Jupiter was the first planet other than Earth, where lightning discharges were detected using the radio wave measurements of the Voyager spacecraft in 1979. Since then, all subsequent spacecraft missions to Jupiter detected lightning as bright spots in the optical images of the nightside of the planet. The Juno spacecraft currently orbits Jupiter and its measurements in the audible frequency range below 20 kHz often show rapid whistlers, electromagnetic signatures of electrical discharges. These measurements represent the largest known database of lightning detections at this planet. In this work we explore the Juno measurements of rapid whistlers in order to estimate their amplitudes which, in turn, can help us to estimate the energy radiated in this part of the electromagnetic spectrum from the Jovian lightning discharges. We use a newly developed method based on the search for sufficiently large coherent clusters in the spectrograms of rapid whistlers. The choice of the parameters of this method is supported by extensive modeling to ensure that the probability of false positive detections is reasonably low. Another set of simulations is performed for different backgrounds to estimate the minimum detectable amplitude of the rapid whistlers. In total, our analysis includes 1357 rapid whistlers, and we take into account a correction based on changing attitude of the spacecraft and its varying distance from the top of the ionosphere. After performing these normalizations, we estimate the energy, which was radiated from the source lightning discharges into the rapid whistlers. We obtain a wide distribution of values with a range of 166–1790 J between the lower and upper quartiles, and with the median value of 514 J. These energies are similar to energies of electromagnetic waves radiated at audible frequencies from the terrestrial lightning discharges. Our result differs from most of the previous estimates of lightning energies at Jupiter, which found them much larger than at Earth. However, our results are consistent with the latest optical measurements onboard Juno.