EPHEMERAL ACTIVE REGIONS IN 1970 AND 1973

K. L. HARVEY*
Lockheed Solar Observatory, Burbank, Calif., U.S.A.

J. W. HARVEY
*Kitt Peak National Observatory, Tucson, Ariz., U.S.A.***

and

S. F. MARTIN
Lockheed Solar Observatory, Burbank, Calif., U.S.A.

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Abstract. A study of ephemeral active regions (ER) identified on good quality full-disk magnetograms reveals:

(1) On the average 373 and 179 ER were present on the Sun in 1970 and 1973 respectively. The number varies with the solar cycle.

(2) The median lifetime of ER depends on observation quality and selection rules but is estimated as about 12 hr for our data.

(3) The latitude distribution is very broad but not uniform. The distribution peaks near the equator and shows variations similar to distributions of large active regions.

(4) The longitude distribution is essentially homogeneous.

(5) The spatial orientation of ER is almost random. In 1973 there is a hint of an excess of new cycle orientations at high latitudes.

A comparison of parameters of ER and regular active regions suggests that ER are the small-scale end of a broad spectrum of active regions. The role of ER in the light of present theories of solar activity is investigated but is not yet clear. Heating of the chromosphere and corona may be significantly affected by ER.

1. Introduction

Ephemeral active regions (ER) are small, short-lived centers of activity. The term 'ephemeral' in respect to short-lived active regions was apparently first used by Dodson (1953). Although some ephemeral regions have been tabulated regularly in the calcium plage listings by the McMath-Hulbert Observatory, these regions had generally been regarded as insignificant until the discovery of their regular presence in very large numbers by Harvey and Martin (1973).

The work reported here was undertaken to learn more about the spatial distribution of ER, lifetime, solar cycle variation, association with major active centers. Primary consideration was given to the question of whether or not ER represent, in part, a new class of solar activity or are simply small active regions.

2. Observations and Reduction

Ephemeral active regions are most easily identified on time sequences of magnetograms

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* Visiting Astronomer, Kitt Peak National Observatory.

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with good spatial resolution and good signal-to-noise ratio. On such observations ER appear as tiny, rapidly evolving, bipolar regions with total fluxes $\sim 10^{20}$ Mx. An example of the appearance of ER at a single instant of time is shown in Figure 1.

Unfortunately a large number of observations of the sort shown in Figure 1 has not been available to us until recently. The data used for this study consist of daily full-disk magnetograms taken with the Kitt Peak 40-channel magnetograph having the same spatial resolution as Figure 1 but poorer signal-to-noise ratio. Usually there was only one observation per day. Two time periods were studied as indicated in Table I.

ER were identified by visual inspection of the magnetograms using as the main criterion the appearance of two close, small, opposite polarity features of approximately equal strength. When possible, the time evolution was checked to exclude the few features which later developed into large active regions. It was not possible to detect ER within well-developed active regions but a tally of the solar surface area thus excluded from the analysis was kept as shown in Figure 2 for correction purposes. The approximate orientation of the axis joining the two polarities was recorded for

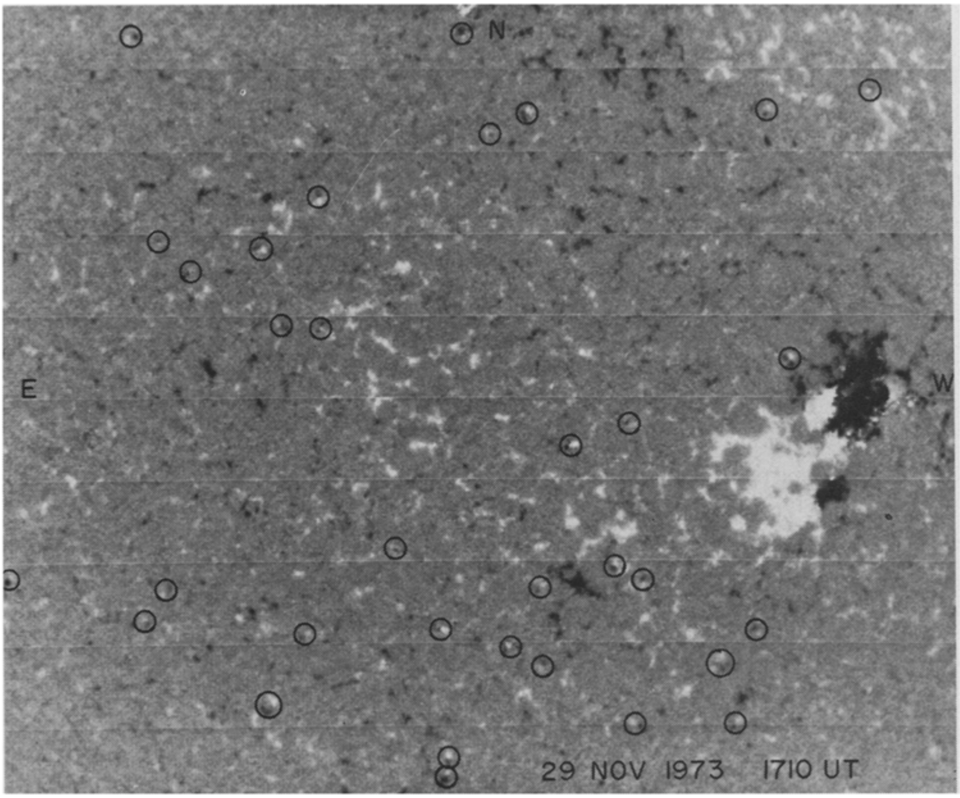

Fig. 1. A magnetogram showing the longitudinal component of the field as bright or dark depending on the polarity of the field. The area is 1000 × 1200″ centered on the disk. Ephemeral regions are circled.

