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THE EFFECT OF MAGNETIC FIELD BUOYANCY ON THE SURFACE TEMPERATURE OF THE SUN.

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Abstract

The solar dynamo is controlled by many factors including the magnetic field. We present a discussion of the possible effects of the magnetic field flux tube buoyancy on the convection zone of the solar surface in relation to temperature. We observe that the effects are due mainly to changes in the solar radius as determined by the contraction or expansion of the sun.

KEY WORDS: Solar dynamo, Magnetic field buoyancy, Convection zone Surface temperature, Flux tube, Photosphere, Corona.

1. Introduction

The broad spectrum of atmospheric features such as sun – spots, prominence and flares observed on the sun are related to, or significantly affected by the presence of magnetic flux. These features have their origin in the photosphere, chromosphere or corona, which are basically the surface regions of the sun. Instabilities arising due to variations in solar density and magnetic flux pressure in these regions may account for the temperature variations from the photosphere to the corona. Nordlund *et. al.*, (1989) have reported that thermal energy (that is temperature variations) is carried to the solar surface by convection and released into radiation flux in a cooling layer. It follows then that unless a significant radiative heating occurs throughout the photosphere the temperature of the chromosphere would be much lower. David *et. al.* (1989) observed that magnetic field changes are responsible for the growth of thermal instabilities at lower temperature.

Early models of the Sun's magnetic dynamo worked on the idea that the dynamo activity occurs throughout the entire convection zone. It has been realised however, that magnetic fields within the convection zone would rapidly rise to the surface and would not have enough time to experience either the alpha or omega effect. The alpha effect results from the twisting of the magnetic field consequent upon the rotation of the Sun, while the omega effect is due to variations in the solar latitude.

Since a magnetic field exerts a pressure on its surroundings, regions with the magnetic field pushes aside the surrounding gas and makes a bubble that rises all the way to the surface. This buoyancy is not produced in the stable layer below the convection zone. The convection zone forms the outer envelope of the Sun and extends to the surface where the Sun's energy is radiated into space (Fix, 1995). Figure 1 shows the internal structure of the Sun. The inner core

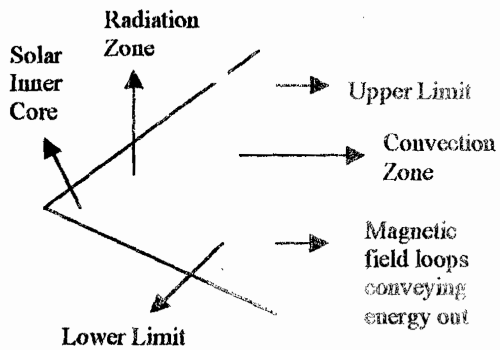

Fig. 1: Internal Structure of the Sun

is the region where the energy producing nuclear reaction takes place. The energy produced by these reactions is carried outward by photons to 70% of the Sun's radius (Fix, 1995). From that distance outward, convection carries the energy to the surface into space. The zone harbours the magnetic flux tubes responsible for the buoyancy effect.

In this discussion, we examine the effect of the magnetic field buoyancy due to variations in magnetic flux in the convection regions over temperature changes.

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2. The Model

Let us consider a toroidal flux tube that circles the sun at a spherical radius R_x and constant latitude θ. Let the tube have magnetic field strength $\vec{B}$ and a cross – sectional area A. By this model, we assume that the radius R_x will increase when the magnetic buoyancy due to variations in the magnetic flux tube increases.

According to Thomas (1979), solar luminosity is affected by these increases. It is known that solar luminosity, L relates with the effective surface temperature, T as $L = 4\pi R^2 \sigma T^4$, where R is the solar radius and σ is the Stefan's constant of radiation. Obviously, if we keep R constant and decrease T, then L will decrease. On the other hand, the cooling or heating of the surface under constant luminosity results from the radial expansion or contraction of the sun. Following this, under constant luminosity, a small change in temperature dT and a small change in solar radius dR will generate the following relationship:

$$\frac{dR}{R} = -2\frac{dT}{T} \quad (1)$$

Considering our magnetic flux tube of field strength $\vec{B}$ within the solar surface, the magnetic pressure $P_m = \frac{B^2}{8\pi}$ inside the tube and the gas pressure P_a also within the tube are balanced by the gas pressure P_o outside the tube, so that

$$P_m + P_a = P_o \quad (2)$$

If the flux tube is in thermal equilibrium with its surroundings, that is, $T_a = T_o$ (where T_a is the temperature inside the flux tube and T_o is the external temperature) then the density inside the tube will be lower than the density of the surroundings, that is, ($\rho_a < \rho_o$) where ρ_a and ρ_o are inner and outside densities respectively, and the flux tube will be buoyant. According to Thomas (1979), if there is a density depression in a flux tube of the sun, this will cause the solar volume to increase.

