EPHEMERAL ACTIVE REGIONS

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Abstract. Ephemeral active regions attain maximum development within 1 day or less of their initial appearance and are typically observed for 1–2 days. They appear mostly as small bipolar regions having a typical dimension of about 30000 km and a maximum total flux of the order of 10^{20} Mx. The ephemeral regions generally do not produce sunspots and flares, though they are identified in Hα as small active centers.

Our observations indicate that the ephemeral regions are frequently generated both near large active centers and in extensive quiet areas of the Sun. The location of emerging ephemeral regions does not appear to be associated with the distribution of the existing network fields. As many as 100 ephemeral regions may form per day. On the average, as much flux may erupt in the form of small ephemeral regions as erupts in larger active centers.

The latitude distribution of ephemeral regions appears to be much wider than that of sunspots and major active centers. Their frequency of occurrence does not appear to follow the sunspot cycle.

1. Observations

This investigation of ephemeral active regions is a consequence of a continuing study of the relationships of Hα activity to magnetic field changes. High-resolution Hα and magnetic field observations of major active regions were obtained about 7 h each day during the periods 15–18 October 1970, 28–31 October 1970 and 16–19 September 1971 at the Kitt Peak National and Lockheed Solar Observatories. Although our scan area was limited, it was found in the course of the data reduction that 36 ephemeral active regions were recorded in and around the active regions being studied in these 12 days of observations. The appearance of ephemeral active regions on magnetograms is shown in Figure 1. Of the 36 ephemeral regions, 26 were observed for periods of about one day or less; that is, they could not be recognized on magnetograms taken about 24 h after the regions were first observed. The lifetimes of the other 10 regions were at least 2 days. In no case were any of these regions assigned plage numbers by the McMath-Hulbert Observatory.

The longitudinal-component magnetograms were made using the 40-channel magnetograph (Livingston and Harvey, 1971) at the McMath Solar Telescope on Kitt Peak. The magnetograms were taken at rates between 2 and 6 h^{-1}. The scanning aperture of the magnetograph was either 1″.2 or 2″.4; the resolution was selected such that our observations were seeing limited. Further details about the magnetic observations are given by Harvey and Harvey (1973).

The Hα filtergrams obtained at the Lockheed Solar Observatory during 1970 were taken using a 1 Å passband filter centered on Hα. During the 1971 period the Hα

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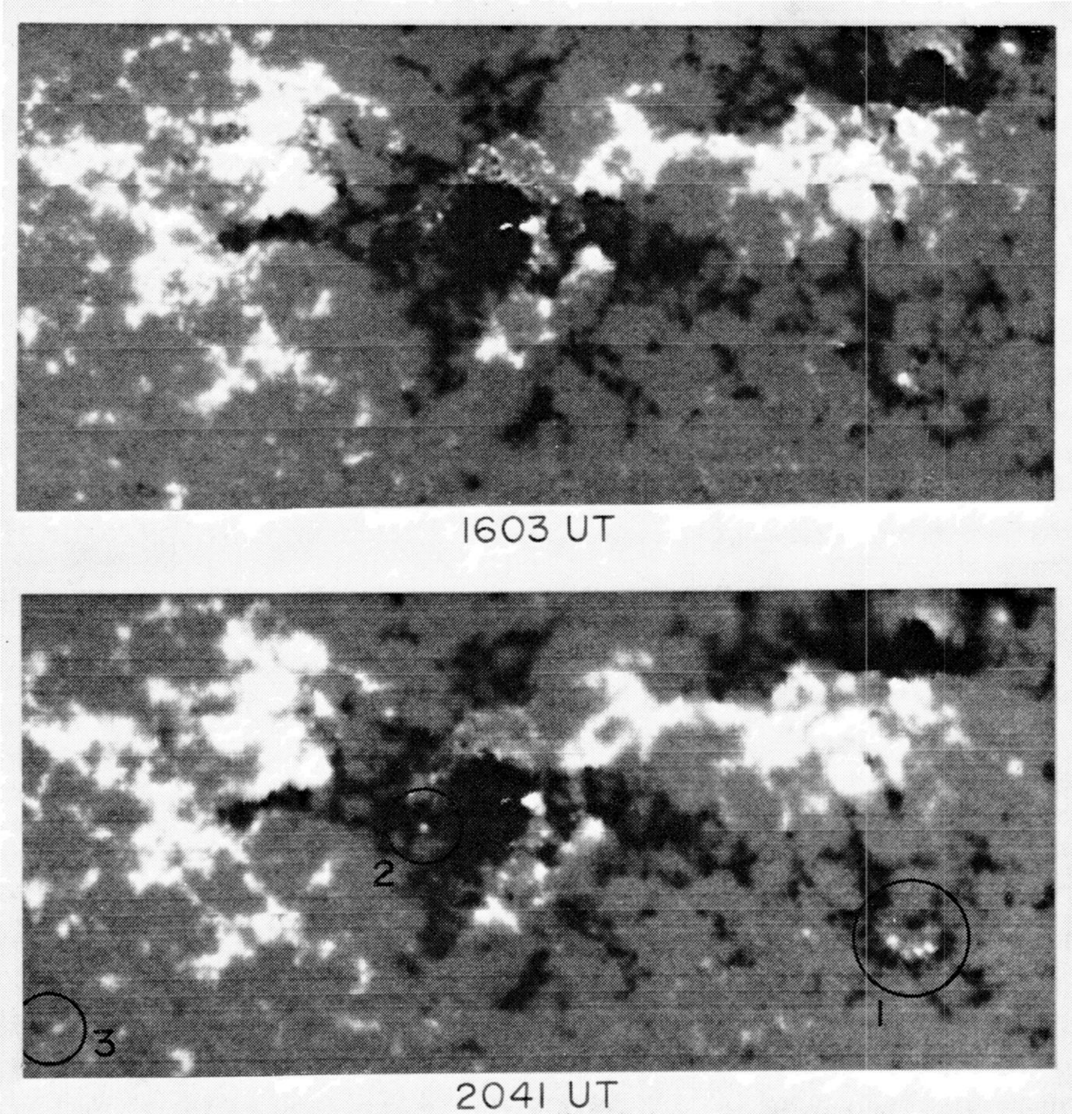

