Radiatively cooling downdrafts as the origin of redshifts in transition region lines

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Red-shifts between 5 and 10 km/s in UV lines have been frequently detected on the solar disk (e.g. Brekke 1993 and references therein) and above 5 km/s on stars (Linsky and Wood 1995). They are not yet fully explained, although several hypotheses have been proposed so far (see Brekke 1993). Extending studies on the thermal stability of perturbations in stratified plasma atmospheres (Reale et al. 1991, Reale et al. 1994) to atmospheres with strong density and temperature stratification, in particular the solar transition region, we propose that the observed redshifts may be caused by downdrafts in the transition region driven by radiatively cooling condensations (Reale et al. 1995a,b).

Our representative model considers a condensation in the atmosphere of an active region loop, with base pressure $p = 3$ dyne cm^{-2}. The temperature of the unperturbed atmosphere at the center of the perturbation is $T_0 = 4.5\ 10^5$ K, the initial density contrast of the perturbation is $\delta\rho/\rho = 1$, and its radius is $R = 3\ 10^6$ cm. The perturbation is all contained in the transition region and, therefore $<<$ 1 arcsec. We compute its evolution with a two-dimensional hydrodynamic code (Reale 1995), assuming isotropic thermal conduction and fully 2-D cylindrical geometry (r, Z) with Z perpendicular to the sun's surface.

We find that the outer shells of the perturbation initially expand, being heated from outside by thermal conduction, and both the temperature and density contrast rapidly decrease, most at the top of the condensation; the density contrast increases, instead, around the center of the initial perturbation and the dense central core shifts downwards, and flattens at the base of the transition region after ~ 3 s. After ~ 1 s the velocity field is mostly downward with speed around 6-8 km/s, which rapidly decrease to $v \sim 3$ km/s after ~ 3 s. The first two pictures in Figure 1 show the density contrast maps of the region around the perturbation at the beginning and at t=0.5 s. The boundaries of the computational domain are located far lower, as well as far outside in any other direction, than the region shown. The lower boundary of the pictures, however, is the base of the transition region, where the density suddenly increases to much higher chromospheric values.

To allow comparison with available data, we have synthesized the emission in four resonance UV lines, whose temperatures of maximum emissivity span the temperature range of the transition region (Reale et al. 1995a). In Figure 1, the left half of the third panel shows the map of the vertical effective speed ($v_{eff} = (v_z\ n^2\ G(T))/(n^2\ G(T))$, v_z is the vertical speed component, n the particle density, T the plasma temperature, $G(T)$ is the plasma emissivity of the

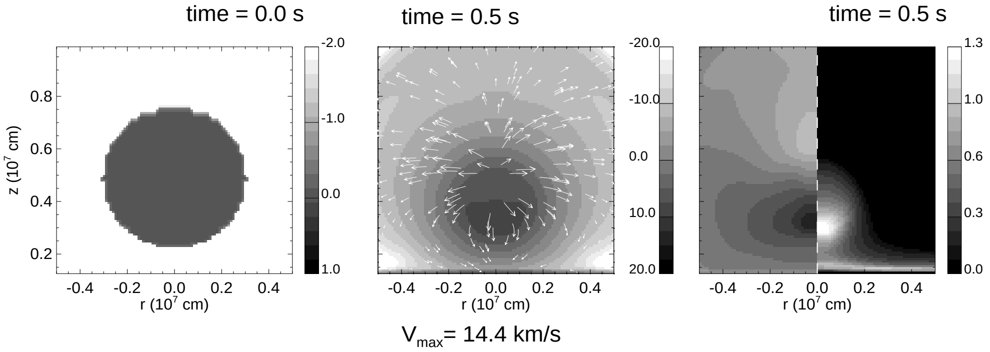

Figure 1. Left and middle panel: pictures of the logarithm of the density contrast and of the velocity field at t = 0 s (zero velocity everywhere) and t = 0.5 s (maximum velocity below the picture). The relevant grey scale is between the two panels. Right panel: picture of the effective vertical speed (left half, positive downwards, grey scale in units of km/s on the left) and of the line emission per unit volume (right half, grey scale in units of 10^{-1} erg cm^{-3} s^{-1} on the right) at t = 0.5 s.

line) and the right half the line emission per unit volume in the O IV 1401.16 Å(1.4 10^5 K) line ($I = n^2\ G(T)$) at $t = 0.5$ s. The effective velocity provides a measure of the Doppler shift we would observe in the selected UV line. After less than 1 s, up to $t \sim 3$ s, the only significant vertical speed components are in the lower region of the picture and directed downwards. For most of the time the same region is where the line emission is more intense: therefore we expect significant redshifted emission. We find the same result, with slightly different quantitative values and timing, also for the other three UV lines.

We have also extensively explored a region of the parameter space centered on the reference model and representative of a wide spectrum of conditions likely to be present in the solar atmosphere (Reale et al. 1995b): base pressure in the range $0.1 < p_0 < 10$ dyne cm^{-2}, from quiet sun to active regions, initial density contrast in the range $0.1 < \delta < 3$, and perturbation sizes from a fraction to the whole thickness of the transition region. We find that the maximum vertical speeds are dominantly downward and with values above 5 km/s in most of the explored parameter space, for all the lines considered, and that high speeds are generally associated with high maximum flux contrast over the steady background emission. For further details and the evaluation of the magnetic field effects see Reale et al. (1995a,b).

References

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