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QUANTIFICATION OF BIRD MIGRATION - DIFFERENT MEANS COMPARED

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Swiss Bird Radar

ABSTRACT

The paper briefly reviews and valuates the methods used in the past to quantify bird migration and presents the results of a recent comparison of three methods. Combined observations by telescope in front of the moon, by passive infrared, and by a pencil-beam radar provided the possibility to calibrate the different means against each other, making use of the specific advantages of each of them. The paper emphasizes the limitations and advantages of the three methods and provides correction factors to render the results comparable within the defined limits.

Key Words: Radar, infrared, moonwatching, quantification of bird migration

INTRODUCTION

Quantification of bird migration is an old aim of ornithological research. During the last decennia it obtained increasing importance for practical purposes, such as the estimation of population trends or the estimation of collision risks between birds and aircraft.

Longterm trends in populations may be detectected by standard capturing sites (e.g. Berthold et al. 1986). For large diurnal migrants standardized and coordinated visual observations may provide some cues (e.g. Bijlsma 1987). Visual counts from the ground may be complemented by counts from aircraft and by radar observations in order to reach a more coherent view and information on high altitude migration (Leshem 1988). Catching birds in actual migratory flights on Alpine passes is a valuable means to obtain data on the diurnal and seasonal pattern of passerine migration per species (Dorka 1966, Jenni 1984). The seasonal and diurnal pattern of migration are important means to predict the times with highest collision risk. Additional information is needed about concentrations of migration in certain areas (due to topography), at certain times (due to weather), and at certain heights; all this is best shown by radar (Buurma & Bruderer 1990). Radar can also help to provide actual bird warnings for pilots, particularly if automatic quantification of bird densities is available (Buurma, this volume). Radar is especially important for the observation of nocturnal migration, being in many respects superior to other means, such as recording calls, observation by telescope against the moon or along a light beam, by light amplification equipment or by active and passive infrared.

The radar's superiority is, however, often too easily accepted and questions about the significance of the output too often neglected. Very often the acquired data help to reduce bird strikes, in spite of the fact that they do not show real numbers and distributions of birds. They provide the data which passe the numerous filtering effects of the different radars and may be transformed into improved information by interpretation, but only rarely do they provide real bird numbers. Therefore, this paper aims in a first part to briefly recall some of the basic limitations of radar observations for quantitative studies on bird migration; in a second part it reviews some important papers attempting quantification of nocturnal migration by radar and other means. In a third part it compares different optical means with a pencil-beam radar and concludes by defining the advantages and disadvantages of these methods.

1. RADAR QUANTIFICATION OF BIRD MIGRATION

The standard book on radar ornithology is still the one by Eastwood (1967) and in fact it describes nearly all the problems of radar quantification which still hamper our research, such as the properties of the bird targets (horizontal and vertical distribution, size, aspect, grouping, reflectivity and its variation in time) and the equipment characteristics (horizontal and vertical performance diagram of the radar beam, pulse volume, sensitivity of the equipment according to the radar equation, display limitations). One might add the recording technique as an essential end piece of the chain. Eastwood also emphasizes the effect of wave-length on the radar cross section of targets with a circumference close to the wave-length. The practical conclusion which has to be derived from his theoretical explanations is that the radar cross section of targets with a circumference corresponding exactly to the wave-length is most strongly increased (by interference of waves which are directly reflected and curved around the small object, respectively; Bruderer 1969, Buurma & Bruderer 1990). Due to the same effect, the radar cross section decreases with the 6th

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Suggestions to replace photo recording by electronic counting of echoes on surveillance radars were first made by Houghton (1971) and by Clausen (1973). Important suggestions to use such information in an operational environment and to combine it with data received by vertical-beam or height finder radar were presented by Hunt (1973, 1974, 1975, 1976). The idea was further developed in the Netherlands, where the KIEVIT was the solution of the 80th (Buurma 1984) and where the ROBIN system reached highest level of electronic assessment of migratory intensity (Buurma, in press and this volume). However, even this system which is highly efficient in reducing bird strikes of the Royal Netherlands Air Force, does still not provide real bird numbers. Considering the effect of this system on bird strike reduction, it is obvious that real bird numbers are not essential from an operational point of view, but the scientific aim remains.