TABLE I

Summary of observational data

Year	1970	1973
Date	8 Febr. - 30 Dec.	23 April - 8 Oct.
Number of magnetograms	45	141
good	36	104
fair	8	25
poor	1	12
Number of ER on good magnetograms		
certain	1160	1746
possible	157	621

each ER as well as its heliocentric coordinates and position relative to nearby large-scale activity. Although analyses of both certain and possible ER identified on good magnetograms were made, the results were similar and only certain ER are discussed further here.

3. Analysis

3.1. VISIBILITY

ER are more easily detected near the disk center on magnetograms. We determined the visibility as a function of μ, the cosine of the angle θ between the Earth and the ER as seen from the solar center, for certain ER both with the 1970 and 1973 data separately. To do this we constructed 10 zones of equal increments in $\sin\theta$ from the disk center to the limb limited in latitude extent to within $\pm 25°$ of the solar equator. The numbers of ER in each zone were counted for the data sets in 1970 and 1973. These numbers were divided by the solar surface area within each zone and the corrected numbers fit by least squares to a $(\cos\theta)^n$ function. This procedure assumes that there is little latitude dependence of spatial distribution of ER within $\pm 25°$ of the equator and that the effects of any irregularities in the spatial distribution of ER in longitude are smoothed by the large time base which sampled each Carrington longitude with about equal probability. We believe these assumptions are justified for the data considered here.

The results for 1970 and 1973 show that the probability per unit solar surface area of making a certain identification of an ER on a good magnetogram varied as $\mu^{4.6}$ and $\mu^{4.3}$ respectively. These large exponents are due to several factors: foreshortening toward the limb, decrease of the strength of the line-of-sight component of the magnetic field toward the limb, increased noise near the limb due to limb darkening and the availability of a 'possible' category of ER identification. Subsequent calculations have been corrected by the respective inverses of the determined visibility functions. Although these corrections are quite large near the limb, we believe they are reliable because of the similar results obtained for 1970 and 1973.

3.2. NUMBER OF ER

The average number of ER identified as certain on single magnetograms was 32.2 in

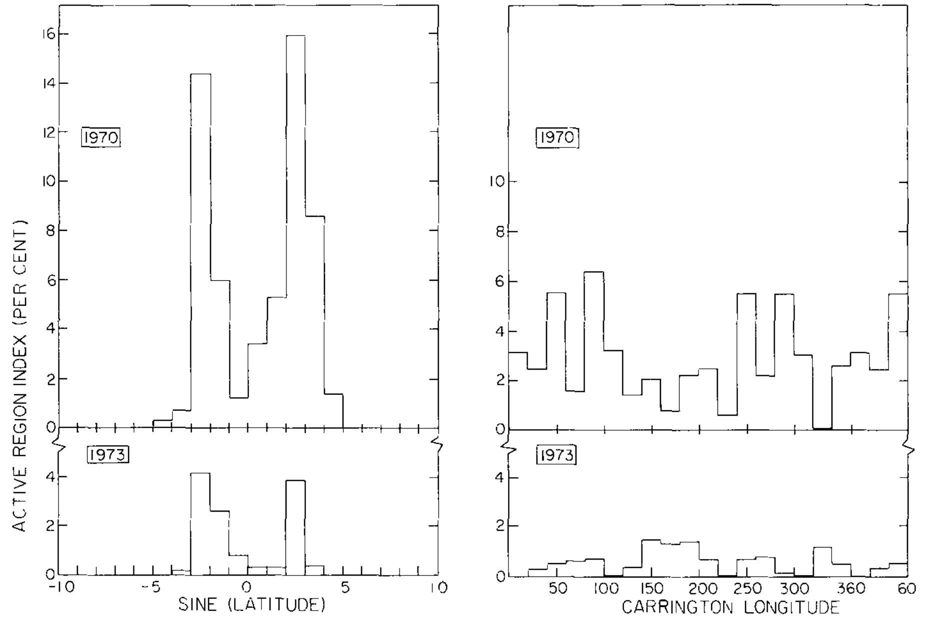

Fig. 2. The area of each latitude and longitude zone which is occupied by active regions which preclude the detection of ephemeral regions. The decrease in area from 1970 to 1973 is a result of declining solar activity.

1970 and 16.8 in 1973. Correcting the effects of the visibility function leads to averages of 362 and 178 ER in 1970 and 1973 respectively present on the entire surface of the Sun at any time. These numbers should be increased to 373 and 179 to allow for the fact that 3% of the surface was blocked by active regions in 1970 and about 0.5% in 1973.

We did not make flux measurements in this investigation but assuming from earlier work (Harvey and Martin, 1973), that each ER has a total magnetic flux of 10^{20} Mx, leads to average values of 3.7×10^{22} Mx and 1.8×10^{22} Mx in 1970 and 1973 respectively present on the entire solar surface in the form of identifiable ER.

