Kodaikanal Obs Bull (1988) 9 201 204

REDUCTION OF PHOTOHELIOGRAMS BY IBM-PC CONTROLLED DIGITIZER

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Abstract

A method is described here to determine heliographic coordinates of sunspots on a photoheliogram using an IBM PC controlled digitizer Sunspot proper motions and buildup of magnetic energy in solar active regions may be studied using this method We discuss also other applications of this technique

Introduction

Flares are one of the most spectacular transient phenomena on Sun involving energy release of around 10^{28} 10^{31} ergs in time span ranging from few minutes to several hours One may ask how this energy is built up and stored in localized regions on Sun

As flares occur mostly in the neighbourhood of solar active regions, it is natural to expect that the energy build up may be related to magnetic field structures We know that sunspots are seats of large magnetic fields representing foot points of magnetic loop structures of an active region These sunspots rotate with the background photospheric material as a whole However, they are not necessarily anchored rigidly in the photosphere and are known to possess proper motions over the general rotational motion, around tens of meters to few hundred meters per second These motions may lead to stretching, shearing and twisting of the overlying magnetic loops thereby increasing/decreasing magnetic energy content of the region (Sakurai, 1976, Zirin and Tanaka, 1973)

Evaluation of Magnetic Energy Build-up

Magnetic energy buildup by sunspot proper motion in a force free magnetic field can be derived from equation of magnetic field induction, which in hydrodynamic approximation is given by

$$\delta \tilde{B} / \delta t = \tilde{\nabla} \times (\tilde{v} \times \tilde{B}) \quad \tilde{\nabla} \times (\tilde{J}/\sigma)$$

On scalar multiplication of B/4π and simplification one gets

$$\delta / \delta t \, (|\tilde{B}|^2 / 8\pi) - 1/4\pi \tilde{\nabla} \, [\tilde{v} \times \tilde{B}) \times \tilde{B}] \quad |\tilde{J}|^2 / \sigma$$

where one has used relations $4\pi\tilde{J} = \tilde{\nabla} \times \tilde{B}$ and $\tilde{J} \times \tilde{B} \quad 0$ Rate of variation of magnetic energy ΔM, is thus

$$\Delta M = \delta / \delta t_V \int |\tilde{B}|^2 / 8\pi \, dV = B_0^2 / 15\pi^2 \{L_x L_y / [1 + (L_x/L_y)^2]^{\frac{1}{2}}\} \; \{u \sin \nu \quad v \cos \nu\}$$

(Tanaka and Nakagawa, 1973) Here, L_x and L_y are the separation between sunspots and penumbral diameter, respectively, B_0 is the peak magnetic field and u, v are components of sunspot proper motions as illustrated in figure 1 Also, ν is the angle between the neutral line and the line joining the sunspots

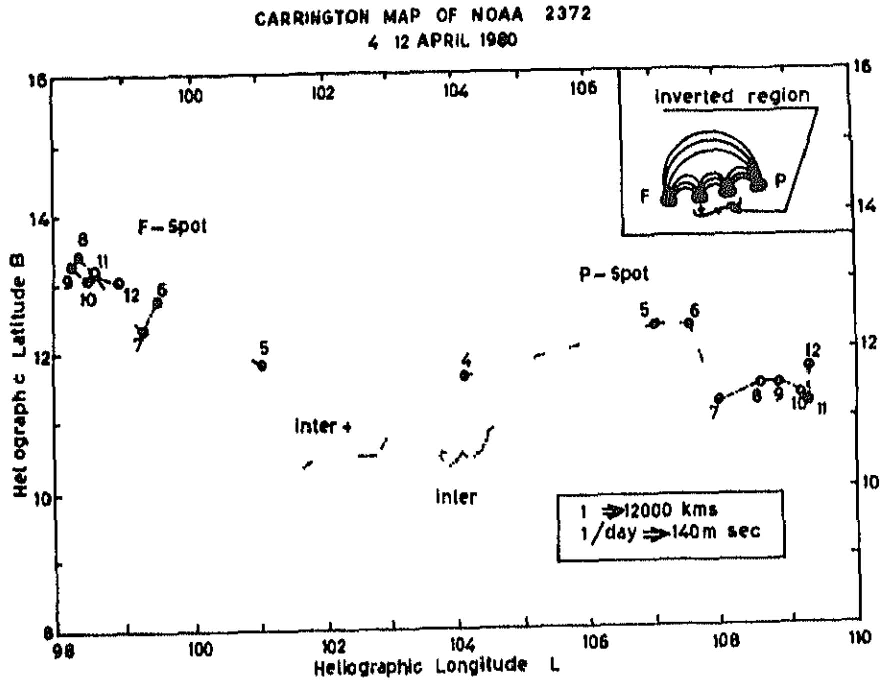

Fig. 1 Heliographic (Carrington) Map of Active Solar Region NOAA 2372 (April 4 12, 1980, SMY Period) displaying daily displacement of some sunspots

