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Meteor Forward Scatter Studies.

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Meteor Forward Scatter Studies.

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1. Introduction.

This report deals with the operation of a meteor forward-scatter system between sites located near Ottawa, Ontario and London, Ontario, a distance of about 500km. and well over the horizon of line-of-sight communications. The interest in such forward scatter systems has increased in recent times due to improvements in the technical aspects involved in making practical use of the technique. The main limitation of such systems is their inherent low data rate due to the infrequent occurrence of suitably oriented meteor trains from which a signal may reflected on its way from transmitter to receiver. It might be remarked that there are considerable numbers of meteoroids incident upon the earth each day, but the geometrical specular reflection requirements mean that only a small fraction are suitable for the establishment of over-the-horizon communications on a given link.

A meteor train is essentially a column of electrons a few kms in length which occurs at a height in the range 90 - 110 kms and, if suitably oriented, allows a reflected signal from the transmitter to the receiver (see fig.1). The duration of the contact between the two is limited by the life-time of the train which in turn is determined by dissipative processes such as diffusion and chemical processes and by deformation of the train with time. Typically, this ranges from perhaps 0.2 seconds up to several seconds with the likelihood decreasing with increasing duration; occasionally, durations of several minutes may occur. In addition to this, the received echo power and echo duration are both sensitive to operating frequency such that each decreases with increased frequency. As a result of all this, severe limitations in terms of availability and operating flexibility are imposed meteor-scatter communications systems.

Nevertheless, such systems have their attractive side which includes some degree of security in that the geometry both limits the reception area for a transmitted signal and provides some resistance to interference (from natural and man-made sources). Additionally, the mechanism itself is not subject to disturbance by unusual circumstance (such as, for example, severe magnetic storms) and modern electronics allows simple and highly reliable systems. Recent developments on the "software" side, involving improvements in protocol and coding, hold out the promise of much increased throughput under given echo conditions and this is an area which more gains may be expected. Other aspects of potential systems which might be expected to provide gains include the hardware (transmission and modulation techniques) and experimentally generated statistics relating to the occurrence of meteors and the resulting modelling of the system. These last areas are those towards which this research effort is directed.

Useful reviews of the basics and of recent activity in the field may be found in the work of Yavuz [1] and Schanker [2] and research related to coding in meteor burst communications in Metzner [3].

2. The Experimental System and Approach.

The equipment used here was designed to measure accurately the angles-of-arrival (azimuth (α) and elevation (β)) of the signal reflected from a meteor train so that the position in space of the train may be estimated based on the restricted height range of occurrence for such trains; the principle is illustrated in fig. 1.

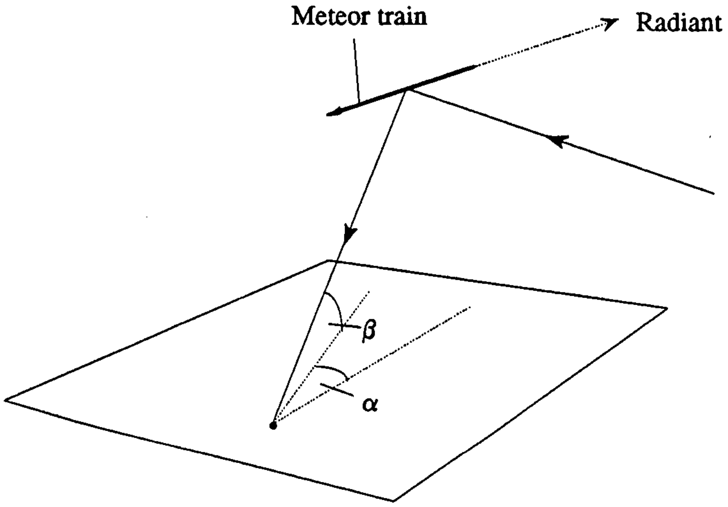


Fig.1 Illustrating the geometry for forward-scatter communications via a meteor train.

The angles α and β at the receiving end are measured generally to better than 1 degree (though the accuracy deteriorates at very low elevation angles) using a collection of five appropriately spaced antennas as illustrated in fig. 2; each antenna is a simple two-element Yagi array with modest gain in the direction of the transmitter and the height above ground is accurately the same for all. Simultaneous amplitude and phase measurements on the received signal from these five elements, using the centre antenna as a phase reference, gives an unambiguous measure of the required angles.

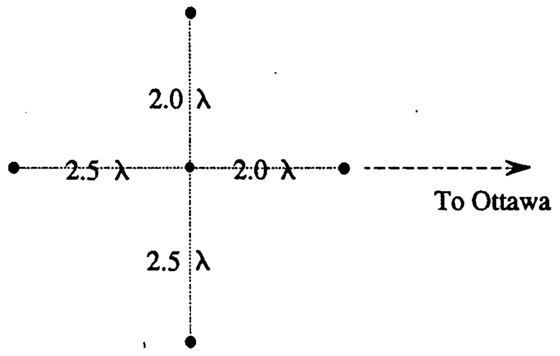


Fig. 2 Plan view of the layout of the receiving antenna array near London, Ontario.

The transmitter, near Ottawa, Ontario, operates on CW at a frequency of 48.70 MHz. A full description of the system and methods employed in handling the data may be found in a previous report [3].

The measurements described here are aimed at providing statistics useful to the prediction of the performance of a forward scatter link. These include the rate of incoming meteors suitable for reflection and their radiant distributions which will allow such predictions to be made. Because of the earth's orbital motion around the sun, there is a well understood general maximum in the meteor rate in the early morning which is matched by a minimum in the early evening. This is a direct consequence if the high velocity of the earth (30 $km.s^{-1}$) compared with that of meteoroids in orbit around the sun (up to 40 $km.s^{-1}$) so that the earth "runs into" meteors on the forward side, that is, in the direction of the apex of the earth's way (see fig. 3). As a result of this and meteoroid orbital constraints, the **geocentric** meteoroid velocity is limited to the range 11 to 72 $km.s^{-1}$.

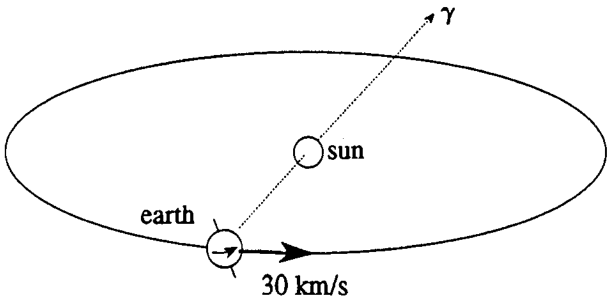


Fig. 3 The earth's orbit around the sun; shown at the vernal equinox (March 21) when the sun is located at the first point of Aries (γ) on the celestial sphere.

In describing the radiant distribution of the incoming meteors, as will be done here, use is invariably made of the celestial coordinate system which refers to the position on the celestial sphere in relation to the position of the sun at the vernal equinox; this position is at the first point of Aries (γ). The resultant coordinates of declination (δ) and right ascension (R.A.) are shown in fig. 4.

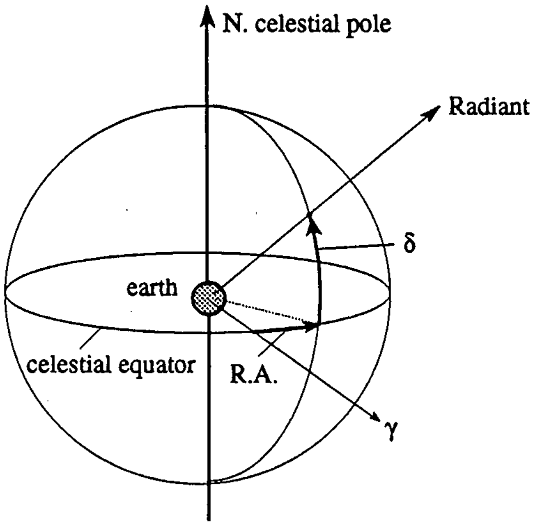


Fig.4 The celestial coordinate system used for the radiant distribution.

3. Experimental Results.

The system has been operational from late February 1991 and continues to operate at the present time (April 1992) so that a considerable amount of data has been accumulated. Because of the way in which data are collected and subsequently analyzed, results covering the period **March to December 1991** (representing a total of about 80,000 individual echoes) are available at this time and are presented here. Since a large number of graphs is involved, these results are presented as an Appendix.

As a starting point, fig. A1 shows the diurnal variation in the rate of meteor echoes on a monthly basis, and the expected general maximum at around 6 a.m. is well illustrated throughout the entire period (note that the times used here are E.S.T. which is about 20 minutes behind the true local time of the path centre). Departures from a smooth diurnal variation may be ascribed to significant departures from a uniform radiant distribution, especially with the occurrence of meteor showers in which relatively large numbers of particles are travelling in essentially the same orbit around the sun and hence appear to have the same radiant when interacting with and viewed from the earth; the "anomalous" peak in activity in June is most certainly due to meteors associated with the daytime Arietid shower. Fig. A2 shows the same data rearranged on the basis of 4 hour intervals through the day.

The above data have been processed to derive, on a statistical basis, the radiant point of individual echoes from the measured angles-of-arrival. As a first check on the accuracy of the overall processing procedure, days on which known meteor showers (with well defined radiants) were active were chosen and examples of the resulting radiant maps are shown in fig. A3. The agreement with the accepted values measured by other means and found in the literature is convincing testimony to the accuracy of the technique. It should be noted that the results presented here are in terms of the radiant point as observed, which is relevant in this application, and are not corrected for zenith attraction due to the earth's gravitational field; the correction would amount to no more than a degree or two. The contour lines in these radiant maps are based essentially on the incident number density, that is the observed numbers with radiants within an area of (1 degree)^2 on the celestial sphere.

Fig. A4 shows radiant maps for 30 day intervals (corresponding approximately to the indicated calendar months) from the beginning of March, 1991, to the end of December, 1991. Again the contours are based on the total observed numbers within the 30 day interval. In these maps. the area of maximum activity is highlighted with shading and the relationship to the changing direction of motion of the earth as the year progresses is apparent. The right ascension of the apex of the earth's way is as indicated (note that the declination is not shown since this is negative between the winter and summer solstice).