2. QUANTITATIVE STUDIES OF NOCTURNAL BIRD MIGRATION

2.1. Moonwatching and flight-call counting

A fundamental introduction into quantitative studies by telescope in front of the moon was presented by Lowery (1951). Lowery & Newman's (1955) comparison of moonwatching and flight-call counting indicated that there is often an inverse relationship between the numbers provided by the two methods, suggesting that the auditory method might be restricted to birds close to the ground, while the visual method might improve (up to the visibility limit) with the distance dependent increase of the observation cone and with the elevation of the moon. In a well organized campagne of moon-observations in large parts of the United States, Lowery & Newman (1966) manged to obtain an encouraging continentwide view of relative intensities and directions of migration. The disadvantages of this method are, 1) that the surveyed space per observer is extremely small, 2) that it is restricted to (nearly) full moon phases and clear sky, 3) that calculation of migration traffic rates (MTR) is often based on the assumption of a uniform vertical distribution of birds up to a ceiling of 1500 m. Neither the uniform distribution nor the constant ceiling correspond to reality. The effect of such assumptions on the results has to be checked (Liechti et al. in prep.). Russian observers (Bolshakov 1985) suggested an improvement of the method by estimating the size of the silhouttes seen in front of the moon. However, there was no real calibration of the silhouette sizes versus distance, and the range of visibility was overestimated considerably (see below).

2.2. Visible light beams and infrared

The old light houses, using permanent light beams (before the second world war) were famous to attract nocturnal migrants in foggy nights, and by this to show at least part of the nocturnal activity (Drost 1960). Graber & Hassler (1962) demonstrated that migrating birds could be counted in a powerful narrow light beam. Gauthreaux (1969) took up this idea and developed a portable ceilometer for studying low-level nocturnal migration. According to his calibration, all birds could be seen by a 20-powered telescope up to 300 m, most birds up to 450 m, large passerines up to 700 m. At close ranges the light beam is, however, often contaminated by dust and/or insects, a fact which made us dismiss this method in our experiments in the Negev (own unpubl. data). Gauthreaux (1979) improved the method by adding an electronic image-intensifier; thus obtaining migration traffic rates which were well correlated with simultaneously gathered moonwatch data, and suggesting that the range of the system was at least doubled.

Active infrared can be used to observe the behaviour of birds at close distance, such as their behaviour when confronted with mist-nets (own unpubl. data); observation of migrants at distances beyond 100 m is, however, barely possible.

Buurma (1986, 1988) suggested the use of passive infrared (thermal camera or heat picture camera) in combination with a tracking radar. Observing the radar tracked birds by the thermal camera provided information on visibility limits. Thrushes became visible at about 1 km at the beginning of the night and at low levels. This maximum distance increased to about 2 km in the colder parts of the night and at high elevations due to the better heat contrast against the upper parts of the sky and increased radiation of the birds when seen from below. Buurma (1988) made also first promising experiments to use the thermal camera vertically upwards, but in this case did not use the combination with radar.

2.3. Surveillance radars and comparison with visual observations

The normal procedure to quantify bird migration on a surveillance radar is to compare the actual appearance of echo density (usually recorded by photographic means) to an arbitrary reference scale, as first suggested by Sutter (1957) and Lack (1959). Gehring (1963) published a standardized scale for diurnal migration which was extended to nocturnal migration by Steidinger (1968). The method was later adopted by many authors and is still a valid approach to describe relative variation in the appearance of echoes. It is, however, important to bear in mind that the number of echoes appearing on the screen is influenced by all the effects of radar equipments and target properties mentioned in the introduction. Neglecting size and clumping of the birds, the changes in the vertical distribution of targets are probably the most embarrassing source of changes in the non-density-dependent appearance of echoes on the screen. Important parts of migration may fly above or below the most sensitive parts of a radar beam according to weather and time of day. Evans (1966) and Buurma (1984) described visible diurnal migration and migration detected simultaneously by radar as complementary.

Eastwood (1967) stated: "One swallow does not make a summer, neither does it make an agel." The larger the pulse volume of a radar the more targets are artificially combined into one echo; the more the birds are in flocks, the more biases occur also in radars with small pulse volumes.

