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RADIO-WAVE SCINTILLATIONS AND IONOSPHERIC
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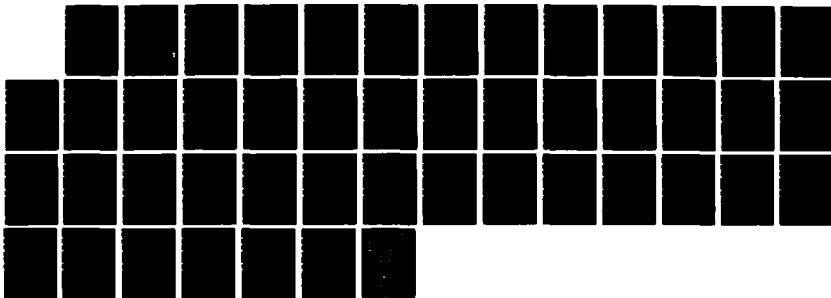
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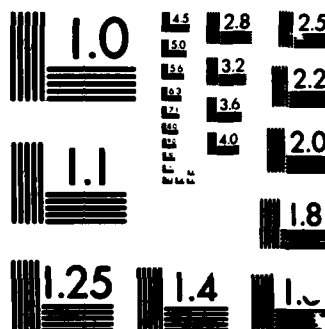
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Radio-Wave Scintillations and Ionospheric
Irregularities at High Latitudes

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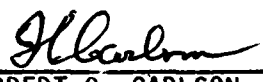
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Results are presented of studies of ionospheric scintillation obtained by monitoring of transmissions from NNSS satellites at Kiruna, Northern Sweden during a two year period from September 1984 to September 1987. Attention is concentrated in this report on phase scintillation morphology. Also presented are results of model studies of the geometrical influences in amplitude and phase scintillations at a high-latitude site aimed at interpreting the observations and understanding the nature of the ionospheric irregularities responsible for the scintillations. Also discussed are results of two coordinated studies of ionospheric irregularities using scintillation observations and data from HF and VHF backscatter radar systems respectively.					
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INTRODUCTION

In the highly structured medium of the high-latitude ionosphere, irregularities can have a severe effect on transionospheric radio wave propagation. Radio waves traversing the irregular medium undergo spatial modulations in phase producing random fluctuations in amplitude and phase of the resultant wave received at the ground which are known as scintillations. The fluctuations of the radio signals are of importance to users of the transionospheric propagation channel in a variety of applications like for example space borne synthetic aperture radars.

RINO et al. (1983)¹ have reviewed the structure and morphology of auroral zone F-region irregularities, while theoretical aspects have been discussed by KESKINEN and OSSAKOW (1983)². Ionospheric scintillation

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1. Rino C.L., Livingston R.C., Tsunoda R.T., Robinson R.M., Vickrey J.F., Senior C., Cousins M.D., Owen J. and Klobuchar J.A. Recent studies of the structure and morphology of auroral zone F-region irregularities. Radio Sci., 18, 1167, 1983.
 2. Keskinen M.J. and Ossakow S.L. Theories of high-latitude ionospheric irregularities: A Review. Radio Sci., 18, 1077, 1983.

has been reviewed by YEH and LIU (1982)³ with current knowledge of morphological aspects of scintillation being considered by AARONS (1982)⁴.

Soft-particle precipitation and plasma instabilities play important roles in irregularity production in the high-latitude F-region. One possible creation process has been considered by KELLEY et al. (1982)⁵. In this large-scale structures or 'blobs' are carried by convection across the polar cap into the nightside auroral zone. Plasma instabilities operating on the gradients of these large scale structures cause breakdown to the sub-kilometer irregularities responsible for VHF scintillation. In an earlier report KERSLEY et al. (1986)⁶ discussed coordinated scintillation and EISCAT observations which provided evidence for irregularity production by several means. In one example the evidence indicated a steep gradient in electron density could have been destabilized by the Ex B mechanism. In others structured

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3. Yeh K.C. and Liu C.H. Radiowave scintillation in the ionosphere. Proc. IEEE, 70, 324, 1982.
 4. Aarons J. Global morphology of ionospheric scintillations. Proc. IEEE, 70, 360, 1982.
 5. Kelley M.C., Vickrey J.F., Carlson C.W.. and Torbert R. On the origin and spatial extent of high-latitude F-region irregularities. J. Geophys. Res., 87, 4469, 1982.
 6. Kersley L., Pryse S.E. and Wheadon N.S. Radiowave scintillations and ionospheric irregularities at high-latitudes. Report AFOSR-85-0190, University College of Wales, May 1986. AFGL-TR-87-0247

particle precipitation was considered a possible mechanism although further examination of one case has revealed that a strong shear in plasma velocity may have been an important factor.

Scintillation morphology at high latitudes has been discussed by BASU and AARONS (1980)⁷ using measurements made in the 70°W longitude sector. During times of magnetic quiet a 2:1 summer to winter seasonal dependence was found. This was attributed by the authors to modulation of particle precipitation in the North Atlantic sector of the auroral oval due to the tilt angle of the Earth's dipole. The authors also suggested that there should be no such marked seasonal variation in either the Alaskan or Scandinavian sectors of the auroral oval. From observations made using the single Wideband satellite in the midnight and morning sectors of the auroral zone RINO and MATTHEWS (1980)⁸ concluded that there was no seasonal variation in scintillations. The nighttime data showed the highest scintillation occurrence levels but significant scintillation was present in the morning hours. Increased scintillation occurred during magnetically active periods. The latitudinal distribution of the auroral zone scintillation showed that phase and amplitude scintillation enhancements occurred at the point where the satellite to ground propagation path lay within an L-shell. It was apparent that scintillation observations are influenced by

7. Basu S. and Aarons J. The morphology of high-latitude VHF scintillation near 70°W. Radio Sci., 15, 59, 1980.

8. Rino C.L. and Matthews S.J. On the morphology of auroral zone radiowave scintillation. J. Geophys. Res., 85, 4139, 1980.

propagation and irregularity geometry. The power law phase screen model for weak scatter theory developed by RINO (1979)⁹ gave an insight into the effects of the axial ratios of the irregularities both along and transverse to the principal field-aligned axis. The modelling of the Wideband observations in Alaska suggested that irregularities were sheet-like with a three-dimensional power law index of -3.5. Earlier work by MIKKELSEN et al. (1977)¹⁰ using data from the NIMBUS 4 polar orbiting satellite observed from Narssarssuaq in the midnight local time zone suggested elongation of the irregularities along the field line by a factor of 2.5 and by 1.3 in the magnetic East-West direction. Recent Hilat observations (FREMOUW, 1985)¹¹ provide some evidence for rod-like irregularity structures in the nighttime polar cap region with more sheet-like irregularities at auroral zone latitudes.

The aim of the current work was to investigate scintillations of both amplitude and phase by means of observations at a high-latitude site in the European sector using transmissions from the multi-satellite polar orbiting NNSS system. The morphology of the scintillations is discussed

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9. Rino C.L. A power law phase screen model for ionospheric scintillation. 1. Weak scatter. Radio Sci., 14, 1135, 1979.
 10. Mikkelsen I.S., Aarons J. and Martin E. Geometrical considerations of 136 MHz amplitude scintillation in the auroral oval. J.A.T.P., 40, 479, 1977.
 11. Fremouw E.J. Recent Hilat results. AGARD-CP-382, 2.1, 1985.

here together with reports of studies of the geometrical influences on the observations aimed at achieving a better understanding of the shape and distribution of the irregularities causing the scintillation.

EXPERIMENT

Details of the NNSS satellite system and the experimental arrangement have been given in earlier reports in this series (KERSLEY AND WHEADON, 1985 and KERSLEY et al. 1986)^{12,6} These reports also included information on the auroral zone location of the experiment at Kiruna in Northern Sweden and presented some results of amplitude scintillation morphology and irregularity studies made in conjunction with the EISCAT ionospheric radar facility.

It can now be reported that the experiment was operational at Kiruna for the two year period from September 1984 to September 1986. During this time observations were obtained from a total of 12022 satellite passes, that is an average of almost 17 passes per day. The average pass duration was in excess of 12 minutes yielding a total of 441832 data records, with each record containing S_4 , σ_f and other parameters characterising the scintillation during a 20 second element of satellite pass.

12. Kersley L. and Wheadon M.S. Scintillation using NNSS satellites.

Report AFOSR-84-0037, University College of Wales, January, 1985.

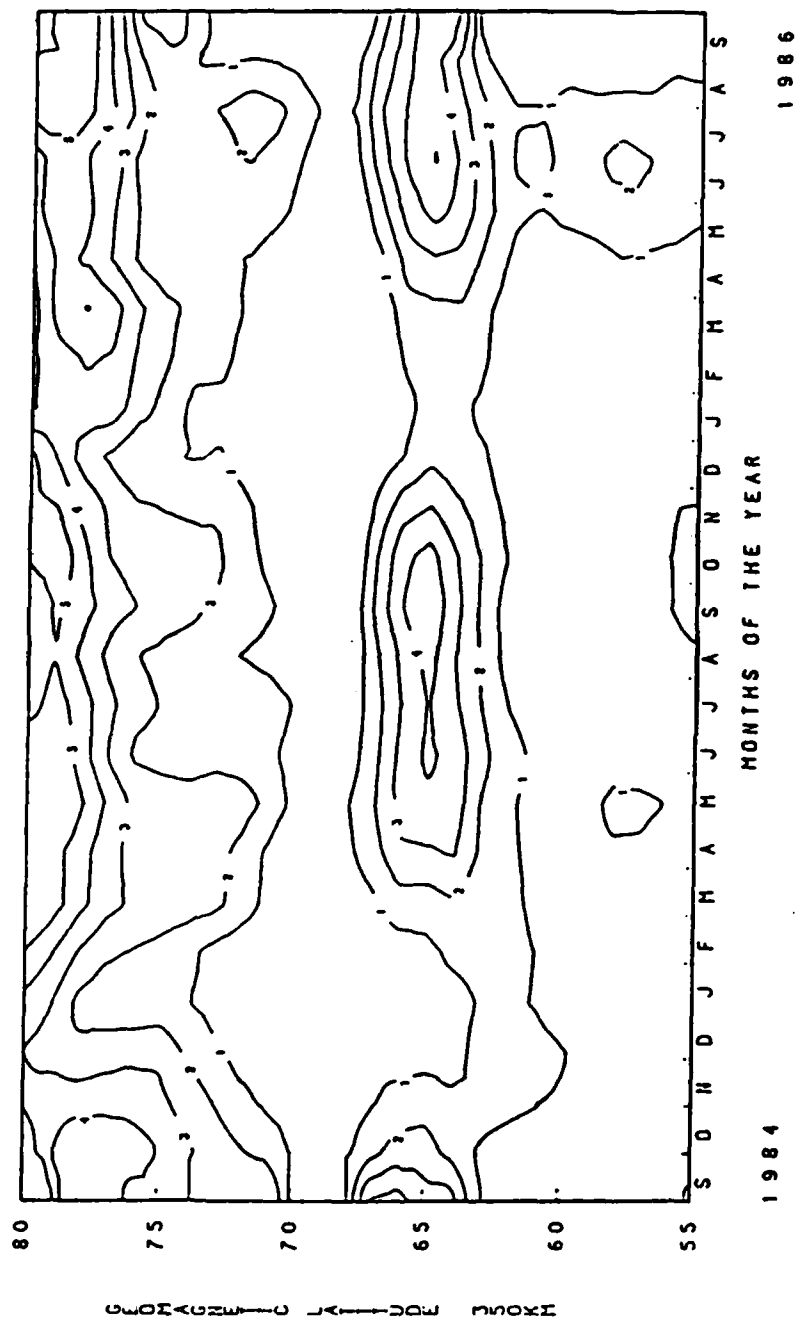
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The present report is concerned largely with scintillation morphology studies using this vast data base of observations. It updates the results given earlier on amplitude scintillation by inclusion of more data but concentrates on analysis of the phase scintillation observations. The importance of geometrical influences on high-latitude scintillation studies was discussed briefly in a previous report. The results of more detailed investigations are presented here, where the geometrical factors in both amplitude and phase scintillation observations have been modelled for different irregularity anisotropies.

