J. Astrophys. Astr. (2000) **21**, 149-153

Results from Kodaikanal Synoptic Observations

K. R. Sivaraman, *Indian Institute of Astrophysics, Bangalore 560 034*
e-mail:siva@iiap.ernet.in

Abstract. The synoptic observations of Kodaikanal form one of the longest unbroken solar data from the beginning of the 20th century to the present day, and consists of the white light and monochromatic images of the sun. In this review, I shall discuss the results of the investigations in two areas using these data: (i) Tilt angles of the magnetic axes of bipolar spot groups, and (ii) structure and dynamics of large scale unipolar magnetic regions on the solar surface.

The observed properties and patterns of behaviour of the tilt angles can be used as effective diagnostics to infer the physical conditions in the subsurface layers of the sun, and thus get an insight into the physical effects that act on the rising magnetic flux tubes during their journey through the convection zone to the surface.

The second topic of discussion here, namely, the studies of the dynamics of unipolar regions over several solar cycles, show that the global solar activity has a high latitude component which manifests in the form of polar faculae, in addition to the well known sunspot activity at the middle and low latitudes. This raises the question about the origin of this high latitude component.

Key words. Synoptic observations—tilt angles of sunspot groups—global solar cycle.

1. Reduction of data and results

The synoptic observations of Kodaikanal starting from the beginning of the 20th century and continuing to the present day consist of:

- White light images from 1904,
- Ca II K_{232} spectroheliograms from 1907,
- H_α spectroheliograms from 1914.

1.1 *White light images*

The positions and areas of all sunspots were measured from the daily white light images for the period of 82 years (1906-1987). These measurements have been used for determining

- the solar rotation, differential rotation and their variations with the solar cycle (see S.S. Gupta *et al* in these proceedings),

- the tilt angles of the magnetic axes of bipolar spot groups and this will be discussed below.

Tilt angle of sunspot groups is a parameter that can be measured on the solar surface and that can serve as a good diagnostic to infer the relative effects of the forces (namely magnetic buoyancy, magnetic tension and Coriolis force) that act on the strands of magnetic flux tubes during their journey from (probably) the layers just beneath the convection zone all the way to the surface. The Coriolis force acting on the rapidly rising and expanding flux loop twists the loop such that it finally emerges at the surface with a tilt of the axis joining the centroids of the leading and following sunspots of a spot group with reference to the local parallel of latitude. Our study shows that the distribution of the tilt angles of the spot groups, their variations with latitudes of the spot groups, their areas, daily expansion rates, polarity separation, age and the derivatives of these parameters provide clues to infer the physical conditions and the forces that act on the these flux tubes while in the interior, and to the conditions that lead to the operation of the solar dynamo (Sivaraman *et al.* 1999; and Howard *et al.* 2000).

Main results from this study are:

1. It is the delicate balance among the forces - magnetic buoyancy, magnetic tension and the Coriolis force - that decides what the final value of the tilt angle of a sunspot group is.
2. The distribution of tilt angles shows a peak around $+5^\circ$ and not at zero (Fig. 1). It is seen that maximum number of spot groups possess this value of the tilt angle which is the equilibrium value. The tilt angle increases linearly with increase in latitude. Near the equator, the average tilt angle is about $+2^\circ$ and at 35° latitude the tilt angle increases to about $+8^\circ$. This variation of tilt angle with latitude is known as the "Joy's law".
3. Spot groups with tilt angles greater than the average value (which is the most commonly occurring value of 5°) tend to rotate their axes towards the average value and this motion is more for the growing spot groups than for those decaying.
4. Sunspot group tilt angle changes are correlated with polarity separation changes (expansion or contraction), and is in the right direction, and of the correct magnitude one would expect if Coriolis force is the agency responsible for causing the tilt.
5. The average tilt angle for spot groups varies with solar cycle, being higher during solar minimum periods than during maximum periods . This variation in tilt angles can be caused by variation in the field strengths of the sub surface toroidal flux tubes, between the two phases of the cycle. A decrease in magnetic tension because of the weaker field strengths in the rising flux tubes would offer less resistance to the effect of the Coriolis force, which in turn tends to increase the tilt angle of the spot groups that appear during the minimum years.

2. Structure and dynamics of large scale unipolar magnetic regions on the solar surface

From the daily H_α spectroheliograms we have constructed the H_α synoptic charts for every rotation of the sun for the period 1910-1985 (Makarov & Sivaraman 1983).