3.3. LATITUDE DISTRIBUTION

To determine the probability of finding an ER in a unit surface area as a function of latitude we made counts of the number ER found within $\pm 35°$ of the central meridian longitude in equal zones of 0.1 in the sine of the latitude. The counts were also kept in a form corrected for the visibility function as shown in Figure 3. Correction for masking by active regions is also shown in Figure 3. The functions plotted are on the same absolute basis, i.e., the difference in the total number of observing days in 1970 and 1973 is removed.

The diagrams show that more ER were present in 1970 than in 1973 as described above. The difficulty in detecting regions near the limb makes the function somewhat uncertain at high latitudes but it is certain that ER have a very broad distribution in

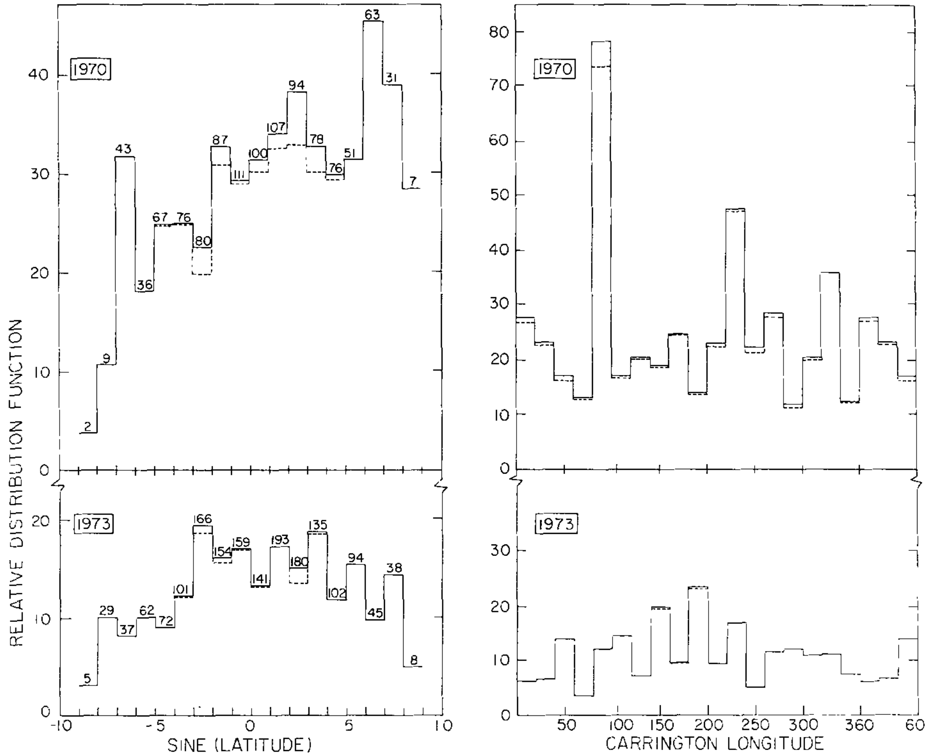

Fig. 3. Distributions of ephemeral regions in 1970 and 1973 in latitude and longitude. These distributions have been corrected for the increasing difficulty of detecting ER near the limb. The dashed line is the distribution uncorrected for masking by large active regions and the solid line includes this correction. The actual number of counted ER is included in the latitude distribution. Uniform distributions per unit surface area would appear as horizontal lines.

atitude, particularly in comparison to the distribution of normal active regions shown in Figure 2. It is not impossible that the ER were actually distributed equally per unit surface area as a function of latitude in 1973 but a uniform distribution in 1970 seems impossible. The large excess of 1970 ER in the north is similar to the north-south imbalance of regular active regions in 1970 shown in Figure 2. We have been unable to detect any association between isolated peaks in the distribution functions and other solar phenomena.

3.4. CARRINGTON LONGITUDE DISTRIBUTION

Similar to the determination of distribution in latitude, we counted ER in increments of 20° in Carrington longitude for regions observed within ±35° of the central meridian longitude. The weight of each count was corrected for the visibility function and the different total observing times in 1970 and 1973 with the results shown in Figure 3. Correction for masking by regular active regions are also shown in the figure.

The distribution functions show that the probability of finding an ER per unit surface area is relatively independent of longitude both in 1970 and 1973. The large peak in 1970 is not clearly associated with other forms of solar activity. There is little or no association between the longitude distribution of regular active regions and ER.

3.5. ASSOCIATION WITH LARGE SCALE ACTIVITY

Each ER was categorized by the character of the magnetic field pattern in its neighborhood. The categories were: near an active region, in a region of old, mixed polarity flux and in a region of old, predominantly unipolar flux. There was a marked tendency for ER to appear preferentially in the latter type of region without regard to the local polarity. However, since most of the area of the Sun is covered by such predominantly unipolar flux regions in our observations, this tendency does not appear to be significant. There was no tendency detected for ER to congregate around or avoid large active regions.

Using data from various sources we have been able to compare the positions of ER with respect to coronal holes. We could not detect any association between coronal holes and ER.