Concerning studies of the scintillation producing ionospheric irregularities themselves, a section at the end of this report outlines investigations which have been made combining NNSS observations from the data base with results from two different coherent radar systems.

MORPHOLOGY

Further analysis has been carried out on the large data base of S_4 values which characterize the amplitude scintillation at 150 MHz for each 20 second segment of satellite pass. The morphology has been studied in terms of occurrence of an S_4 value above a specified threshold, expressed as a percentage of the total number of observations within that given category. The variation of scintillation occurrence ($S_4 > 0.2$) as a function of geomagnetic latitude by month is illustrated in Figure 1 incorporating data from satellite passes within $\pm 5^\circ$ longitude of Kiruna over the entire two year period of observations. The main features are the enhancements in activity close to the

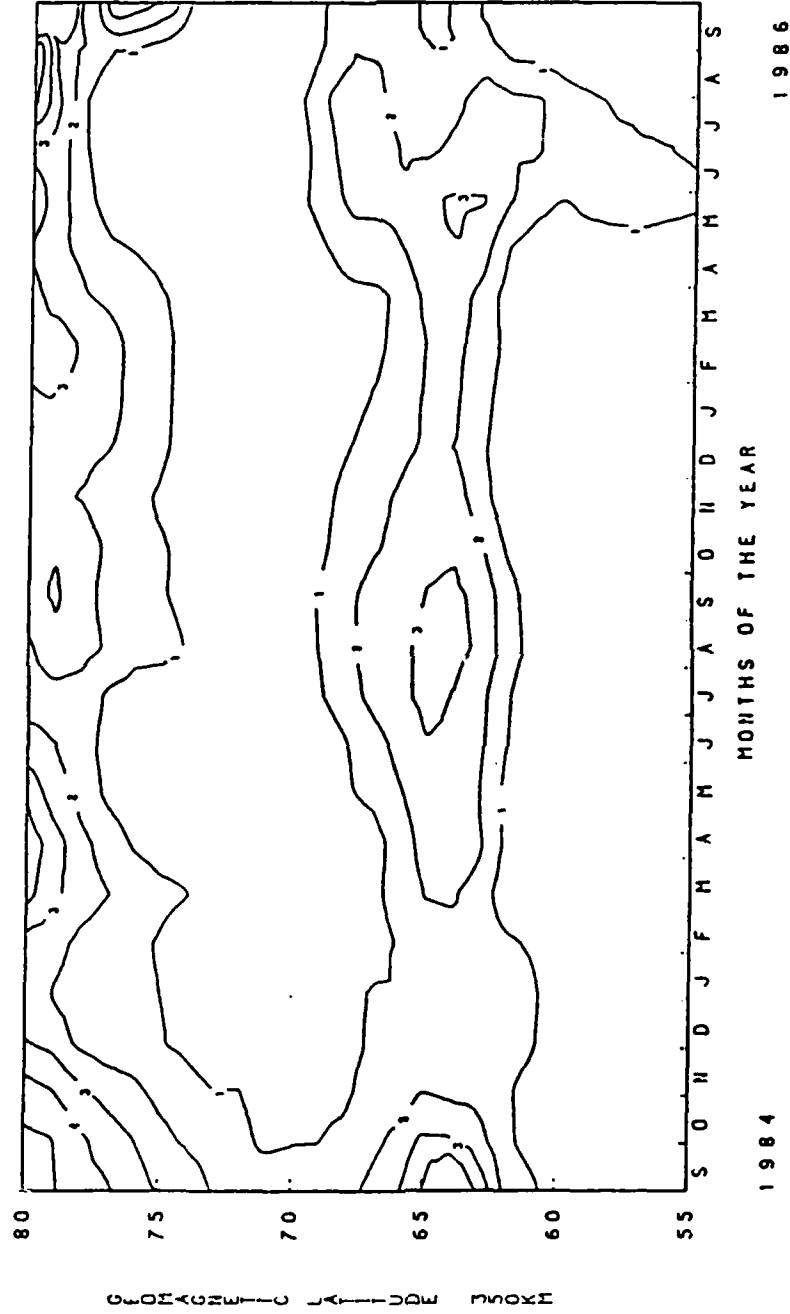


SCINTILLATION OCCURRENCE BY MONTH (S4 > 0.2)
OBSERVED AT KIRUNA (64.3N, 102.8E CGM)
FROM SEPTEMBER 1984 TO SEPTEMBER 1986

FIGURE 1

observing latitude corresponding to propagation approximately aligned to the magnetic field and the gradient of scintillation occurrence to the North as the radiopath travels further through the polar cap region. For the peak close to the observing station it is clear that scintillation occurrence is much greater in the summer and autumn than in winter and early spring confirming the conclusion of the earlier report. The summer maximum shows a 60% exceedence whereas the winter minimum shows occurrence levels just over 25%. North of the station there is evidence for reduced levels of scintillation extending into the polar cap in winter possibly reflecting low plasma densities in the unlit ionosphere during this period of minimum solar activity.

A corresponding plot for phase scintillation is presented in Figure 2. The contours represent exceedence levels of the phase scintillation index σ_ϕ above a threshold of 25 degrees. The σ_ϕ index is defined as the root mean square deviation of the detrended phase fluctuation. In the current experiment the routine processing uses a detrend filter with cut-off at 0.2Hz. This value is of importance in understanding the significance of the choice of 25 degrees as a σ_ϕ threshold. The phase measured here is that of the received 150MHz signal with respect to the 400MHz reference. Given an f^{-1} dependence of phase scintillation and an assumed correlation between the two channels the true σ_ϕ will be some 16% more than that measured. However, more important to σ_ϕ is the



CONTOUR LEVELS: 1=10% 2=15% 3=20% 4=25% 5=30%

RMS PHASE OCCURRENCE BY MONTH (RMS > 25 DEG)
OBSERVED AT KIRUNA (64.3N, 102.8E CGM)
FROM SEPTEMBER 1984 TO SEPTEMBER 1986

FIGURE 2

effect of the choice of detrend filter cut-off at 0.2Hz. Observers of the Wideband satellite in Alaska (FREMOUW et al. 1978)¹³ used 0.1Hz. For an assumed scintillation spectral slope of -3, the effect of filter cut-off and that of phase reference would combine to make the 25 degree threshold of the present results comparable to about 1 radian in the Wideband VHF observations.

Figure 2 shows that phase scintillation also peaks for ray paths close to alignment along the geomagnetic field direction. Here again a 2:1 variation in occurrence between summer and winter is also apparent.

It has already been noted that RINO and MATTHEWS (1980)⁸ claimed to find little evidence of a seasonal variation in their observations from Alaska. More recently, BASU et al. (1987)¹⁴ also report little evidence for a seasonal variation in scintillation occurrence from HILAT observations made in Tromso, Norway.

13. Fremouw E.J., Leadabrand R.L., Livingston R.C., Cousins M.D., Rino C.L., Fair B.C., Long R.A. Early results from the DNA Wideband satellite experiment -Complex-signal scintillation, Radio Sci., 13, 167, 1978.

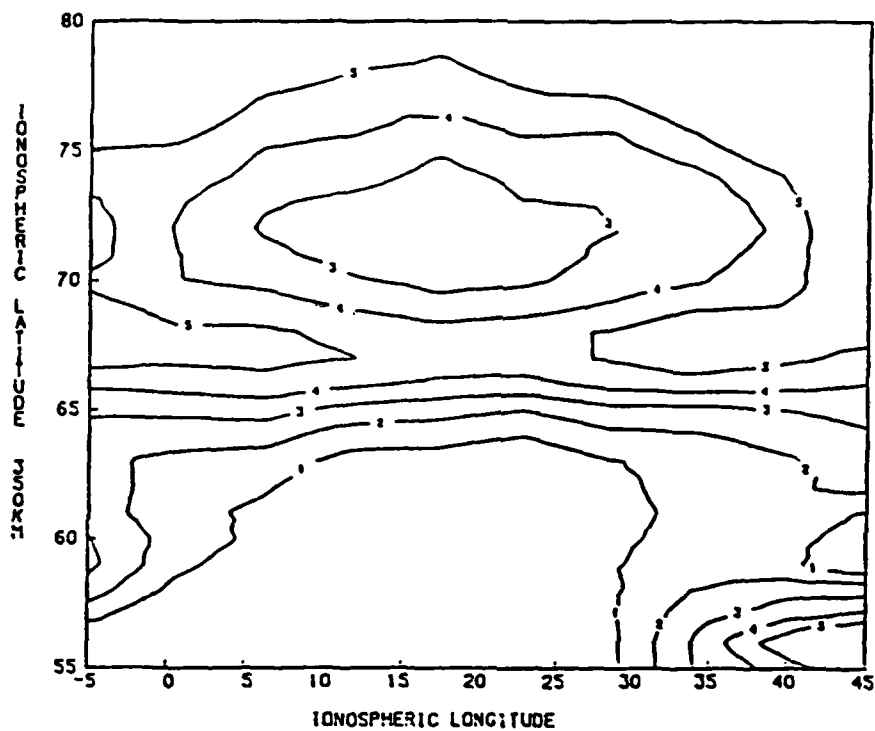
14. Basu S., Basu S. and Mackenzie E. Ionospheric scintillations and in-situ measurements at an auroral location in the European sector. Proc. AGARD conference, Rome, 1987

However, it must be noted that both the Alaskan and Scandinavian conclusions were obtained from observations made using only a single satellite so that data covering a range of longitudes but for relatively restricted time sectors have been taken together. In the present work only overhead passes, within ± 5 degrees longitude of Kiruna, have been used to compile Figures 1 and 2.

Figures 3 to 6 show contours of phase scintillation occurrence ($\sigma_p > 25$ degrees) on a latitude/longitude grid with the station at the centre, each graph representing a different season. Close to the edges of the plots caution must be exercised in interpretation because of the contouring routines used. However, in general the data base is large enough to give a reliable guide to scintillation occurrence.

A feature common to all the plots is the saddle-like nature of the contours in the vicinity of the observing station. Higher values are found in phase scintillation occurrence for propagation directions essentially confined within an L-shell. Depleted values are to be seen for propagation paths to satellites immediately North of the station although occurrence is again enhanced towards the Northern horizon.

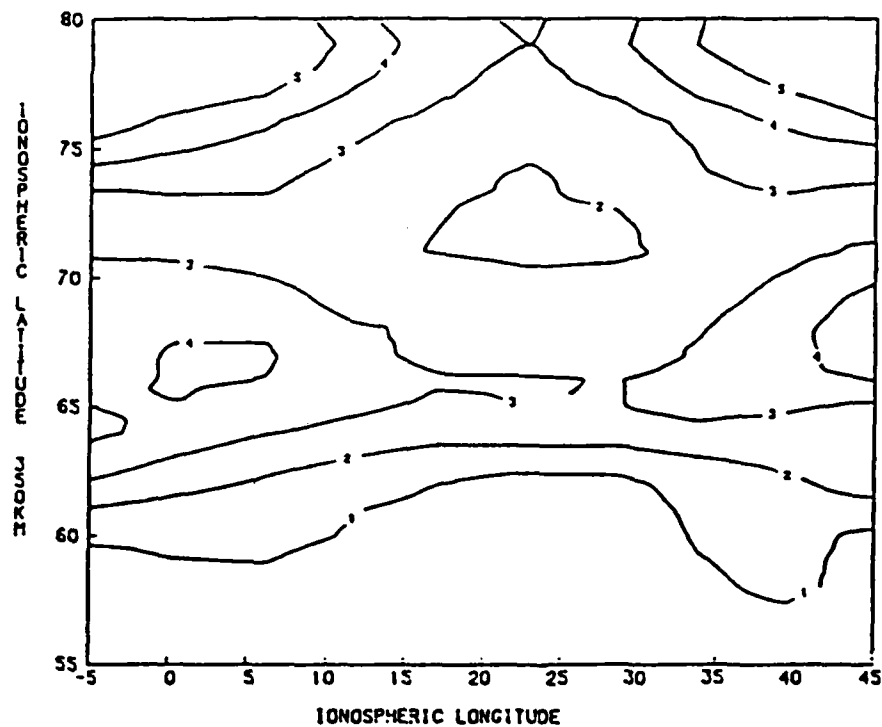
As with amplitude scintillation the features shown in Figures 3 to 6 largely reflect the biases present in the observations for differing propagation geometries. However, it can be noted that the plots show significant differences from those for amplitude scintillation presented earlier where a field-aligned enhancement was a significant feature.