Fig. 1. Two magnetograms, taken on 30 October 1970, illustrate the location and appearance of several ephemeral regions relative to large active centers. Three of the regions (1, 2, and 3) emerged during our observations. The display shows the longitudinal field as departures from grey and saturates at 150 G. Each frame is 2.1×10^5 km high.

filtergrams were made with a Lyot filter having two 0.3 Å passbands centered on Hα − 0.3 Å and Hα + 0.3 Å. Both passbands were photographed simultaneously on adjacent frames of 35 mm film. During all of the observing periods, exposures were taken at a rate of 4 min^{-1}. In the best frames, features with a size of 1″ are resolved.

2. Characteristics of Ephemeral Active Regions

2.1. Appearance

The pair of magnetograms in Figure 1 shows several of the ephemeral active regions which formed both before and during our observations on 30 October 1970. As compared with the nearby major active centers, the ephemeral regions are characteristically small, extending over 2–4 $\times 10^4$ km and having areas less than 7×10^8 km^2. Most of the ephemeral regions exhibit a basically bipolar magnetic configuration, but with few exceptions these regions do not develop pores or sunspots. Their appearance in Hα is marked by organized fibril structures and plage (Hα active center), though identification of the ephemeral regions strictly on their appearance in Hα is difficult.

Because we observed an average of 7 out of 24 h, we were able to study only a portion of the life-cycle of any individual ephemeral active region. Of the 36 ephemeral active regions observed, eight emerged during our observing periods; five additional regions had emerged overnight and were growing during our observations. The remaining 23 regions appeared to have reached their maximum development or were in their decaying phase when first observed. In no case did we detect the actual death (or disappearance) of an ephemeral region during our observations, though 26 of the regions disappeared overnight.

2.2. Distribution

Although our observations are biased towards areas having major active regions, we observed no preferential distribution of the 36 ephemeral regions within the scan area and relative to the active regions. Ten of the 36 regions formed within existing active regions, but at no preferential location in these regions in agreement with a study by Weart (1972) of the appearance of new flux in active regions. The remaining 26 regions were located within 100000 km of the boundaries of existing active regions, a limit set by the scan area. In some instances, more than one region formed at nearly the same location in successive intervals of time, as for example in Region 1, Figure 1.

2.3. Magnetic field

All of the ephemeral regions had a basically bipolar magnetic configuration, though we often observed the appearance of more than one pole located in and near the main bipolar components of the regions. This behavior is seen in two developing regions in Figures 2 and 3 as described in the next section.

The magnetic flux (ϕ) was measured for each region at the times of best seeing. Because these measurements are not necessarily at the time of maximum development of the regions, they are used only as an indication of the flux in the ephemeral regions. The measured total flux ($|\phi_+| + |\phi_-|$) ranged from 10^{19} Mx to 4.7×10^{20} Mx with an average value of 10^{20} Mx. The noise is estimated to be $1\text{–}2 \times 10^{19}$ Mx for the *total* flux and $2\text{–}5 \times 10^{18}$ Mx for the *net* flux depending on the size of the measured area. The flux appears to be balanced in 12 regions (five of which emerged during our observations) positioned near the central meridian at the time of the measurements and which could be isolated from the surrounding network fields. This is in agreement with the results of Bumba (1961), Sheeley (1966), Stenflo (1968), and Wiehr (1970) for larger active centers observed in the later stages of development, but disagrees with the measurements of the net flux in emerging regions by Bumba and Howard (1965), Bumba *et al.* (1968), and Bappu *et al.* (1968).