An idea of the availability of the link for communications may be obtained from fig. A5 which shows the distribution in decay times of representative samples of echoes. The short durations observed are consistent with a preponderance of under-dense meteor trains, which in turn is quite in line with the sensitivity of the equipment. The apparent cut-off below about 0.2 seconds is due to the "echo ceiling" introduced by the initial train radius effect, that is , the smaller meteors occur at greater heights and as a consequence have shorter decay times and reduced (observed) amplitude. Further details on this point may be found in [5].

4. Discussion.

The results presented above represent a first step in resolution of the problem of predicting the availability of a meteor burst communications system at any location. The link used introduces biases of its own and the data include these biases.

The first limitation is the area of sky "seen" by the sytem as the earth rotates on its axis which results in an absolute limitation in declination of (latitude - 90)°, or about -48° for this link. In fact, close to this limit radiants are so low in the sky that few usable meteors would be observed; the radiant maps presented are limited to -20° in declination for this reason. For a complete radiant map of the entire sky, several observational systems would have to be deployed covering the desired range in declination, though this could be accomplished in principle by one further system located in the southern hemisphere. For the northern hemisphere alone, the present location collects sufficient information in principle, though again the limitations for radiants low on the local horizon must be kept in mind.

Given this, it should be noted that the while the present system is deliberately set up to be "all round looking", to the extent that this is possible, the sensitivity does vary with direction and this influences the radiant distribution to some degree. For example, the geometry dictates that no echoes will be observed on the line joining the two sites, and that "hot-spots" occur on either side of this line. As a result the observed radiant structure will differ from the actual, though the averaging effect of the rotation of the earth smooths out the difference. Some uncertainty in the actual value of the radiant coordinates is introduced by the need to assume an average height for the meteor train in the processing procedure. Since the height range is fairly small (about 90 - 100 km.), this effect is not a large one and is not expected to produce errors of more than a few degrees at the most.

Some of the above limitations of the forward-scatter system can be partially alleviated by using a back-scatter system where the transmitter and receiver are close together or even at the same site. Both the "hot-spot" and meteor height problems are removed by using such a system and for the radiant distribution exercise alone it is the preferred approach. However, information on the performance of an actual forward-scatter link is lost, of course, with the use of a back-scatter system alone. Simultaneous operation of both types of system would be desirable.

In any event, the radiant structure data presented here represents a good estimate of the real situation, which can be refined with due allowance for the characteristics of the measuring system. This aspect needs further work and will be pursued as part of the ongoing effort to provide data relating to the performance of the general meteor burst communications system.

5. References.

1. Yavuz, D., "Meteor Burst Communications", IEEE Comm. Mag., 28, 8, 40-48, 1990.
2. Schanker, J. Z., "Meteor Burst Communications", Artech House, 1990.
3. Metzner, J. J., "Improved Coding Strategies for Meteor Burst Communication", IEEE trans. Comm., 38, 2, 133-136, 1990.
4. Webster, A. R. and Jones J., "A Study of Meteor Scatter Communications", Final Report, D.S.S. Contract #36001-9--3601/01-SS, April 1991.
5. McKinley, D. W. R., "Meteor Science and Engineering", McGraw-Hill, 1961.

Appendix

Experimental Results

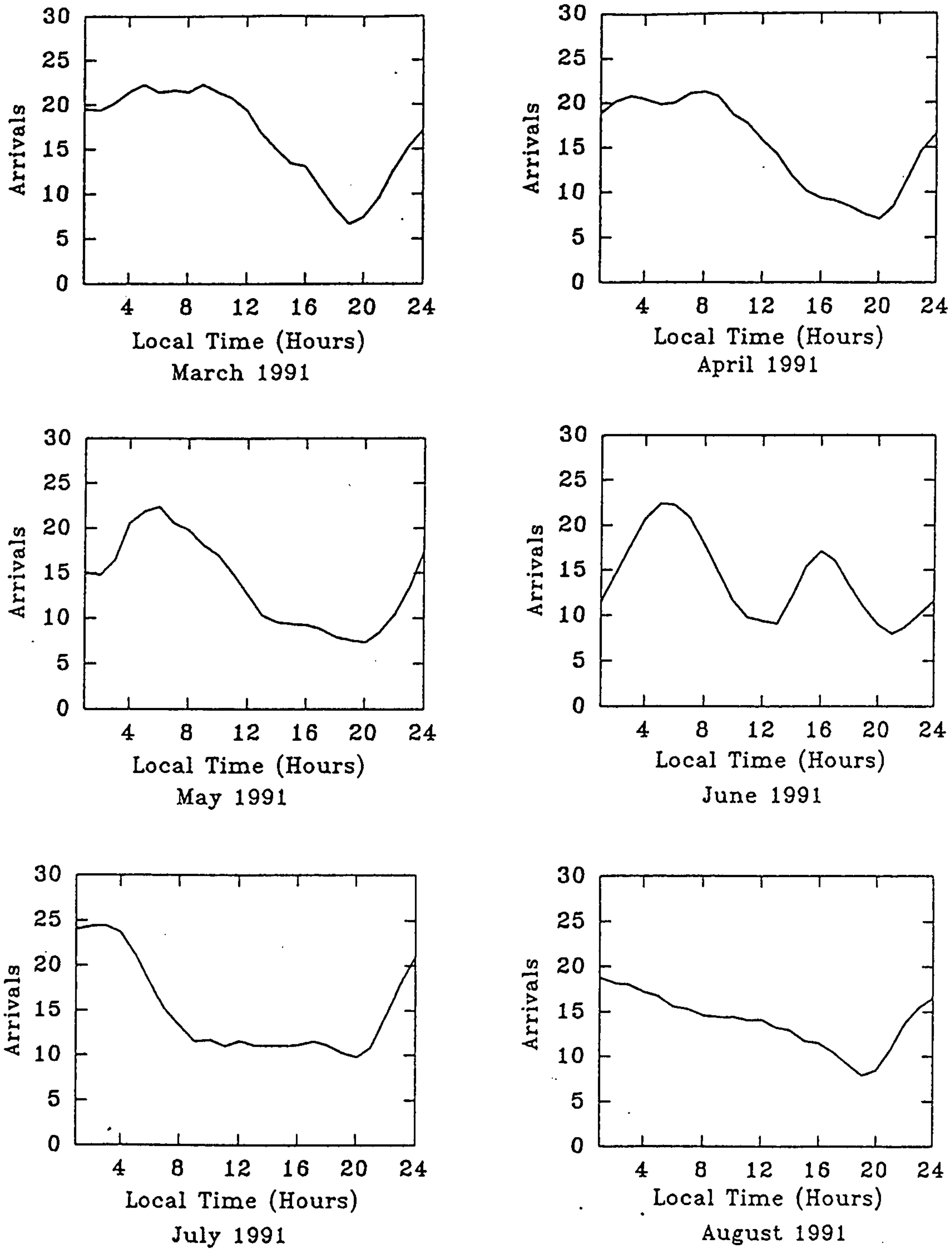
Fig. A1 Diurnal variation of received meteor echo rate on a monthly basis.

Fig. A2 Monthly variation of received meteor echo rate for the indicated 4-hour periods.

Fig. A3 Radiant distributions relating to major meteor showers; (a) the Quadrantids (4 Jan. 1991), (b) the δ-Aquarids (27 July 1991), (c) the Geminids (12 Dec.1991).

Fig. A4 The distribution of radiants on the celestial sphere for 30 day intervals over the period March - December, 1991.

Fig. A5 Echo duration distributions for selected periods.