CONTOUR LEVELS: 1=10% 2=15% 3=20% 4=25% 5=30%

OCCURRENCE OF RMS PHASE > 25 DEGREES
OBSERVED AT KIRUNA (67.8N, 20.4E)
AUTUMN 1984

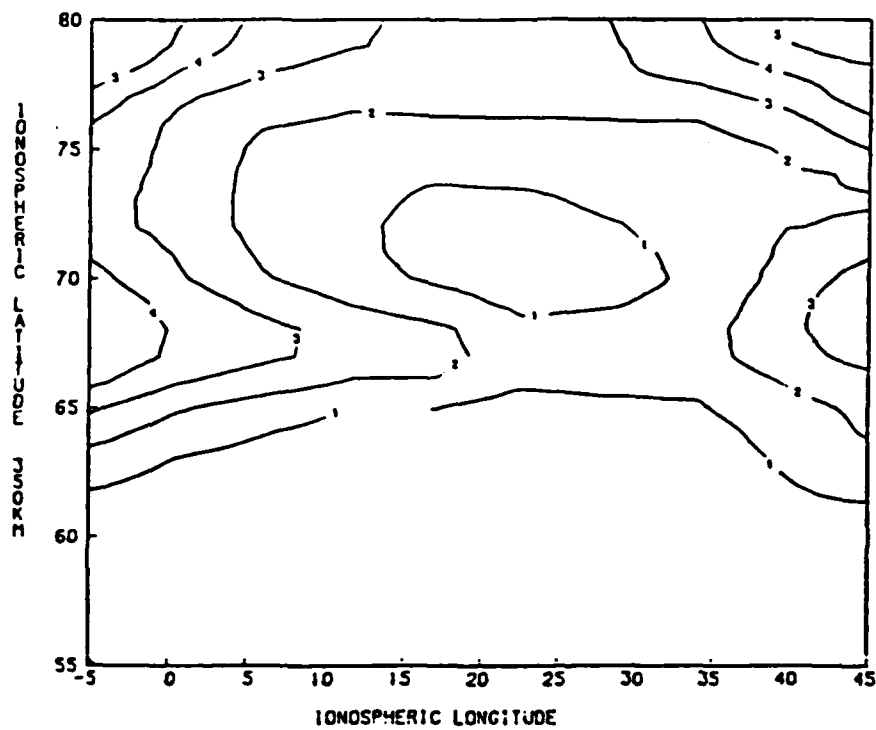
FIGURE 3



CONTOUR LEVELS: 1=10% 2=15% 3=20% 4=25% 5=30%

OCCURRENCE OF RMS PHASE > 25 DEGREES
OBSERVED AT KIRUNA (67.8N, 20.4E)
WINTER 1984/85

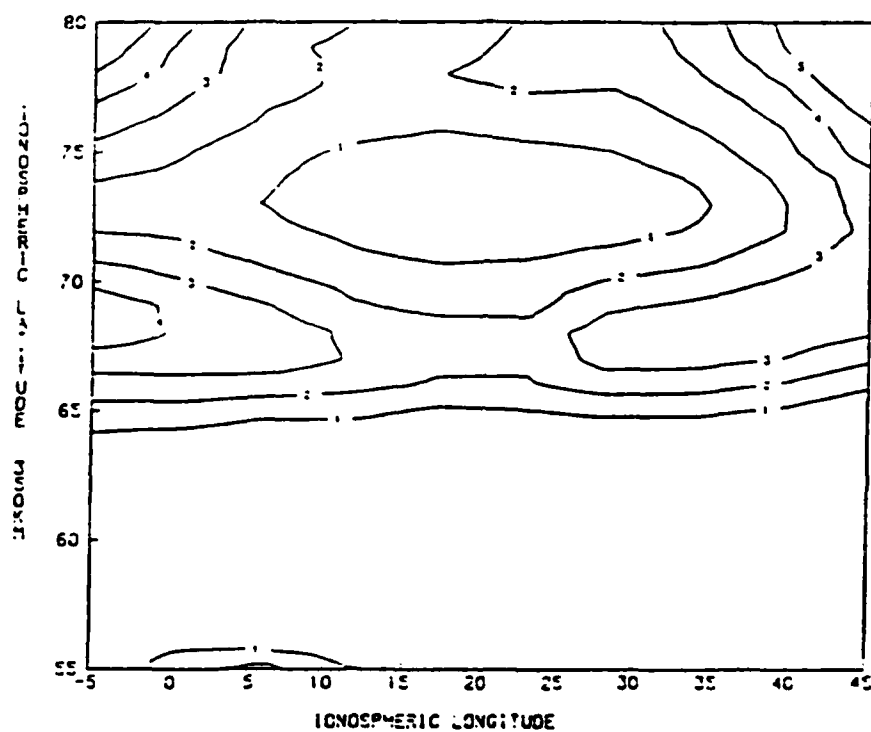
FIGURE 4



CONTOUR LEVELS: 1=10% 2=15% 3=20% 4=25% 5=30%

OCCURRENCE OF RMS PHASE > 25 DEGREES
OBSERVED AT KIRUNA (67.8N, 20.4E)
SPRING 1985

FIGURE 5



CONTOUR LEVELS: 1=10% 2=15% 3=20% 4=25% 5=30%

OCCURRENCE OF RMS PHASE > 25 DEGREES
OBSERVED AT KIRUNA (67.8N, 20.4E)
SUMMER 1985

FIGURE 6

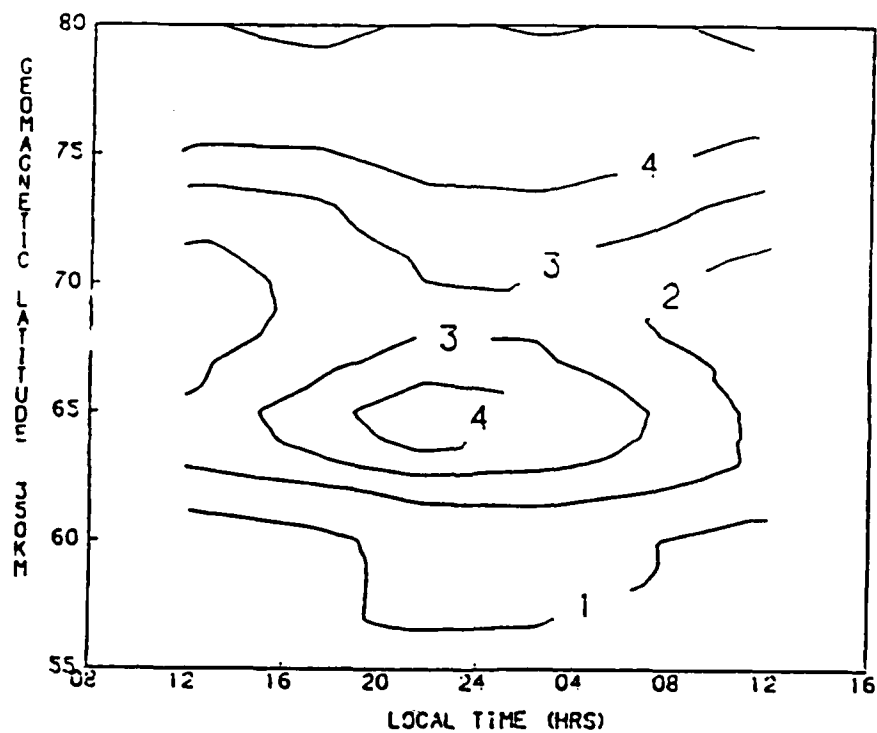
This topic will be discussed in greater detail later when results are presented of studies carried out to model the geometrical effects.

Diurnal variations in phase scintillation occurrence ($\sigma_{\phi} > 25$ degrees) can be seen in the plots of Figures 7 to 10. These plots, on a geomagnetic latitude/local time grid, have been obtained using data from passes within 10 degrees longitude of the observing station and are representative of the four seasons. Scintillation activity is shown to increase at night although the maximum is more closely centred on local midnight than was apparent in the amplitude data, where a premidnight maximum could be seen for the same data groupings.

MODELLING OF GEOMETRICAL INFLUENCES

RINO and FREMOUW (1977)¹⁵ and RINO (1979)⁹ have developed a general model of scintillation based on phase screen theory in which the irregularity size distribution is characterised by a power law spectral density function. Using the notation of RINO (1979)⁹ it can be shown that for amplitude or intensity scintillation.

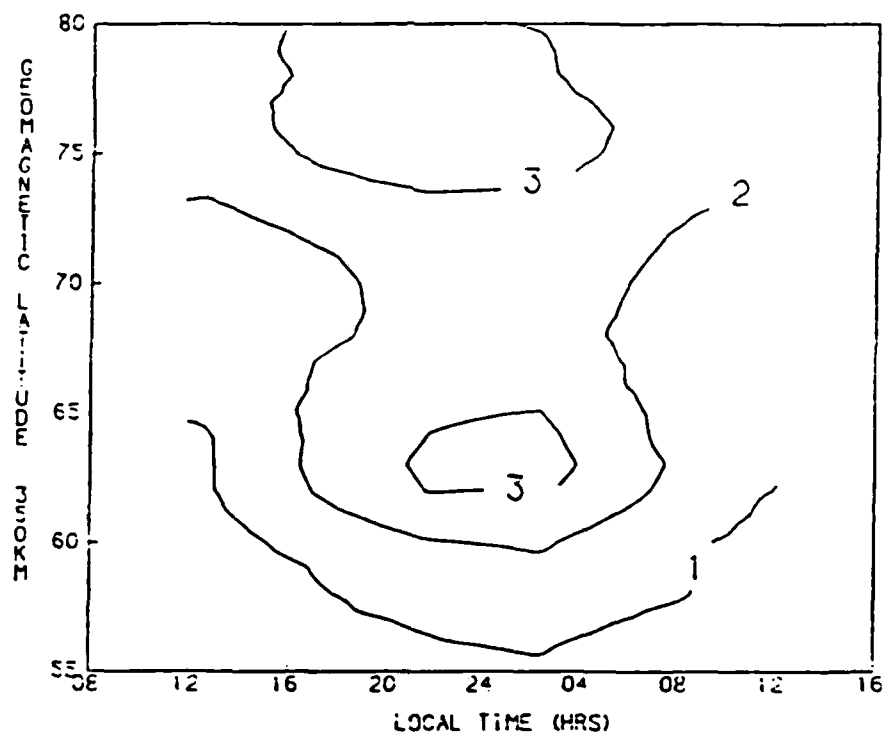
15. Rino C.L. and Fremouw E.L. The angle dependence of singly scattered wavefields. J.A.T.P., 30, 859, 1977



