NUMERICAL SIMULATIONS OF HIGH-SPEED SOLAR WIND STREAMS WITHIN 1 AU AND THEIR SIGNATURES AT 1 AU

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Abstract. A parametric study of the evolution within, and signatures at, 1 AU of high-speed streams is performed with the use of a MHD, 2½-D, time-dependent model. This study is an extension of an earlier one by Smith and Dryer (1990) who examined the ecliptic plane consequences of relatively short-duration, energetic solar disturbances. The present study examines both the erupting and corotating parts of long-duration, high-speed streams characteristic of coronal hole flows. By examining the variation of the simulated plasma velocity, density, temperature, and magnetic field at 1 AU, as well as the location of the solar coronal hole sources relative to the observer at 1 AU, we are able to provide some insight into the identification of the solar sources of interplanetary disturbances. We present and discuss two definitions for angle locating the solar source of interplanetary disturbances at 1 AU.

We apply our results to the suggestion by Hewish (1988) that low-latitude coronal holes are suitably positioned to be the sources of major geomagnetic storms when the holes are in the eastern half of the solar hemisphere at the time of the commencement of the storm. Our results indicate that, for these cases, the streams emanating from within the hole must be very fast, greater than 1000 km s⁻¹, or very wide, greater than 60°, at the inner boundary of 18 solar radii in our simulation.

1. Introduction

The observations of quasi-stationary stream structures in the solar wind are now well documented (cf. Gosling et al., 1972; Burlaga, 1974; Gosling, 1981). The accepted description of these structures is that of alternating fast and slow streams. The fast stream runs into a preceding slower stream and at the same time outruns the following slower stream. The basic anatomy of these corotating structures has been described by Belcher and Davis (1971), who pointed out that it does not matter whether the various regions are bounded by discontinuities such as shocks or contact surfaces, whether they are extended collisionless shock structures, or more-or-less continuous transition zones. These observational studies confirmed the early theoretical studies by Sarabhai (1963) and others.

The stage for the linear theoretical and nonlinear numerical studies of driven, corotating solar wind streams was, therefore, established. A one-dimensional (1D), non-magnetic study was made by Siscoe and Finley (1970) and a two-dimensional (2D) magnetic study was made by Matsuda and Sakurai (1972). These studies were performed, respectively, in linear and quasi-radial method-of-characteristics frameworks. Within the numerical, nonlinear framework, albeit still with an ideal, single fluid, 1-D, non-magnetic (Hundhausen, 1973) and 2-D magnetic (Nakagawa and Wellck, 1973) studies were performed. Different input pulses were used by these workers. The former used a 100-hour duration temperature pulse which increased in linear ramps in azimuth.
to a maximum of four times the initial value at 0.133 AU. The latter used simultaneous increases of radial velocity and temperature to maximum values of 1.5 and 2.0 times the steady-state values, respectively, and used a 60° wide sinusoidal form for the azimuthal extent at 30 solar radii ($R_\odot$). Nevertheless, both studies reproduced quite well the Vela 3 observations by Gosling et al. (1972). The flexibility of the latter 2-D study was demonstrated by Hirshberg, Nakagawa, and Welleck (1974), who first produced a corotating, non-magnetic stream with a simple temperature pulse. The peak value of 3.5 times the ambient value at 30 $R_\odot$ was reached using linear ramps over an azimuthal extent of 66°. This corotating disturbance, after achieving a steady state, was then disturbed by a symmetric, azimuthally independent flare-like pulse that was simulated by an enhancement of 4.0 times the initially ambient temperature.

The approach of Nakagawa and Welleck (1973) and Hirshberg, Nakagawa, and Welleck (1974) was pursued in the 2-D, time-dependent magnetic approach by Wu, Dryer, and Han (1976, 1983) and Dryer et al. (1986). The latter authors first produced a corotating stream by using an input pulse at 18 $R_\odot$ in which the velocity increased from 250 km s$^{-1}$ to 320 km s$^{-1}$ and which had the form of a symmetric, 35° wide trapezoid in azimuth. At the same time, the density was changed so as to maintain invariance of the momentum flux density as found in statistical studies by Steinitz and Eyni (1980) and Lopez, Freeman, and Roelof (1986). Compound effects were then produced by a series of shock waves that were taken as simulations of those produced by a sequence of solar flares and an eruptive prominence during 8–21 August, 1979 (STIP Interval VII, which initiated the Solar Maximum Year).

In a complementary study based on Helios observations at 0.3 AU, Pizzo (1981, 1985) performed 1-D, 2-D, and 3-D magnetic simulation studies, as well as a 2-D non-magnetic ones, with the use of a numerical, time-stationary (but corotating) model. His input functions, velocity, density, and temperature, were also trapezoidally distributed over an azimuthal extent of about 40° at 0.3 AU. The density decrease, from 120 cm$^{-3}$ to 40 cm$^{-3}$, and temperature increase, from $1.5 \times 10^5$ K to $4.6 \times 10^5$ K, were designed to keep the pressure constant across the stream at this inner boundary. The velocity increased from 300 km s$^{-1}$ to 600 km s$^{-1}$ so as to maintain the momentum, not the momentum flux, constant*. Pizzo (1981) clearly demonstrated that the 2-D and 3-D results have not produced shocks and showed only minor differences at 1 AU in the ecliptic plane. Moreover, he showed that the ‘...differences between the two (magnetic and non-magnetic results) are of nearly the same order as that (the considerable differences) between 1-D and 2-D MHD models’ (Pizzo, 1985). Thus, he confirmed earlier studies that concluded that the magnetic field really does substantially magnify the effects of the nonradial flow, as had been previously argued in analytical

* In recent work with a steady-state, corotating 2-D MHD model, Pizzo (1989) maintained the constancy of the radial momentum flux density. This work demonstrated the importance of dynamic effects in comparison with kinematic effects. The latter were shown to be important only in a very small region near the Sun.