3.6. LIFETIME

Most of our data were taken at daily intervals. Very few ER are identifiable after 1 day (about 3%). We studied a few pairs of magnetograms taken on the same day (time intervals between 54 and 316 min) and obtained confusing results. The main problem is quality variation due to seeing changes. Pending a detailed study of ER lifetimes we believe that they can be identified as ER on magnetograms of the quality we used for a median period around 12 hr. Higher quality magnetograms such as used in the study by Harvey and Martin (1973) allow identifications for longer periods of the order of 1 day or more.

3.7. ORIENTATION

The ER were categorized into 3 orientation classes: proper, reverse and north-south according to whether the poles were oriented in accord with the Hale law of sunspot polarity, or had a reverse polarity configuration for their hemisphere or the axis joining the poles were oriented within about ±30° of the local meridian direction. The fractional distributions of these orientations as functions of longitude and latitude are shown in Figures 4 and 5.

About 15% of ER are oriented roughly north-south while the remaining ER are about evenly divided between proper and reverse orientations with a slight preference for proper. No significant longitude variation of orientation is apparent either in 1970 or 1973. The latitude distribution of ER orientations shown in Figure 5 is more interesting. The fraction of reverse polarity regions appears to be a minimum near the equator and increases toward the poles primarily at the expense of ER's with north-south orientation. The fraction of proper orientations seem about equal at all latitudes, particularly allowing for the poor statistics in the ±0.8 to 0.9 sine latitude intervals. This increase of reverse orientation away from the equator and its possible relation to the onset of the new solar cycle was mentioned by Gillespie *et al.* (1973). We regard

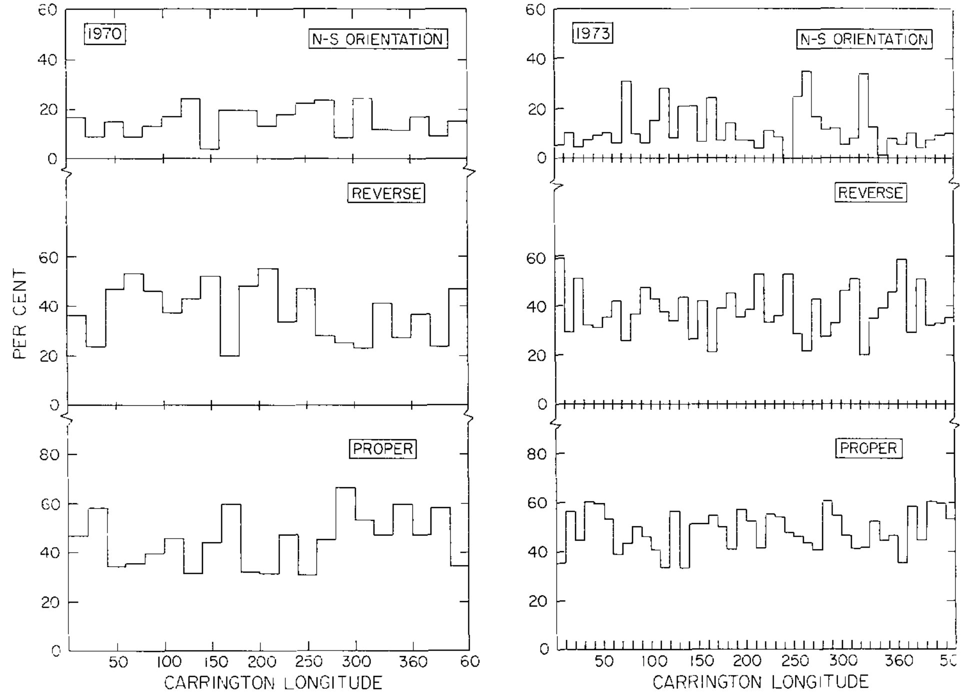

Fig. 4. Fractional distribution of ER in longitude by orientation.

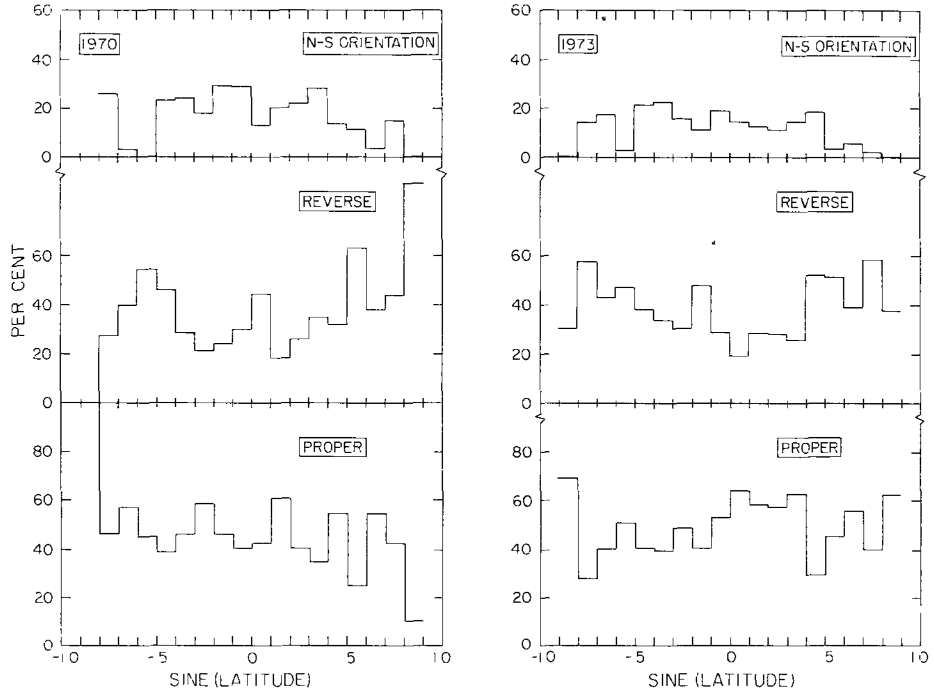

Fig. 5. Fractional distribution of ER in latitude by orientation.