CONTOUR LEVELS: 1=10% 2=20% 3=30% 4=40% 5=50%

DIURNAL VARIATION OF RMS PHASE >25 DEGREES
OBSERVED AT KIRUNA (64.3N, 102.8E CGM)
AUTUMN 1984

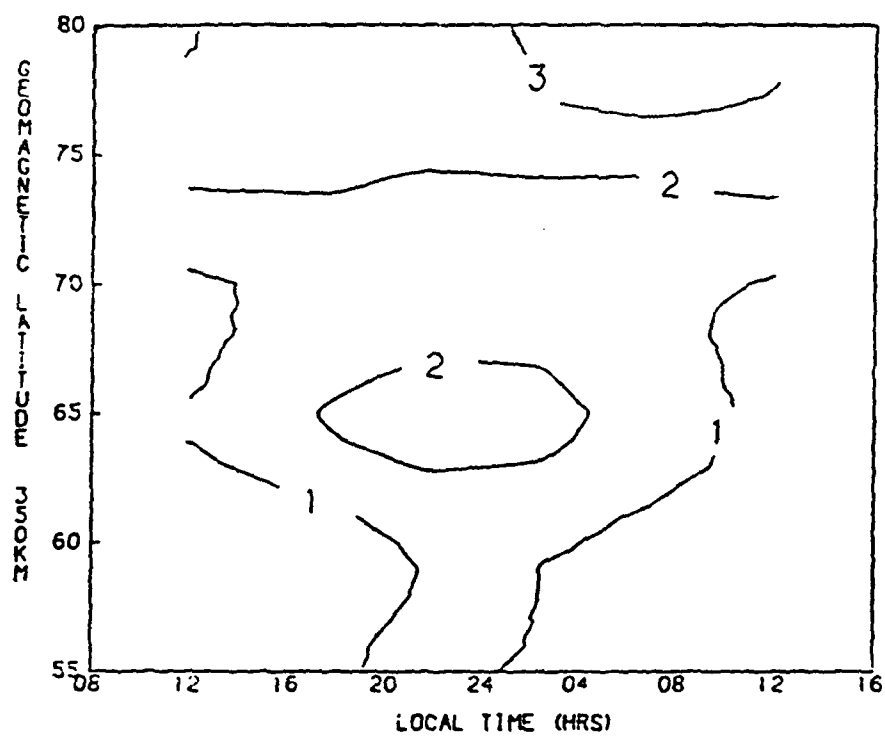
FIGURE 7



CONTOUR LEVELS: 1=10% 2=20% 3=30% 4=40% 5=50%

DIURNAL VARIATION OF RMS PHASE >25 DEGREES
OBSERVED AT KIRUNA (64.3N.102.8E CGM)
WINTER 1984/85

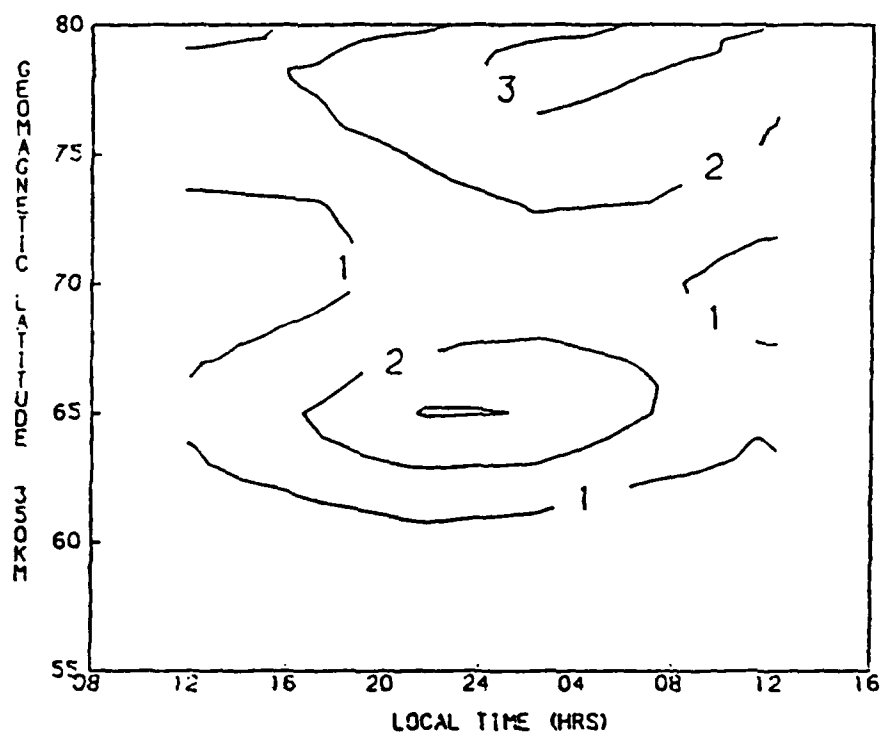
FIGURE 8



CONTOUR LEVELS: 1=10% 2=20% 3=30% 4=40% 5=50%

DIURNAL VARIATION OF RMS PHASE >25 DEGREES
OBSERVED AT KIRUNA (64.3N, 102.8E CGM)
SPRING 1985

FIGURE 9



CONTOUR LEVELS: 1=10% 2=20% 3=30% 4=40% 5=50%

DIURNAL VARIATION OF RMS PHASE >25 DEGREES
OBSERVED AT KIRUNA (64.3N, 102.8E CGM)
SUMMER 1985

FIGURE 10

$$S_4^2 = r_e^2 \lambda^2 (L \sec \theta) C_s z^{v-1/2} \left[\frac{\Gamma(2.5 - v)/2}{2\sqrt{\pi} \Gamma((v-0.5)/2) (v-0.5)} \right] J$$

$$\text{where } J = \frac{ab}{\sqrt{A''} C''} v {}_2F_1\left(\frac{1}{2} - v, \frac{1}{2}; 1; \frac{A'' - C''}{A''}\right)$$

This formula contains factors dependent on irregularity axial ratios and propagation and magnetic field geometry. For an assumed spectral slope the influence of propagation and irregularity geometry on S_4 can thus be calculated. In practice, in the present work the magnitude of the phase spectral index $p = 2v$ was taken to be 3. The constraint placed on S_4 by the Fresnel zone parameter Z can also be seen. This parameter was calculated to allow for wavefront curvature from a finite source distance. The irregularity inner scale is taken to be zero and all irregularities are assumed to be less than the Fresnel zone size. For phase scintillation the corresponding expression for phase variance is given by

$$\langle \delta \phi^2 \rangle = r_e^2 \lambda^2 (L \sec \theta) G C s \frac{q_0^{-2\nu+1} \Gamma(\nu - \frac{1}{2})}{4\pi \Gamma(\nu + \frac{1}{2})}$$

$$\text{where } G = \frac{ab}{\sqrt{AC - B^2/4} \cos \theta}$$

This is similar to that obtained for S_4 but does not depend upon Fresnel zone size.

From the two equations given above the effects in both S_4 and σ of propagation and irregularity geometry have been computed for conditions appropriate to observations at Kiruna and for differing irregularity anisotropies.

The influence of propagation and irregularity geometry on S_4 is shown in Figures 11 to 13. These are azimuth elevation plots where the geometrical factor in S_4 has been normalised to the overhead value. These plots are shown for rod-like irregularity structures with the field aligned axial ratios ranging from 3:1 to 8:1. The graphs