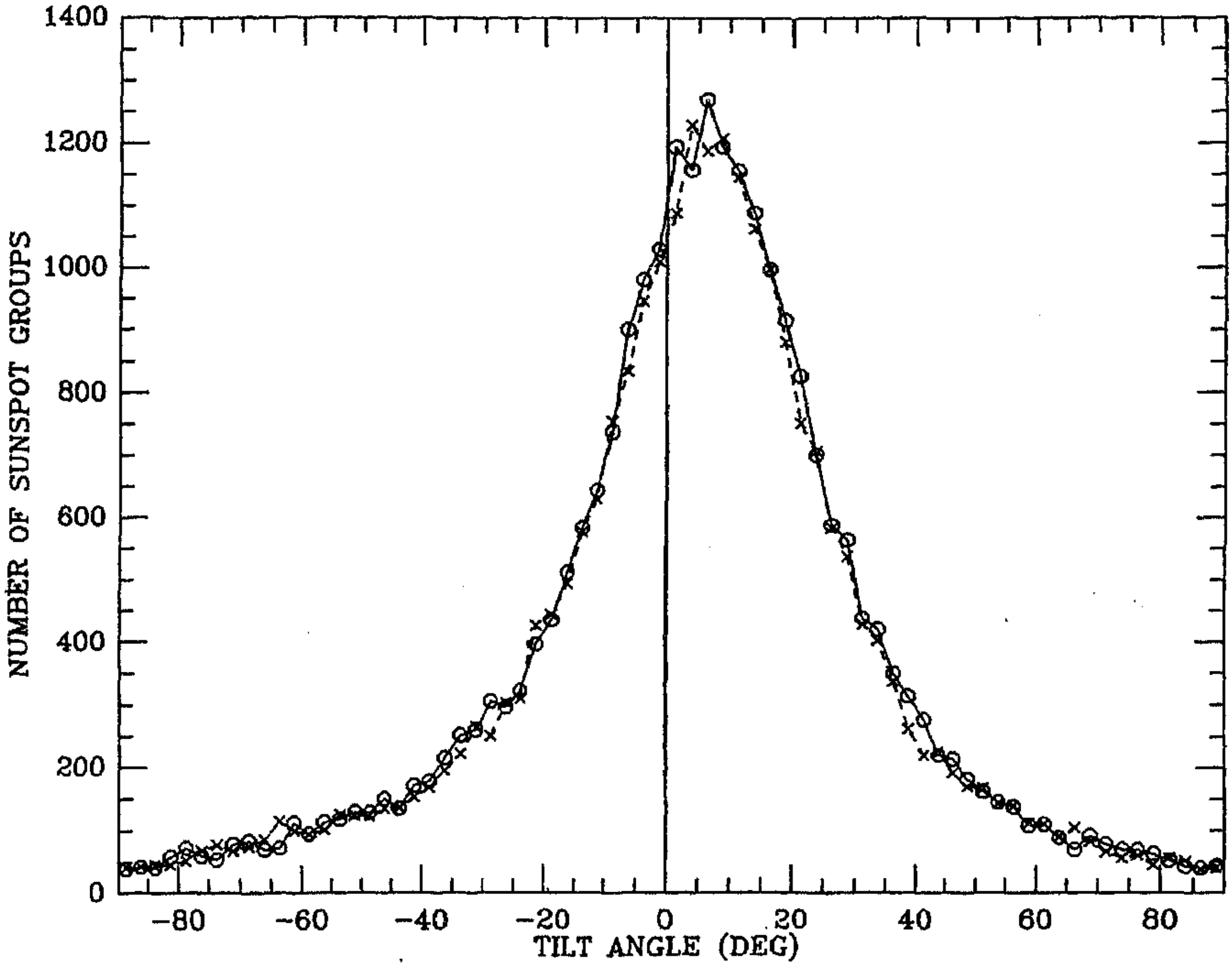

Figure 1. Distribution of tilt angles of multi-spot sunspot groups. The solid line is from Kodaikanal data for the years 1906–1987 and the dashed line from the Mount Wilson data for the years 1917-1985. Notice the peak around +5° and the close agreement between the results from the two stations.

Using these, we constructed the Latitude-Time diagrams for this period which show the poleward migration of the filament bands (and hence the migration of the unipolar magnetic regions) and the epochs of the polar field reversals (Makarov & Sivaraman 1989). The polar reversal marks the end of the current sunspot cycle. We have also plotted the distribution of the polar faculae for four cycles (for the years 1940-1985) picking up the faculae from the K-line spectroheliograms of Kodaikanal and Kislovodsk. These are shown in Fig. 2. During the years of solar minimum that follow the polar reversal, polar faculae appear first in the latitude zones 40–80°. The equatorward boundaries of the zones of appearance of the faculae progressively shift towards the respective poles as the cycle progresses. The polar faculae have strong magnetic fields in the range of 1600 Gauss associated with them (Homann *et al.* 1997) .