these trends only as suggested since our data are somewhat subjective and the statistics are inadequate to prove the reality of the trends.

4. Are ER a New Type of Solar Activity or Small Active Regions?

At first glance the large number, short lifetime, random orientation and broad spatial distribution would seem to suggest that ER are a new class of solar activity. It is probable some of our identifications of ER are simply chance encounters of unrelated patches of opposite polarity flux elements. However, there is no discernible increase of ER in mixed polarity regions where one would expect to see more chance encounters so we believe the number of 'accidental' ER to be small in our data. If the remaining ER are significantly different from regular active regions it should be possible to demonstrate a clear distinction in one or more of the properties of both types of activity. To aid in the search for such a distinction we have studied calcium plage identifica-

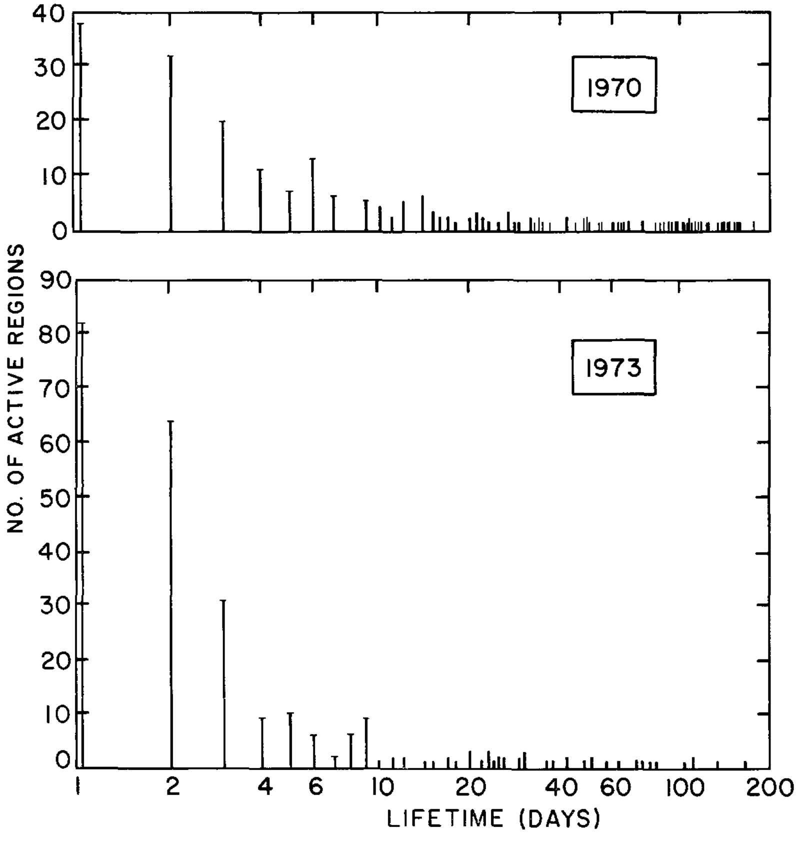

Fig. 6. The distribution of active region lifetimes identified on calcium spectroheliograms reported by McMath-Hulbert Observatory for April to October 1970 and 1973. Each region is counted only once and a correction function ranging from 2 at a lifetime of 1 day to 1 at 14 days has been applied to the data.

tions of active regions made by the staff of the McMath-Hulbert Observatory for the same time periods as our ER observations. In the comparative study below we seek a clear distinction between the properties of ER and regular active regions.

4.1. LIFETIME AND NUMBER

We have only an estimate that the median lifetime of ER as magnetically identifiable entities on our observations is about 12 hr. Studies of sunspot groups (Gnevyshev, 1938; Ringnes, 1964; Sheeley, 1964; Lopez Arroyo, 1968) show that the distribution of sunspot lifetimes is strongly skewed toward short lifetime. The mean lifetime is about 4 days while the median is slightly over 1 day. Information about the lifetimes of plages not necessarily associated with sunspots is scarce. Butler (1924) studied only large plages and found they lasted at least one week. Weart (1970) turned attention to small plages accompanied by arch filament systems and found the majority to disappear within 1–2 days. Our compilation in Figure 6 indicates a median lifetime between 2–6 days and a mode lifetime of 1 day.

