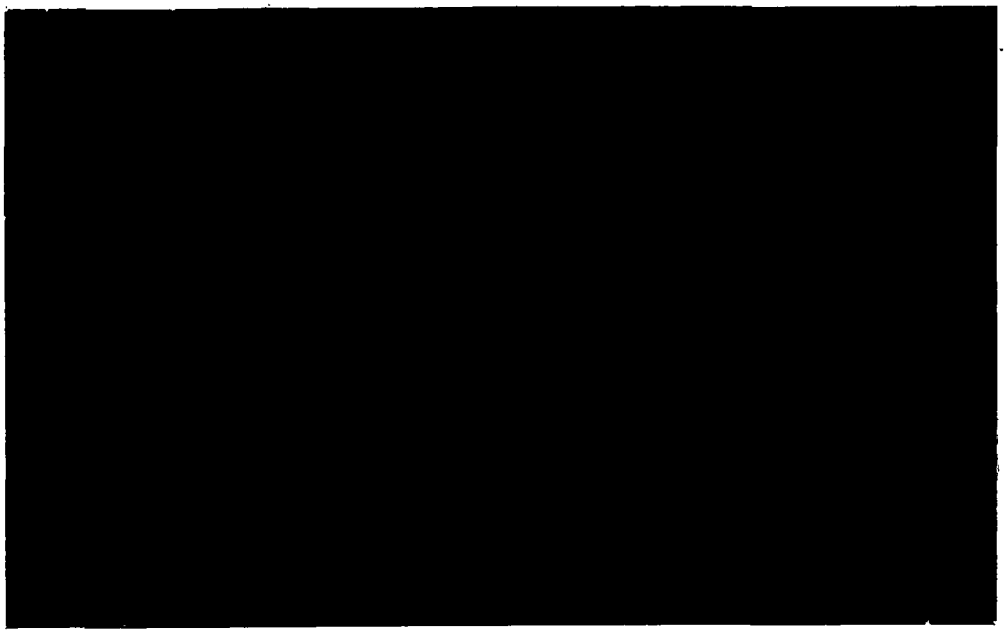

Arbeitsberichte der Schweizerischen Meteorologischen Zentralanstalt
Rapports de travail de l'Institut Suisse de Météorologie
Rapporti di lavoro dell'Istituto Svizzero di Meteorologia
Working Reports of the Swiss Meteorological Institute

Zürich

26375

No. 32

Long term variation of VLF signals over transauroral paths

by
Dr. Jean Rieker, Payerne

Published in VLF-PROPAGATION, proceedings from the VLF-SYMPOSIUM, Sandefjord, Norway, 27th to 29th October 1971, edited by G. GJØNTEGAARD

Radio météorologie

621.371:551.510.62

March 1972

Résumé

L'amplitude et la phase relative des signaux NPG et NPM sont représentés synoptiquement dans un système d'axes perpendiculaires pour la période d'une année. Les résultats sont interprétés en fonction des interférences des modes convertis. Les profils de l'amplitude le long des lignes de transition (lever et coucher du soleil) au cours de l'année, montre une variation quasi-semi-annuelle avec des maxima en été et en hiver et des minima au printemps et en automne. La discussion est faite du point de vue du comportement des angles zénithaux du soleil sur les trajets NPG-, NPM-Payerne.

Summary

One year period synoptic representation of NPG and NPM field strength and relative phase are shown in a system of rectangular coordinates. Results are interpreted as far as possible in terms of interferences of mode conversion. Profiles of field strength along specific transition lines in the course of days show a quasi-semi-annual variation with maxima in summer and in winter and minima in spring and in autumn. Discussion is done from the point of view of computed sun zenith angles over the wave paths NPG-, NPM-Payerne.

Zusammenfassung

Die Feldstärke und die relative Phase der NPG- und NPM-Signale sind synoptisch in einem rechteckigen Achsensystem für ein Jahr dargestellt. Die Resultate sind in Funktion der Interferenzen der Modenkonversion interpretiert. Die Profile der Feldstärke entlang der Schattengrenze (Sonnenaufgang und Sonnenuntergang) zeigen im Laufe des Jahres eine quasi-halbjährliche Aenderung mit einem Maximum im Sommer und im Winter und einem Minimum im Frühling und im Herbst. Die Erklärung nimmt auf den Zenithwinkel der Sonne auf der Wellenstrecke NPG- und NPM-Payerne bezug.