March 1991

April 1991

May 1991

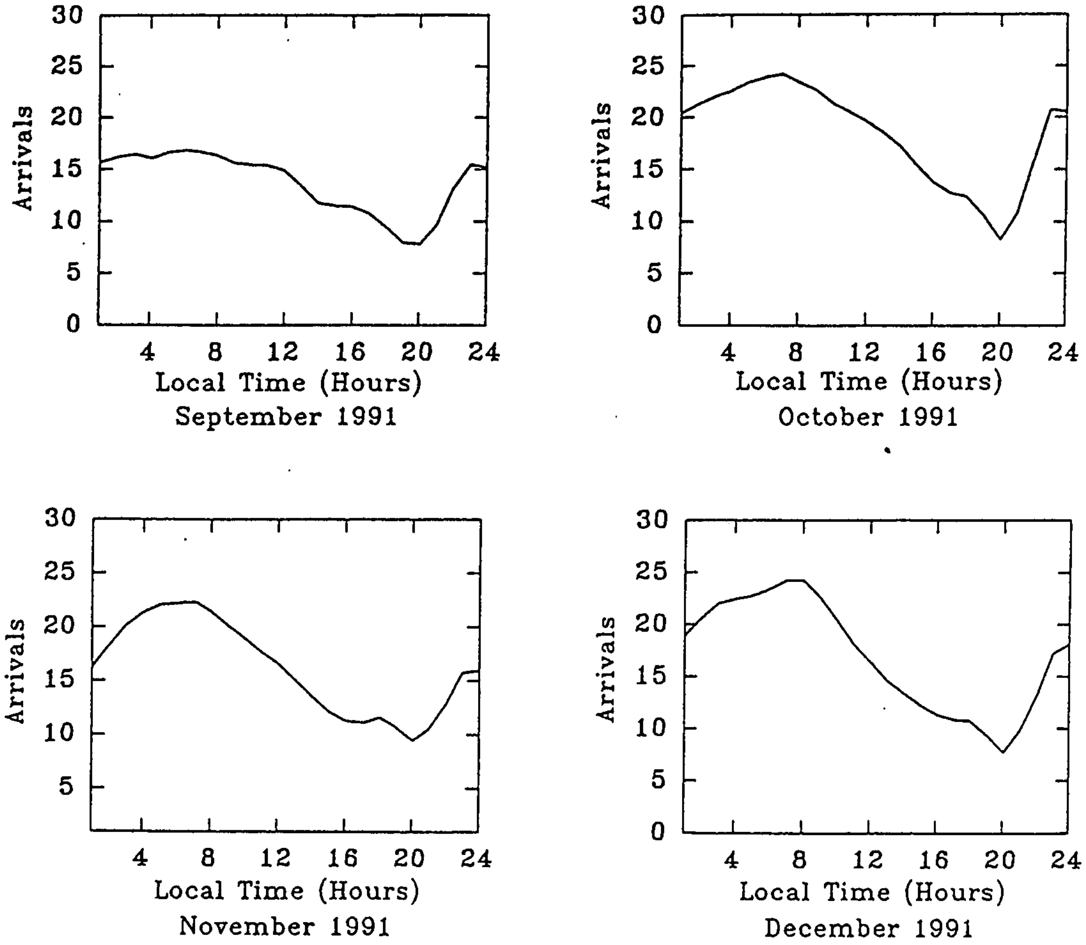
June 1991

July 1991

August 1991

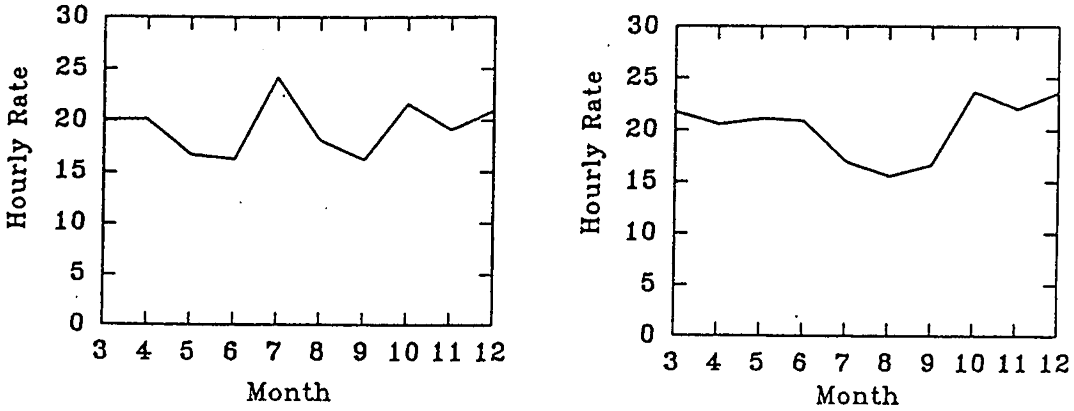
Mean Diurnal Variation (Mar.–Aug.,1991)

Fig. A1 The diurnal variation of the hourly rate of meteor echoes on a monthly basis.



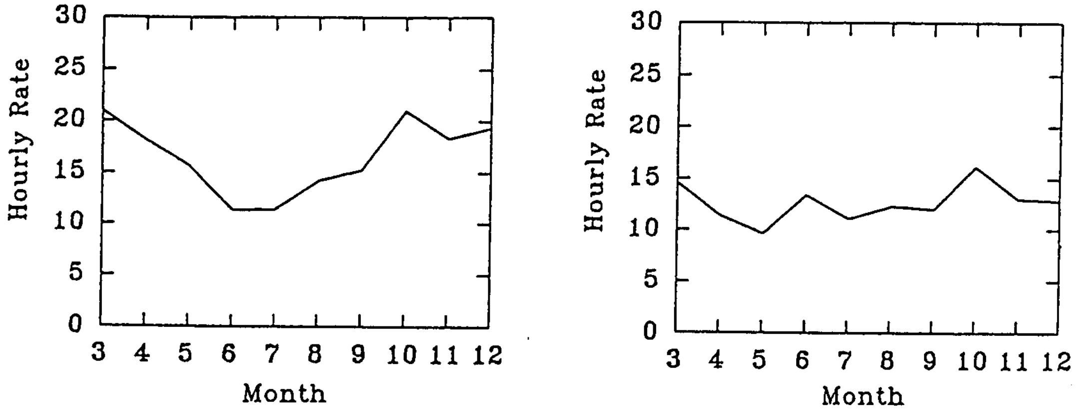
Mean Diurnal Variation (Sept.–Dec.,1991)

Fig. A1 continued.



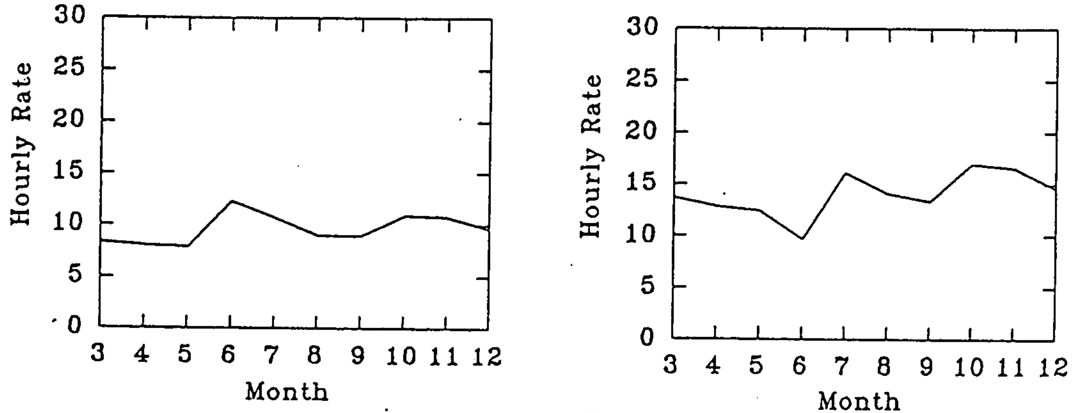
Hours 1-4

Hours 5-8



Hours 9-12

Hours 13-16



Hours 17-20

Hours 21-24

Monthly Arrival Variation (1991)

Fig. A2 Average hourly rates of meteor echoes from March to December 1991 for the indicated four hour periods

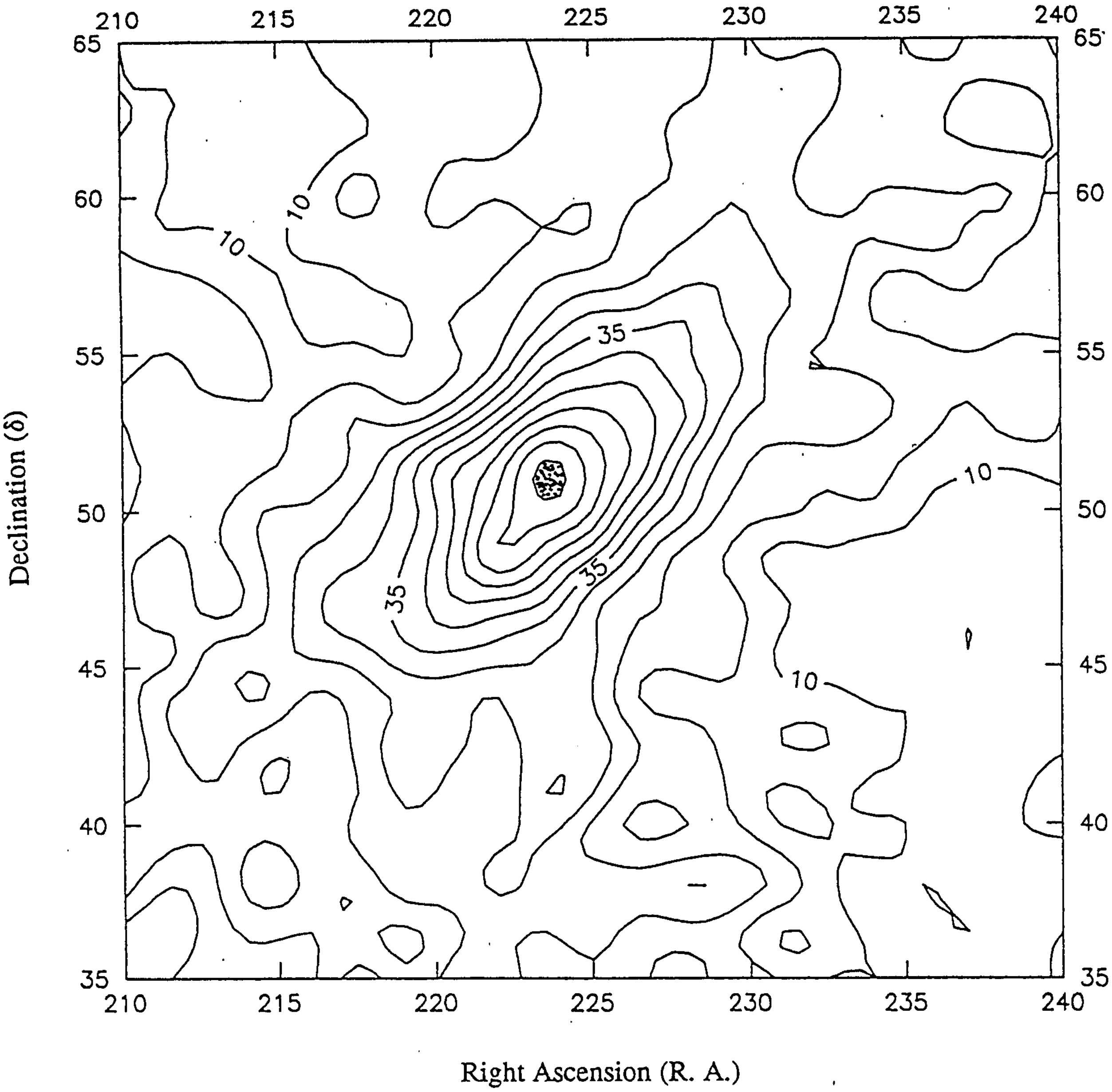


Fig. A3 (a) Radiant distribution of meteor echoes on 4 January 1991 in the vicinity of the radiant of the Quadrantid meteor shower. Average values from many sources suggest R.A. ≈ 230° ± 10°, δ ≈ 50° ± 10° for the shower radiant.