There is every reason to expect sunspot and plage lifetime studies to underestimate the number of short-lived features because of observational and identification difficulties. Despite this expectation all studies of active region and sunspot lifetimes show very skewed distributions in favor of short lifetimes. If the studies could be made with better spatial and time resolution, we think much larger numbers of regions with short lifetimes would be detected. The number of ER in 1970 and 1973 to be compared with the results in Figure 6 are 1.3×10^5 and 6.4×10^4 respectively at a lifetime of 12 hr. We believe that the extreme selection effects which reduce the number of short-lived active regions detected can account for the large difference between active region and ER numbers. Our conclusion is that lifetime statistics of active regions are not complete enough at short lifetimes to demonstrate a clear distinction between active regions and ER.

4.2. EVOLUTION

Sunspots appear to form rapidly and decay slowly. Similarly Butler (1924) demonstrated the same behavior for Ca plages, as did Bumba and Howard (1965) for large magnetic regions. Harvey and Martin (1973) found the rate of growth of ER to decrease with age so there appears to be no difference between ER and regular active regions in this aspect of their behavior. In particular, both ER and active regions appear to be basically eruptions of magnetic flux from beneath the photosphere.

4.3. ORIENTATION

Our data are consistent with a nearly random orientation of ER with respect to parallels of latitude except that there is a slight preference for orientations in accord with the present sunspot cycle at low latitudes and, in 1973, an increasing preference at high latitudes for the orientation expected during the next sunspot cycle. The nearly random orientation of ER sampled at random times in their lifetimes does not mean that they emerge with the same random orientations. Indeed, Harvey and

Martin (1973) showed an example of a marked orientation change during several hours of observation of an ER.

Other types of solar activity sampled randomly during their lifetimes exhibit more definite orientations. Major sunspot groups are usually oriented nearly east-west (Waldmeier, 1955). Calcium plages show a broader distribution of orientations than sunspots but are still essentially east-west (Butler, 1922). Small active regions after their initial emergence period also are usually oriented nearly east-west (Weart, 1970).

It is well established that the east-west orientation of active regions usually develops after the initial appearance of the region. The first appearance is associated with a random orientation (Weart and Zirin, 1969; Weart, 1970; Frazier, 1972). We do not have comparative statistics on the orientation of young ER. It is possible that all magnetic flux regions initially emerge with a random orientation and develop an east-west orientation only provided they live beyond a certain time or contain more than some certain amount of flux. In this event, the random orientation of ER is not indicative of a fundamental difference compared with larger active regions.

4.4. Transient activity

Large active regions are the site of flares, surges and other transient events. Such activity, however, is strongly associated with complex configurations of the magnetic field. Conversely, simple bipolar regions are the least frequent sites for flares (Smith and Howard, 1968). Since ephemeral regions appear to be simple bipolar regions, at least in magnetograms with the resolution of 2–3″, one would not expect a high incidence of flares in ER. Nevertheless, Harvey and Martin (1973) have already observed clear examples of flare-like brightenings and surges in a fairly large ephemeral region. Thus, the occurrence of flares and transient events is not a means of making a clear distinction between ER and larger active regions provided that future high resolution observations show that some ER may have complex magnetic field configurations.

4.5. Variation with solar cycle

The average number of ER present on the Sun in 1970 was almost exactly twice the number in 1973. This same ratio applies to the number of McMath plages lasting more than 14 days for which sampling should be complete (short-lived plages show an anticorrelation with the sunspot cycle (Harvey and Martin, 1973) which is probably due to selection effects). The Zürich sunspot number also decreased by about a factor of two between 1970 and 1973. We conclude that the number of ER varies with the solar cycle in the same way as regular activity. It is interesting to note that Tsap and Laba (1973) find a solar cycle variation of the brightness of K_{232} network elements which may be related to the number of ER.

4.6. Longitude distribution

The longitude distribution of regular active regions is a somewhat controversial subject (see review by Sawyer, 1968). However, there is little doubt that while major spot

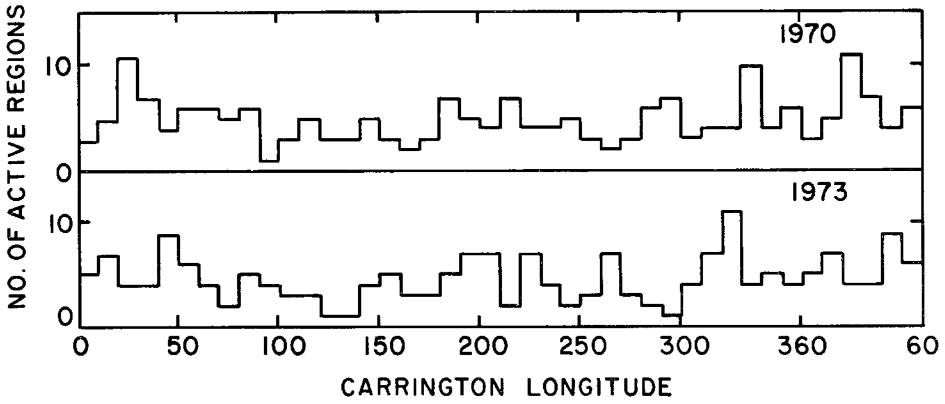

Fig. 7. Longitude distribution of McMath-Hulbert calcium active regions for April through October 1970 and 1973. Regions are counted only once.

activity tends to recur in certain persistent longitudes, if one includes all regular active regions then any significant departure from a random distribution in longitude is very difficult to detect. Glackin (1973) was unable to detect any longitude preference for small active regions which develop arch filament systems. Our counts of calcium plages, shown in Figure 7, also show an essentially uniform longitude distribution. Since ER behave the same way, there is again no distinction between ER and active regions.