Long term variation of VLF signals over transauroral paths

by Jean Rieker
Laboratoire de radiométéorologie, CH-1530 Payerne
Switzerland

Abstract

One year period synoptic representation of NPG and NPM field strength and relative phase are shown in a system of rectangular coordinates. Sunrise and sunset lines at the 70 km level are involved in the general picture taking into consideration a 30 km screening height. Experimental results are interpreted as far as possible in terms of interferences of mode conversion after Crombie's model (CROMBIE 1964).

Profiles of field strength along specific transition lines in the course of days show a quasi-semi-annual amplitude variation with maxima in summer and in winter, and minima in spring and in autumn. From computed zenith angles over the wave paths it can be concluded that the ionization rate in D-region required for the formation of the field strength winter maxima do not rely upon the sun ionizing radiation, but on other causes and probably on dynamical and aeronomical effects in the mesosphere. The apparent contradiction between results on LF absorption measurements by LAUTER and NITZSCHE (1967) and the present computation is to be explained by the height difference between VLF and LF reflecting layers.

1. Introduction

The purpose of this investigation is to provide a representation to enable the annual control at a glance of all daily recordings and bring out the daily, seasonal and annual shift of amplitude and relative phase of the signal received, taking into account sunrise and sunset times over the wave paths. The amplitude and the relative phase of signals NPG (18.6 kc/s) [Seattle, Wash, 48.2°N-121.9°W] and NPM (23.4 kc/s) [Hawaii, 21.4°N-158.2°W] recorded in Payerne (46.8°N-47.0°E) are presented for a period of two years: from April 1, 1967 to April 1, 1969 for NPG and from July 5, 1967 to July 4, 1969 for NPM. The path lengths are respectively 8.3 Mm and 12.2 Mm, the azimuths from Payerne 327.5° and 345.2° (figure 1).

2. Instrumentation and Calibration

Textran receivers, model 599H and Rustrak recorders are used. Reception is done by means of a loop and vertical antenna permitting to obtain a receiving cardioid feature. The Sulzer's frequency standard used is controled by the HBG signal (75 kc/s) [Prangins, Switzerland]. The daily variation of the standard frequency does not exceed 2 to 4 microseconds.

The calibration of the amplitude recorders was done for a frequency of 25 kc/s assuming that the dependency of the frequency can be neglected between 25 kc/s and 18.6 kc/s. The curves of calibration are shown in figures 2 and 3.

The phase recorders are calibrated by a unit incorporated in the receivers. The scales of the phase shift are indicated in figure 4.

3. Method

3.1. Amplitude and relative phase

The first step consists in computing the amplitude (code of indexes, figures 2 and 3) and relative phase (microseconds, figure 4) recordings by checking them every 15 minutes. Amplitude and phase data are thereafter plotted in a system of rectangular coordinates: in ordinate the sun declination, the seasons succeding each other from top to bottom; in abscissa the interval of one day expressed in 24 hours UT. As the variation of the sun declination is very slow around the solstices, it was necessary to shift from the scale of the sun declination to the scale expressing successively the course of days for the sun declination comprised between 22° before and after the summer solstice, and -22° before and after the winter solstice (see for instance figures 5 and 6). By drawing the lines of equal amplitudes (isoamplitudes) and equal relative phase (isophases), a synoptical picture is obtained.

The phase and amplitude synoptic representation are shown for a one year period: from April 1, 1967 to April 1, 1968 for NPG (relative phase: figures 5 and 6; amplitude: figures 7 and 8); from July 5, 1967 to July 5, 1968 for NPM (relative phase: figures 9 and 10; amplitude: figures 11 and 12).
Considering that the NPM signal was monitored by a cesium frequency standard since April 9, 1968 only, and that the U.S Naval Laboratory published its drift in the "Daily Relative Phase Value, Serie 4" from August 13, 1968, the synoptic representation of the NPM relative phase must be viewed with caution. Further, it was necessary to discontinue it from November 8, 1967 until January 26, 1968, because the phase shift, instead of featuring regular daily periodicities and taking again the magnitude reached the day before, ran steadly away.

