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HYDRODYNAMICAL SIMULATIONS OF SLOW CORONAL WIND, CORONAL INFLOWS AND POLAR PLUMES

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Abstract. We use a hydrodynamical time-dependent coronal flux tube model extending from $\sim 1\ R_\odot$, where nonreflecting boundary conditions are applied, to $30\ R_\odot$, which includes a transition region sustained by the equilibrium between thermal conduction, radiative losses and a prescribed mechanical heating flux. We recover the observed inverse relationship between asymptotic wind speed and expansion factor if the coronal heating rate is a function of the local magnetic field strength. We show that inflows can be generated by suddenly increasing the rate of flux-tube expansion, and suggest that this process may be involved in the closing-down of flux at coronal hole boundaries. We also simulate the formation and decay of a polar plume, by including an additional, time-dependent heating source near the base of the flux tube.

1 Introduction

The slow solar wind comprehends a wide variety of flows with different measured velocities, composition, as well as spatial and temporal variability. It is often considered the slow wind originates from within closed field regions. We adopt here the opposite view in which both high- and low-speed wind come from coronal holes (open field regions), and that it is the rate of flux-tube expansion and/or the location of the coronal heating which control the measurable characteristics of the slow wind. Considering flux tubes which cross the vicinities of active regions and/or boundaries between neighbour coronal holes may account for the high variability of the slow wind flow. Swarms of overdense small-scale inflows are observed around the heliospheric current/plasma sheet between $2-5\ R_\odot$ (Sheely & Wang 2002), which seem to be connected to the the closing-down of magnetic flux at coronal hole boundaries. Coronal plumes are filamentary structures aligned along open field lines with densities ∼2–5 times higher than the interplume regions. Plumes are found to overlie EUV bright points, these having a shorter lifetime (Wang 1994).

We use the 1D time-dependent hydrodynamical numerical model of a coronal flux tube described in Grappin et al. (*in preparation*) and Pinto et al. (*submitted*) to study the effects of varying the expansion factor near the coronal base and the coronal heating function on the solar wind flow. We set the computational domain from near the photosphere to $30\ R_\odot$. Non-reflecting boundary conditions are imposed both at the bottom and the top of the domain. The momentum, mass and energy (with $\gamma = 5/3$) conservation equations read

$$\partial_t \mathrm{u} + (\mathrm{u}\cdot\nabla)\,\mathrm{u} = -\frac{\nabla P}{\rho} - \frac{GM}{r^2}\hat{\mathrm{r}}, \qquad \partial_t \rho + \nabla\cdot(\rho \mathrm{u}) = 0 \tag{1.1}$$

$$\partial_t T + \mathrm{u}\cdot\nabla T + (\gamma-1)\,T\nabla\cdot\mathrm{u} = -\frac{\gamma-1}{\rho}\left[\nabla\cdot F_h + \nabla\cdot F_c + \rho^2\Lambda\,(T)\right] \tag{1.2}$$

where $F_h,\ F_c$ are respectively the mechanical heating and conductive fluxes, and $\Lambda\,(T)$ is a fit to the radiative loss function in Athay (1986). In the above, the divergence operator is defined in terms of the tube's expansion factor The magnetic field is $B \propto r^{-2}$ for $r \geq 2.5\ R_\odot$ and $B \propto r^{-\nu}$ below.

The background heating function is either a standart phenomenological form (Eq. 1.3, left) or proportional to $B^{1/2}$ (Eq. 1.3, centre). Heating perturbations are achieved through variations of the expansion factor ν, a

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time-dependant combination of two heating sources (the two expressions in Eq. 1.3, left and centre) and the addition of a heating source concentrated just above the coronal base (Eq. 1.3, right; $\delta r \sim 10^{-3}\ R_\odot$)

$$F_h^1 = F_{p0}\left(\frac{B}{B_0}\right)\exp\left[-\frac{r-R_\odot}{H_p}\right], \quad F_h^2 = F_{b0}\left(\frac{A_0}{A}\right)\left(\frac{B}{B_0}\right)^{1/2} = F_{b0}\left(\frac{B}{B_0}\right)^{3/2}, \quad \nabla\cdot F_r \propto e^{-\frac{(r-r_0)^2}{\delta r^2}} \qquad (1.3)$$