S4 Geometrical Factor 3:1:1 Kiruna

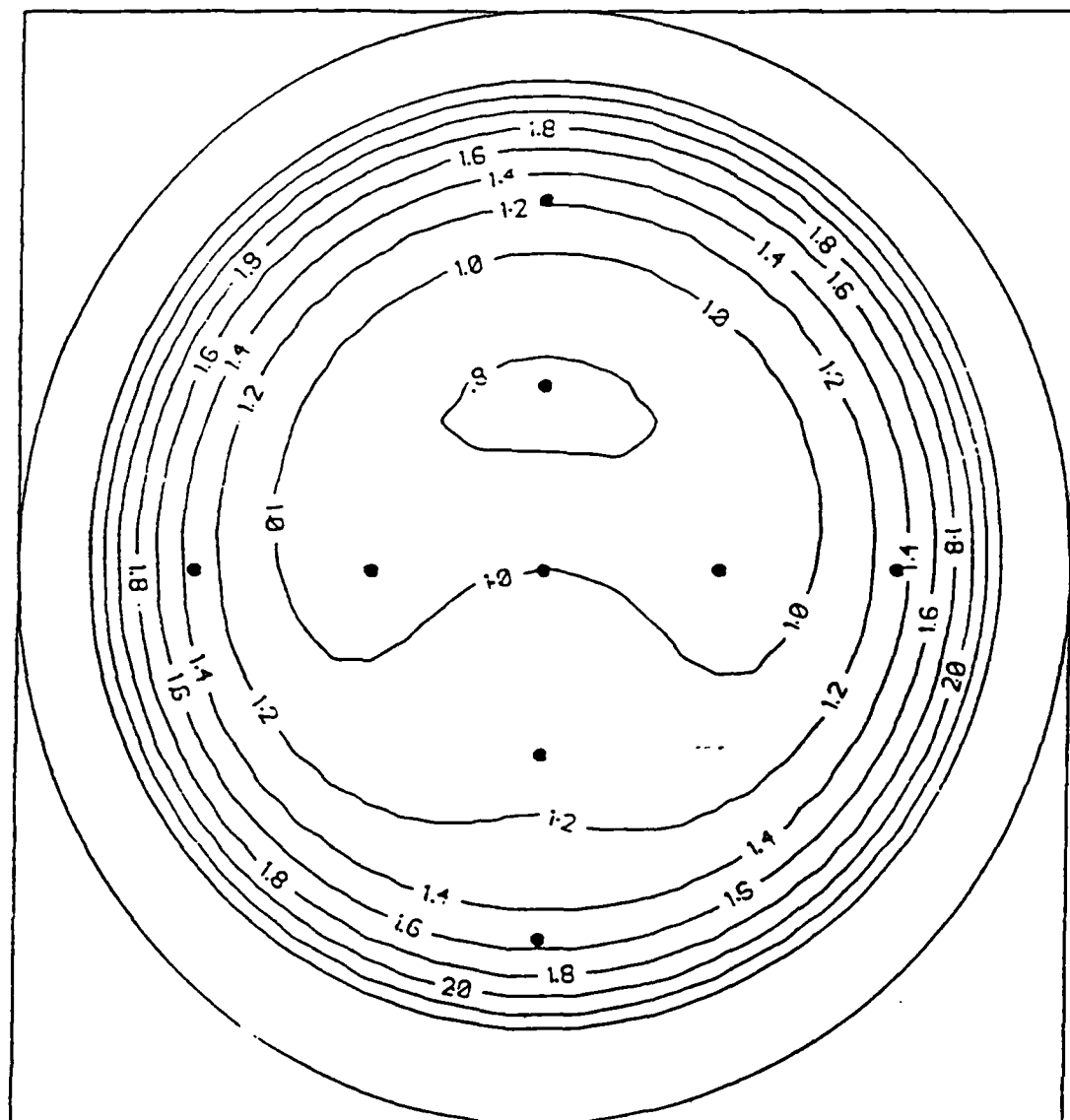


FIGURE 11

S4 Geometrical Factor 5:1:1 Kiruna

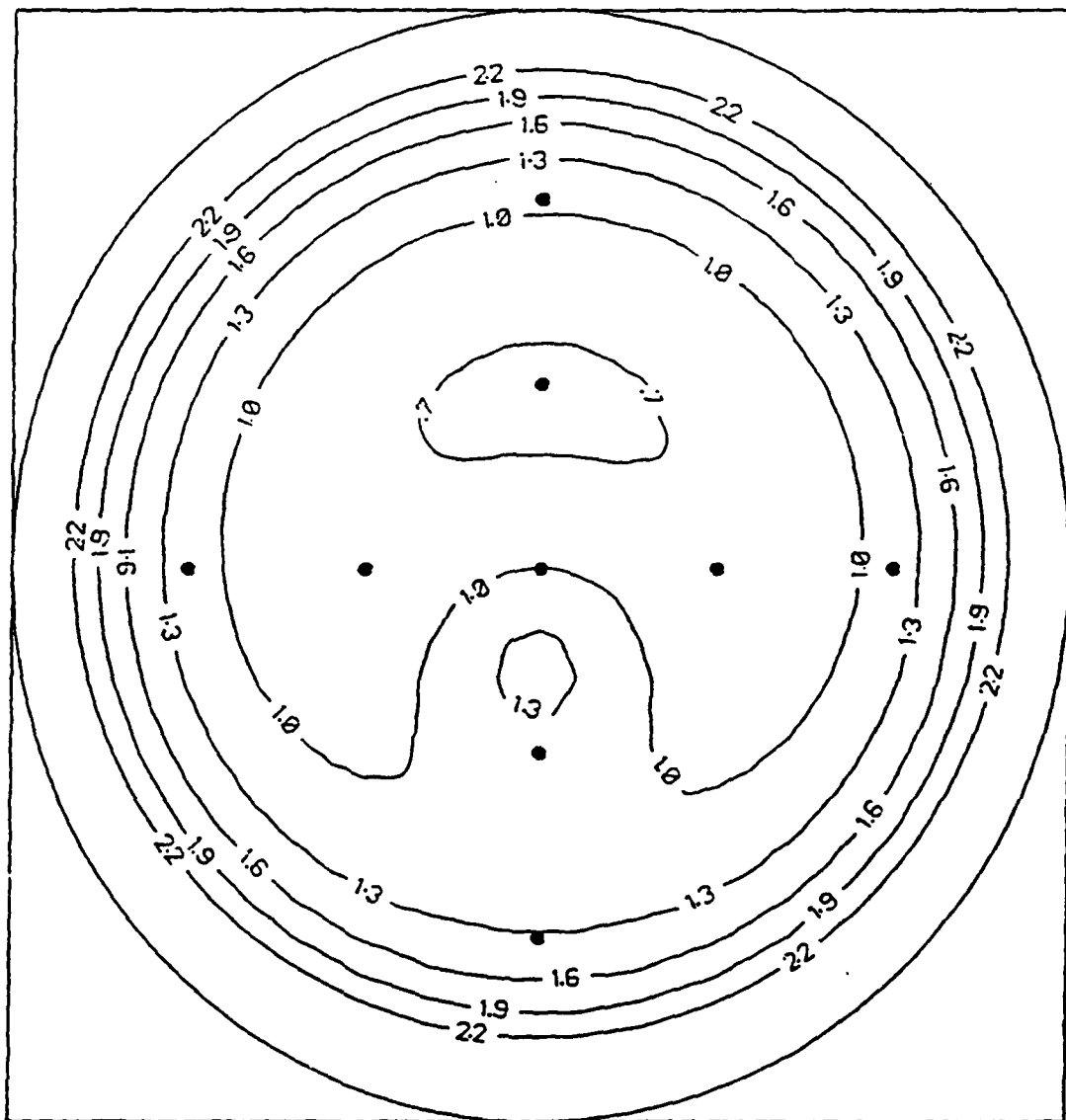


FIGURE 12

S4 Geometrical Factor 8:1:1 Kiruna

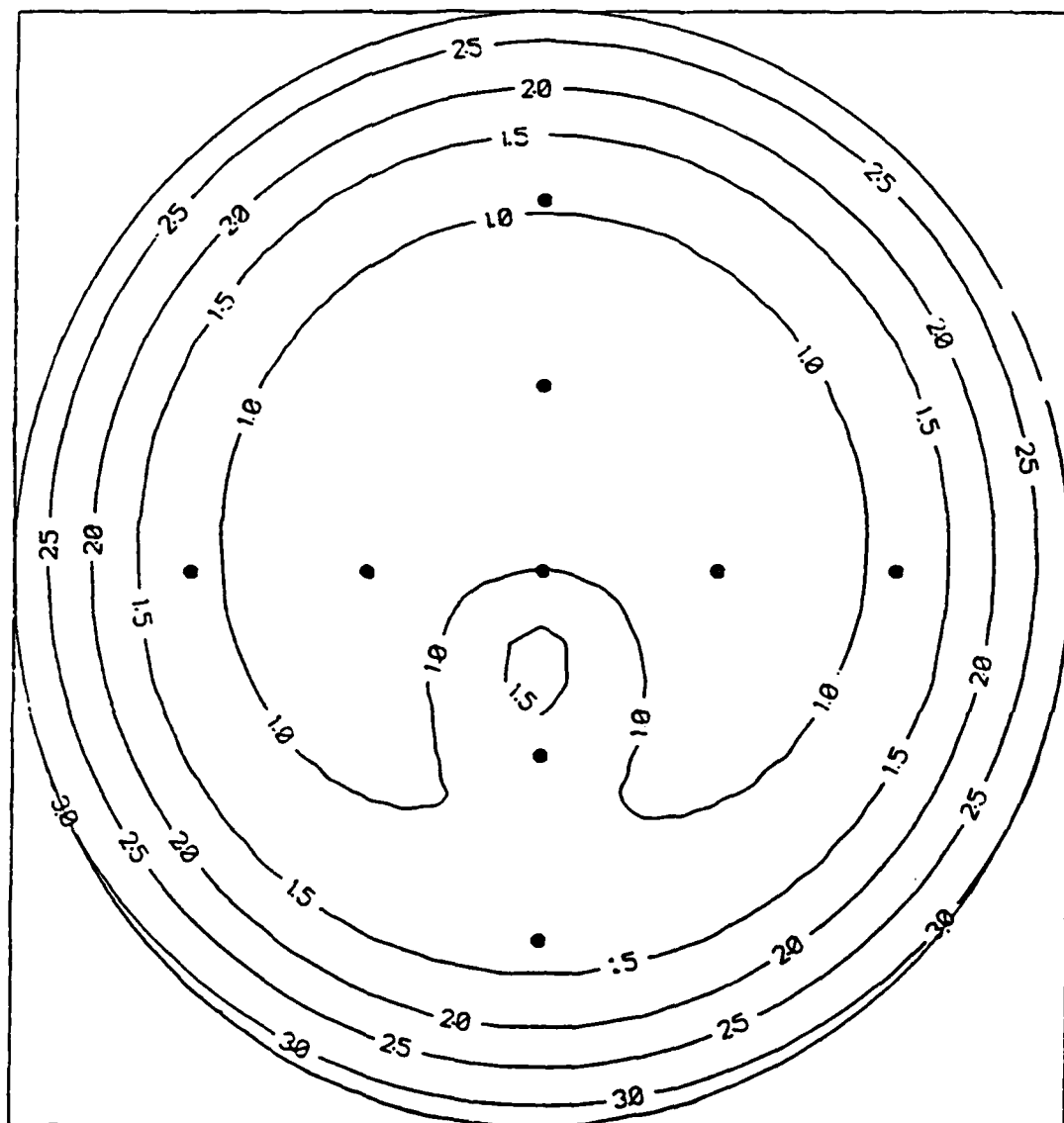


FIGURE 13

correspond to observations made at Kiruna and the irregularity height has been assumed to be 350km.

With increasing axial ratio the effects of the field-aligned enhancement in S_4 become more apparent. For example for 8:1 rod-like irregularities the observed S_4 will be enhanced by more than 50% for field-aligned propagation compared to measurements made in the zenith. To the North of the station the effects of propagation geometry cause depleted values of S_4 over a wide range of angles. It should be noted that the contour interval differs in the three figures. A low elevation angle influence on S_4 is also apparent in the figures with enhanced values in the normalised geometrical factor towards the horizon.

The effect of cross-field anisotropy of the irregularities on S_4 is shown in Figures 14 to 17. Figures 14 and 15 are for 'wing-like' structures with axial ratios 5:2:1 and 3:4:1 respectively. The region of geometrical enhancement which was concentrated on the field-line direction for rod-like structures has now become extended along L-shells in the magnetic East-West direction. The saddle-like enhancement becomes steeper for greater axial ratios of the irregularities.

Another extreme form of possible irregularity shape is that of 'sheets', extended uniformly in both the field-aligned and magnetic East-West directions. Figures 16 and 17 show the effects of propagation geometry on S_4 for sheet-like structures with axial ratios of 5:5:1 and 8:8:1 respectively. The saddle-like feature along the L-shells is more pronounced for such structures and the multiplying factors in S_4 are