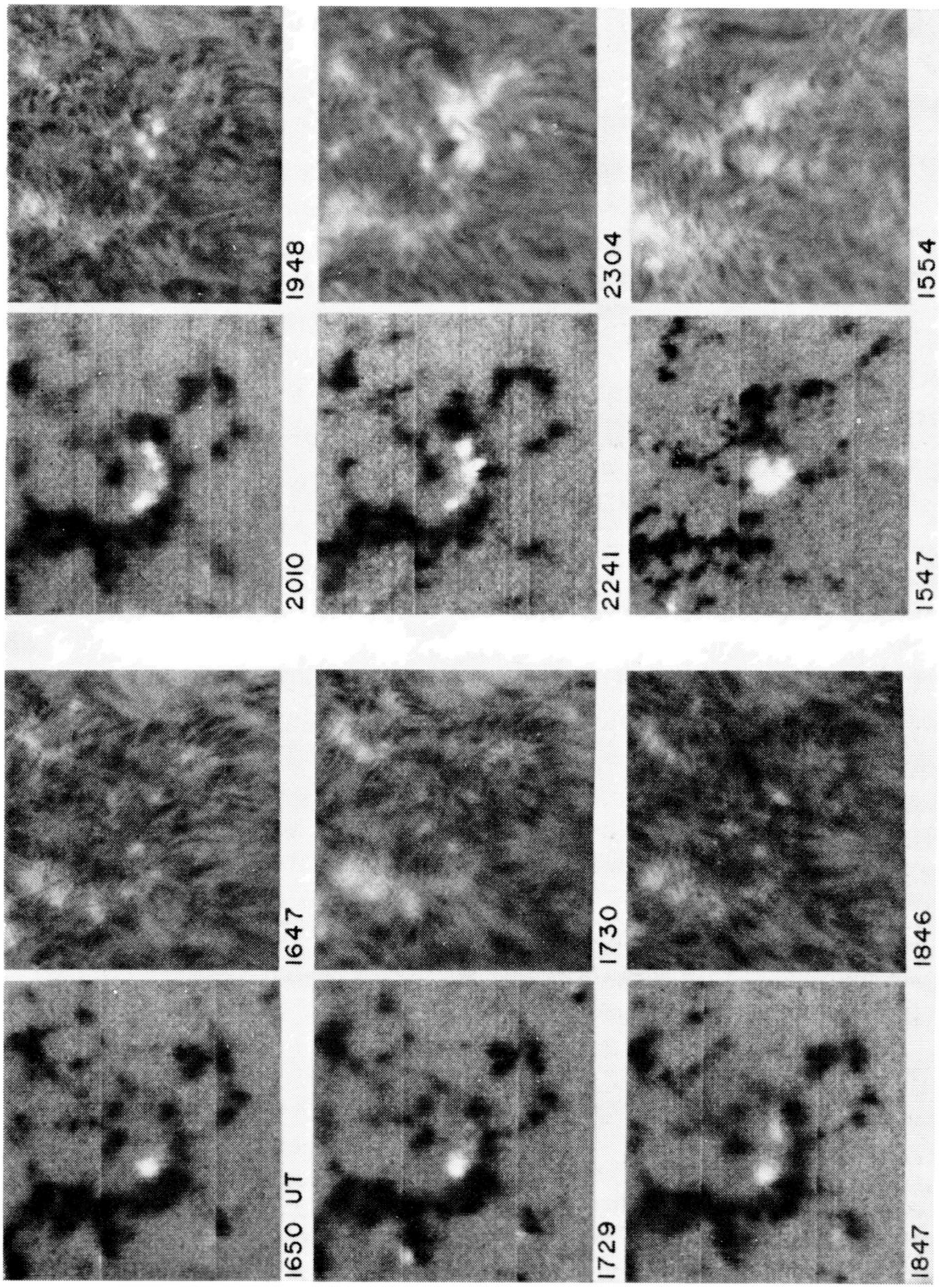

Fig. 2. This sequence of magnetograms and Hα filtergrams shows the emergence and initial development of Region 1 during 30 October 1970 and its appearance on 31 October 1970 in the last frames. This region was the largest of the 8 emerging ephemeral regions. The display saturates at 150 G. Each frame is 8.4×10^4 km high.

2.4. Birth and initial development

The sequence of magnetograms and Hα filtergrams in Figures 2 and 3 show the emergence of two of the eight emerging ephemeral regions. We have not observed the emergence of a larger active center at Kitt Peak and, therefore, we cannot relate the birth characteristics of the ephemeral active regions to those of major active centers. However, Bumba *et al.* (1968) have suggested that initially the development of the regions of Zürich classification C or greater is the same as for simpler regions.

All but two of the eight regions emerged outside existing active regions (e.g., Regions 1 and 3, Figure 1). The two regions located in active regions emerged about 16000 km from the outer edge of the penumbra of the leader spots (e.g., Regions 2 in Figure 1).

The eight ephemeral regions first emerged as bipolar regions adjacent to rather than co-spatial with existing network fields. Contrary to the observations of Bumba and Howard (1965), none of the ephemeral regions formed at the supergranule boundaries as inferred from the distribution of network fields. However, it is possible that there are inherent differences between ephemeral active regions and the larger active regions studied by Bumba and Howard which might cause this discrepancy. The emergence of the regions was accompanied initially by little change in the distribution of nearby magnetic fields. However, during their subsequent development, the regions often expanded into pre-existing network fields. As the regions developed and expanded, we observed a strengthening of the initial bipolar configuration and the appearance of fine structure in the magnetic fields. The tendency to increase in complexity occurred very soon after the regions' birth due to the emergence of new areas of flux (poles) in and near the region, as for example in Region 1, Figure 2.

The subsequent emergence of new but stronger poles in the leading or following polarities resulted in an apparent rotation of several tens-of-degrees in three of the emerging ephemeral regions. For example, Region 1 (Figure 2) and Region 4 (Figure 3) showed an apparent rotation of 30° and 60°, respectively, in a period 1.5 h due to the development of a second but stronger pole in the leading portion of the regions. The apparent rotation of a region resulting from new emerging flux has been suggested previously by Weart (1970, 1972) and by the observations of Harvey *et al.* (1971) and Frazier (1972). The emergence of a region with an inverted polarity configuration or high inclination did not appear to be a necessary condition for rotation to occur. Of the five regions which showed no apparent rotation, four regions emerged and developed with an inverted polarity configuration, e.g., Region 3 in Figure 1 and Region 5 in Figure 3. Region 6 had the proper polarity configuration but an inclination of 55° to its line of constant latitude. There was no tendency for the regions to emerge with any preferred orientation.

