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Two-Spacecraft Reconstruction of Magnetic Clouds in the Solar Wind

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Numerical solution of the Grad-Shafranov equation is a powerful and versatile technique for reconstructing the magnetic field structures of systems with an invariant direction. Here we show its potential in two-spacecraft observations of interplanetary magnetic clouds, which have been considered as magnetic flux ropes of local straight cylindrical geometry. To illustrate this, we take as example the fast (v $\sim$ 730 km/s) magnetic cloud which reached Earth on November 20, 2003, giving rise to the strongest geomagnetic storm of this current cycle. It was observed by spacecraft ACE and, about 1.2 hours later, by WIND when the spacecraft were $\sim$ 460 Re apart. First, we compare three standard static models based on single-spacecraft measurements, with particular emphasis of their predictions for the orientation of the underlying flux rope as this is a major factor determining the strength with which this ejection couples to the magnetosphere. Second, we extend the Grad-Shafranov reconstruction technique in the interplanetary context by optimizing the results with the aid of a second spacecraft and by ingesting data from both observations into the analysis, producing a single optimal field map with an invariant axis. This affords an excellent opportunity to study the robustness of the results obtained. The method opens new vistas in the probing of the spatial structure of magnetic clouds in STEREO-STEREO or STEREO-WIND coordinated studies.