3.2. Sunrises and sunsets over the wave paths versus sun declination

The second step consists in drawing the transition lines (sunrises and sunsets lines) over the wave path considered in an identical system of rectangular coordinates. The wave paths are divided for the purpose of the study into 10 equal segments (figure 1). For the end of each of these, the hours of sunsets and sunrises are computed in terms of sun declination. Starting from the curves obtained by connecting the hours of sunrise, respectively of sunset, at the end of one single segment, the percentage of the wave path in the dark can be obtained

immediately at any time selected (figures 5 to 12). In figure 1, for instance, the sun is setting at 06 UT on July 12, 1967 at 70 km above point 8 on the NPG path: this means that 20% of the path is in the dark side; and at the same time at 70 km above the point 9 on the NPM path, which means that 10% of the path is in the dark side. The 0% quota means sunrise or sunset at one of the ends of the wave path, when the whole path is an daylight, while 100% quota sunrise or sunset at one of the ends of the path, when the whole path is in the dark.
The transition lines were computed for three different levels: the ground, 70 and 80 km. For 70 and 80 km, the altitude of the screening height is set at 30 km. Only the curves corresponding to the 70 km level are presented.

From the same daily rhythm of sunsets and sunrises over the NPG- and NPM- Payerne paths which radically changes during one year cycle, the year can be subdivided: In the case of NPG path into two periods (figures 5 and 6, 7 and 8):

-- The first (winter), from approximately August 15 to April 30 during the period for which the whole path lies in the dark at 70 km height once a day; no polar night is noted in winter at 70 km height on the northest part of the path.
-- The second one (summer), from approximately April 30 to August 15, corresponding to the duration of the polar day at 70 km height on the northest portion of the path. The whole path which is illuminated completely twice a day, from about 12 UT to 20 UT and from about 03 UT to 0430 UT, lies never completely in the dark side of the earth.

In the case of NPM path into four periods (figures 9 and 10, 11 and 12):

-- The first (summer), approximately from March 31 to September 13, corresponds to the duration of the polar day on the northest part of the path at 70 km height. Twice a day the sun illuminates completely the whole path between 15 UT to 20 UT and 03 UT to 06 UT.
-- The second (autumn), from September 13 to November 9 and
-- The third (spring) from February 2 to March 31 are symmetrical with regard to the summer solstice. For both periods the path lies alternately in daylight and in darkness during a 24 hours day.
-- The forth (winter) from November 9 to February 2 corresponds to the duration of the polar night over the northest part of the path at 70 km height. The sun never completely illuminates the whole path, which lies twice a day in the dark side of the earth, at about 1645 UT and between 5 UT and 6 UT.

As NPG transmitter and receiver in Payerne are pratically at the same latitude, the transition lines are almost symmetrical with regard to the vertical straight

line joining their points of convergence at about 04 UT (figures 5 and 6). The symmetry is in return not observed for NPM-Payerne path (figures 9 and 10).

3.3. Signal profiles along individual transition lines correlated with sun zenith angles

The third step consists of examining the behaviour of the relative phases and amplitudes along individual transition lines, correlated with sun zenith angles on the wave path. This is done for a two years period, from April 1, 1967 to April 1, 1969 for NPG signal (figures 13 and 14), and from July 5, 1967 to July 5, 1969 for NPM signal (figures 15 and 16). Three transition lines (0%, 50%, 100%) are considered in the case of NPG signal, four (0%, 10%, 50%, 100%) in the case of NPM signal. Because of the reasons given before (see § 3.1), the NPM phase shift is not represented.

Amplitude and relative phase, as computed on a daily basis for the time of the "crossing" of the transition line considered, have been plotted against time.

The zenith angles of the sun are computed every day for the ends of each of the ten equal segments dividing the wave path at the time of the crossing of the transition line on a specific path point and determined by range numbers from the receiver to the transmitter (figures 13 to 16). The computation was done on the basis of the geographical representation of WATT (1967). According to the 30 km screening height and the 70 km level, the zenith angle of the sun is $\chi = 96.4^{\circ}$ at the time of crossing of the transition line above the point considered.

