

## Modeling of temporal variations in the solar chromosphere

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**Abstract.** We have performed dynamical wave calculations for the solar atmosphere including a time-dependent treatment of the chemical reactions that lead to the formation and destruction of carbon monoxide (CO) molecules. These calculations show that, at densities corresponding to the classical temperature minimum, formation and destruction time scales are such that an almost stationary concentration of CO is maintained, notwithstanding the passing of acoustic shock fronts.

### 1. Introduction

Steady-state chromospheric models successfully account for various EUV chromospheric diagnostics, including the C I continuum shortward of 110 nm and the wings of the H I Lyman alpha line (Vernazza et al. 1981). These models imply that the temperature is at least 6000 K at a height of 1000 km above the photosphere, and that temperature variations of only a few hundred degrees are needed to match the range of quiet-Sun EUV intensities observed at high spatial resolution. However, infrared CO lines do not show any evidence of a chromospheric temperature rise; a steady-state model based on these CO lines (which form in LTE, cf. Ayres & Wiedemann 1989) alone has a temperature of 4100 K at a height of about 700 km, and lower temperatures at greater heights. An explanation for these conflicting chromospheric diagnostics is that CO line absorption is enhanced at low temperatures and diminished at high temperatures at different times as waves travel through the atmosphere. Evidence for substantial time variations in brightness temperature at each position is shown in spatially and temporally resolved spectra obtained by Uitenbroek et al. (1994).

### 2. Modeling and results

We are attempting to model the observed time variations in CO lines by studying the effects of acoustic waves of various periods (ranging from 30 to 300 s) traveling through the atmosphere. We solve the hydrodynamic equations with the method of characteristics (Rammacher & Ulmschneider 1992) and solve the

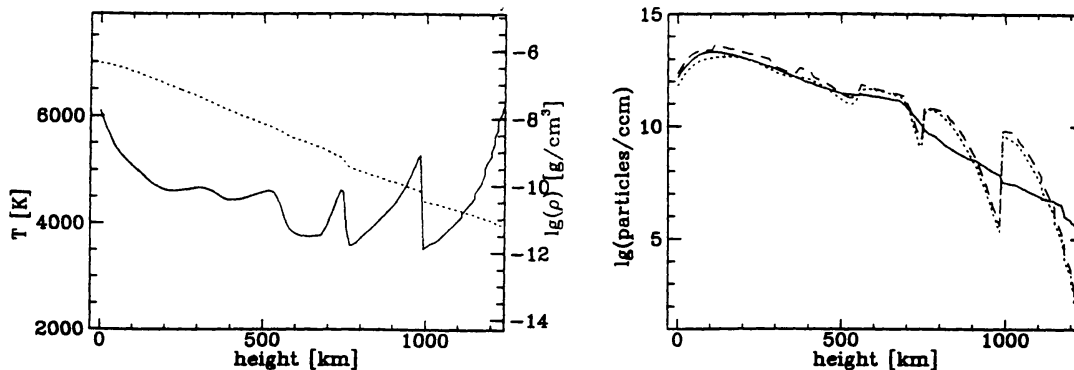


Figure 1. Left hand panel shows temperature (solid line) and density (dotted line) of a snapshot from a 30 s period simulation. Right hand shows the simultaneous total CO number density as determined from the time-dependent rate equations (solid line). Also drawn are the CO densities corresponding to the solution of instantaneous chemical equilibrium (but including effects of Non-LTE radiative transfer, dotted line), and the LTE/chemical equilibrium solution (dashed line).

non-LTE radiative transfer and statistical equilibrium equations and the non-LTE time-dependent rate equations for the formation of CO and CO<sup>+</sup>.

Our calculations show that, while the fine-structure levels of the rotation-vibration bands have relative populations in LTE, the total amount of CO cannot follow rapid temperature changes (see Fig. 1). Typical time scales for the formation of CO range from a minute at a height of 100 km to hours at 1000 km, i.e., much longer than typical hydrodynamic time scales. The total CO concentration effectively corresponds to a time-averaged temperature structure, while the relative populations of the fine structure levels are in LTE corresponding to the instantaneous local temperature. Hence variations in CO line intensities reflect local electron temperature variations rather than shifts in optical depth.

In addition, we find that 30 s period waves provide the right amplitude of brightness variations (but such short periods are not observed), while 300 s period waves (at the necessary flux to reproduce the Ca II resonance lines) result in too large brightness variations. Our results suggest that the mechanical flux responsible for the CO brightness variations must consist of a broad spectrum of intermediate frequencies with a tail towards shorter periods needed to reproduce the chromospheric temperature rise observed in the UV and EUV.

## References

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