful discharges during the whole 2015 year. In total 126,651 lightning events were located. The monthly and seasonally averaged maps of the powerful lightning as well as corresponding longitudinal and latitudinal distributions were calculated and analyzed. These results are in good agreement with literature and distributions obtained earlier by the OTD satellite. In February–April 2019, a new VLF facility was tested recording two horizontal magnetic and vertical electric field of atmospherics in the frequency range 750 Hz – 24 kHz at the Antarctic UAS concurrently with existing ELF magnetometer. Observations demonstrated that about one-half of detected ELF transients corresponds to VLF atmospherics. Analysis of tweeks recorded at UAS showed that they arrived from distances reaching 10,000 km. This value probably determines the ultimate range available for combining the ELF and VLF data for locating the parent powerful discharges from the single observatory. The ELF-VLF technique has several advantages. Application of the VLF atmospherics for the source bearing considerably improves accuracy because the VLF data usually have greater signal to noise ratio than ELF. The distance to the source of VLF tweek atmospheric is calculated from the spectrogram of the longitudinal magnetic field component by using frequency – time signatures of the first and the second harmonics. It is worth noting that tweek’s technique is applicable only in the ambient night conditions. Simultaneously, the distance to the parent lightning stroke may be estimated from the waveform of ELF transient associated with the VLF atmospheric. We rotate the local coordinate system so that the recorded orthogonal magnetic field components of ELF pulse turn into the longitudinal and the transverse component. The transverse magnetic field of ELF transient is coincident with the pulse onset corresponding to the direct wave from the lightning stroke to the observer propagating along the short arc of the great circle path. This stronger direct pulse is followed by a delayed smaller pulse of the opposite polarity and arriving along the longer great circle path that crosses the source antipode. This pulse is regarded as ‘antipodal wave’. After superposing the fronts of the observed direct wave and of the model ELF transient, we can adjust the source distance of the model pulse so that the antipodal waves also become coincident. The source distance may be also estimated by comparing the observed and modeled spectrum of ELF transient calculated for the set of different distances from the source to the observer. Presence of three field components in the VLF atmospheric measurements allows computing the horizontal components of the Poynting vector thus providing an unambiguous determination of the radio wave arrival direction. This advantage also allows determining the polarity of the parent lightning stroke and this allows obtaining the separate spatial distributions and the temporal dynamics of positive lightning strokes. These discharges are associated with the transient luminous events in the mesosphere and the lower ionosphere – the sprites and elves. The source current moment, and the duration of current in the lightning discharge also might be estimated by using the transverse magnetic field component of the ELF transient. For this purpose, a simple exponential model is used describing the continuing current of the stroke, which is responsible for radiation in lower part of the ELF band.