However, if using the approximate formula (BRADY 1964)

$$\chi \cong 90^{\circ} + 1.01 \quad [h - \Delta_r]^{1/2} \qquad (1)$$

where h and Δ_r expressed in kilometers are respectively the height of the reflection layer and the screening height, it can be seen that for h + u and Δ_r + u, the sun zenith angle χ expressed in degrees remains the same. WESTERLUND and SVENNESSON (1971) use for instance the following values: h = 90 km and Δ_r = 50 km for the NPM-Kiruna path.

4. Analysis of the synoptic representation

4.1. From the transition lines computed at the ground-, 70 km- and 80 km- levels, those at the ground are not representative. Of the transition lines at the 70 km- and 80 km-levels, it is difficult to choose the best fitting curve system because of their small differences. A daylight ionospheric reflection layer about 70 km height and a screening height of 30 km are however assumed to exist throughout the year over both VLF paths. As mentionned (equation 1) the transition line system adopted is pratically the same as that computed for a 90 km level and

a 50 km screening height.

4.2. When the whole path lie in daylight and the propagation is not disturbed, the VLF signal is more or less constant, which gives per definition the zero on the phase scale. The phase shifts gradually as the sun illumination diminishes over the path and reaches its highest magnitudes when the whole path lies in the shadow between the 100% transition lines. Generally it shifts more rapidily when transition lines lie close together. The isophases and amplitudes follow pretty well the transition lines by normal propagation. In summer the daily variations of phase and amplitude are also weakest.

4.3. As it can be seen by comparing the phase shift and field strength minima at the same time on the present synoptic representation, the well known stepwise phase shifts coincide with amplitude minima. The periodic fading of VLF signal received over long path is to explain by using a simple model based on mode conversion which is assumed to take place on particular transition lines (CROMBIE 1964, 1966; RIES 1967; STEELE and CROMBIE 1967; KAISER 1968a, 1968b; WESTERLUND and SVENNESSON 1971). In spite of the heterogeneity of the synoptic configuration due to propagation disturbances, some NPM results can be compared with those of WESTERLUND and SVENNESSON (1971) in the same conditions of path illumination. Two field strength minima appear near the 25% and 5% transition lines at sunrise from April to July between 12 UT and 15 UT (figures 11 and 12). That means the length D between the geographical positions on the great circle path of both field strength minima D = 2.44 Mm. The same length D is observed too at sunset in July 1967 between 0530 UT and 0630 UT (figure 11).

Westerlund and Svennesson found D = 2.41 $\pm$ 0.10 Mm for the NPM-Kiruna path. D is furthermore related to the phase velocity of the first and second order mode by the equation

$$D = \frac{c^2}{f\,(v_2 - v_1)} \qquad (2)$$

where c is the light velocity and f = 23.4 kc/s, the NPM signal frequency.

According to VLF mode calculations for spherical earth-ionosphere waveguide by WAIT and SPIES (1964), the theoretical D value is 2.24 Mm, assumption beeing done of an isotropic ionosphere, an exponential electron profiles ($\beta = 0.5$ km^{-1}), a night ionosphere height h = 90 km and a seawater path.

Because of the strong heterogeneity of the NPG synoptic configuration, it seems difficult at first sight to compare theoretical and experimental results. However, starting from the theoretical value of D = 2.05 Mm computed after WAIT and SPIES (1964) for a 18.6 kc/s signal and expressed in percent of the total path length D = 24.1%, it can be observed that at sunset in August and September the amplitude minima lie along the 10% and the 35% quota [D = 25%] (figure 7), in March at

sunrise near the 45% and the 15% quota [D = 30%] (figure 8).
In any case according to the accuracy of the NPM and NPG synoptic representations, it seams allowed to conclude that experimental results and theoretical model of CROMBIE (1964) are in relative good agreement.

4.4. NPG and NPM field strengths at night are higher than during the day. The theoretical field strength using the first three order modes after Wait's model (WAIT and SPIES 1964) and computed by BROOKES et al. (1967) gives, as already mentioned by OELBERMANN (1969), nightly magnitudes lower then during the day for long distance propagation at the frequencies considered. However theoretical computations were done for seawater at middle latitudes.