2.5. Region expansion

As the regions develop, the borders and poles expand and separate with time. In Figure 4 we have plotted the positions relative to surrounding network fields of the

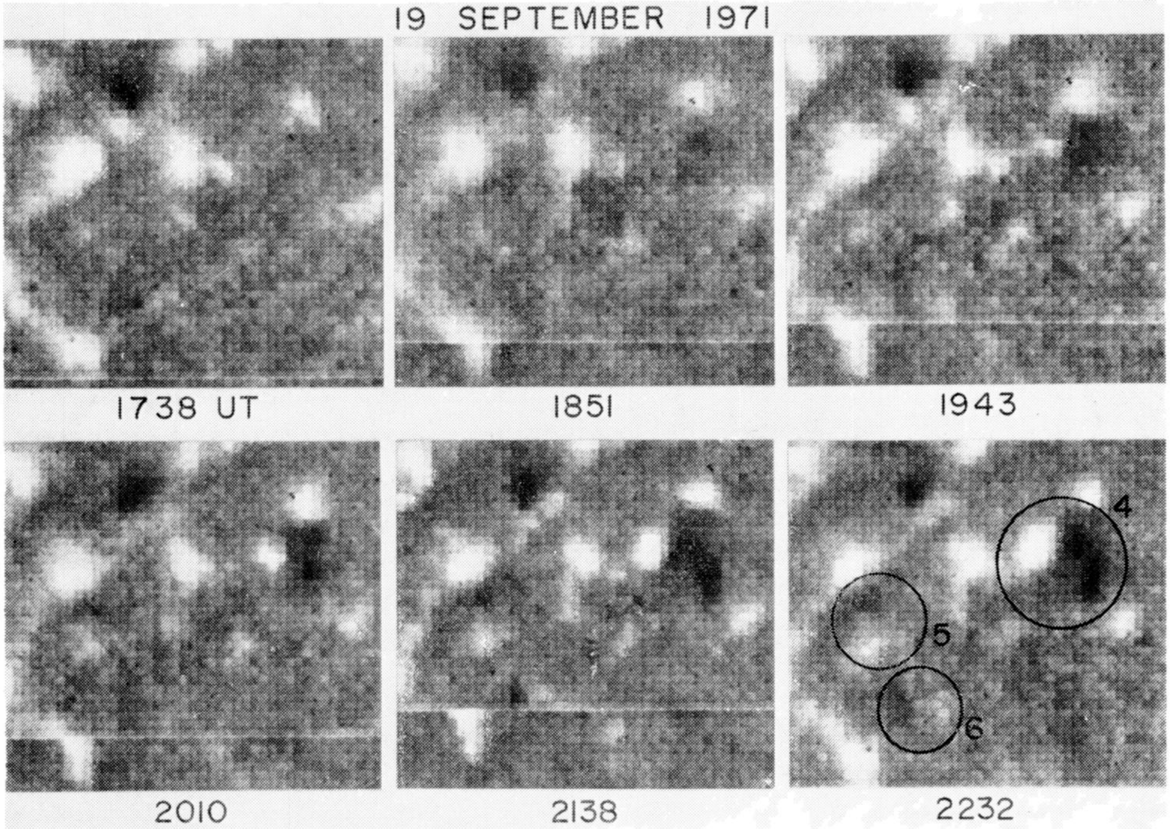

Fig. 3. Region 4 emerged and developed with an inverted polarity configuration. The $\lambda 5173$ Mg I magnetograms also show the development of Region 5 and 6 at a distance of about 41000 km from Region 4. The display saturates at 150 G. Each frame is 7.25×10^4 km high.

individual poles of three of the emerging regions as a function of time. The maps clearly show the separation of the poles as the regions develop. The individual poles move with an average velocity of 0.5 km s^{-1} (range 0–0.7 km s^{-1}) relative to the network. This is higher than the velocities of magnetic knots observed in a young region by Frazier (1972). The displacement of individual poles appears to be partially inhibited by the proximity of network fields, e.g., the following poles in Region 1 move through a smaller distance than the leading poles.

Based on our measurements of the area and dimension along the major axis of the regions, the rate of expansion appears to decrease from birth. The observations suggest that in the first few minutes after the region's emergence, the expansion rate (along the major axis) is the order of 5 km s^{-1}. This value agrees with the velocities observed by Sheeley (1969) in the separation of CN bright points in the first 30 min after their appearance.

From about 30 min to 6 h after emergence, both the area and dimension along the major axis of all the regions appear to increase at a constant rate. The expansion rate along the major axis ranged from 0.7 to 1.3 km s^{-1}. Similar velocities have been reported in emerging regions by Vorpahl and Pope (1972). As shown by the example in Figure 5, the borders of this region were separating at a rate of 1.3 km s^{-1} during this interval. However, by the next observing period nearly 24 h after its birth, the