Our study has brought out the fact that the polar faculae is the second component of the global solar activity, the first component being the well known sunspot activity and the butterfly diagram. These two components occur at different latitude belts each lasting for about 11 years but with a phase difference of 5-6 years, the polar faculae leading the sunspot activity (see Fig. 2). This gives rise to the concept of the extended solar cycle which starts from the appearance of the first polar faculae (following the polar reversal) and ends with the last sunspots of the cycle. The

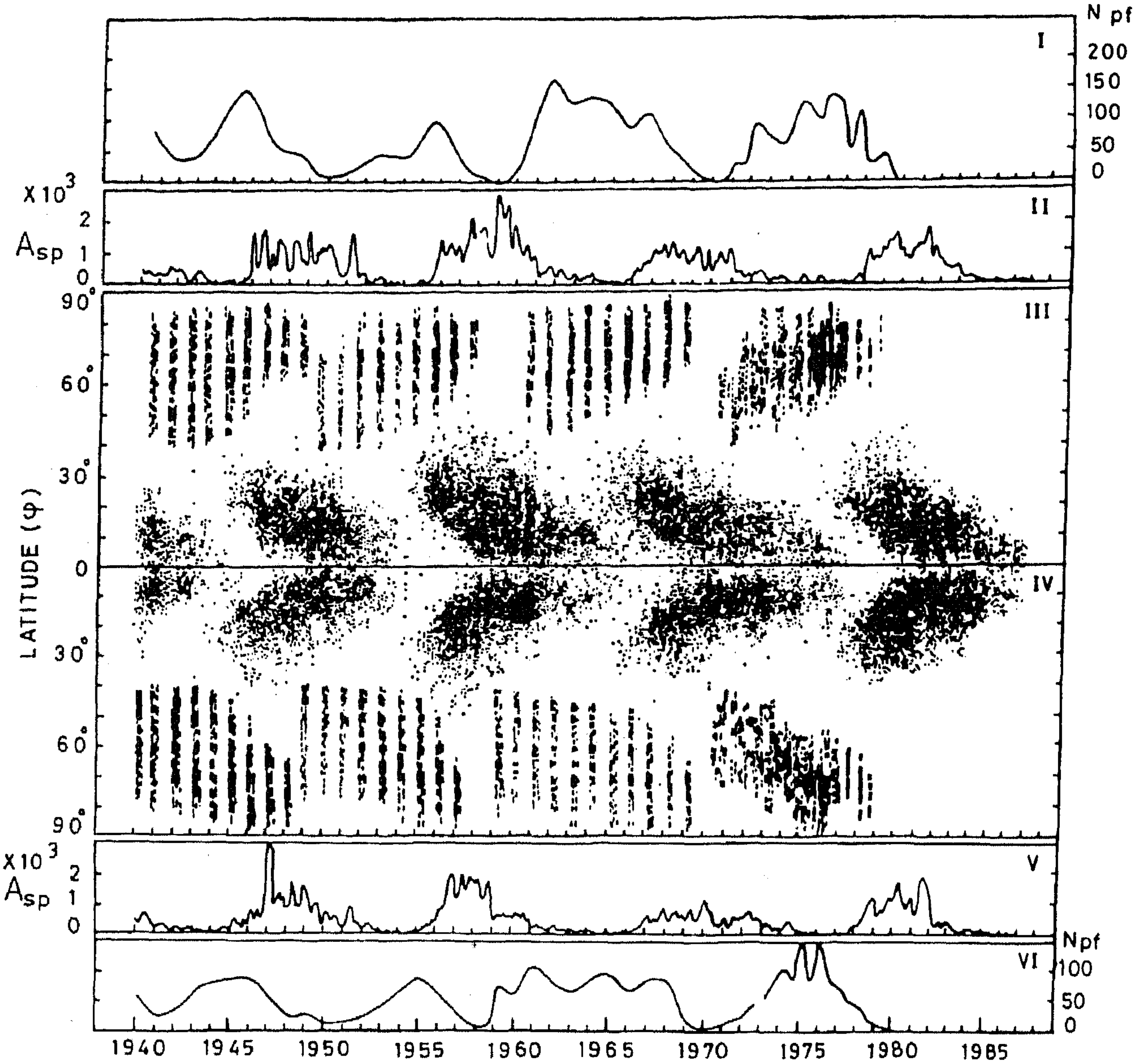

Figure 2. Latitude distribution of polar faculae and sunspots (butterfly diagram) in the N-hemisphere (box III) and in the S-hemisphere (box IV) for the years 1940-1985. Notice that the faculae appear first in the 40-80° latitude zones in the N and S hemispheres and the equatorward boundaries of these zones shift towards the respective poles as the cycle progresses. The plots of sunspot areas A(Sp) are shown in Boxes II and V and the number counts of polar faculae in Boxes I and VI for the N and S hemispheres for these years.

properties of the polar faculae such as their morphology, magnetic flux content, the duration and location they occur in relation to the sunspot activity raise the important poser whether these fields are due to a polar dynamo, and if so, how it is related to the main dynamo that generates the sunspot active region magnetic fields.

Acknowledgements

We wish to express our deep gratitude to the several generations of observers who made these observations covering many decades and which made these studies possible.

References

Homann, T., Kneer, F., Makarov, V. I. 1998, *Solar Phys.,* **175**, 81.
Howard, R., Sivaraman, K. R., Gupta, S. S. 2000, *Solar Phys.,* (in press).
Makarov, V. I., Sivaraman, K. R. 1983, *Solar Phys.,* **85**, 227.
Makarov, V. I., Sivaraman, K. R. 1989, *Solar Phys.,* **123,** 367.
Sivaraman, K. R., Gupta, S. S., Howard, R. 1999, *Solar Phys.,* **189,** 69.