4.5. The Sudden Phase Anomalies (SPA), although of short durations, can be noted on the synoptic representations shown -especially on NPG path- for instance on April 3, 1967 at 1445 UT (sun declination $5^{\circ}13'$); on April 10 at 1725 UT (dec. $7^{\circ}51'$); on May 19 at 1545 UT (dec. $19^{\circ}43'$); on May 20 at 1530 UT (dec. $19^{\circ}55'$); on May 22 at 1930 UT (dec. $20^{\circ}22'$); on August 29 at 1315 UT (dec. $9^{\circ}29'$); etc.
The related Sudden Enhancement of Signal (SES) on the other hand are scarcely recognizable on corresponding synoptic representation of field strengths.

4.6. It is known that Polar Cap Absorption events (PCA-events), occuring in the auroral zone, have durable effects on propagation lasting from several hours to several days, both with respect to signal absorption and phase shift with regard to normal conditions.
PCA-events are remarkably conspicuous, for instance between May 23 and May 31, 1967 (dec. from 20.5° to 22°); on June 6, October 10 (dec. -6.5°); on November 2 (dec. -14.5°); 6 (dec. -15.7°) and 11 (dec. -17.5°); on December 3 and 16, January 11, 1968; on February 11 (dec. -14.2°), etc.

4.7. Propagation disturbances on NPG representations are noted too between August 18, 1967 (dec. 13.5°) and August 20 (dec. 12.5°).

4.8. It appears that on occasion the NPG propagation is more disturbed by PCA-events than the NPM propagation.

5. Analysis of some signal profiles along specific transition lines

The behaviour of sun zenith angles shown in figures 13 to 16 can be explained as follows: in figure 13, for instance, the 0% transition line and the associated zenith angles on a given day in June lie between $\chi = 96.4^{\circ}$ at Payerne and $\chi \cong 25^{\circ}$ at the NPG transmitter. The intermediate curves numbered 1, 2, ..., 9 give at the same time the sun zenith angles at the end of each of the ten equal segments dividing the NPG wave path (see figure 1). On a specific day in December the sun zenith angles lie between $\chi = 96.4^{\circ}$ at Payerne $\chi \cong 87^{\circ}$ at the NPG transmitter at the same time. The sun is very close to the horizon over the whole wave path.

Once choosen the appropriate transition line, the daylight portion of the path remains the same every day during the whole period considered; one can therefore assume that the modal VLF propagation under normal conditions does not undergo any sensible modification from one day to the next. Only the sun zenith angle change every day over the daylight portion of the path.

The NPG field strength behaviour along the transition lines at sunset and sunrise shows a quasi-semi-annual variation with maxima in June/July and December/January and minima in October and March (figures 13 and 14). So far as the necessary conditions of illumination exist over the NPG and NPM paths, the semi-annual variation appears also along other transition lines (for instance along the 50% transition line of NPG) and along the 0% and 10% transition lines of NPM (figures 15 and 16) as well at sunset as at sunrise. In other words, the absorption of the received NPG and NPM signals is the lowest in summer and in winter, and highest in autumn and in spring. LAUTER and NITZSCHE (1967) found reverse results from A_3-measurements in the frequency range between 100 kc/s and 2000 kc/s. This statement is in fact not a contradiction but can be explained by the height difference of the reflection levels between LF and VLF signals. VLF signals are reflected from the lower edge of the D-region, while LF-signals go through the D-region and are reflected from the low E-region. A large electron density in the D-region results in a better reflection for VLF signals and a greater absorption for LF signals going through the D-region.

The ionization rate in the reflecting D-region required for the formation of the field strength summer maxima results from the sun ionizing radiation which is related to the sun zenith angles behaviour over the wave path. In winter other sources produce the D-region ionization. It can be assumed that the electron density in the low ionosphere in winter is mostly due to dynamical and aeronomical effects in the mesosphere (BEYNON and JONES 1965; NESTRONOV 1965; LAUTER and NITZSCHE 1967; GREGORY and MANSON 1969; BEYNON and WILLIAMS 1970; LAUTER and TAUBENHEIM 1970; ZIMMERMAN and NARCISI 1970).

GREGORY and MANSON (1969) found mean noon electron density at about 45°N and 44°S to be larger in winter and in spring than in summer between 79 km and 88 km and some evidence points to the existence of a weak winter maxima below 70 km.

