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AREA-WEIGHTING OF SUNSPOT GROUP POSITIONS AND PROPER MOTION ARTIFACTS

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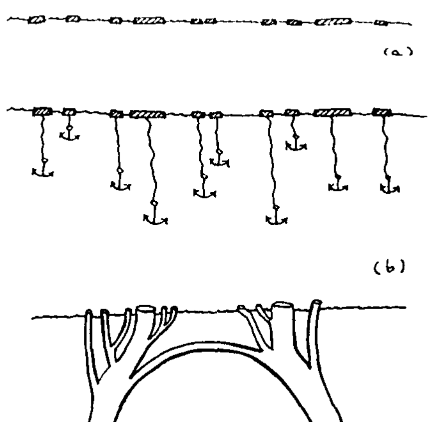
ABSTRACT Two simple examples are presented to show that concepts about the physical nature of sunspot groups may significantly influence the statistical data analysis process. In particular, the second example shows that the well-known difference in the decay rates of preceding (p-) and following (f-) polarity parts of sunspot groups may lead to a fake proper motion effect when area-weighted group positions are used. This effect may be responsible for some recent contradictory findings concerning the motions of sunspot groups. It is therefore argued that while area-weighting is adequate when calculating the mean positions of p- and f-parts of a sunspot group separately, defining the position of the group as a whole by the *unweighted* average of the mean positions of the p- and f-parts is more satisfactory from the theoretical point of view (whenever it is possible to distinguish between spots of different polarities). Similarly, it is best not to "correct" sunspot proper motions for internal differential rotation within groups.

INTRODUCTION

Our notion of the nature of forces determining the motions of sunspots has changed several times in the past (Figure I). At the beginning, sunspots were simply thought of as "corks" floating on the solar surface and following the motions of the ambient photospheric material. Later it became clear that, apart from the dependence on heliographic position, the motions of sunspots and sunspot groups also depend on their physical properties (size, age etc.—see e.g. Howard 1984 for a review of these effects). Consequently the motion of sunspots cannot simply reflect the motion of the surrounding plasma; instead, it was assumed that different sunspots and sunspot groups reflect motions occurring at different depths *under the photosphere.* This concept therefore treated the spots as corks fitted with heavy anchors at different depths in the solar convective zone.

In the last 10 or 20 years this view has gradually been replaced by the now prevailing "magnetic tree" picture (Zwaan 1985) of the subsurface structure of active regions (though the anchoring concept may still be relevant for the late, decaying phases of sunspot group evolution). Beside observational indications of a subsurface link between different spots of the same group, this new scenario was mainly motivated by advances in dynamo theory and in particular in the study of magnetic flux tube dynamics. It has been realized that the motion of the thick magnetic flux ropes producing the active regions is dominated by dynamic forces (buoyancy, magnetic curvature force, etc.) and *not* by the drag—consequently, their motion is independent from that of the plasma to a large extent. So the motions of their crossing points with the solar surface (i.e. sunspots) need not reflect the motion of the plasma in *any* layer of the Sun. Instead, these motions are determined by a complicated interplay of (a) the emergent motion of the magnetic flux loop driven by buoyancy (e.g. Moreno-Insertis 1986, Chou and Fisher 1989, Choudhuri 1989. Shibata *et al.* 1990); (b) geometrical projection effects (van Driel-Gesztelyi and Petrovay 1990); (c) wavelike motions, driven e.g. by the Coriolis force (Caligari 1991); (d) the drag due to ambient flows (Meyer et al. 1979; Petrovay et al. 1990).

Despite the wide acceptance of this scenario today, much of the terminology and, worse, many of the standard data reduction methods applied in solar physics still originate from the age of the previous "paradigms". A relatively harmless example is the term *tracer* that is clearly related to the old anchoring concept. As long as one keeps in mind their inappropriateness such misnomers are not really misleading. Implicit assumptions based on the "cork" or "anchoring" concepts which are inherent in some traditional data reduction methods may however cause serious confusion when it comes to the statistical analysis and interpretation of the results. The aim of this paper is to call attention to these catches by briefly presenting two examples.