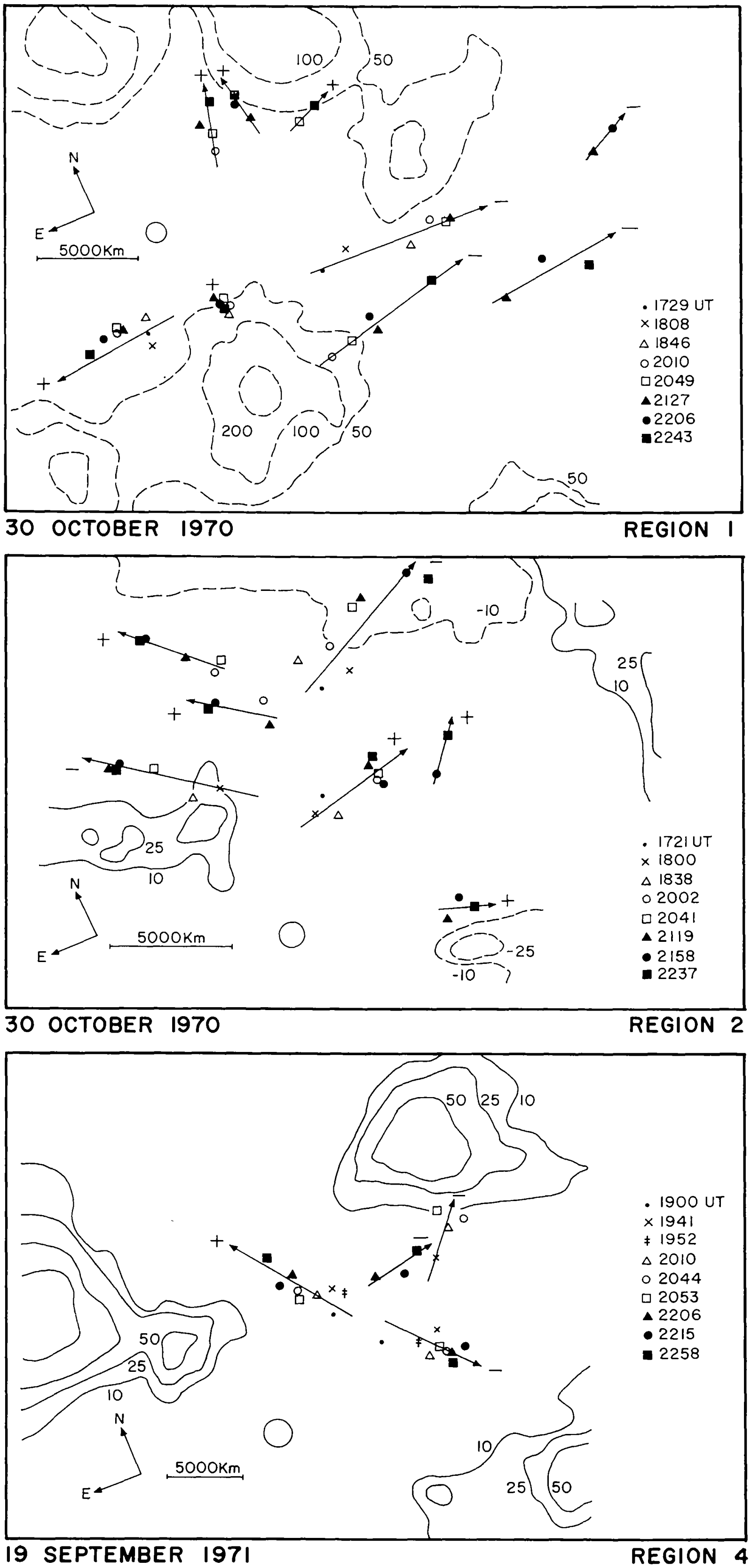

Fig. 4. The motion of the individual poles during the development of Regions 1, 3, and 4 are shown relative to surrounding network. The circles indicate the estimated errors of a single position measurement. The sign of the poles is indicated with a + or −. The contours of the surrounding network have been drawn in, the dashed line indicating negative polarity and the solid line positive polarity. The contour levels are indicated in G.