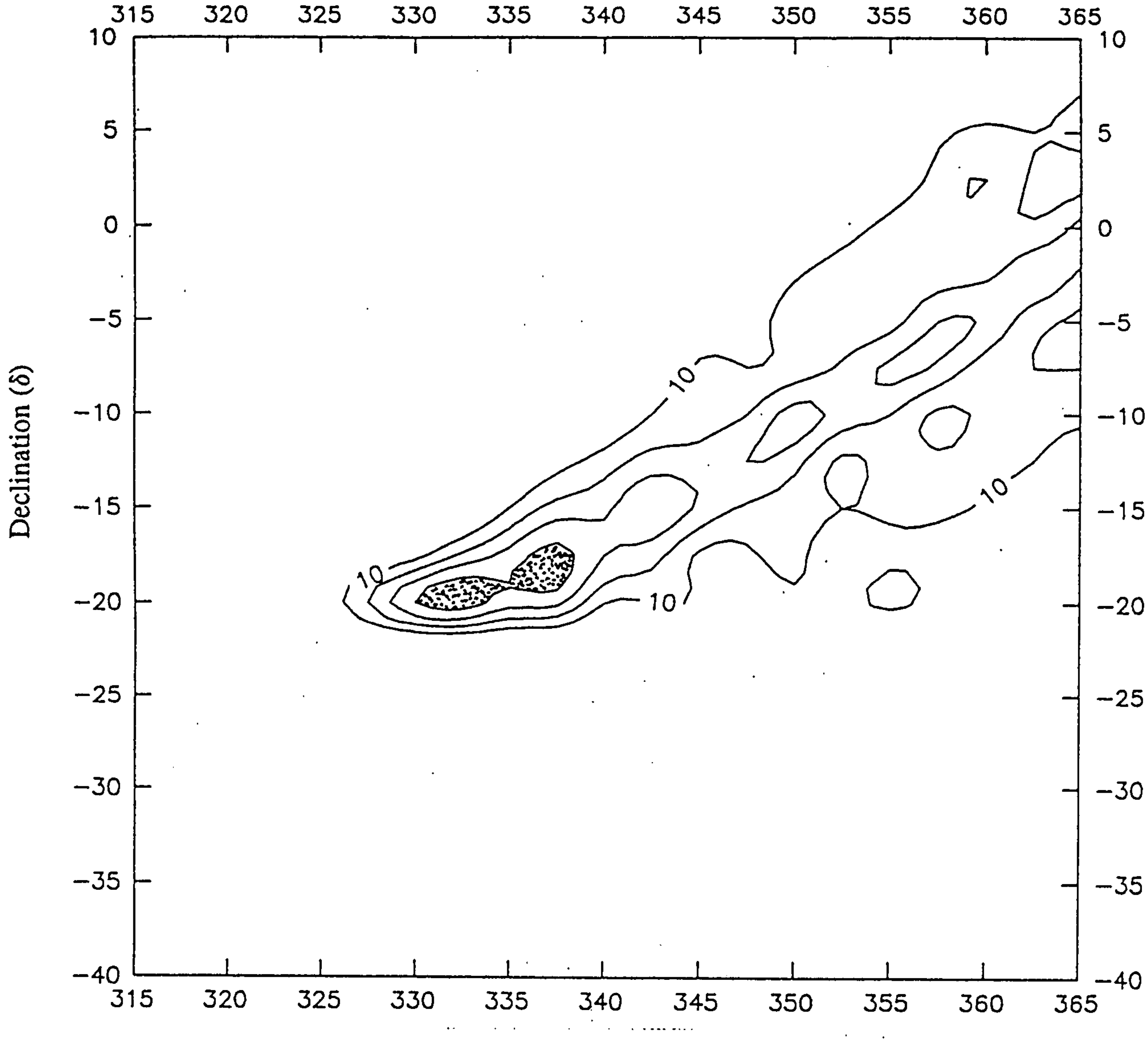


Fig. A3 (b) Radiant distribution of meteor echoes on 27 July 1991 in the vicinity of the radiant of the δ-Aquarid meteor shower. Average values from many sources suggest R.A. ≈ 337° ± 10°, δ ≈ -18° ± 10° for the shower radiant.

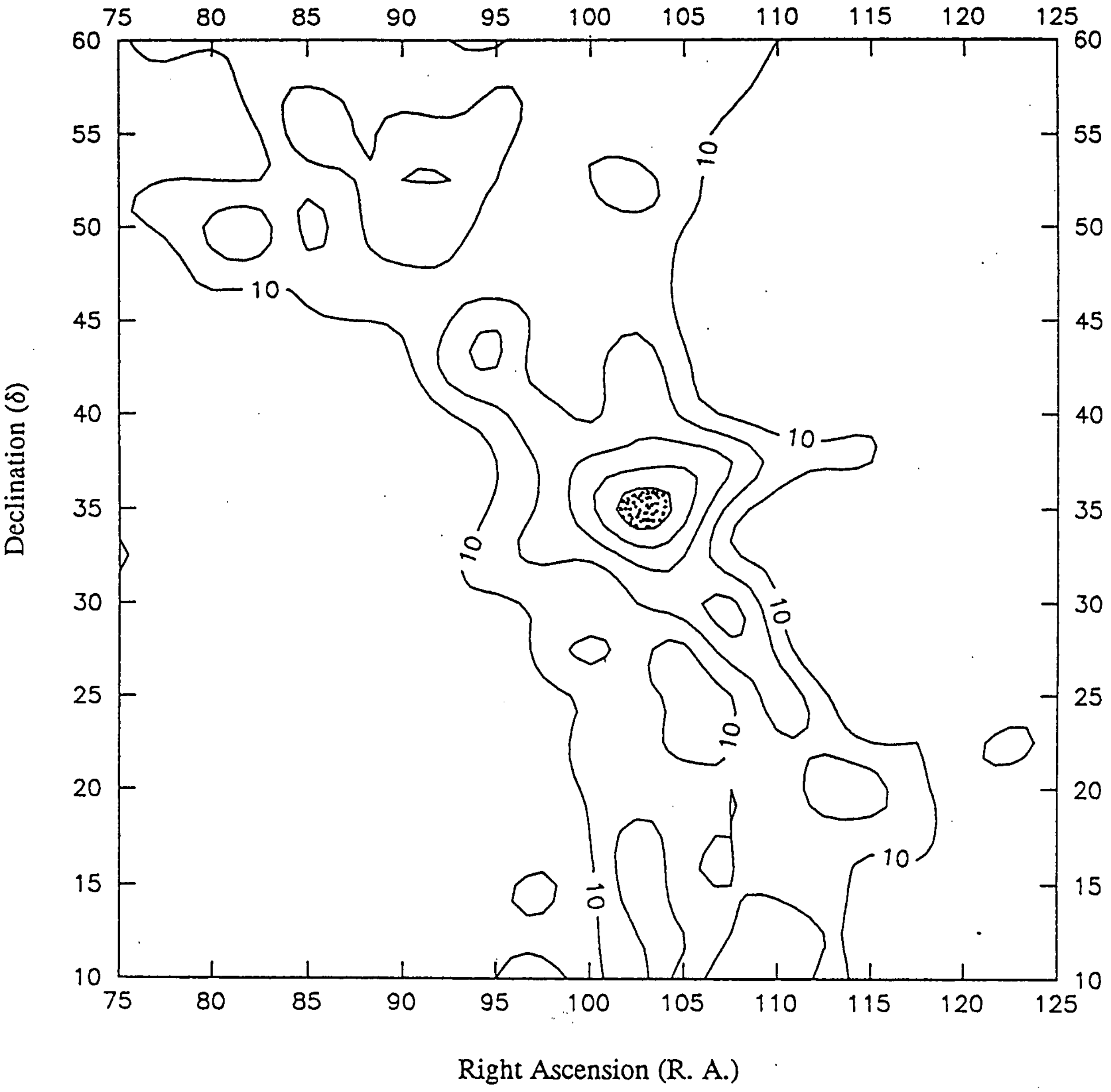


Fig. A3 (c) Radiant distribution of meteor echoes on 12 December 1991 in the vicinity of the radiant of the Geminid meteor shower. Average values from many sources suggest R.A. ≈ 110° ± 5°, δ ≈ 32° ± 5° for the shower radiant.

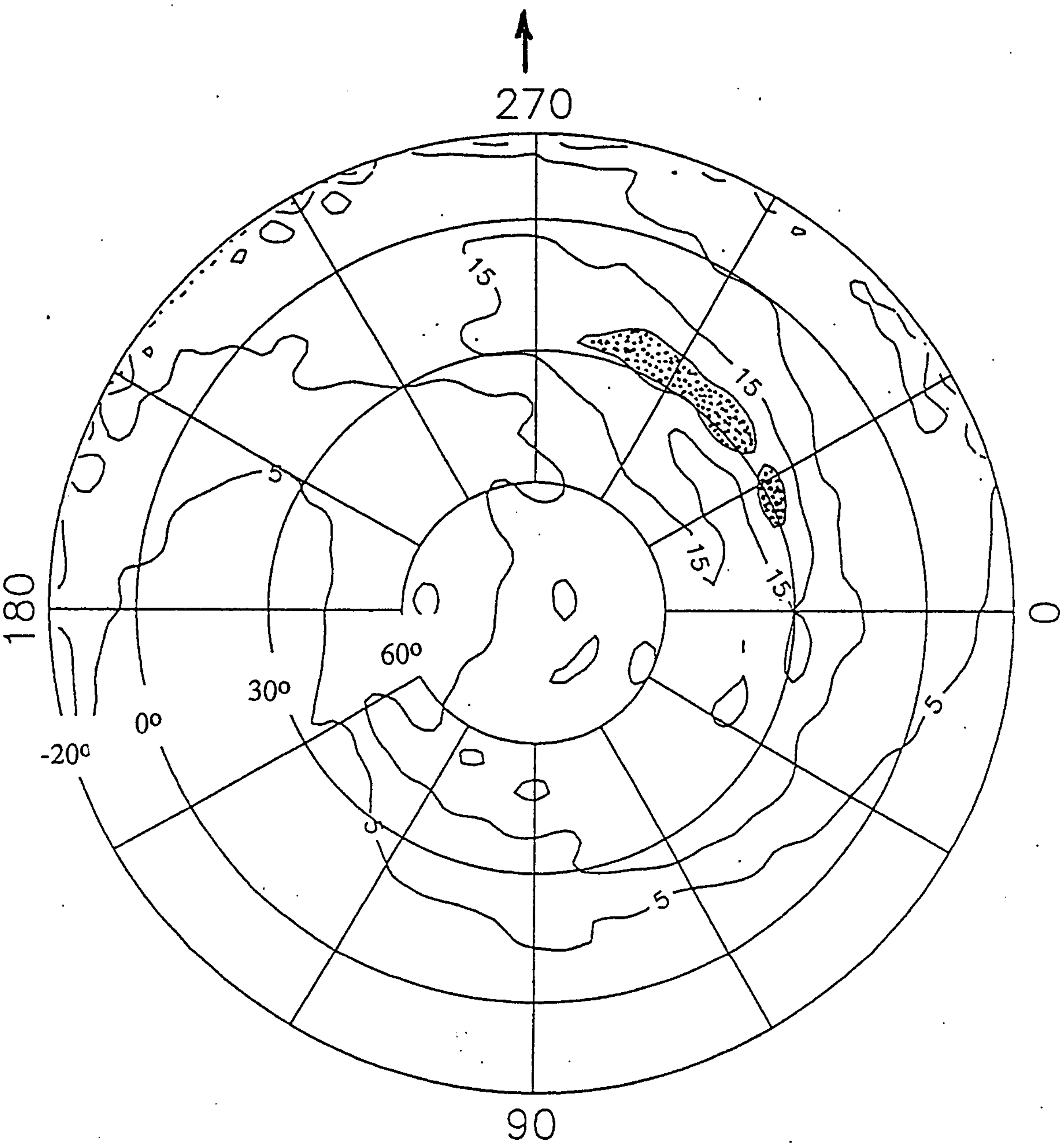


Fig. A4 (a) The radiant distribution for days 61 to 90 (approx. month of MARCH).