4.7. LATITUDE DISTRIBUTION

The latitude distribution of sunspot groups is well-known (e.g., Becker, 1954). The latitude distribution of regular active regions extends to about 10° further away from the equator but is otherwise similar to that of sunspot groups. Glackin (1973) found that small plages with arch filament systems can be found still closer to the poles (~45° latitude) but are still concentrated in the sunspot belts. Our results for calcium plages (Figure 8) show a broad distribution extending to ±45° for short-lived active regions and a distribution similar to that of sunspots of long-lived regions.

The latitude distribution of ER is much more uniform than that of larger active regions. Nevertheless, as shown in Figure 8 the distribution of ER tends to maximize at the same latitudes as larger active regions. The essential difference between larger active regions and ER is the existence of ER at high latitudes. We interpret the results in Figure 8 to indicate that the latitude distribution of active regions is strongly dependent on the lifetime of the regions. According to this interpretation there is no basis for distinguishing between ER and larger active regions.

4.8. ASSOCIATION WITH X-RAY FEATURES

Large active regions are associated with spectacular features in X-ray photographs (Vaiana *et al.*, 1973). Krieger *et al.* (1971) demonstrated that small X-ray bright points are associated with small magnetic bipoles which we would generally identify as ER on

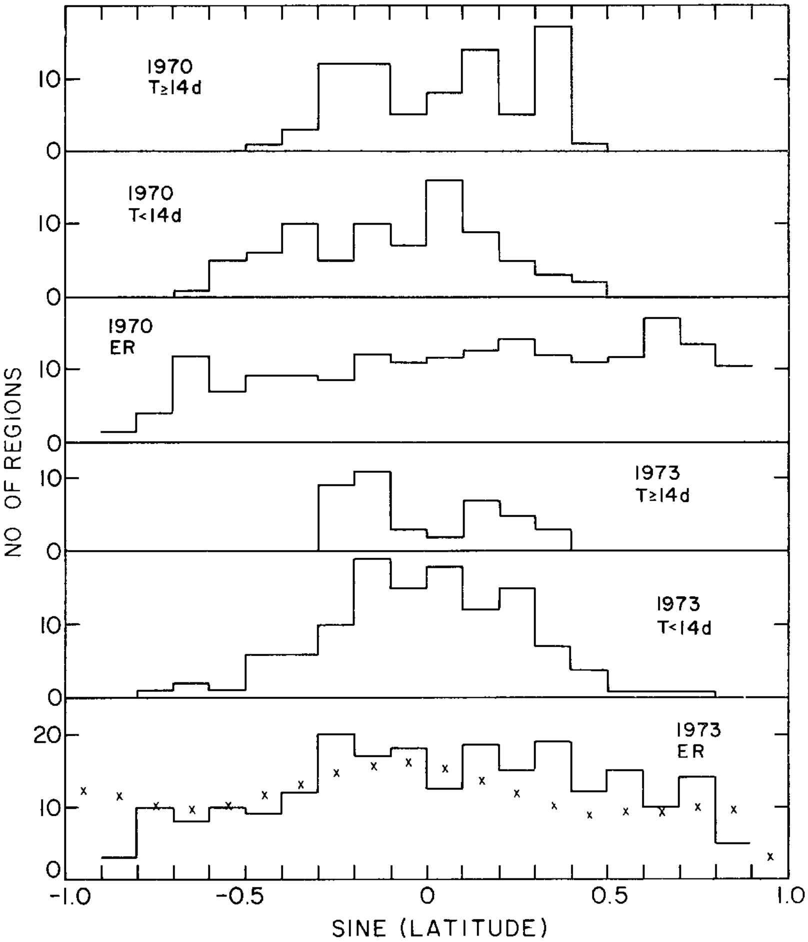

Fig. 8. Comparison of the relative latitude distributions per unit surface area of ephemeral regions and McMath-Hulbert calcium active regions counted only once. Shorter lifetimes are associated with broader latitude distribution. The ER distribution for 1973 is compared with the latitude distribution of X-ray bright points (X) from Golub *et al.* (1974).

magnetograms. Golub *et al.* (1974) have confirmed this association. Although it has not yet been demonstrated that ER are always associated with X-ray features, it is probably safe to conclude that most ER are manifest at X-ray wavelengths during some period of their lifetime and therefore that ER and larger active regions cannot be distinguished on the basis of simple association with X-ray emission.

Further support for an association between ER and X-ray bright points comes from comparing our present ER results with those of Golub *et al.* (1974) on X-ray bright points. The comparison of number, lifetime, size, flaring activity and spatial distribution is now better than shown by Golub *et al.* (1974). For example, we have plotted in Figure 8 the latitude distribution of X-ray bright points from Golub *et al.* (1974) on our 1973 distribution of ER. The similarity provides additional evidence of an association between the two phenomena. The details of the association are currently being investigated as a separate study.