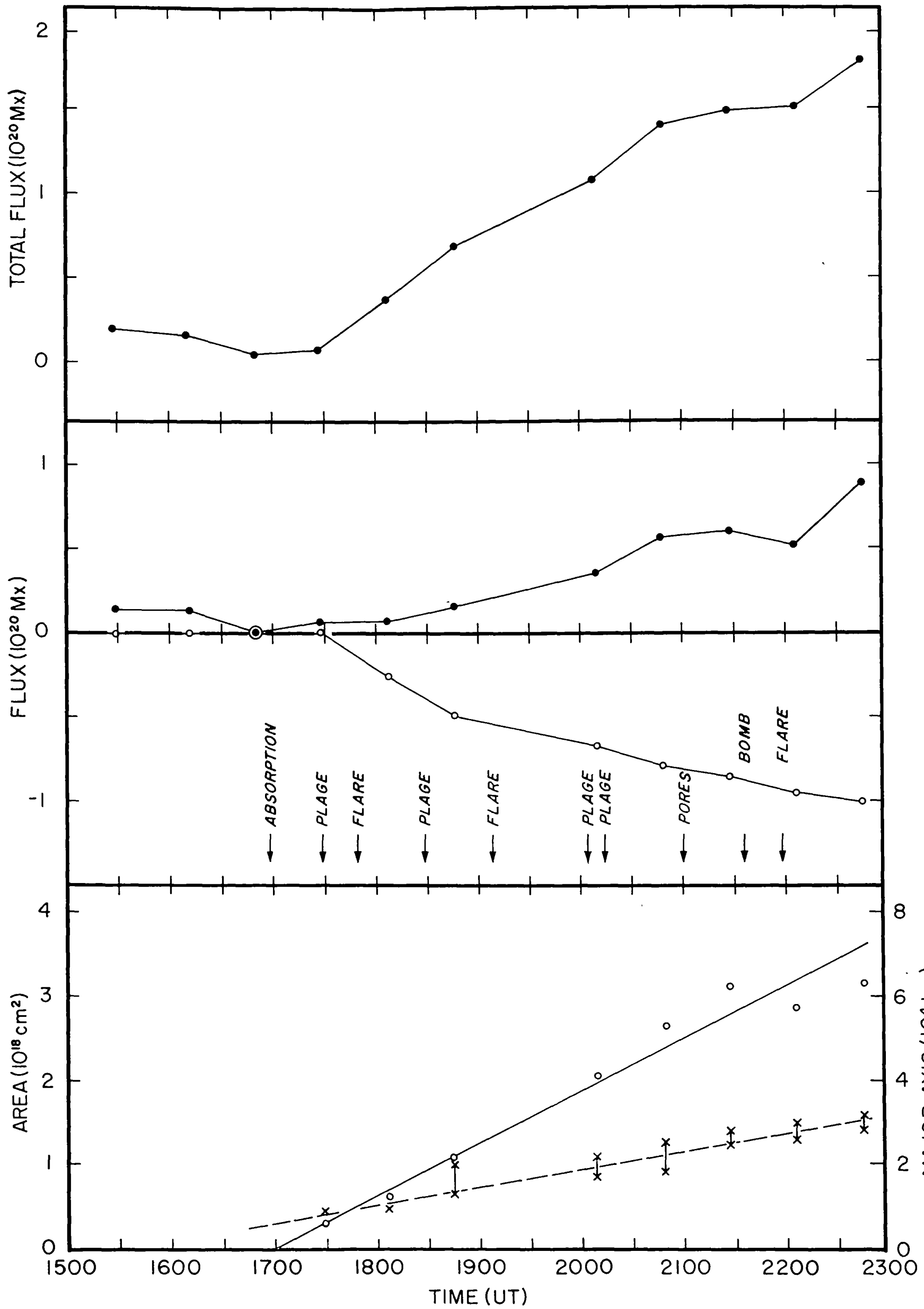

Fig. 5. The typical growth observed in the emerging regions is illustrated by Region 1 (in Figure 3). The *bottom graph* shows the increase in area (solid line) and dimension of the major axis (dashed line). The bars show the spread of two separate measures of the major axis. The *middle graph* shows the positive and negative flux with an estimated noise 8×10^{18} Mx. The Hα development is shown, the arrows indicating the start of each event. *Plage* designates a brightening and expansion of the Hα plage. *Flare* is the start of a sub-flare in each case accompanied by a surge. *Pores* were first observed in white light 4 h after the region emerged. The *top graph* shows the increase in total flux ($|\phi_+| + |\phi_-|$). The estimated noise is 10^{19} Mx.

region's borders were separating at a rate of only 0.2 km s^{-1}. This reduced velocity is consistent with the expansion velocities measured in growing regions by Bumba and Howard (1965) and Sheeley (1966, personal communication). The reduction of the rate of expansion has been observed in emerging Hα regions.

2.6. Magnetic flux

We have measured the flux (ϕ) of the eight emerging regions observed from birth by calculating ϕ_+ and ϕ_- in an area containing the emerging region. The observed change in flux over the specified area as a function of time was assumed to be due to the emergence of the region. The noise level in the ϕ measures is 5×10^{18} Mx. All eight regions show an approximately linear increase in flux during their initial development. As an example, the positive and negative flux, (ϕ_+ and ϕ_-) and total flux ($|\phi_+| + |\phi_-|$) are plotted as a function of time for Region 1 in Figure 5.

An extrapolation of the flux to the background level yields a time of emergence consistent with that extrapolated from the area curve. A decrease has been noted in the flux prior to the emergence of the region which appears to be due to a breakup or apparent fading of some of the opposite polarity network immediately adjacent to the emerging region. The total flux appears to increase approximately linearly; the flux density also increased during our observations indicating we are detecting the emergence of new flux. Both results agree with Wiehr's (1970) observations of flux and flux density in a growing region. The ratio of flux to area for the eight new regions ranged from 30–50 G at about 5 h after their birth. Wiehr's measurements give a flux density of 270 G for a region approximately 2 days old. Sheeley (1966) found, for regions at maximum development, a flux density of about 1200 G.

2.7. Hα development

We have been able to study the Hα development in relation to the magnetic field development for the five of eight emerging ephemeral regions for which we have simultaneous high-resolution (1–2″) Hα filtergrams. For the other three regions, only Hα patrol observations (resolution ≈5″) were available. In these latter cases only, there was no detectable Hα active center. We presume that the lack of detectability was due to inadequate resolution since all 30 of the 36 ephemeral regions, for which high-resolution Hα filtergrams were available, were associated with small plages in Hα.

Only one region showed the short-lived appearance of Hα absorption prior to the formation of plage. The absorption feature appeared coincident with the emergence of the longitudinal magnetic field. This event may be similar to the absorption features preceding the appearance of regions observed by Martres and Soru-Escaut (1971). If absorption structures in Hα map the horizontal field, the absorption features preceding plage formation may result from the initial passage of the region flux tube through the chromosphere.

With one exception (Region 4, Figure 3), Hα plage is first detectable within 30 min after the emergence of the magnetic field. In Region 4 Hα plage forms 2.8 h after the appearance of the magnetic region; based only on Hα observations, however, this region is difficult to recognize as an emerging region.

The development of the regions in Hα was observed as a succession of brightenings, which were often accompanied by surges, each leaving the plage brighter and more extended than before. The intensity and frequency of the brightenings appeared to depend on the rate of flux increase and on the degree and strength of the adjacent network fields. Those regions developing in the vicinity of extensive network generally showed more activity, such as Region 1 and the two regions which developed near sunspots (Region 2, Figure 1). Anomalous poles in close proximity to sunspots have been found to be the site of frequent flares and flare-surges (Rust, 1968, 1972; Rust and Smith, 1969; Zirin, 1970; Vorpahl, 1973).

Arch Filament Systems (AFS) usually observed in emerging regions (see for example Bruzek, 1969), could not be positively identified in the five emerging ephemeral regions for which we had good Hα pictures during their birth. A possible AFS may have formed in Region 1 about 6.5 h after it emerged (total flux $\approx 2 \times 10^{20}$ Mx) and about 3.5 h after pores were first observed. AFS were observed in only four of the 30 ephemeral regions for which corresponding Hα observations were available. These four regions were growing and had a total flux exceeding 1.5×10^{20} Mx. When the AFS were observed, the major axis of the four regions was about 22000 km consistent with the observed length of AFS (Bruzek, 1969; Weart, 1972). These observations suggest that a minimum total flux ($\approx 1.5 \times 10^{20}$ Mx) may be necessary to support an arch filament system.