The coordinates are Right Ascension (R.A.), from 0° to 360°, and the circles represent -20°, 0°, +30° and +60° in declination, as shown. The arrow represents the R.A. of the apex of the earth's way in the centre of the period.

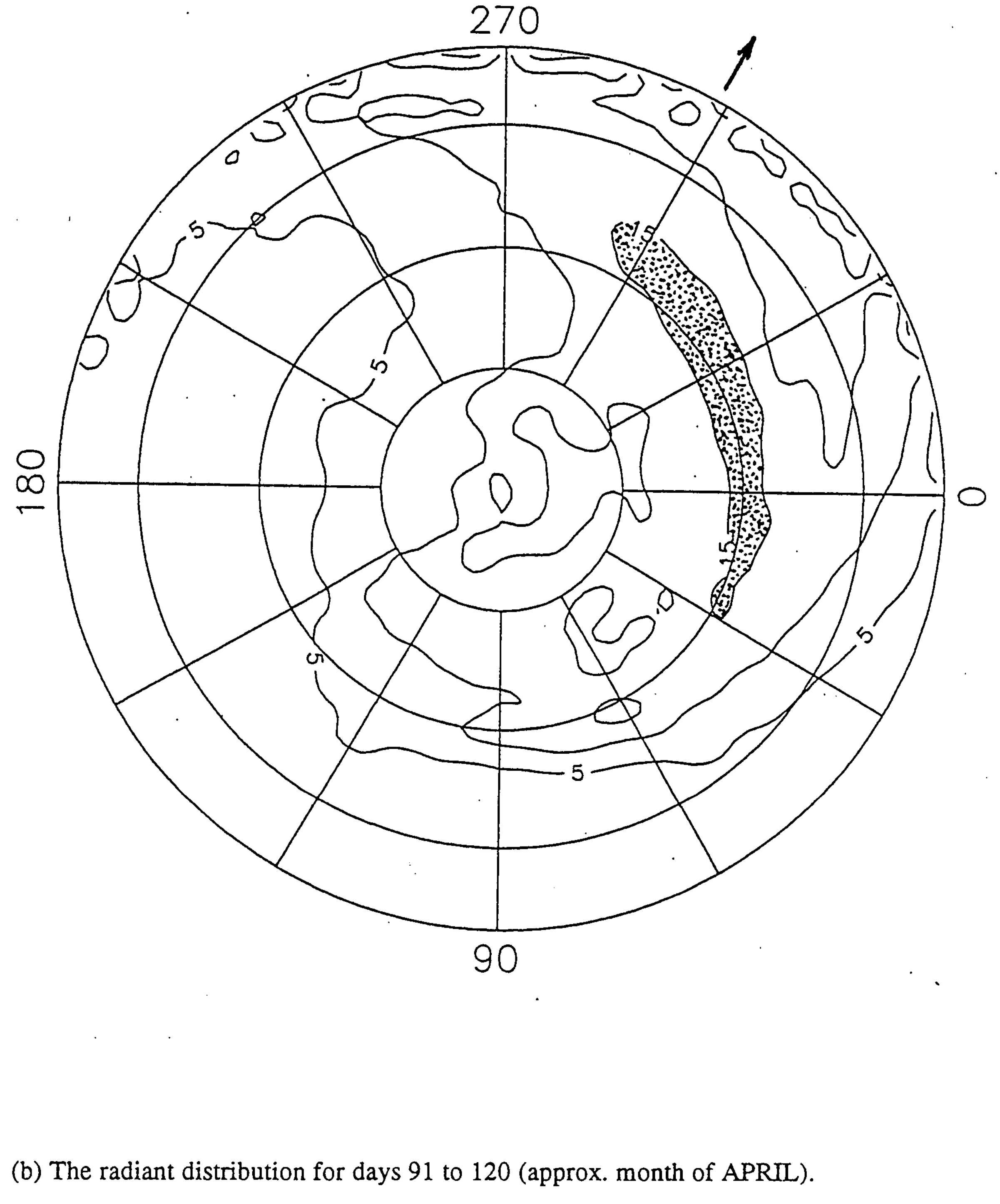


Fig. A4 (b) The radiant distribution for days 91 to 120 (approx. month of APRIL).

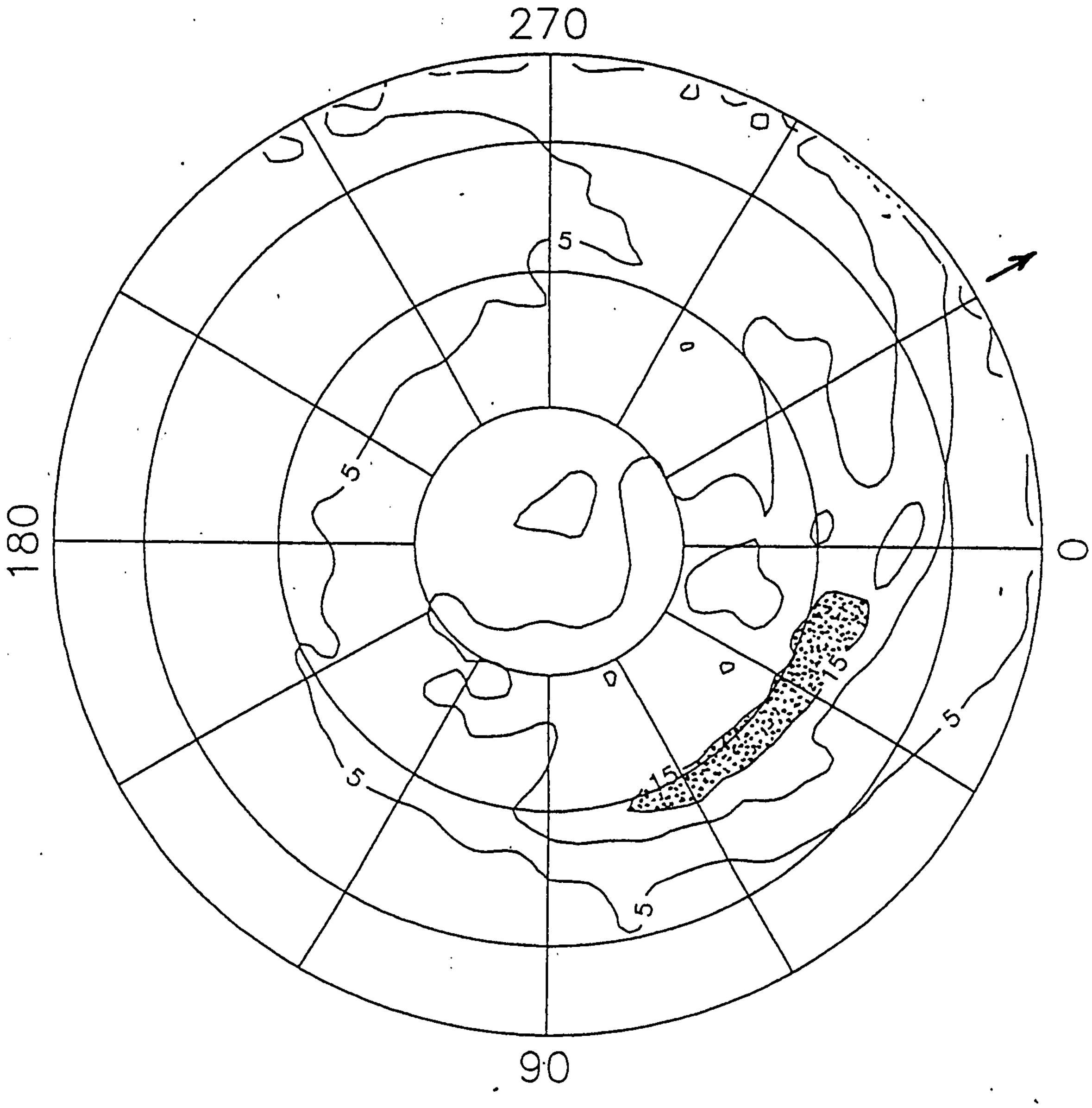


Fig. A4 (c) The radiant distribution for days 121 to 150 (approx. month of MAY).