It seems further that the field strengths roughly shows also a maximum in winter along the 100% transition lines of NPG and NPM. This would maybe mean that an increase in electron density occurs during winter not only in the daylight ionosphere but also during the night.

As it can be seen the top of the summer and winter maxima appears at about two weeks after the solstices. Field strength minima in March seem to be lower than those in October, especially for the NPM signal along the 0% and 10% transition

lines. The NPG field strength in winter appears to lie some decibels higher than in summer. Results of field strength ratios between maxima and minima are shown in Table I.

It may be interesting to note that similarly the magnetic activity has two yearly maxima around the equinoxes while the horizontal intensity of the earth's magnetic field shows two maxima at the same period (BHARGAVA 1970) and that EBEL (1970) in analysing the temporal and spatial variations of the electron content in the ionosphere, find strong evidence for the existence of a semi-annual variation with maximum around the equinoxes.

An oscillatory behaviour of the NPG relative phase is noted too along most of the transition lines. It has not been investigated if this feature has some significance concerning a possible height variation of the reflection layer, because a good frequency standard is required.

The NPG field strength minima seems to coincide with regular mean phase decreases or increases. Weak phase minima are observed in December/January, especially in 1967/1968 at sunrise along the 50% transition line (figures 13 and 14).

During winter months, relative phase value undergo large variations from one day to the next, while in summer they are regular most of the time. This feature has already been mentioned by many workers. The seasonal coefficient of variation (standard deviation/mean) of noon electron density computed by GREGORY and MANSON (1969) in three altitude ranges (65-69 km; 70-79 km; 80-88 km) at 44°S shows a maximum around the winter solstice. The change in noon electron density is therefore large from one day to the next during winter. The cause of this variability can be found in the dynamical and aeronomical structure of the mesosphere.

7. Conclusions

The synoptic representation of VLF signals has undoubted advantage since it enables the control at a glance of a whole period of recordings, computed up to now almost on specific samples only. The 70 km level transition lines clarify the understanding of the daily and seasonal rhythm of the sun illumination over the wave path, which, as can be seen, becomes complicated over transauroral paths. Some results seem confirm the validity of Crombie's model (CROMBIE 1964).

Whatever the causes may be of the semi-annual variation of the NPG and NPM signal strengths, it is important to note that it exists and that the ratio between maxima and minima is large enough to be evaluated. It can be assumed that the same variation would appear in measurements of long term integrated field and counting rate of sferics in the VLF-range. Further VLF investigations are required in order to obtain more evidence on the laws governing the behaviour of maxima and minima in terms of latitude, distance between transmitter and receiver,

frequencies, sun activity, etc., in order to deduce the variation rate of sferic parameters, which must be computed without propagation influences, when related to global thunderstorms activity.

References

Beynon, W.J.G. and Jones, E.S.O. 1965 Nature, Lond. 206, 1243-1245

Beynon, W.J.G. and Williams, E.R. 1970 J. Atmosph. Terr. Phys., 32, 1325-1329

Bhargava, B.N. and Yacob, A. 1970 J. Atmosph. Terr. Phys., 32, 1489-1493

Brady, A.H. and Crombie, D.D. 1964 NBS Technical Note No. 209

Brookes, C.B.Jr.; McCabe, J.H. and Rhoads, F.J. 1967 NRL Report 6663

Crombie, D.D. 1964 J. Res. NBS, 68D, 27-34

Crombie, D.D. 1966 Radio Sci., 1, 47-51

Ebel, A. 1970 J. Atmosph. Terr. Phys., 32, 1649-1660

Gregory, J.B. and Manson, A.H. 1969 J. Atmosph. Terr. Phys., 31, 703-729

Kaiser, A.B. 1968a Radio Sci., 3, 545-549

Kaiser, A.B. 1968b Radio Sci., 3, 1084-1090

Lauter, E.A. and Nitzsche, P. 1967 J.Atmosph. Terr. Phys., 29, 533-544

Lauter, E.A. and Taubenheim, J. 1970 Ann. Géophys., 26, 631-641

Nestronov, G.T. 1965 Pure and Appl. Geophys. 62/III, 148-160

Oelbermann, E.J. 1969 Observations of long term solar particle effects on polar VLF propagation, presented at 1969 USNC-URSI Spring Meeting, Washington, D.C. Commission 3, Section 2.