S4 Geometrical Factor 5:2:1 Kiruna

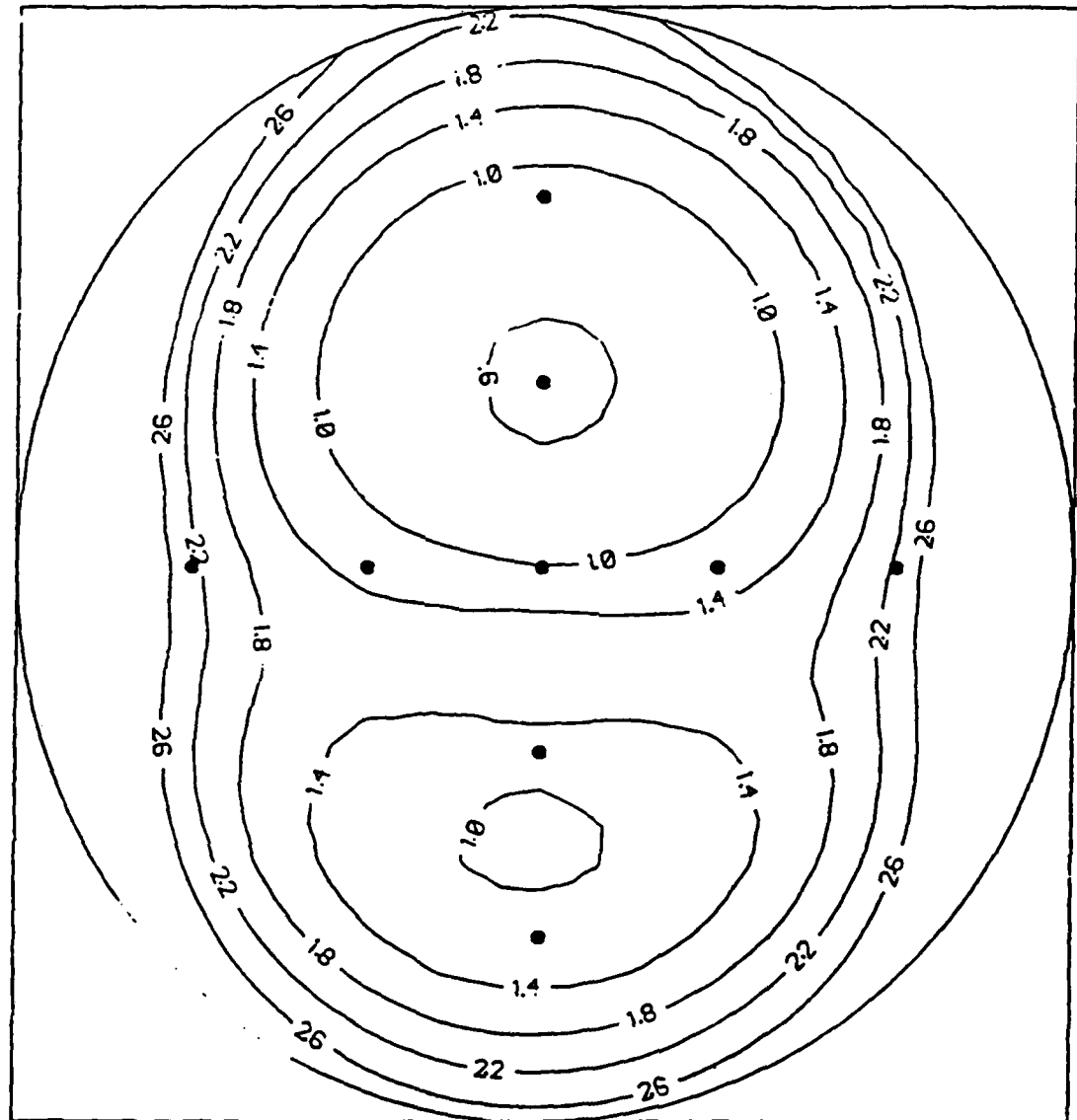


FIGURE 14

S4 Geometrical Factor 8:4:1 Kiruna

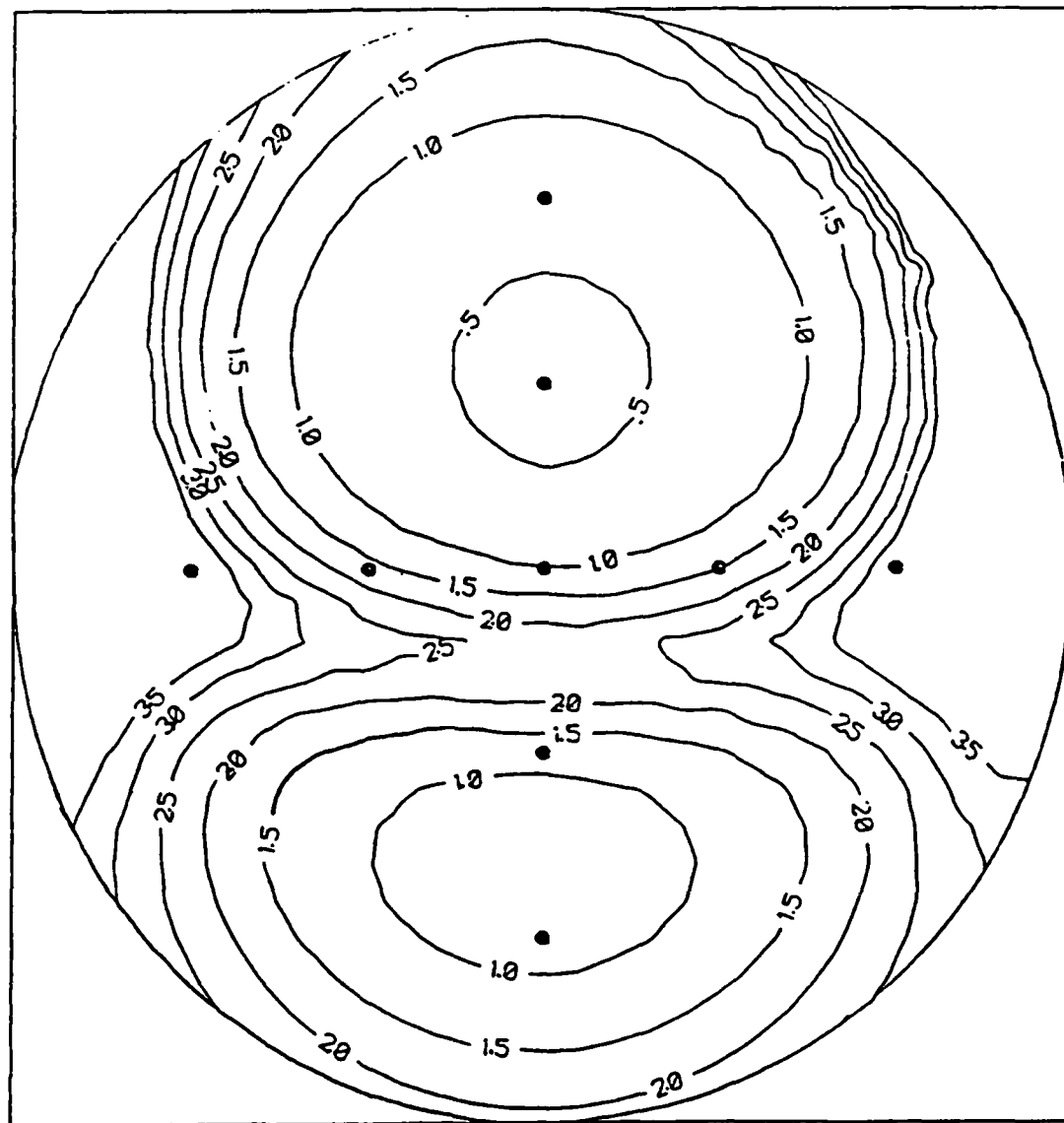


FIGURE 15

S4 Geometrical Factor 5:5:1 Kiruna

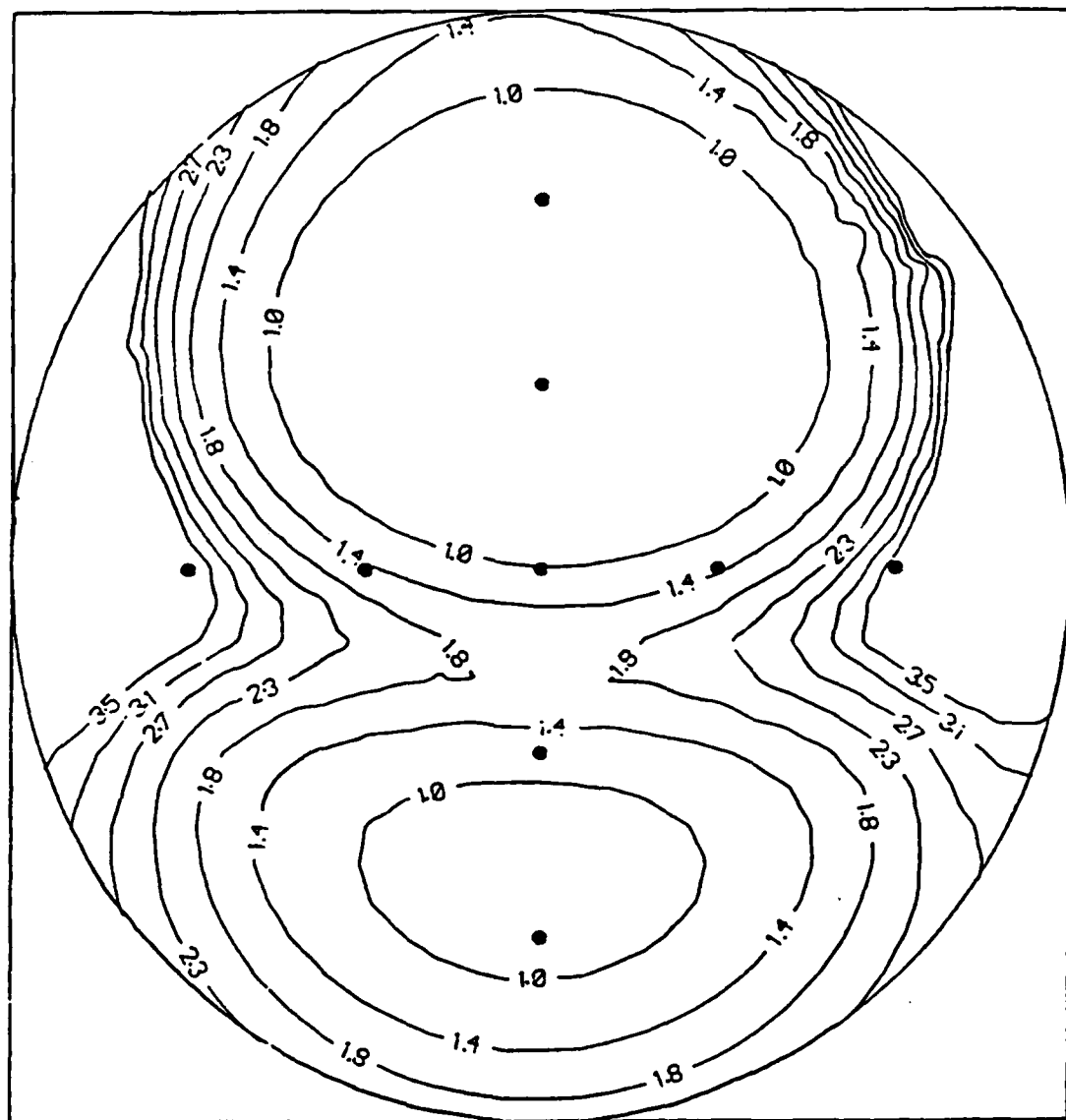


FIGURE 16

S4 Geometrical Factor 8:8:1 Kiruna

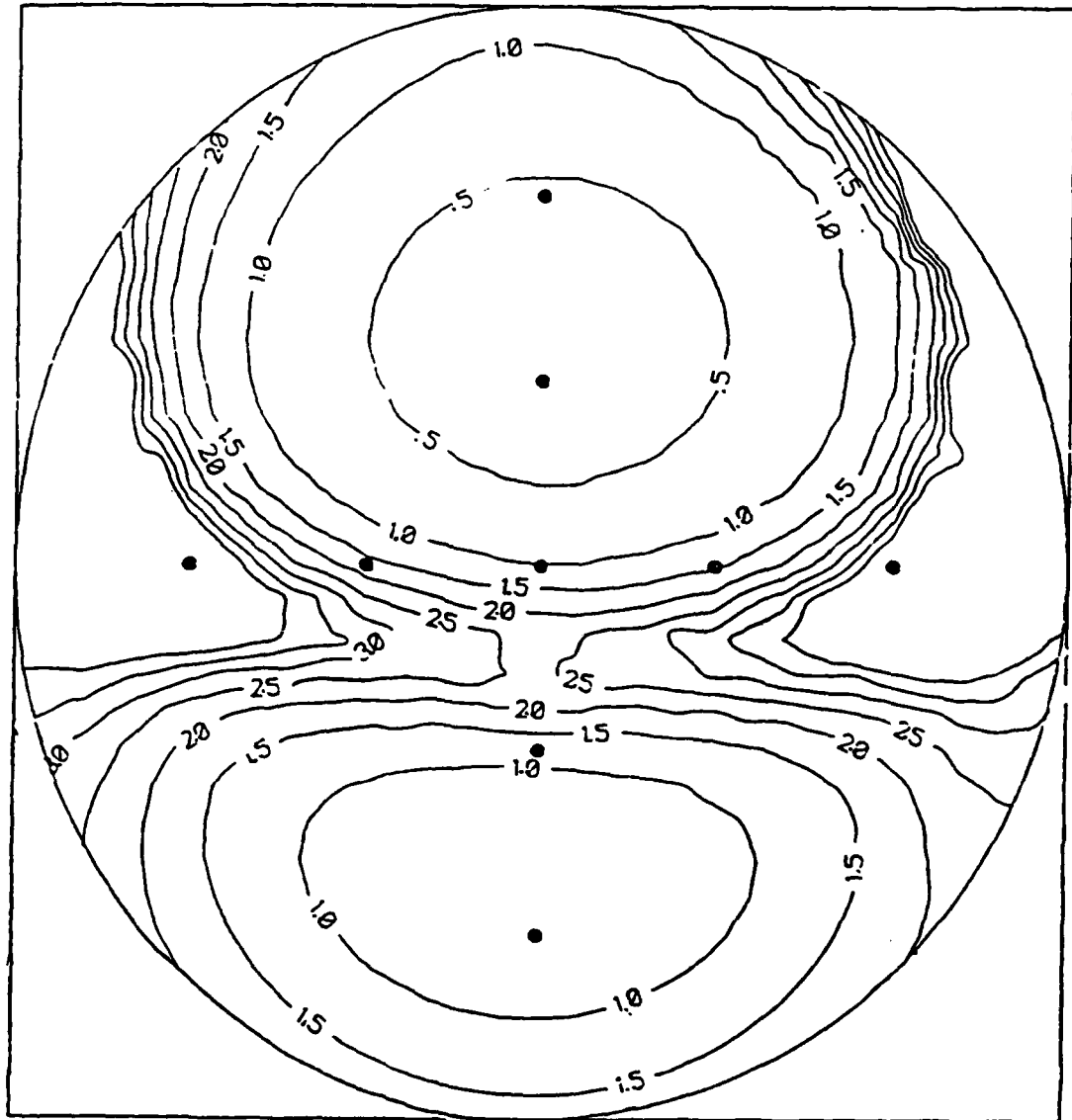


FIGURE 17

magnified with increasing axial ratios. The large regions of reduced S_4 particularly to the North of the station, but also to a lesser extent to the South are also features of interest. It should be noted that the small scale perturbations evident on some of the figures are artifacts of the grid system used in the computations so that visual smoothing should be exercised in interpreting some of the finer details of certain of the figures.

It has been noted from the equations given earlier that the geometrical factors in S_4 and σ_{θ} are different, because of the limitations imposed by Fresnel filtering on the development of amplitude scintillation. It is thus possible to make separate estimates of the geometrical influence in σ_{θ} for comparison with the observed data.

Azimuth elevation plots of the geometrical influence in σ_{θ} , again normalised to observation in the zenith, are presented in Figures 13 and 19 for 8:1:1 rod-like irregularities and 8:8:1 sheet-like irregularities respectively. Comparisons between Figures 13 and 18 and 17 and 19 show the differences in the geometrical influences on amplitude and phase scintillation for the two extremes of rod and sheet-like irregularities.

