Observations and simulations of foreshock waves during magnetic clouds

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The foreshock is a region of intense wave activity, situated upstream of the quasi-parallel sector of the terrestrial bow shock. The most common type of waves in the Earth’s ion foreshock are quasi-monochromatic fast magnetosonic waves with a period of about 30 s. In this study, we investigate how the foreshock wave field is modified when magnetic clouds, a subset of coronal mass ejections driving the most intense geomagnetic storms, interact with near-Earth space. Using observations from the Cluster constellation, we find that the average period of the fast magnetosonic waves is significantly shorter than the typical 30 s during magnetic clouds, due to the high magnetic field strength inside those structures, consistent with previous works. We also show that the quasi-monochromatic waves are replaced by a superposition of waves at different frequencies. Numerical simulations performed with the hybrid-Vlasov model Vlasiator consistently show that an enhanced upstream magnetic field results in less monochromatic wave activity in the foreshock. The global view of the foreshock wave field provided by the simulation further reveals that the waves are significantly smaller during magnetic clouds, both in the direction parallel and perpendicular to the wave vector. We estimate the transverse extent of the waves using a multi-spacecraft analysis technique and find a good agreement between the numerical simulations and the spacecraft measurements. This suggests that the foreshock wave field is structured over smaller scales during magnetic clouds. These modifications of the foreshock wave properties are likely to affect the regions downstream - the bow shock, the magnetosheath and possibly the magnetosphere - as foreshock waves are advected earthward by the solar wind.