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A granulation model: possible effects of contrast variations on the solar irradiance along the cycle

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Abstract. Several numerical models simulate realistically the solar granulation, but without any calibration possibility. We present an analytic granulation model to estimate the effects of possible granulation changes on the irradiance and assess if those changes can contribute significatively to the solar variability.

Key words. Sun: activity – Sun: granulation

1. Introduction

Several numerical models of solar granulation (e.g. Vogler et al. 2005) reproduce the observed characteristics by resolving the non-local HD equations ab-initio. The calibration of these models is difficult, because they are without free parameters and it is therefore not feasible to evaluate possible changes over the solar cycle.

The Total Solar Irradiance (TSI) varies of $\sim 0.1\%$ in phase with the magnetic activity (Frohlich & Lean 1998). This variation is well reproduced by tacking into account active region (AR) phenomena alone (Krivova et al. 2003). However, Muller et al. (2007) detected granular contrast variations in antiphase with the activity, which can be explained by supposing that the granulation size and contrast are modulated by energy flux variations induced by the interactions between convection, rotation and magnetic fields.

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We present a simplified analytic model of a convective cell to estimate the effects of such contrast variations on the TSI.

2. Analytic model

The model is calculated by perturbating a 0-order model where the density is calibrated via a best-fit to the Kurucz's model and P is derived from HE:

$$\rho_0 = \tilde{\rho}\frac{e^{z\beta}}{1+e^{z\beta}}$$
$$P_0 = \tilde{P}\, ln(1+e^{z\beta})$$

where $\beta = 1/H$ (H=110 km), $\tilde{P} = \tilde{\rho} g H$. T satisfies the perfect gas law.

The perturbation is a velocity field satisfying the continuum equation:

$$V_x = v\alpha\frac{e^{(\alpha-\beta)z} + e^{\alpha z}}{k} sin(kx)$$
$$V_y = -v\alpha\frac{e^{(\alpha-\beta)z} + e^{\alpha z}}{k} sin(ky)$$
$$V_z = v(e^{(\alpha-\beta)z} + e^{\alpha z})(cos(kx) + cos(ky))$$

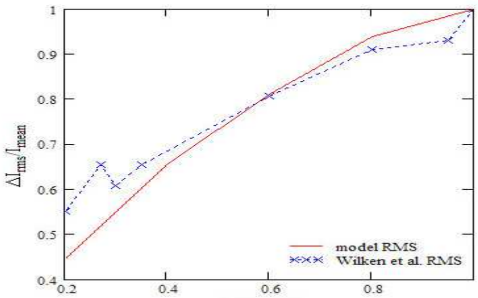

Fig. 1. Contrast CLV: solid line for the model and crosses and dashed line for real data (Wilken et al. 1997).

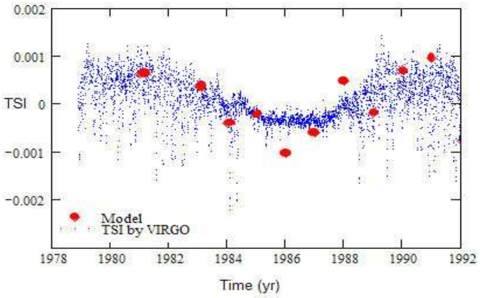

Fig. 2. A TSI reconstruction, considering contributions from faculae, spots and a variable quiet sun.

where $\alpha = \frac{3}{2}\beta$ and v=1 km/s. The P and ρ perturbations are obtained via linearised Navier-Stokes equations:

$$P_1 = -\eta_0 \tilde{\rho} v (cos(kx) + cos(ky)) \frac{e^{\alpha z}}{1 + e^{\beta z}} A(z)$$

$$\rho_1 = -\frac{\eta_0 \tilde{\rho} v}{g} (cos(kx) + cos(ky)) \frac{e^{\alpha z}}{1 + e^{\beta z}} B(z)$$

where A(z) and B(z) are functions of $e^{\beta z}$ and η_0 is the turbulence viscosity. T_1 again satisfies perfect gas law.

3. Continuum intensity

The continuum intensity is computed via LTE radiative transfer equation, at 5300 Å with an opacity $\propto \rho^{\frac{1}{2}} e^{\frac{7}{2}} P$. As expected, we obtain a pattern where bright features are hot and move upward, dark lanes are cold and move downward. The contrast ($\sim$ 0.12) and the centre-to-limb variation (CLV, Fig. 1) are suitable for $\eta_0 = 3 \cdot 10^{11} cm^2/s$.

4. Flux variations

By operating heuristically on the viscosity ($\eta \propto \eta_0 \delta_C$), we reproduce the measured contrast variations δ_C and then compute the associated total flux F. The variation of the flux of the quiet sun due to granulation changes we derive is $\sim 2 \cdot 10^{-3} F$.

It is possible to take into account such a modulation in a usual TSI reconstruction (e.g. Krivova et al. 2003). In Fig. 2 we present a TSI reconstruction where the facula and spot fluxes are computed by Fontenla's models (Fontenla et al. 1999) and the quiet sun contribution is multiplied by $(1 + \delta F/F)$. For this reconstruction, the AR areas have been taken from Chapman et al. (2005) for 1985-1990 and from their MgII index correlation for 1980-1985.

5. Conclusions

We have presented a simple analytic model of a granular cell which reproduces quiet sun contrast and CLV compatible with observations. To reproduce the solar cycle contrast variation measured for the quiet sun, the model gives a flux variation of $\sim$ 0.2%. We therefore present a possible TSI variation model taking into account both AR and quiet sun modulation.

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