An aim of the present work is to exploit these differences and use the observations of S_4 and σ_{θ} in an attempt to assess both the anisotropy and the distribution of the irregularities causing the scintillation. The aim is to try to obtain an irregularity anisotropy model, or a series of models for different times of day, from which geometrical factors of the kind presented in the previous figures can then be

Phase Geometrical Factor 8:1:1 Kiruna

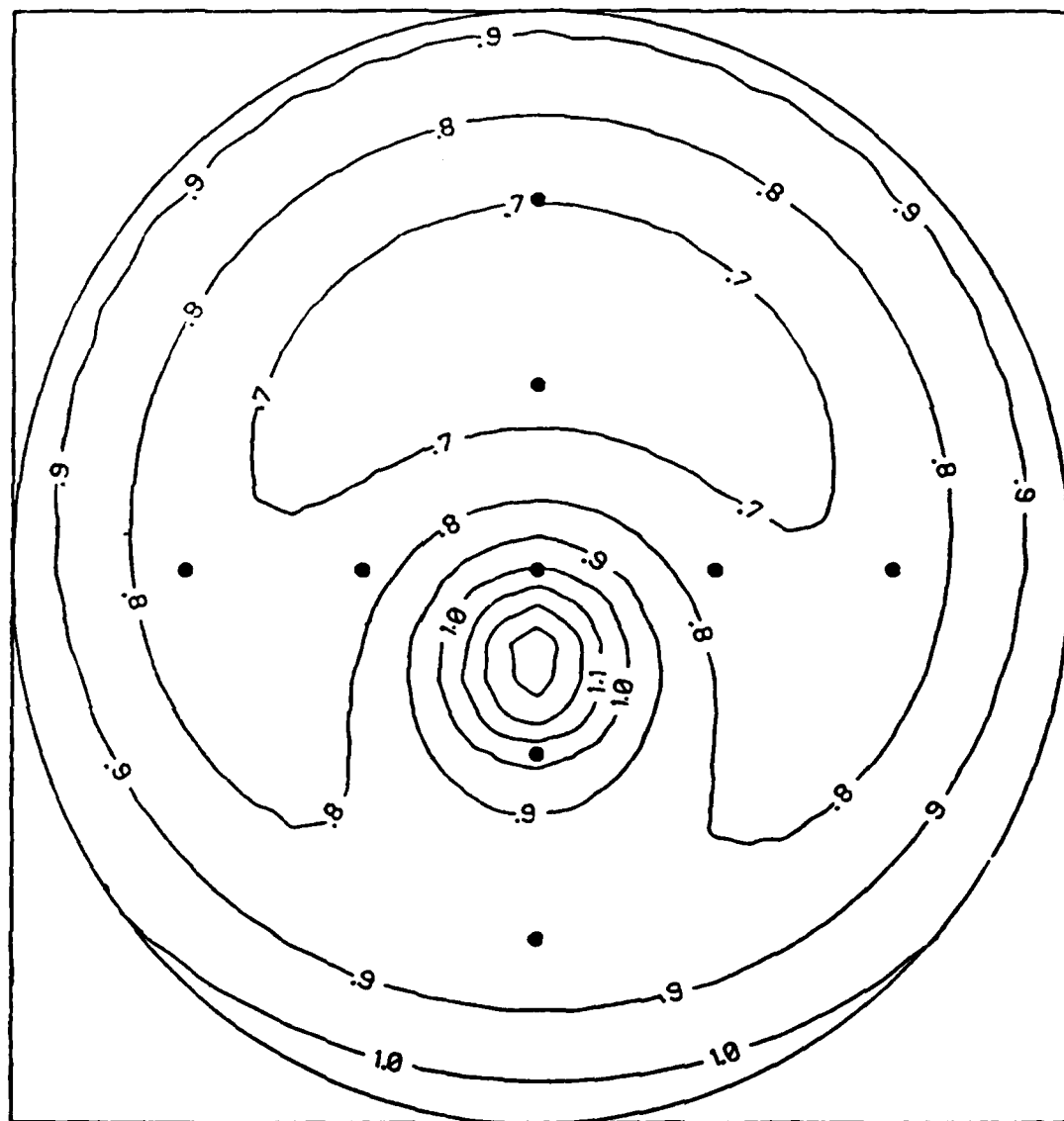


FIGURE 18

Phase Geometrical Factor 8:8:1 Kiruna

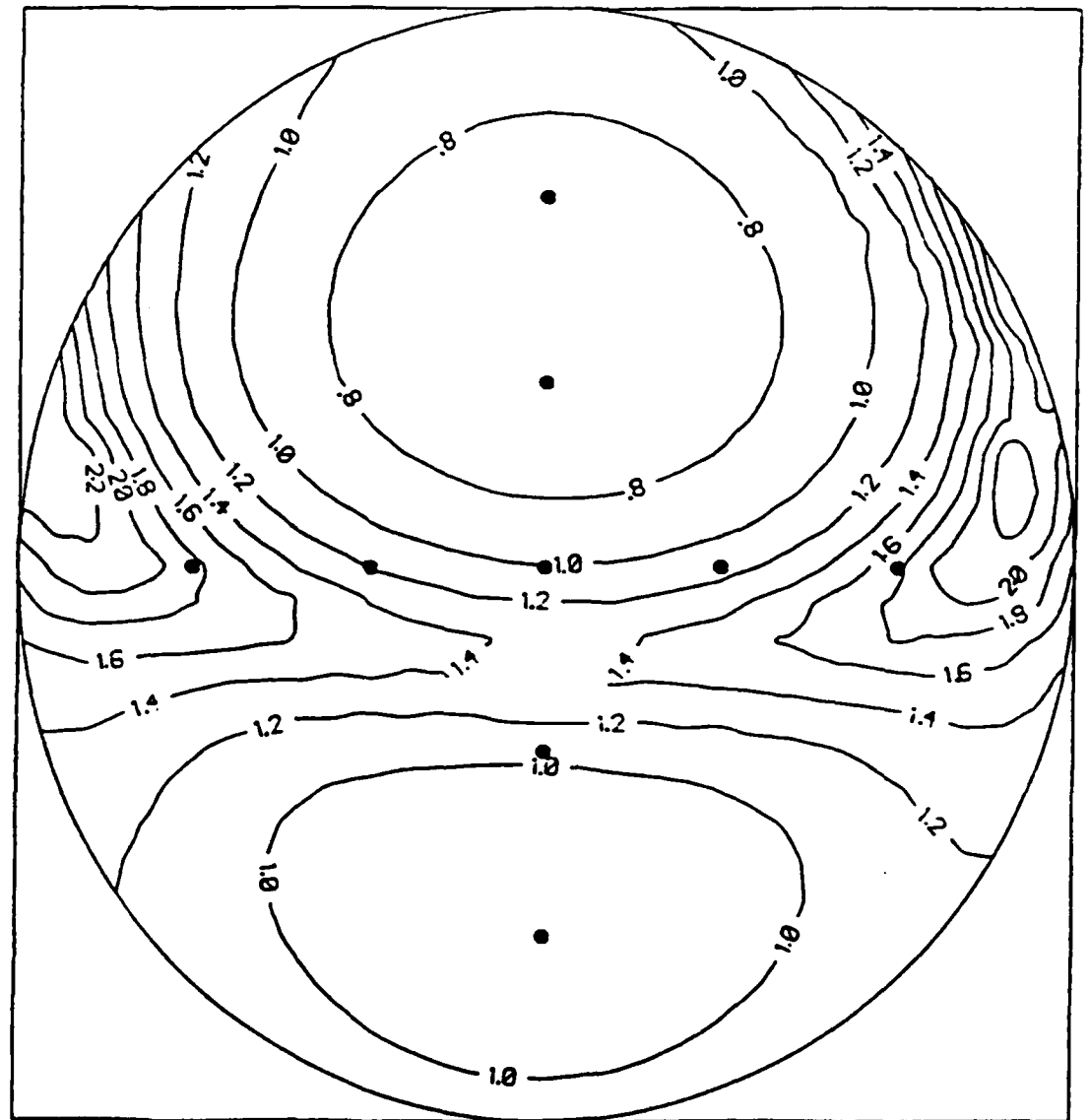


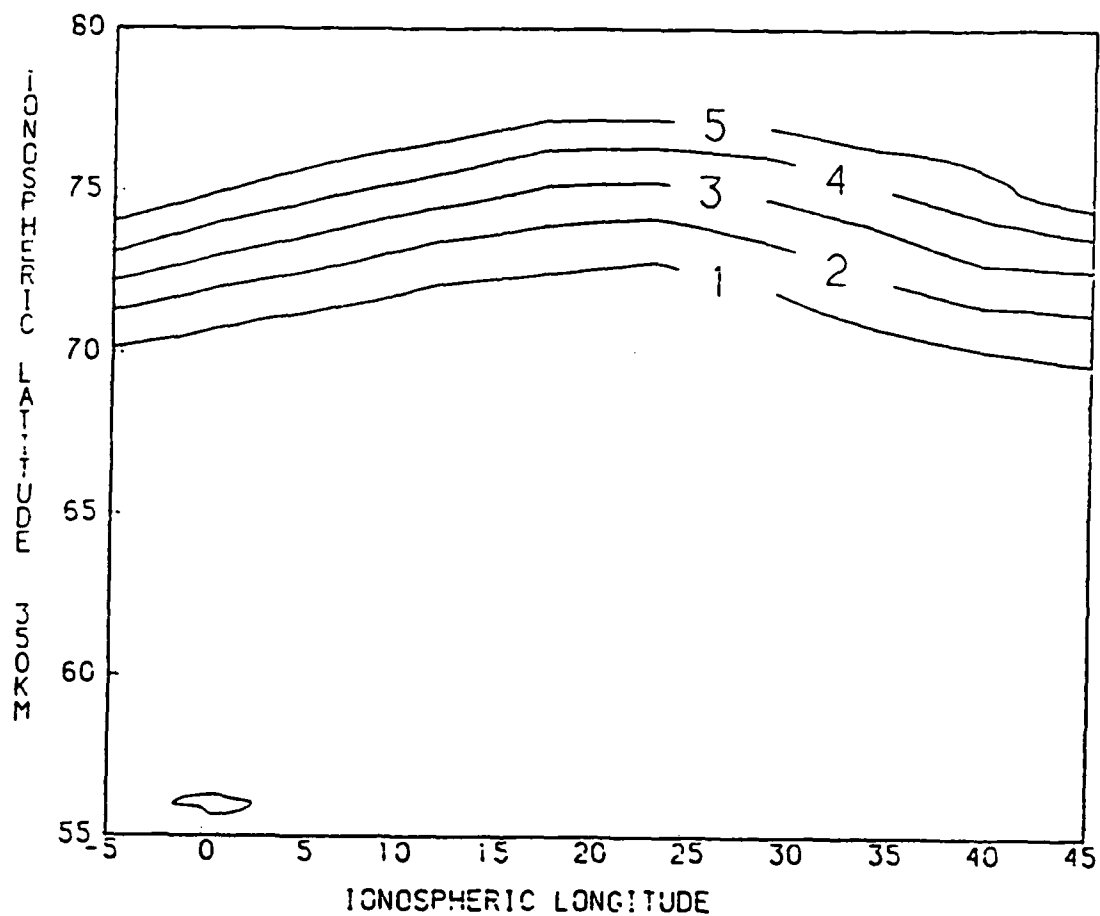
FIGURE 19

calculated for both amplitude and phase. The values of S_4 and σ_ϕ can then be modified to remove geometrical effects and if the anisotropy model is correct then a self consistent pattern for irregularity occurrence should, it is hoped, be found for both amplitude and phase data.

An early example of the results of this procedure on S_4 is shown in Figure 20. Here 5:5:1 sheet-like irregularities have been used to calculate the geometrical factors shown in Figure 16. The actual values of S_4 for Autumn 1984 have then been weighted by the factor appropriate to the particular observing geometry and the occurrence plot for S_4 0.2 redrawn. Compared with the plot of the raw observations (Figure 21) it can be seen that the enhancement associated with field-aligned and L-shell confined propagation has been removed and that the resulting contours are generally aligned East-West at latitudes greater than the station with a clear lower latitude scintillation boundary. It must be noted that data from all times of day and all levels of magnetic activity for one season have been used in the compilation of this figure. Work continues using both amplitude and phase observations from restricted time sectors to try to assess whether rod-like or sheet-like irregularities are more appropriate at different times of day and under different magnetic conditions.