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First attempts to correlate echo densities with numbers of birds or flocks were those suggested by Sutter (1957) and Gehring (1963) using direct visual observation for diurnal migration and those for nocturnal migration by Graber & Hassler (1962) using a light beam, and by Nisbet (1963) using moonwatch data. In spite of the good idea and excellent procedure, Nisbet's attempt had to fail, because he used 23-cm radar and, unfortunately, most small passerines are not visible by L-band radars. Gauthreaux (1970) used two scales (one for diurnal and one for nocturnal migration) on a 10-cm WSR-57 weather surveillanc radar and calibrated them against moonwatch data or ceilometer observations at night and by a vertically mounted telescope during the day. Saturation of the radar was compensated by a calibrated attenuation procedure. The methods were again described and extended to airport surveillance radars by Gauthreaux (1975, 1977). This comparisons were an important step forward, but the accuracy of the calibration was limited by the limitations of visual methods, which was still to be determined (see below) and by the spatial restrictions of the visual samples (see above). Alfiya (1990) tried to overcome the spatial restriction by flights with light aircrafts equipped with a light beam, flying at different altitudes perpendicular to the main stream of migration. All these methods improved the interpretation of radar data, but cross-checking different means by direct comparison of equal volumes of space was still lacking (see below).

2.4. Pencil-beam radar and calibration by visual means

Eastwood (1967) described the use of vertical-beam radars, including photographic recording of the Z-modulated A-scope by a slowly moving film. Bruderer (1971) applied these methods intensively to monitor the distribution of bird targets in time and space; in order to cover the lowest levels, a beam at low elevation angle perpendicular to the main direction of migration was used. Two steps to eliminate insect contamination were applied, and an average antenna diagram for birds of 8 cm^2 radar coss section to compensate for the distance dependent changes of the surveilled space was used. However, the system was not calibrated by comparison with visual means. In order to increase the surveilled space, vertical scanning perpendicular to the principal direction of migration (Bruderer 1980) and conical scanning at different elevations were used later (Bruderer 1992, Bruderer et al. in press a).

Gauthreaux (1984) combined a low-powered 3-cm surveillance and vertical-beam radar with his vertically looking visual system which integrated image intensifier, video camera, and ceilometer. He was able to display the vertical-beam information of the radar and of the visual system simultaneously on the same TV-monitor. According to the specifications of the system (see above) the operational range of this combined system for nocturnal passerine migration was mainly within one kilometer.

3. THREE METHODS OF QUANTIFICATION IN A DIRECT COMPARISON

3.1. Methods

The tracking radar "Superfledermaus" was used in a standard 24-hrs programm to surveille the spatial distribution of migrating birds in southern Israel during spring and autumn 1991/92 (80 days and nights per season). A quantitative measurement was done every second hour at least throughout the night and morning by conically scanning the sky at nine elevation angles, thus covering a half-sphere of 6 km radius around the radar (Bruderer 1992, Bruderer et al. in press a).

In spring and autumn 1992 a second radar of the same type could be used for additional experiments at the same site. A 40-x telescope (KOWA TSN2) and a passive infrared camera (LORIS, IRTV-445L produced by Inframetrics) were mounted at the antenna support, parallel to the pencil-beam of this experimental radar (Liechti et al. in prep.). The infrared picture was transferred to a TV-screen next to the radar operator. The nominal opening angle of the radar beam was 2.2°, the opening angle of the LORIS was 1.1°, the angle which is observable by telesope in front of the full moon is 0.5°. During full moon phases, the three nearly concentric "beams" were aimed at the moon. For the radar/LORIS comparison the beams were directed vertically upwards. For all birds reported by the moonwatcher or recorded by the LORIS, the distances were recorded immediately by the radar operator. The size of the birds' silhoutte was assigned to one of three classes (large - medium - small) independently by the moonwatcher and on the LORIS screen (Liechti et al. in prep.).

By the direct combination of methods it was possible to determine on the one hand the range of moon and IR observations and on the other hand the operational opening angle of the radar. In the vertical radar beam all passerine birds (exposing large radar cross sections from below) were detectable at least up to distances of 4 km. The comparison with the optical means was confined to 3 km.

3.2. Results of the comparison

IR versus radar: The proportion of birds seen by radar and IR did not change with distance between 0.5 and 3 km, indicating that the IR system was able to detect all birds up to at least 3 km when seen from below against the cloudless zenit. According to the opening angles of the two systems a proportion of 50% should be visible in the IR compared to the radar. The observed proportion was, however, about 25% (Liechti et al. in prep.). As the cone of the IR is exactly defined, while the relatively long-waved radar energy is also scattered outside the 3-dB points used to define the antenna diagram, we concluded that the operational beam-width of our radar is about double the nominal beam width at the close ranges which are relevant for birds. This conclusion forced us to adapt the first calculations of bird densities in Israel. All the reports and publications after the first preliminary report by Bruderer (1992) comprise values based on the operational instead of the nominal beam-width (e.g. Bruderer 1994, Bruderer et al. in press a, b).