The amount of increase or decrease will therefore vary with the degree of depression or increase in flux tube density. The difference in densities outside and inside the tube is given by

$$d\rho = \rho_o - \rho_a = \frac{P_o - P_a}{RT} = \frac{P_m}{RT} \quad (3)$$

where $T = T_o - T_a$ is the temperature of flux tube and its immediate environment. The variations in the flux tube density also will cause mass variations. The total mass defect dm in the tube will be equal to the volume of the tube times the change in density $d\rho$ or

$$dM = (2\pi R_x Cos\theta)\,\pi A^2 \left(\frac{P_m}{RT}\right) \quad (4)$$

where M is the mass of the flux tube.

Assuming the change in mass dM is spread over a thin spherical shell of mean radius R and thickness dR, then the mass in this shell is given by

$$dM = 4\pi R_x^2 \rho_o\, dR \quad (5)$$

Equating (4) and (5), we have

$$\frac{dR}{R} = \left(\frac{\pi}{2}\right) Cos\theta \left(\frac{R}{R_x}\right)\left(\frac{A}{R}\right)^2 \left(\frac{P_m}{P_o}\right) \quad (6)$$

This expression gives an estimate of relative change in radius due to a single toroidal flux tube.

3. Results and Discussion

We are considering about the solar surface where the temperature is about 6,000K as against the solar interior estimated at 2×10^7 K (McDaniels, 1979). From equation (1), a drop in solar surface temperature of 1K would correspond to a relative expansion, $\frac{dR}{R} \approx 3\times10^{-4}$.

The radius and field strength of the flux tube respectively vary slowly from 5,000 km and 5, 100G at the bottom of the convection zone to 14, 000km and 600G at the photosphere (Thomas, 1979). Following this, we observe that the ratio P_m/P_o varies greatly from 6×10^{-6} at the bottom of the convection zone to 2.8×10^{-1} at the photosphere. It becomes clear that the dominant contributors to dR are the flux tubes near the top of the convection zone. Using the estimates given by Thomas (1979) for A and P_m/P_o in equation (6), for R_x/R in the range 0.98 – 1.0 we obtain the values of dR/R in the range $5\times10^{-8}\,Cos\theta$ to $2\times10^{-4}\,Cos\theta$. A single flux tube, for example, at the depth of 1,000km at middle latitude gives $dR/R \approx 2\times10^{-5}$.

Now to estimate the change in solar radius with solar cycle, we need to estimate the difference in total magnetic flux in the upper convection zone between solar maximum and minimum.

If we assume that the total magnetic flux emerging at the solar surface is approximately equal to the total flux in the uppermost layers of the convection zone, then the total flux difference will be of the order of 10^{23} between solar maximum and minimum. This could cause a relative change in radius $dR/R \approx 5\times10^{-4}$ or more and a corresponding drop of surface temperature of about 1.5K or more. Temperature fluctuations are therefore observed on the solar surface consequent upon variations in magnetic flux changes. Earl (1991) observed that coherent pulses, which are one of the features of the solar surface, may be due to the helical structures of the flux tubes enhancing the scattering of solar particles.

4. Conclusion

We have shown that the temperature observed at the surface of the sun depends on the variations or fluctuations occurring with the magnetic flux tubes.

Higher temperature is related to low density and buoyancy of the magnetic flux tube. The mechanism that creates a radial pressure in the region with magnetic field will increase the magnetic energy density, causing a change in the surface temperature also.

Henoux, *et. al.* (1989) stated that a cooling of the flux tube by advection of ionization energy increases the radial pressure gradient. This effect leads to the formation of concentrated magnetic flux tubes. This has led to the active transport of thermal energy from the photosphere to the corona.

References

David, L. P and Bregma, J. N 1989. The Effects of Magnetic Fields on the Growth of Thermal Instabilities in Cooling Flows. The Astrophysical Journal 337: 97 – 107.

Earl, J. A 1991. Effect of magnetic Helicity upon Rectilinear Propagation of Charged Particles in Random Magnetic Field. 22nd Int. Cosmic Conference, Dublin, Ireland, 3: 264 – 267.

Fix, J. D. 1995. Astronomy: Journey to the Cosmic Frontier. Mosby – Year Book, New York.

Henoux, J. C and Somov, B. V 1989. Generation of magnetic Fields and Electric Current in the Solar Photosphere. Astronomical Union, Symposium No. 138: 273 – 277.

McDaniels, D. K 1979. The Sun: Our Future Energy Source. John Wiley and Sons, New York. 95 – 96.

Nordlund, A and Stein, R. F 1989. Solar Magnetic Convection, Solar Atmosphere: Structure, Convection and magnetic Field. Int. Astronomical Union, Symposium No. 138: 191-211.

Thomas, J. H 1979. Variations of the Sun's Radius due to Magnetic Buoyancy. Nature, 280: 662 – 663.