2 Results

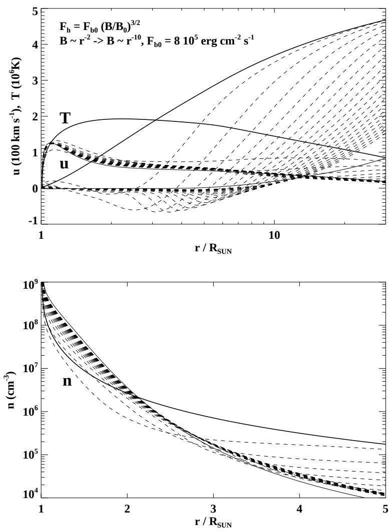

Fig. 1. Here, the magnetic falloff index is suddenly increased from 2 to 10 while keeping F_{h0} fixed. The radial profiles of u, T, and n are shown at $t/\tau = 0$ (thick lines), 1, 2, ..., 20 (dashed lines) and 40 (thin lines). Strong transient inflows are generated below the sonic point.

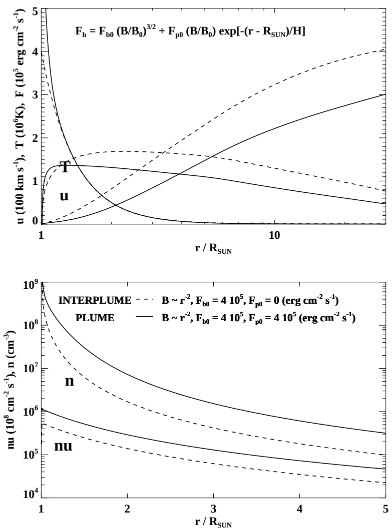

Fig. 2. Effect of an additional heating term near the coronal base. *Solid curves:* steady-state "plume" solution. *Dashed curves:* steady-state "interplume" solution. In both cases, the global heating term is given by $F_{b0}(B/B_0)^{3/2}$, with $F_{b0} = 4\times10^5$ erg cm^{-2} s^{-1} and $\nu = 2$.

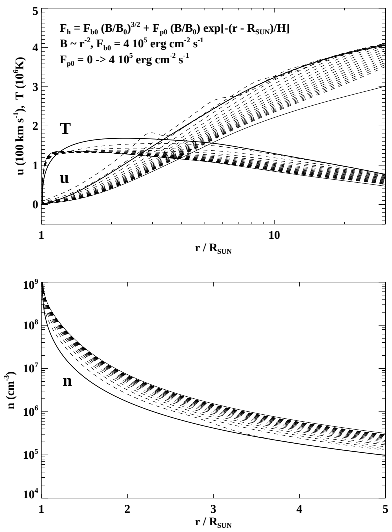

Fig. 3. Formation of a plume. The initial state is the interplume solution ($F_{p0} = 0$); F_{p0} is suddenly increased to $F_{p0} = F_{b0}$. The radial profiles of u, T, and n are shown at $t/\tau = 0$ (thick lines), 1, 2, ..., 20 (dashed lines) and 40 (thin line)

3 Conclusions

a. Variations in the coronal heating function can produce a wide variety of solar wind flows.
b. The observed inverse correlation between wind speed and expansion factor is can be retrieved if $F_h \propto B^\mu$. A rapidly diverging field results in a large mass flux at the coronal base and a low speed far from the Sun.
c. Strong inflows can be generated in the subsonic region by decreasing the local heating rate and/or increasing the field expansion rate, as might occur when opposite-polarity field lines merge at a neutral sheet. The evacuation of the flux tubes would further accelerate the merging and reconnection process.
d. Densities comparable to those observed in polar plumes can be obtained by depositing a large amount of energy just above the coronal base. A steady-state equilibrium is reached only after ~1 day, which may explain why coronal plumes appear to evolve more slowly than their underlying EUV bright points.

References

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