4.9. CONCLUSION

One can imagine other tests to distinguish between active regions and ER such as comparisons of number vs area and magnetic flux or similarity of correlations of two dependent parameters, etc. We cannot perform more sophisticated tests from available data. The strongest support for a real distinction seems to be the very broad latitude distribution of ER. However, we do not believe that this difference is sufficient to claim that ER are fundamentally different from larger active regions. Our present conclusion is that there is no compelling evidence to separate ER from regular active regions and that ER are probably just the small-scale end of a broad spectrum of active region sizes.

5. Discussion

The significance of ER is an important question because of their large number and the large amount of magnetic flux which erupts in ER. However, we note that large scale patterns of magnetic flux seem to be unaffected by ER. The magnetic structure of the atmosphere seems to be controlled by flux which erupts in large active regions. This suggests that ER flux is more easily dissipated than flux from large active regions. Such might be the case if dissipative forces act at least in part on flux systems rather than flux elements provided that large systems are harder to destroy than small systems.

Alternatively and despite our arguments against the idea, ER may be fundamentally different from large active regions. Altschuler (1973) has proposed that magnetic fields responsible for solar activity are generated in the photosphere with little or no contribution from beneath. The basis for this proposal is the Biermann and Schlüter (1951) mechanism for producing magnetic fields from large non-parallel gradients of electron density and pressure. This mechanism has also been explored by Kopecký and Kuklin (1971). According to Altschuler's speculations, magnetic fields are generated at boundaries of convection cells in the photosphere. If we assume that ER are formed by this process then the homogeneous distribution of convection of the Sun explains the broad latitude distribution and random spatial orientation of ER. However, there are problems with this picture. It is not clear that sufficient flux can be quickly created by this mechanism nor can the variation of the number of ER with the solar cycle be understood. Finally, ER seem to appear at places other than the boundaries of supergranule cells. Further development of this idea is necessary before we can consider it as the explanation of ER. We think instead that the lack of long-lasting effects of ER results from a rapid dissipation mechanism.

Such dissipation might play a role in heating of the corona and chromosphere. However, the present consensus is that heating results from acoustic waves generated in the convection zone (see review by Leibacher, 1974). Thus, ER would play no role in heating the atmosphere in this view. Piddington (1973) has criticized this view and revived suggestions that Alfvén waves produce significant heating. Hoyle and Wickramasinghe (1961) and Tucker (1973) suggested heating by ohmic dissipation of twisted and sheared magnetic fields in the corona. Levine (1974) proposed heating results from particles accelerated by collapsing magnetic fields near neutral surfaces. These alternatives to acoustic wave heating would all benefit from the additional complexity introduced to the small-scale coronal magnetic field by large numbers of randomly oriented ER. Further the broad distribution of ER provides the possiblity of heating outside the magnetically active sunspot latitudes. Unfortunately, ER are observed in coronal holes where heating is greatly reduced. Thus ER may be associated with heating only in their immediate neighborhood.

None of the existing models of the solar cycle explicitely recognizes the existence of ER. Do any of the models account for the existence and behavior of ER? According to conventional wisdom (see review by Parker, 1970) differential rotation stretches an initial poloidal field into a shallow subsurface helical field. Magnetic buoyancy lifts amplified flux ropes through the photosphere where they appear as active regions. A new, opposite poloidal field is generated by merging of subsurface twists introduced by cyclonic motion during the emergence of active regions and the process repeats with opposite polarity configurations. In this picture, the variation of the number of ER with the solar cycle suggests that ER are generated from the same reservoir of flux as the large active regions. The broad latitude distribution and nearly random spatial orientation of ER suggests that differential rotation plays little role in stimulating the emergence of ER. We suggest that convective processes are basically responsible for causing the emergence of ER from the subsurface reservoir. In support of this idea is the observation (Harvey and Martin, 1973) that ER emerge away from supergranule boundaries.

Piddington (1972) has criticized the conventional theory of solar activity and developed (1971) ideas suggested by Richardson and Schwarzschild (1953) that the poloidal field is deeply rooted rather than shallow and that the cycle originates as a meridional oscillation. In this theory the development of active regions (and of ER) proceeds very similarly to that of the conventional dynamo picture. Either model appears to account for ER equally well.

6. Summary

We have made a statistical study of ephemeral active regions in 1970 and 1973 as a complement to our earlier study of the detailed properties of ER (Harvey and Martin, 1973). Our earlier discovery that large numbers of ER are found all over the solar surface is confirmed. The lifetime of the ER in our sample is roughly 12 hr; only 3% are identified after 1 day. On the average hundreds of ER were present on the Sun in 1970 and 1973. The number seems to closely follow the sunspot cycle. About as much magnetic flux appears in the form of ER as appears in large active regions. The surface distribution of ER is nearly random with a tendency to maximize in active sunspot zone latitudes. The spatial orientation of ER sampled at random times in their lifetime is nearly random although there is a hint of an increase of new cycle orientation at high latitudes.

We conclude on the basis of a comparison of the properties of ER and regular active regions that ER represent the small scale end of a broad spectrum of active region sizes. The significance of ER in the solar cycle is not yet clear but they may play an important role and should be included in detailed models. Some models of coronal heating benefit from the presence of large numbers of ER; however, the appearance of ER in coronal hole regions where heating is reduced casts doubt on the real significance of ER in heating the corona. It is entirely possible that even smaller, shorter-lived ER than we have observed occur in huge numbers on the Sun. In this case their importance in heating the atmosphere may be very great.

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