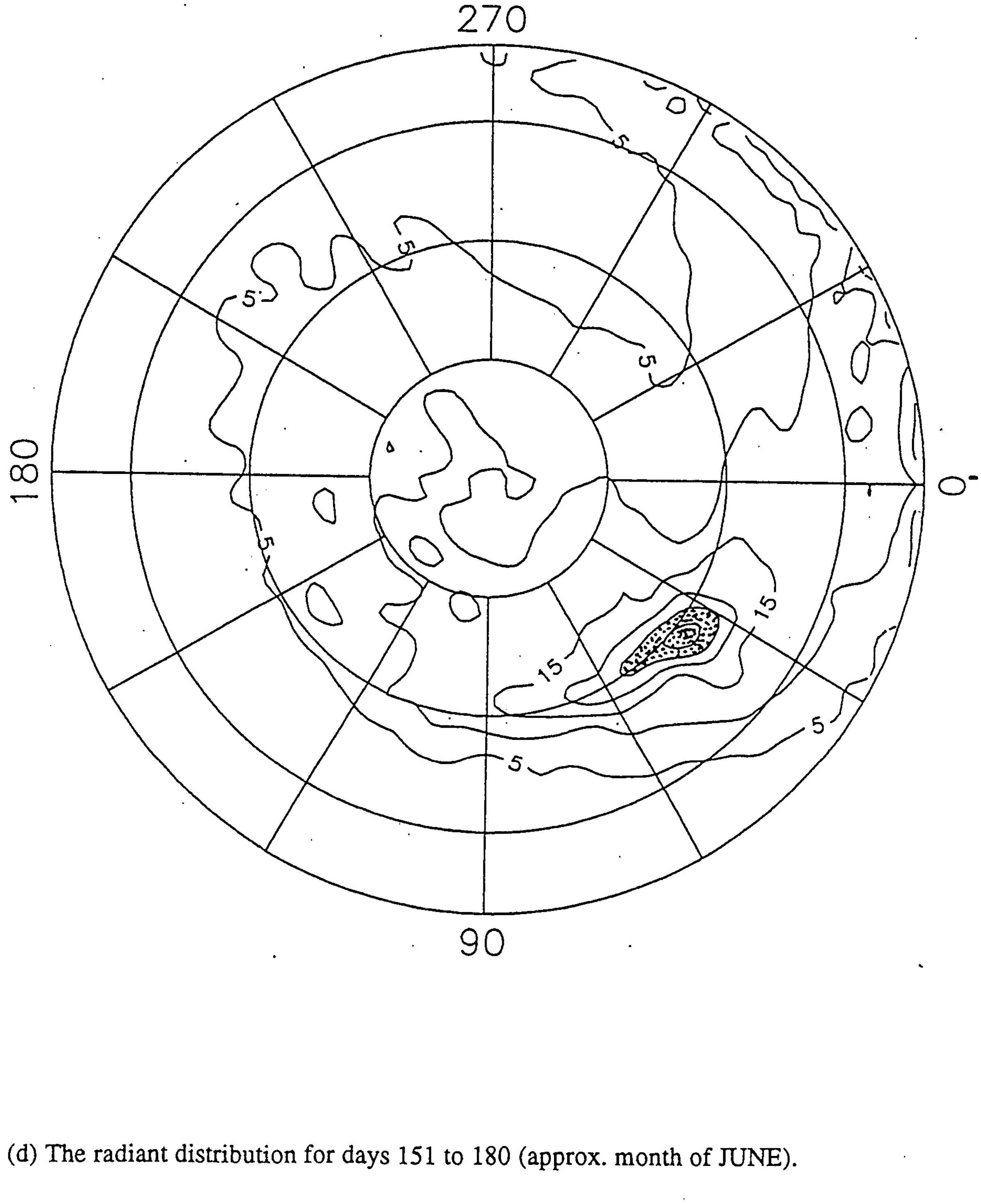


Fig. A4 (d) The radiant distribution for days 151 to 180 (approx. month of JUNE).

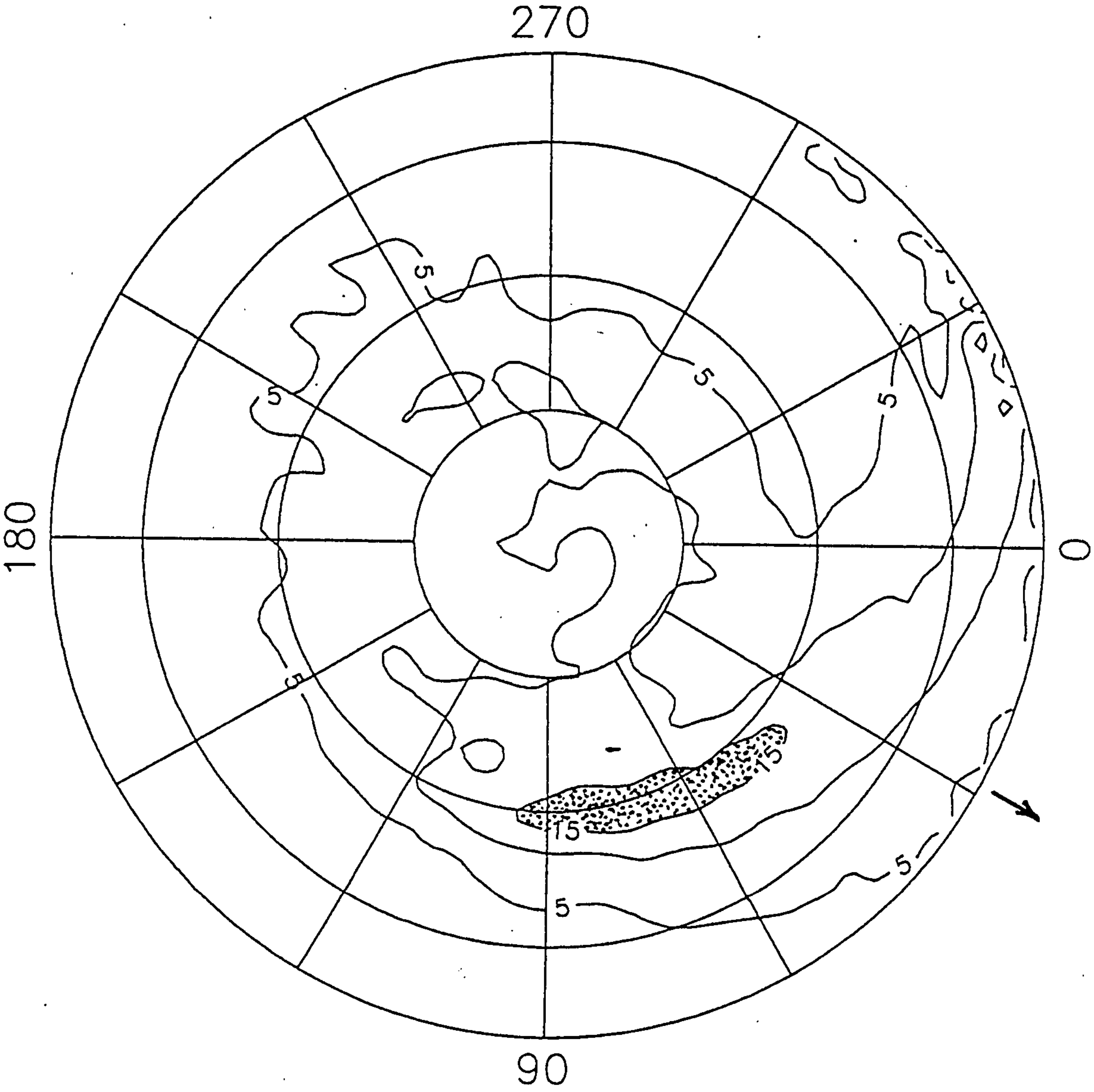


Fig. A4 (e) The radiant distribution for days 181 to 210 (approx. month of JULY).

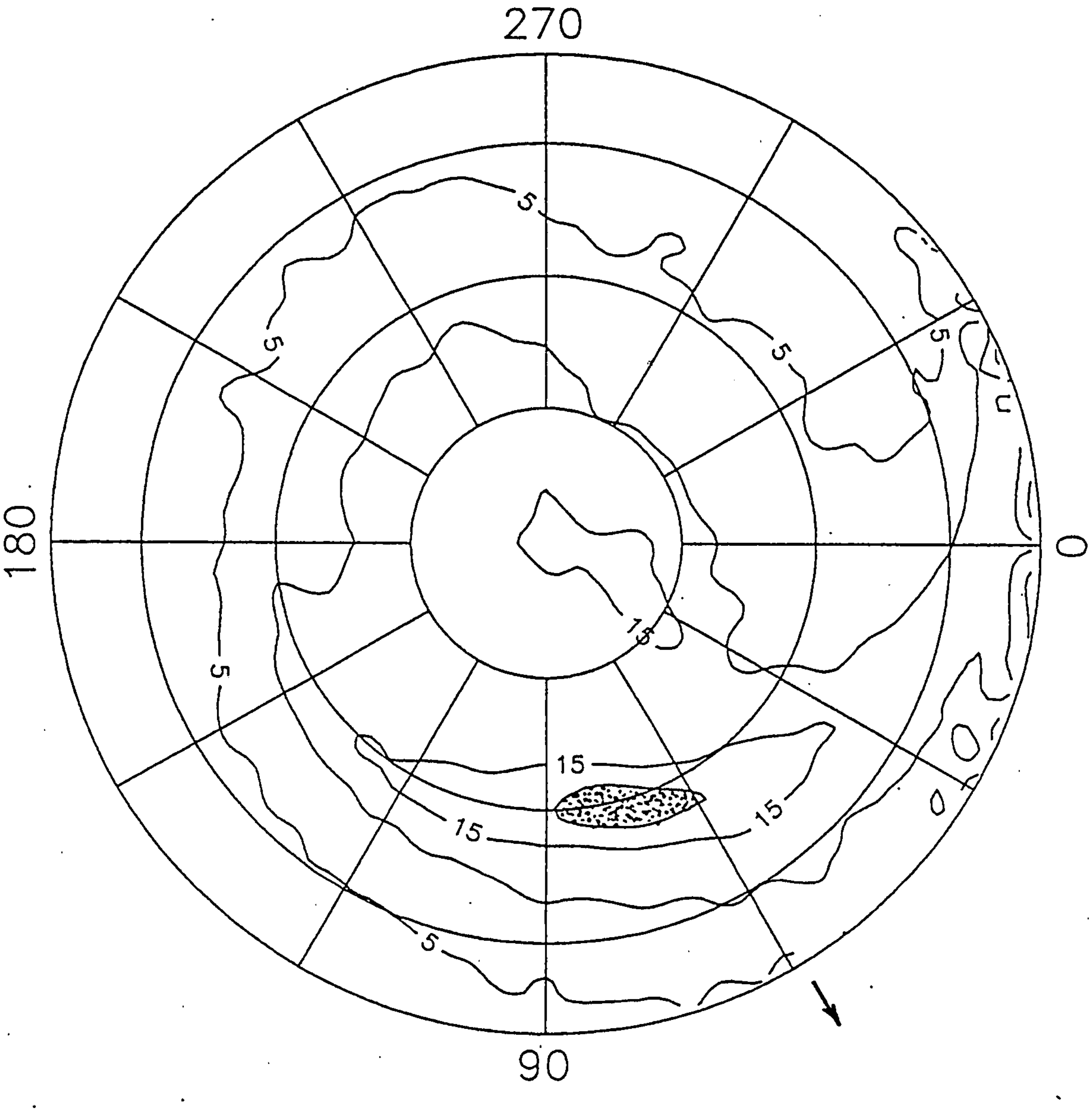


Fig. A4 (f) The radiant distribution for days 211 to 240 (approx. month of AUGUST).