3. Discussion

The ephemeral active active regions appeared at an average rate of 1 region per 6 h within an area of 1.2×10^{11} km^2. This rate is consistent both for the 8 regions which emerged during our observations and for the 28 regions which emerged overnight. The significance of this number depends on the distribution of the ephemeral regions in time and location over the solar surface during the solar cycle and on what ultimately happens to the flux in the ephemeral regions.

On the basis of our magnetograms we can say nothing about the overall spatial distribution of the ephemeral regions. We have, therefore, examined several-day sequences of full disk magnetograms (2$''$.5 resolution) taken at Kitt Peak during 1971, 1972, and 1973 (made available to us by J. Harvey and W. Livingston). Most of the ephemeral active regions identified on the full disk magnetograms were located well outside the strongest active centers. About as many of the regions emerged within the boundaries of old and widespread active centers as occurred in areas of the quiet Sun. As an example, an ephemeral region shown in Figure 6 emerged at a latitude of N40. We also examined the distribution of short-lived (1–2 day) calcium plages identified by McMath-Hulbert Observatory from 1966–1972 (*Solar-Geophysical Data*) and found that ephemeral regions can be observed at any time during the solar cycle at nearly any position between latitudes N55 to S55.

To estimate the number of ephemeral regions that may emerge in a day, we have

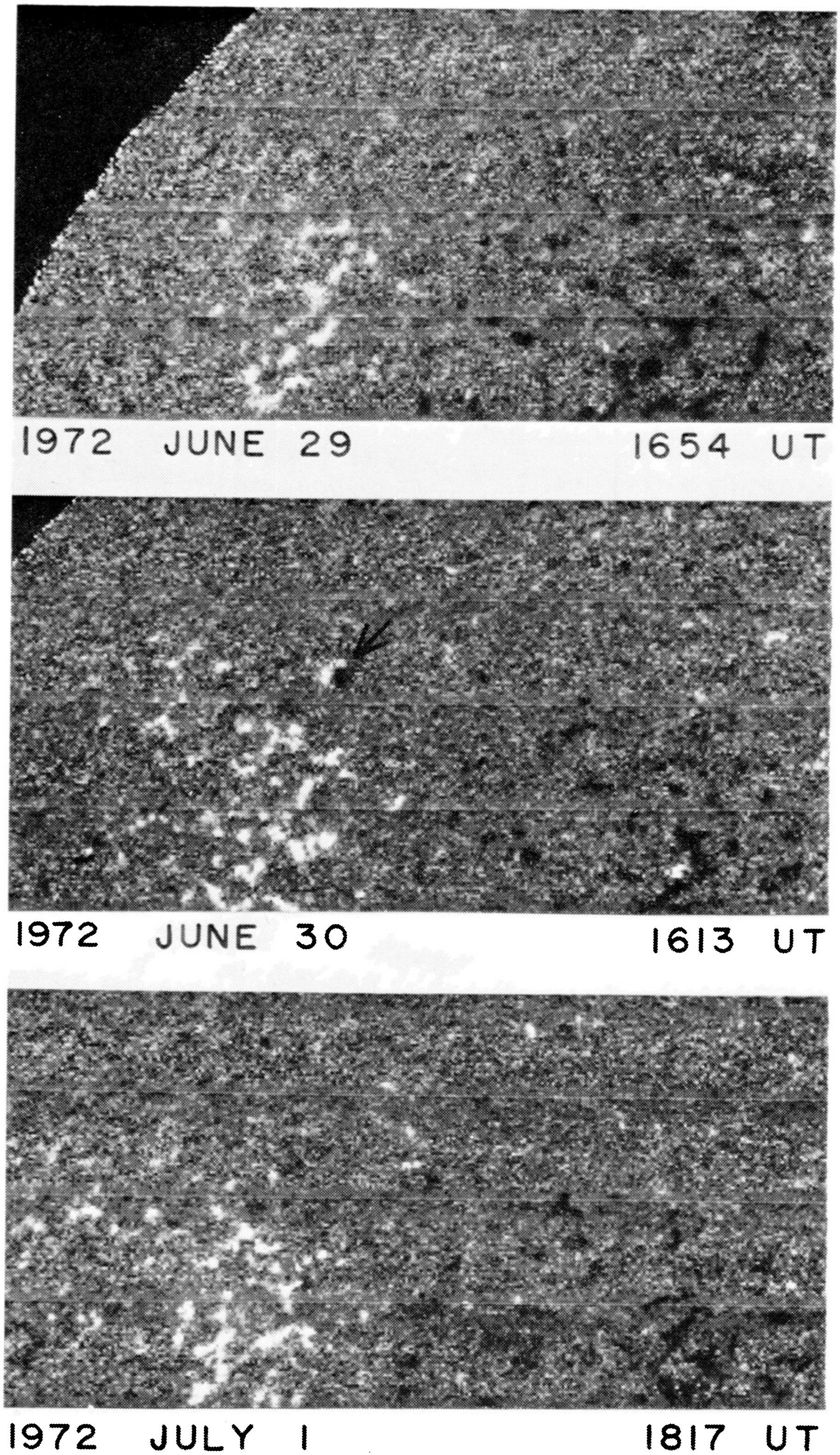

Fig. 6. The sequence of three magnetograms north of the sunspot latitudes shows an ephemeral active region which developed prior to the observation on 30 June 1972 at N40. Each frame is 2.9×10^5 km high.

assumed that the *observed* rate of occurrence persists over the entire sunspot zone between $\pm 30°$. Under these conditions, we would expect about 100 ephemeral regions to form per day, consistent with Sheeley's observations (personal communication). This rate appears to be further confirmed by a study now in progress of ephemeral active regions based on the daily full-disk magnetograms now being taken at Kitt Peak. Since the average total flux of an ephemeral region is about 10^{20} Mx, we infer that about 10^{22} Mx would appear per day in the form of ephemeral regions. According to Sheeley (1966) a 'typical' active center has a total flux of about 2×10^{22} Mx; Weart (1972) and Glackin (1973) have found that one active center forms per day during the epoch of our observations. It follows, then, that the total flux brought to the surface by the ephemeral regions per day may be the same order of magnitude as for the larger active centers during solar maximum.