Moonwatching versus IR and fixed-beam radar: Birds crossing the disk of the moon were easily detected on the IR-screen, when approaching the disc of the moon which covered almost half the diameter of the screen. Even experienced moonwatchers saw not all the birds which were seen to cross the face of the moon by IR. Within 1 km distance (measured by radar) they saw about 80% of the birds. This proportion decreased to 50-60% between 1 and 2 km distance and to 30-40% between 2 and 3 km (Liechti et al. in prep.). This indicates that moonwatchers miss on the one hand some birds passing at the edge of the moon, on the other hand there is a distance-dependent decrease in detectability, which reduces the detectability of bird migration by moonwatching to altitudes which are defined by the visibility range and the elevation angle of the moon, thus mainly below about 1 km AGL.

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3.3. Conclusions

Moonwatching is a method which uses simple equipment and can be applied by anybody, thus, allowing coverage of large areas where there is no radar coverage. According to the elevation of the moon and the detection probability decreasing with range (50% probability around 1500 m), the method covers mainly altitudes below 1000 m AGL and depends considerably on the capabilites and training of the observers. Even trained observers seem to miss about 1/4 of the birds within a distance of 1000 m, due to birds moving too quickly across the edge of the moon. Migration traffic rates (MTR) can roughly be estimated and flight directions calculated by a fairly complicated procedure. The calculation of MTR can be improved and rough estimates of altitude distributions obtained by defining size classes of the targets seen. If three size classes (and by this three distance classes) are defined, a first approach would suggest to correct the counted numbers by a factor of 1.25 for large targets (up to 500 m), by a factor of 2 for medium targets, and by a factor of roughly 3 for small targets. The monthly observation time is confined to 5 (max. 10) nights according to the moon phases, and is further limited by clouds.

Heatpicture/passive infrared: This method depends mainly on the equipment used. Most equipments suffer from a limited depth of focus, some of too long recovery time of the image, some of a wrong "window" of wavelength, and some of unsufficient resolution. The equipment used was exceptional in minimizing all these limitations. The depth of focus was from below 200 m to infinity. All birds could be detected up to 3000 m against the cloudless sky. Flight directions and ground speeds can be measured and headings (of larger birds) recognized directly on the screen, migration traffic rates (MTR) can exactly be calculated if radar-measured distances per bird are available and can be roughly estimated by using three size classes of targets. No corrections are necessary. Detectability of birds is greatly reduced if the birds are not seen against clear sky.

A *pencil-beam radar* can be used either vertically looking upwards or with any elevation parallel to an infrared equipment or a telescope following the moon. Its main advantage is that it provides distances of the observed targets. Its main disadvantage is that the beam is not optically defined, but depends on the size and reflectivity of the targets. The real beamwidth may be considerably wider than indicated by the nominal beamwidth, particularly at close ranges where bird observations are made. In the case of the "Superfledermaus" radar the comparison with a passive infrared system revealed that the operational beamwidth for average bird targets was about twice the nominal beamwidth. MTRs based on the nominal beamwidth had therefore to be reduced by a factor of 2. Further research has to show whether this factor should allow for distance dependent changes in detectability. A wavelength-dependent problem is caused by the detectability of small targets: in X-band radars there is an important insect contamination at short ranges, while in S-band radars some small birds disappear below detectability with increasing distance due to their situation in the Rayleigh scattering zone. The operational beamwidth and the detection range have to be defined for each type of radar by observations at different elevation angles (see below) and/or by comparison with infrared (see above).

A *conically scanning pencil-beam* covering different elevation angles provides a view of the spatial distribution of bird targets in a half-sphere defined by the range up to which a high percentage of birds can be detected. In the case of observations with the "Superfledermaus" radar, nine elevation angles were used and compared under optimal conditions in the Negev. The comparison provided correction factors for changing detectability according to distance, antenna diagram, aspect changes in the vertical and horizontal plane, and scanning speed (hits per target) (Bruderer et al. in press a).

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Captions to Figures

Fig.1. The quasi-concentric beams of radar, passiv infrared, and moonwatch telescope.

Fig.2. Radar antenna, infrared camera, and telescope mounted on the platform of the "Superfledermaus" radar.

Fig.3. Photographic layout of three birds in front of the moon (which is in reality a very rare case).

Fig.4. The image of the infrared camera was sampled over 5 minutes by a special peak-store unit storing the silhouettes of the birds passing through the vertical beam. The closest bird was 400 m high, the faintest traces were those of birds between 2500 and 3000 m above the radar (which measured the distances).