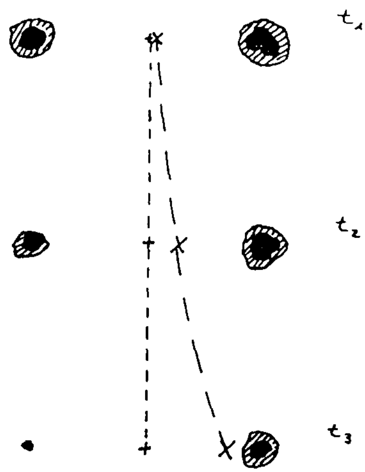


FIGURE I Different scenarios for the interpretation of sunspot proper motions: (a) corks on the water, (b) corks with anchors, (c) magnetic tree.

FIGURE II Fake proper motion as a consequence of area-weighting in a decaying bipolar sunspot group. +: real position of group; X: apparent (i.e. weighted) position.

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2. FIRST EXAMPLE

Both classic textbooks on sunspots (Bray and Loughhead 1964; Vitinsky, Kopecký and Kuklin 1986) recommend that sunspot proper motions should be corrected for differential rotation within the group as a standard practice. This idea obviously stems from the "corks" scenario; it is at least dubious in the case if we think in terms of the "anchoring" concept; and it is clearly nothing but unwarranted meddling with the data in the "magnetic tree" picture where the relative motions of different "branches" of the tree are governed by MHD forces and have little to do with the differential rotation of the surrounding plasma or with the relative motions of different "trees".

This is certainly a case where the advice of the textbooks should not be followed. Fortunately, due to the predominantly East-West orientation of sunspot groups, the errors caused by this "correction" are relatively small. (They usually consist in a slight reduction of the expansion velocity of the spot group, as the preceding (p-) spot is statistically more likely to lie at lower latitudes.)

3. SECOND EXAMPLE

Another traditional practice is to define the heliographic position of a sunspot group as the average of the constituent spots *weighted by their areas.* The idea behind this is that smaller spots can naturally be assumed to be more sensitive to random disturbing effects. This notion still holds in the magnetic tree picture as long as we only consider "branches" of one and the same tree. A typical bipolar active region is however a *double* tree and the center of the magnetic loop is clearly defined by the *unweighted* average of the positions of the two trunks. Consequently, in cases where p- and f-polarity subgroups can clearly be distinguished, area-weighting should only be applied within the respective subgroups and the spot position should be computed as the unweighted average of the two subgroups.

The errors the area-weighting can cause are most serious in the decaying phase of the evolution of sunspot groups when p- and f-spots behave rather differently. The faster decay of f-spots will shift the center of weight towards the p-spots, introducing a fake proper motion for the group as a whole in the direction of the rotation. To estimate the order of magnitude of this effect we take a simplified case where the group consists of two spots only, lying at the same latitude (Figure II). For simplicity we further assume that the two spots have the same area A_0 at the time of the maximal development of the group ($t = 0$) and that their distance Δx remains constant throughout the decay phase. According to Bumba (1963) the $a \equiv \dot{A}$ decay rate is constant, so for the p- and f-spot respectively we have

$$A_p = A_0 - a_p t \tag{1}$$

$$A_f = A_0 - a_f t. \tag{2}$$

A simple geometrical consideration shows that the fake velocity is

$$\Delta v = \frac{a_f - a_p}{4A_0(1 - t/\tau)^2} \Delta x \tag{3}$$

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with

$$\tau = \frac{2A_0}{a_f + a_p}\tau \tag{4}$$

as long as $t < \tau_f \equiv A_0/a_f$ (while the f-spot still exists), and

$$\Delta v = 0 \tag{5}$$

later, until at $t = \tau_p \equiv A_0/a_p$ the p-spot also disappears. The average of Δv over the whole of the decay phase is

$$\overline{\Delta v} = \frac{1}{\tau_p}\int_0^{\tau_f} \Delta v\, dt = \frac{\Delta x a_p}{2A_0}. \tag{6}$$

Inserting typical observed parameters into the formula (6) it turns out that the amplitude of this fake proper motion effect may well reach a few percent of the rotational velocity, i.e. decaying groups will appear to rotate this much faster than their real velocity because of the area-weighting effects. This effect may contribute to the recent curious finding by Howard (1991) that decaying sunspot groups rotate about four percent faster than growing ones.

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