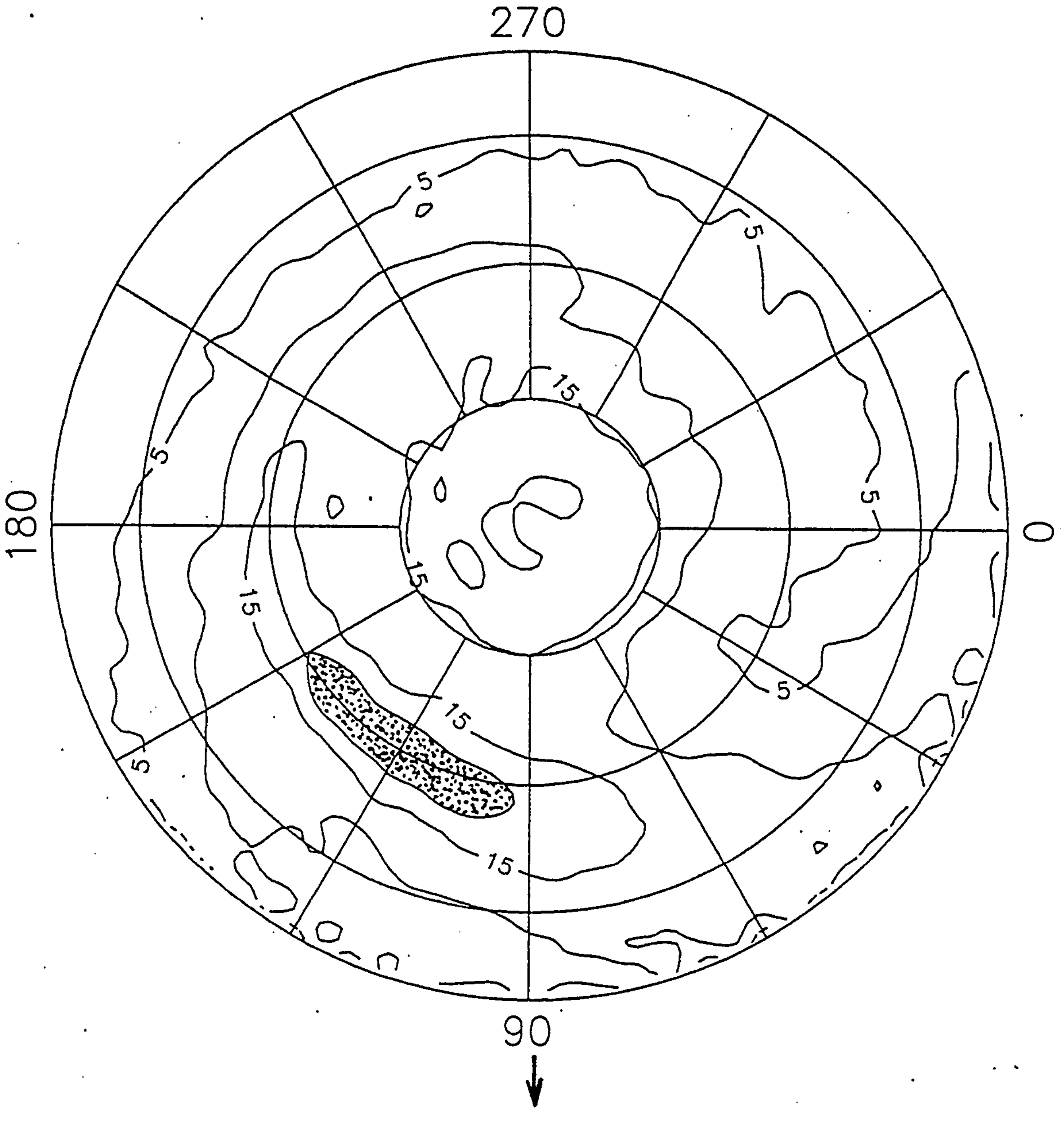


Fig. A4 (g) The radiant distribution for days 241 to 270 (approx. month of SEPTEMBER).

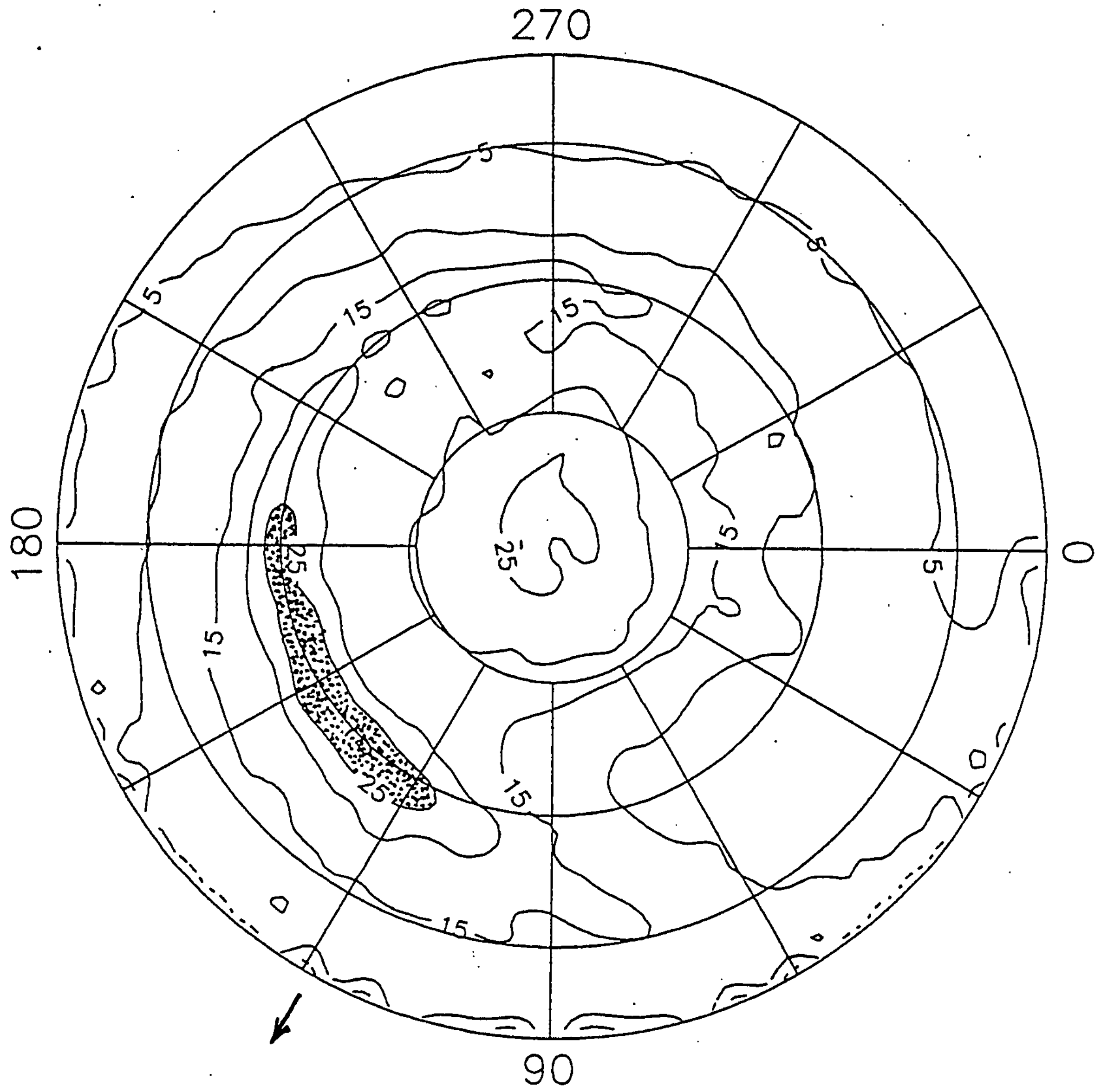


Fig. A4 (h) The radiant distribution for days 271 to 300 (approx. month of OCTOBER).

