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Hysteresis cycles and invariance of the *Dst* index form during geomagnetic storm development

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The results of a study of the relationship between the *Dst* index and heliosphere parameters during 933 isolated geomagnetic storms development presented in this work. We used the catalog of geomagnetic storms for the period 1964-2010, presented on the website of the World Data Center for Solar-Terrestrial Physics, Moscow (http://www.wdcb.ru/stp/geomag/geomagnetic_storms.ru.html) and hourly average data of solar wind plasma parameters, IMF and *Dst* index for the same period from the OMNI database (https://spdf.gsfc.nasa.gov/pub/data/omni/low_res_omni/) as initial data. For the analysis, we used hourly data of the *Dst* index and heliosphere parameters obtained by the epoch superposition method on a time interval covering the average duration of the initial, main phases of the storm and the recovery phase (168 hours from the moment the storms onset). It was shown that the trajectory of the *Dst* index change depending on the solar wind plasma parameter β and the IMF *Bz* component during the main phase of the storm does not coincide with its trajectory during the recovery phase, which is a typical feature of the hysteresis phenomenon. The dependences *Dst*(β) and *Dst*(*Bz*) have the shape of a hysteresis loop for storms with both sudden and gradual onset. It was shown that the *Dst* index forms hysteresis loops with other solar wind parameters at time intervals of geomagnetic storms development. The obtained dependencies indicate a lag in changes in magnetospheric disturbance during storms relative to heliospheric parameters and a nonlinear relationship between the *Dst* index and heliospheric parameters. In addition, it was noted that the shape of the averaged dynamics of the *Dst* index during the storms development does not depend on their intensity, i.e. is an invariant. A invariant behavior is characteristic of the shape of the averaged dynamics as well of the parameter β and the IMF *Bz* component during the magnetic storms development. Based on the nonlinear relationship of the *Dst* index with interplanetary parameters and the invariance of the *Dst* index shape, an integral Volterra-type equation is proposed to describe the dependence of the *Dst* index on solar wind parameters. The approach using integral equations provides an adequate description of the results obtained during the experimental study of hysteresis effects associated with phase shifts between changes in the *Dst* index and heliosphere parameters.