IRREGULARITY STUDIES

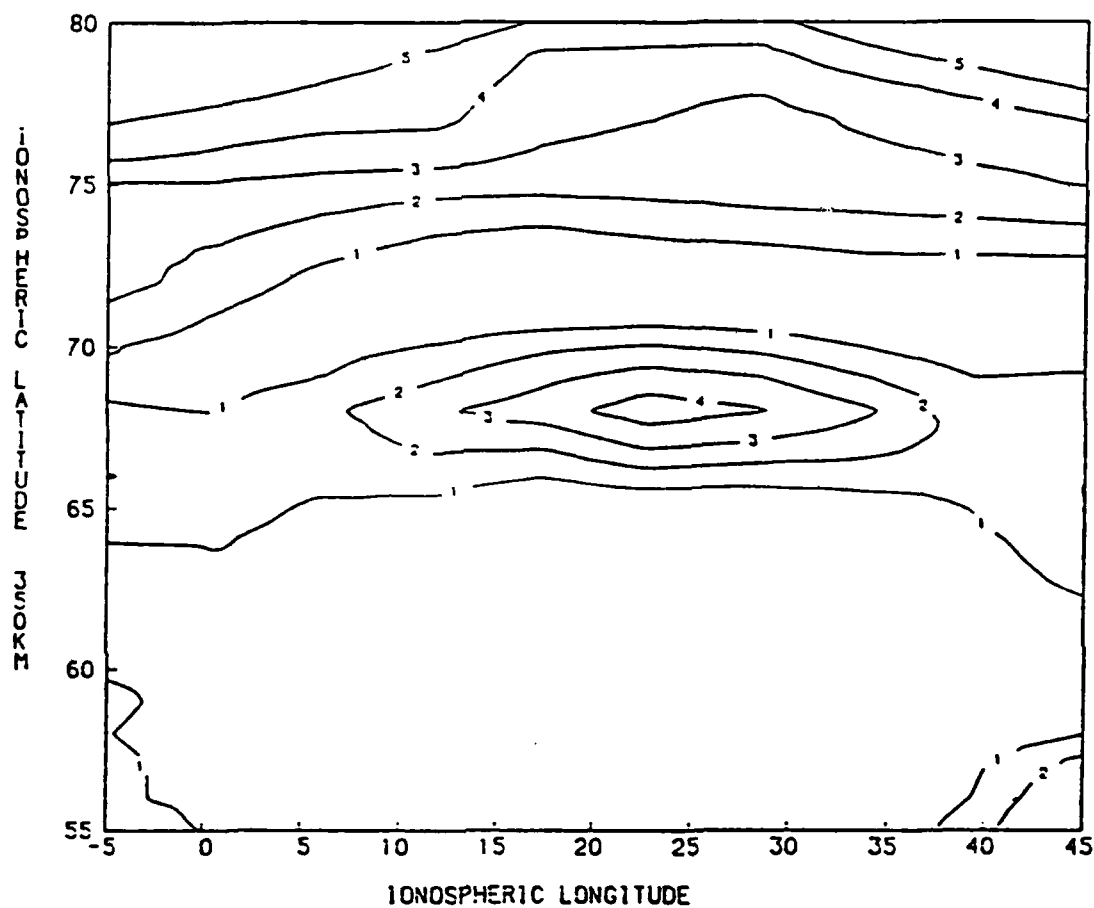
In parallel with the scintillation studies already described work has continued on investigations of the sub-kilometer scale irregularities



CONTOUR LEVELS: 1=10% 2=20% 3=30% 4=40% 5=50%

OCCURRENCE OF $S_4 > 0.2$ WITH 5:5:1 MODEL REMOVED
OBSERVED AT KIRUNA (67.8N, 20.4E)
AUTUMN 1984

FIGURE 20



CONTOUR LEVELS: 1=25% 2=35% 3=45% 4=55% 5=65%

LONGITUDINAL VARIATION IN SCINTILLATION $S_4 > 0.2$
OBSERVED FROM KIRUNA (64.3N, 102.8E CGM)
AUTUMN 1984

FIGURE 21

responsible for the scintillation. In an earlier report coordinated experiments using NNSS observations and the ELSCAT ionospheric radar facility were described. Here two further investigations using other radar facilities are outlined.

a/ HF Radar

During the early phase of NNSS observations at Kiruna a HF radar was operational in Southern England (BRADLEY, et al. 1985)¹⁶. On occasions this radar was beamed so that it obtained coherent backscatter returns from ionospheric F-region irregularities with scales ~ 10 metres in a region in the South-West of the NNSS viewing area seen from Kiruna. Examples of backscatter ionograms were examined which showed a clear minimum range for backscattered echoes over a range of frequencies which could have been indicative of an equatorwards edge of an irregularity boundary. (P.A. Bradley, private communication). Scintillation data from simultaneous passes of NNSS satellites were also examined for a scintillation boundary for sub-kilometer scale irregularities.

16. Bradley, P.A., Gibson, A.J., Schlobohm J.C. and Westover, D.E.

Ionospheric factors affecting the performance of HF sky-wave sea-state radars at high latitudes. AGARD-CP-382, 4.1, 1985.

Little evidence was obtained for co-location of the boundaries for irregularities differing in scale by some two orders of magnitude. In general the edge of the auroral backscatter region observed by the radar tended to occur over a somewhat limited range of one-way group paths, whereas the scintillation boundary was much more variable in latitude. No consistent relationship between the two positions could be found from examination of individual events.

Two comments can be made on this apparent lack of correlation for boundaries of irregularities with different scale sizes. First, it appears that the refractive bending required to achieve orthogonality to the magnetic field and thus obtained coherent backscatter effectively selects out irregularities of the Bragg scale over a restricted range from the radar transmitter. Thus the sharp boundary clearly evident on backscatter ionograms may not give a true indication of the boundary of decametre scale irregularities. A second factor which may have influenced the results was that the geometry for JNSS observations into the volume illuminated by the radar was less than ideal. With the observations being made often to the North of the boundary the results in the vicinity of the boundary could be severely influenced by the geometrical factors in S_4 and σ_f discussed earlier in this report resulting in a false position of the scintillation boundary being estimated. Scintillation boundary observations are generally more clearly defined when the location of the recording station is equatorwards of the edge of the irregularity region. The next phase of the observing programme in this project involves observations being made

at a sub-auroral site in the Shetland Islands. Identification of the boundary for sub-kilometer scale irregularities should be better defined from this site and, given availability of suitable radar observations, a clearer understanding of the relationship between boundaries of irregularities with different scales may be found.

b) SABRE Radar

SABRE is a VHF auroral radar operated by the University of Leicester. The bistatic arrangement with stations at Wick, Scotland and Uppsala, Sweden allows measurements to be made of electric fields and plasma drift by means of coherent backscatter from 1.5 metre scale irregularities in the auroral E-region to the North and East of Scotland (JONES et al. 1985)¹⁷.

An examination of the SABRE data base (VALDOCK, private communication) in conjunction with NNSS observations has yielded some 12 examples in which localized regions of scintillation can be linked to features in the plasma flow in the underlying E-region. A typical example is presented in Figures 22 and 23. The first figure provides a summary of the NNSS data for a particular satellite pass on 26 August 1985. A distinct feature to be seen is the patch of high scintillation indices around 67 - 68°N latitude. The corresponding SABRE data shown in the

17. Jones T.B., Waldock J.A., Thomas E.C., Stewart C.P. and Robinson T.R. SABRE radar observations in the auroral ionosphere. AGARD-CP-382, 6.4, 1985.

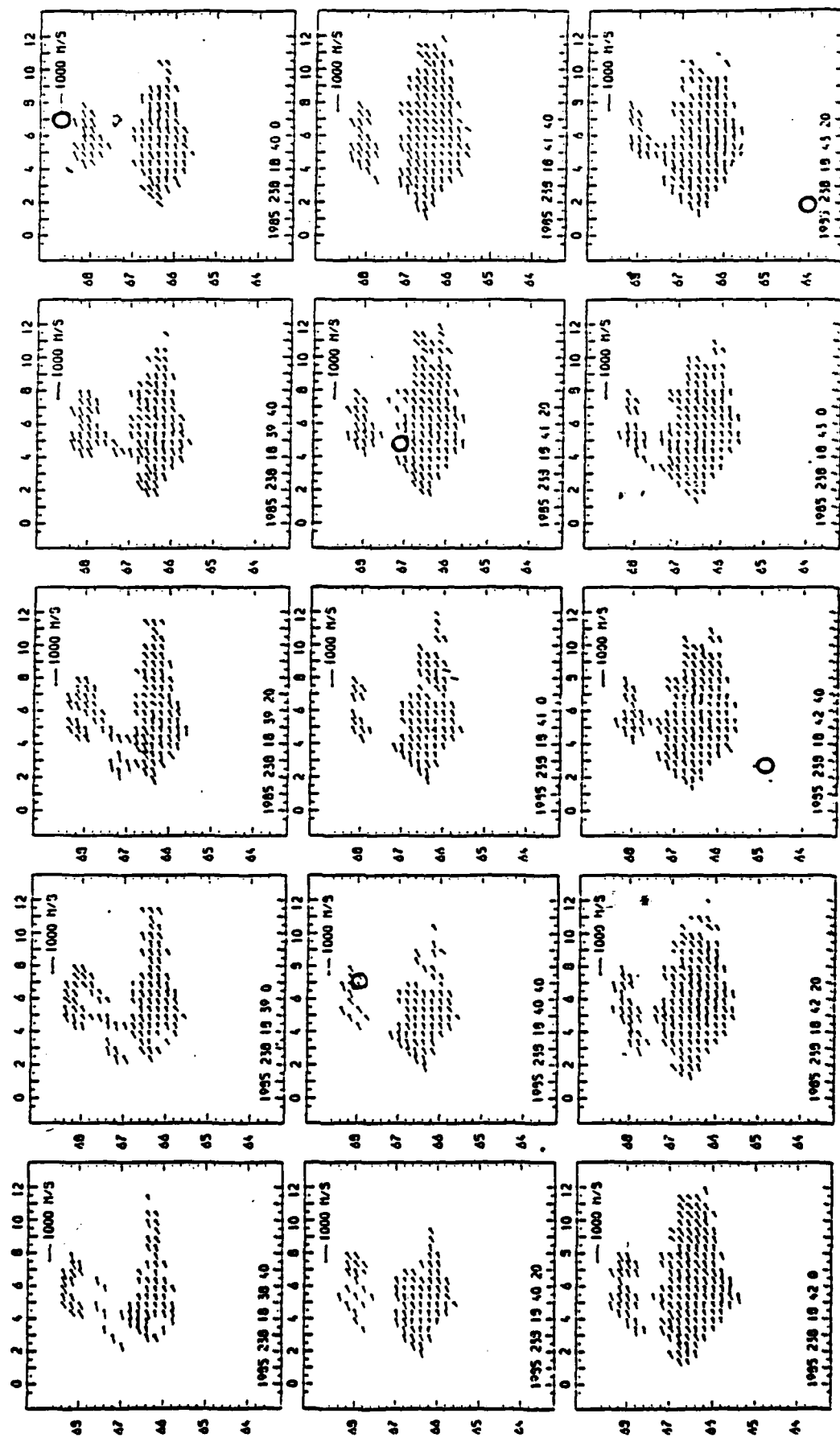


FIGURE 23

next figure gives a succession of E-region plasma flow plots for the SABRE viewing area. Also plotted as open circles are the points at E-region height of the magnetic field lines which map up to the intersection of the WSS signal path with the F-region at 350 km altitude. A region lacking in plasma flow vectors can be seen about 67° - 68° N at the time of the satellite pass. A localised region of this kind can be evidence of hard-particle precipitation causing a modification of E-region conductivity (WALDOCK, private communication). Several examples of this nature have been found linking F-region scintillation producing irregularities to the precipitation of hard particles into the auroral E-region. Several possible mechanisms can be cited for such a link. In an earlier report in this series an example was presented of evidence from a coordinated WSS/EISCAT experiment in which soft particle precipitation into the ionospheric F-region was related to scintillation occurrence. It is possible that the particles penetrating to E-layer height in the present example are part of a broad spectrum with a structured soft-particle tail which is responsible for irregularities in the F-region. Another possible linking mechanism involves shearing of the electric field at the edges of the precipitation zone causing unstable velocity shears at F-region height. It can be noted that other examples linking shearing of the E-region electric field with F-region scintillation have been found. Destabilization of the F-region plasma by means of field aligned currents may also play a role.

Once again the geometry for WSS observations into the SABRE viewing area was rather poor. It is hoped that the new series of observations

from the sub-auroral site will provide more favourable conditions for studies of this kind which may help answer some of the unresolved questions concerning irregularity mechanisms.

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