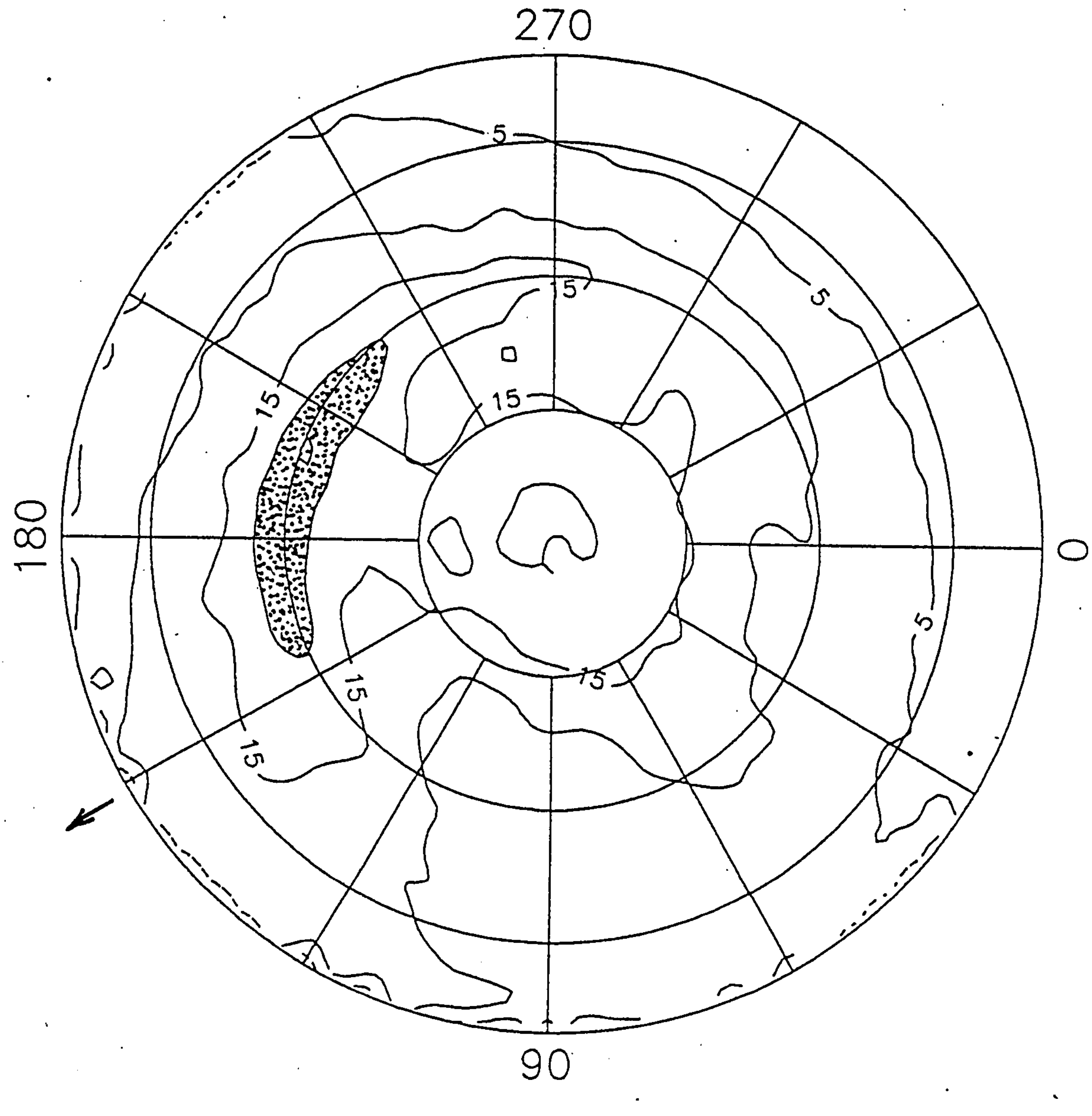


Fig. A4 (i) The radiant distribution for days 301 to 330 (approx. month of NOVEMBER).

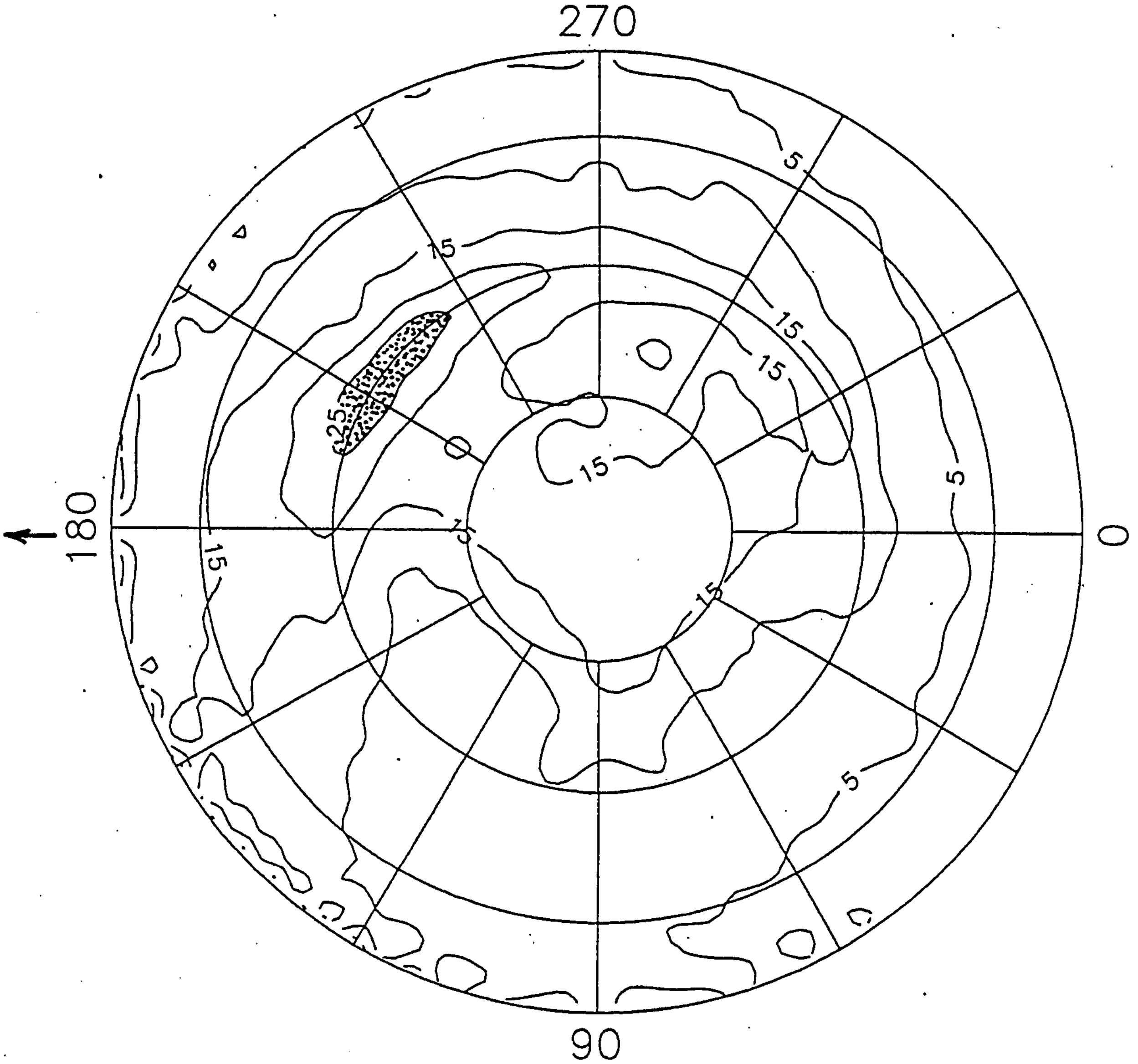


Fig. A4 (j) The radiant distribution for days 331 to 360 (approx. month of DECEMBER).

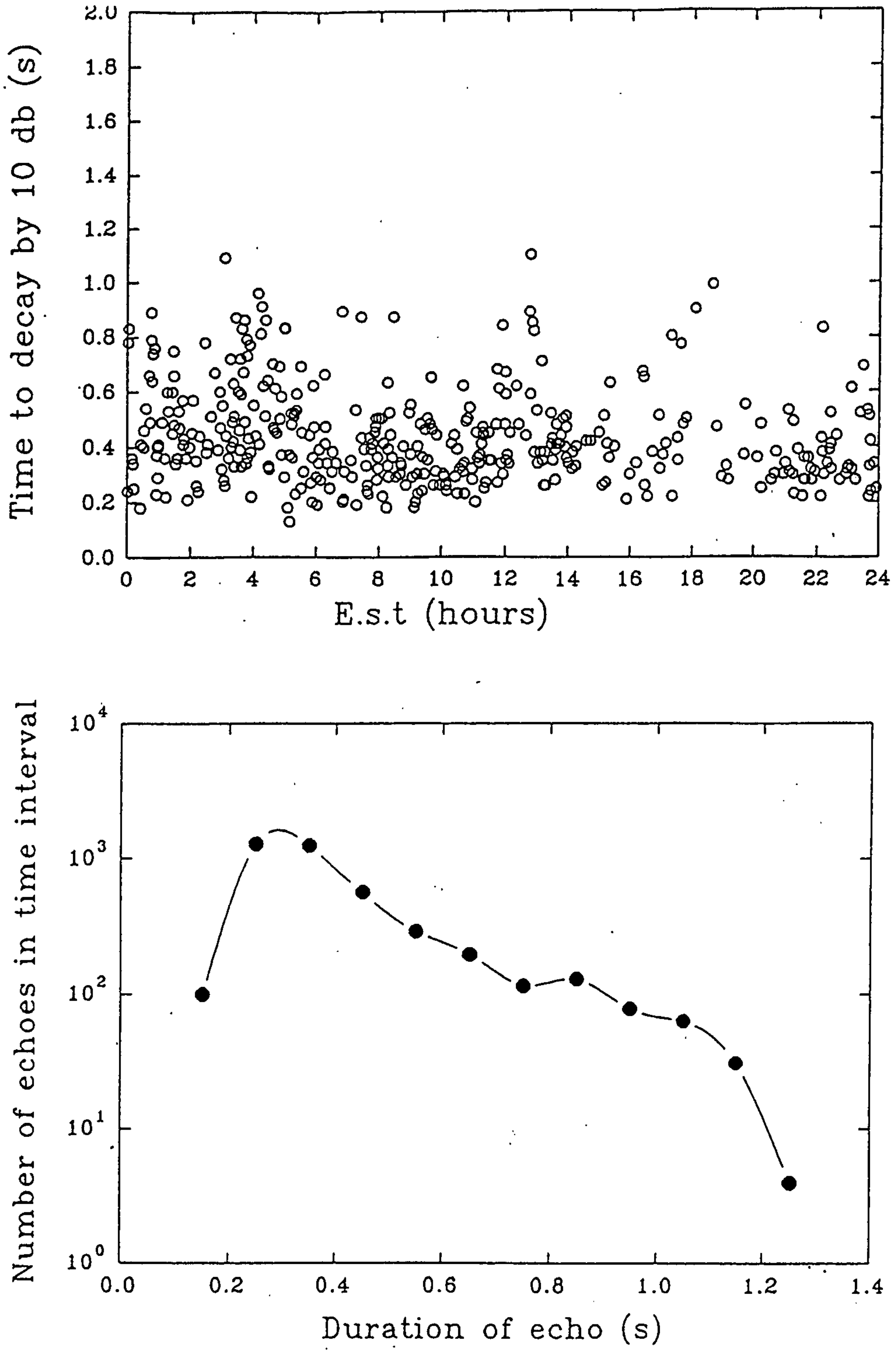


Fig. A5 The distribution in echo durations: (a) the actual values over a single day (24 Feb. 1991) and (b) the density distribution in 0.1 second intervals taken over a period of 10 days in early Sept, 1991

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