If the above estimates are correct, it becomes important to determine what happens to the ephemeral region flux. We have not observed the actual disappearance or death of an ephemeral region. If the ephemeral region flux is dispersed by the processes described by Leighton (1964) and Smithson (1972) and indicated by the observations of Bumba *et al.* (1968), the ephemeral regions certainly become a significant contributor to the flux observed on the solar surface. If, on the other hand, the region flux disappears by the submergence of the flux tube or by annihilation, the long-lived flux produced by the ephemeral regions may be small in comparison to the long-lived flux spread over the solar surface by the major active centers.

How the rate of occurrence varies with the solar cycle we cannot answer with our observations. However, in order to see whether the number of ephemeral regions changes over the solar cycle, we have plotted from *Solar-Geophysical Data* the number of calcium plages reported by McMath-Hulbert Observatory from 1957 through 1972. We have divided the data into two groups: (1) those which are called 'ephemeral' or are reported as having a lifetime of 1 day, (2) all other plages reported as 'new' and having lifetimes of greater than 1 day. Since the data are biased towards the larger and longer-lived magnetic regions, we do not expect to find large numbers of ephemeral plages reported. In Figure 7, these two groups are shown below the sunspot numbers for this period.

It appears that the number of ephemeral regions maximizes during solar minimum. We do not attribute any significance to the increased number of ephemeral plages reported at sunspot minimum because these small plages are probably easier to identify when the disk is relatively absent of large and long-lived active centers. The graph does show, however, that the number of active regions, whether large or ephemeral, does not reflect the solar cycle as represented by sunspot numbers. From this, we infer that with observations of high resolution, ephemeral magnetic regions can probably be observed in large numbers any time during the solar cycle. During solar minimum, the ephemeral regions may be even more significant.

Our present observations are not sufficient to determine the processes by which the ephemeral region flux is dispersed or disappears. Further studies of the velocity pattern and magnetic field are needed to determine interaction of the velocity patterns of

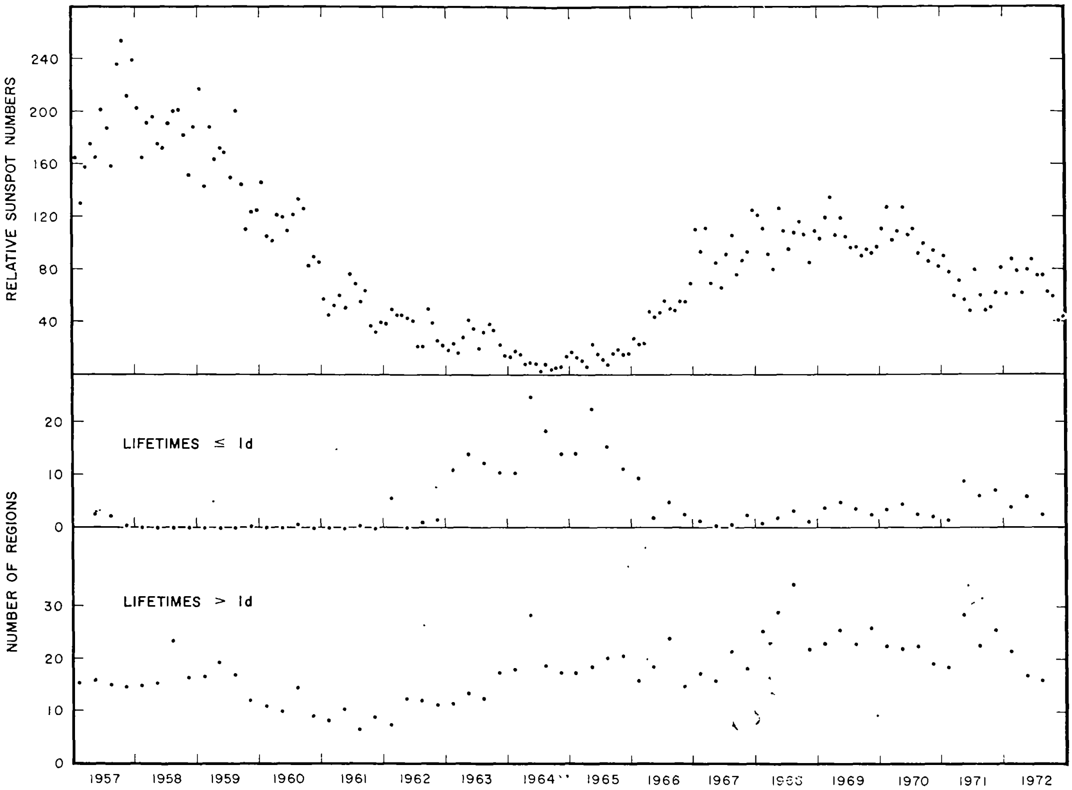

Fig. 7. The number of ephemeral active regions (having lifetimes <1 day (*middle graph*) and active centers with lifetimes >1 day (*bottom graph*) averaged over 3 month intervals is plotted in relation to the monthly relative sunspot numbers (*top graph*).

ephemeral regions with supergranulation both during their formation and dispersal and to determine the importance of the ephemeral regions as a source of flux.

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