Fig.5. The A-Scope of the pencil-beam radar indicating the distances. The lower oszillogram shows 15 km total range; a scale marker indicates 10 km; the distance marker is positioned at 3.5 km. The farest recognizable bird echoe is at 5.3 km. The upper oscillogram shows four bird echoes on a zoomed part of 1.6 km (0.9 km to the lefts and 0.8 km to the right of the marker) of the A-Scope.

Fig.6. The Z-modulated A-Scope filmed with a continuously moving film during 1.5 minutes. The height of the film strip covers 4 km. The upper strip (a) shows dense migration, the lower strip (b) weak migration. Close to the radar the bird echoes are bright points, due to the short appearance of strong signals when the birds pass close-by. Farther away the intensity of the echoes decreases, but they remain longer in the beam because of the beam-width increasing with distance.

FIGURE 1: Pencil-beam radar, passive infrared, and telescope aimed at the moon

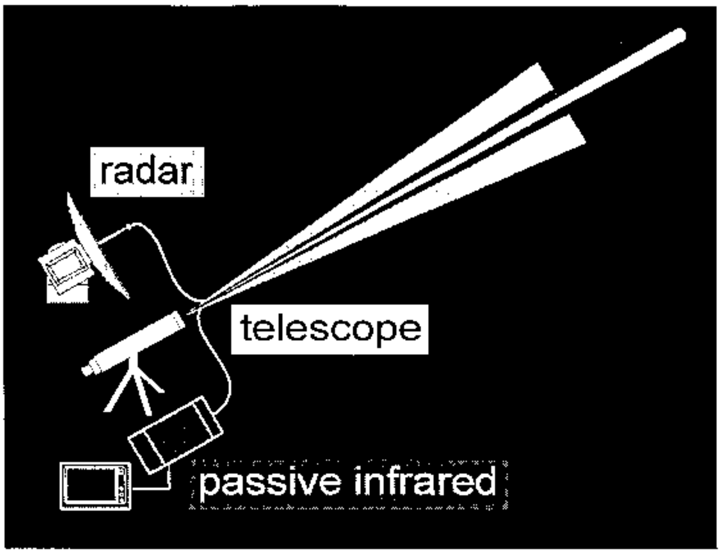

FIGURE 2: "Superfledermaus" antenna with parallel telescope and IR-camera

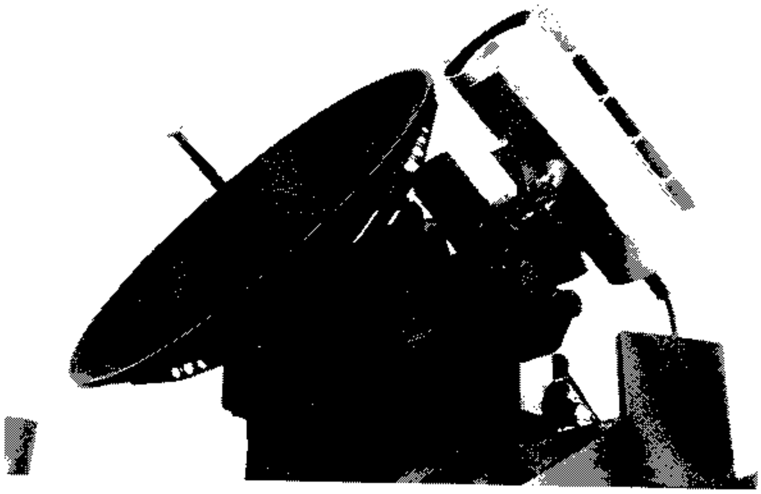

FIGURE 3: Birds in front of the moon

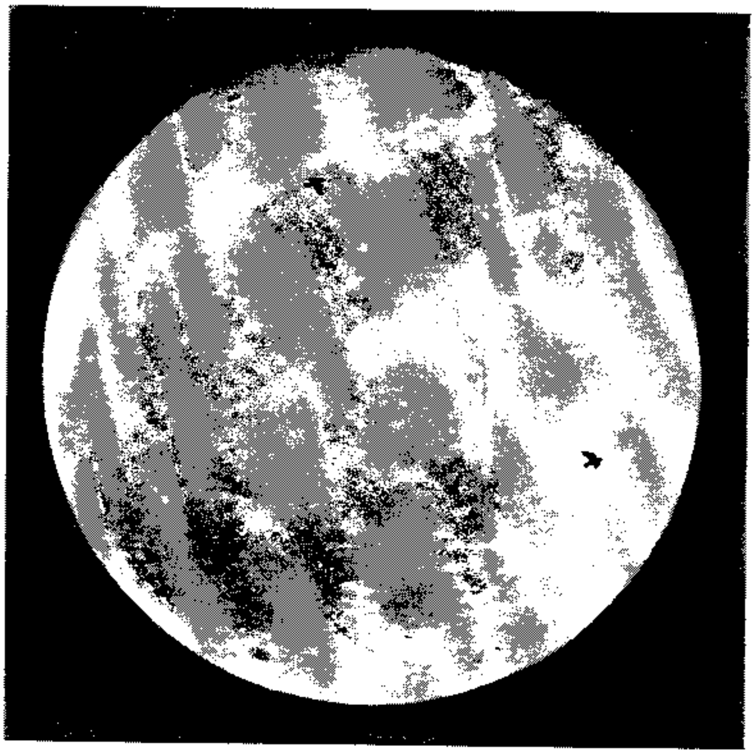

FIGURE 4: Peak store picture of the TV-screen showing thermal images of birds

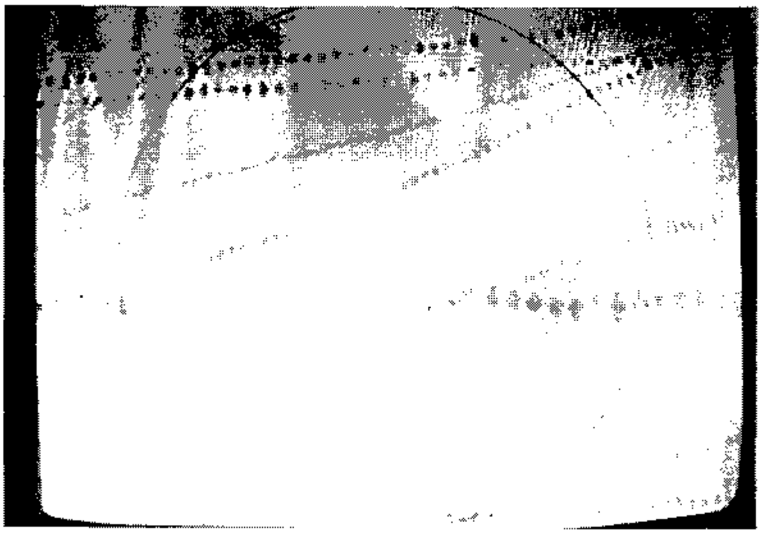

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FIGURE 5: "Superfledermaus" A-scope with several bird echoes

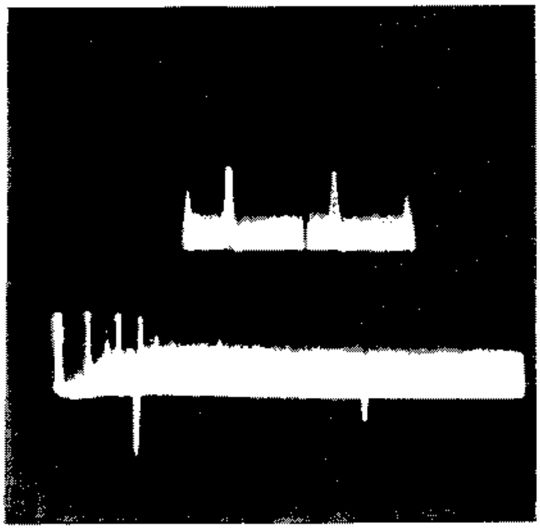
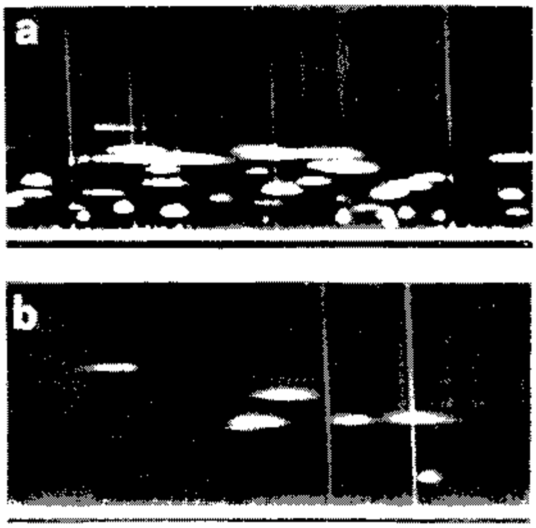


FIGURE 6: 1.5 minutes of continuously moving film taken from 4 km A-scope



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