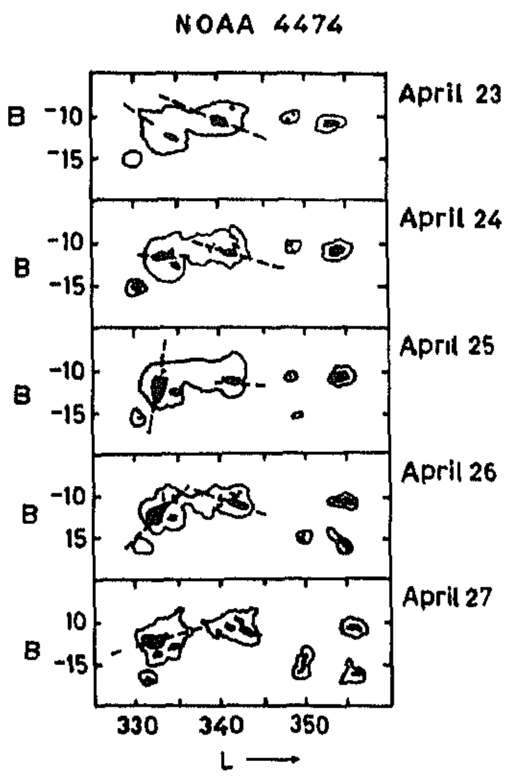

Fig. 2 Reduced heliographic diagram of an active region illus trating rotational motion in some sunspot umbrae

Heliographic Coordinates

In order to evaluate development of magnetic energy buildup in an active region, we need to accurately determine sunspot positions on the solar photosphere removing effects of average photospheric rotation and foreshortening. Sun appears as a flat disk when observed by projection on a screen or photographic plate. The problem here is to transform projected coordinates of a sunspot (ρ_1, θ) into heliographic (L,B) coordinates on the solar sphere. From Smart (1977), we get

$$B = \sin^{-1} [\sin B\theta \cos \rho + \cos B\theta \sin\rho \cos(P\theta - \theta)]$$

$$L = \sin^{-1} [\{ \sin \rho \sin(P\theta - \theta)\}/\cos B\theta] + L\theta$$

where $\rho = \sin^{-1}\{\rho_1/S\} - \rho_1$, S being angular radius of Sun and $L\theta$, $B\theta$ are Carrington coordinates of center of the disk.

$$L\theta = \tan^{-1}[\{ -\sin(\Omega - \lambda_0) \cos I\}/\{ -\cos(\Omega - \lambda_\theta)\}] + M$$

$$B\theta = \sin^{-1}[\sin(\Omega - \lambda_\theta) \sin I]$$

where λ_0 is geocentric eliptic longitude of Sun, I is the inclination of solar equator to the plane of the ecliptic (= 7°15'), Ω is longitude of the ascending node given by

$$\Omega = 74°22' + 84\ T$$

Here T is number of Julian centuries since the epoch 1900 January 0.5. Also, M is given by

$$M = 360 - 360/25.38\ [JD - 2{,}398{,}220.0]$$

where JD is the Julian date. Position angle $P\theta$ of the Sun's rotation axis is given by

$$P\theta = \tan^{-1} \{ -\cos \lambda_0 \tan \varepsilon \} + \tan^{-1} \{ -\cos(\Omega - \lambda_\theta) \tan I \}$$

where ε is the obliquity of the ecliptic.

Digitization of Sunspot positions

We use an IBM PC controlled digitizer to get coordinates of individual sunspots or umbral/penumbral contours. Digitizing pad is made of translucent surface which can be illuminated from below by placing the unit on a light box. Digitizer gives X Y (cartesian) coordinates of a point relative to its axes with a resolution of 0.125 mm. Program DIGHELIO.BAS opens communication between the IBM PC and digitizer and controls data acquisition from the digitizer. It obtains L0, B0 and P0 for the DATE of the given photoheliogram and gets the center and radius of photoheliogram by digitizing any three points on the circumference of the heliogram. Then desired sunspot positions are digitized and transformed for the slope between the digitizer and the photoheliogram axes. The cartesian coordinates are then converted into polar coordinates. Finally L, B are calculated and displayed. When one wishes to generate reduced heliographic diagrams it is also possible to digitize continuously in stream mode and store data for plotting or determination of sunspot area etc.

Applications

(1) To study motion of sunspots on solar photosphere with respect to surrounding medium, one plots their heliographic coordinates over several days using photoheliograms taken at regular intervals. Figure 1 displays proper motion of main spots of a remarkably active region, NOAA AR 2372, observed from Udaipur Solar Observatory during Solar

Maximum Period of April 4 12, 1980 The preceding spot (P) moved rapidly to the west while the following spot (F) trailed to the east such that the separation between them increased (case of stretching the loop) One may note that 1 deg on solar sphere corres ponds to around 12000 kms and a motion of 1 deg /day implies a velocity of around 140 m/sec This active region had an inverted sunspot group which also exhibited interest ing motion The (+)ve spot moved by around 4 degrees to the east during April 5 12, however, the ( )ve spot remained almost stationary Thus, it led to unstretching and unshearing of the loop joining the (+) ( ) spots from a higher energy state to a state of lower energy One can determine u and v components of velocity to evaluate the daily rate of magnetic energy build up, ΔM, as discussed earlier

(2) One can also generate reduced or heliographic diagrams of sunspot umbrae penumb rae using the digitizer in conjunction with a plotter Since these diagrams remove distor tions due to foreshortening, one can see and calculate immediately any variations in their areas Also one can study rotational or twi ting motion of sunspots around their axes (figure 2)

References

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