Ries, G. 1967 Radio Sci., 2, 531-538

Steele, F.R. and Crombie, D.D. 1967 Radio Sci., 2, 547-549

Wait, J.R. and Spies, K.P. 1964 NBS Technical Note No. 300; Numerical Supplement submitted February 15, 1965

Watt, A.D. 1967 VLF Radio Engineering, edited by A.L. Cullen; V.A. Fock and J.R. Wait, Pergamon Press

Westerlund, S. and Svennesson J. 1971 J. Atmosph. Terr. Phys., 33, 1079-1097

Zimmerman, S.P. and Narcisi, R.S. 1970 J. Atmosph. Terr. Phys., 32, 1305-1308

Table I

Ratios of field strength maxima and minima

	NPG signal								NPM signal	
	winter max. 1967/1968 spring minimum 1968		winter max. 1967/1968 autumn minimum 1967		winter max. 1968/1969 autumn minimum 1968		summer max. 1968 spring minimum 1968		summer max. 1968 spring minimum 1968	
Transition line	sunset fig.13	sunrise fig.14	sunset fig.13	sunrise fig.14	sunset fig.13	sunrise fig.14	sunset fig.13	sunrise fig.14	sunset fig.15	sunrise fig.16
0%	-15 db	-14 db	-13 db	-15 db	-11 db	-13 db	-14 db	-12 db	-20 db	-16 db
10%	--	--	--	--	--	--	--	--	-13 db ?	-14 db
50%	-11 db	-12 db	-11 db	-13 db	- 7 db	-11 db	--	--	--	--
100%	- 3 db	- 3 db	- 5 db	- 5 db	?	?	--	--	--	--

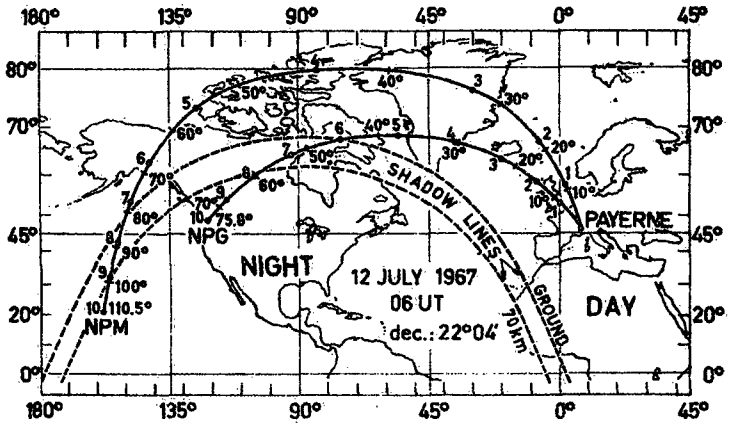

Fig.1. NPG- and NPM-Payerne great circle paths, divided into 10 equal parts with indication of geocentric angles of 10° to 10° from Payerne, and shadow lines on July 12, 1967 at 06 UT at the ground and at 70 km level according to a screening height of 30 km are shown.

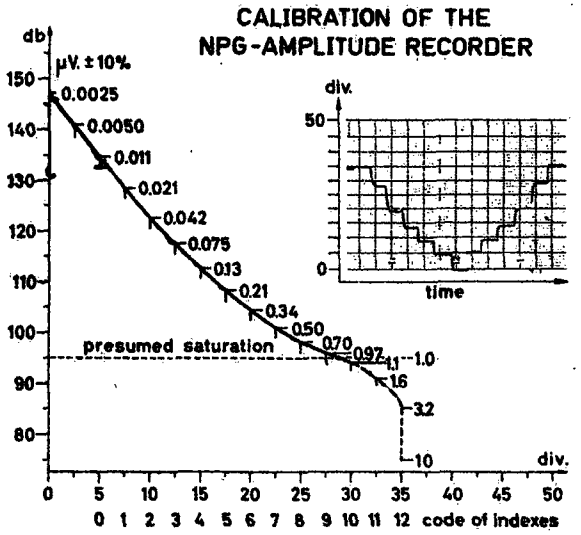

Fig. 2

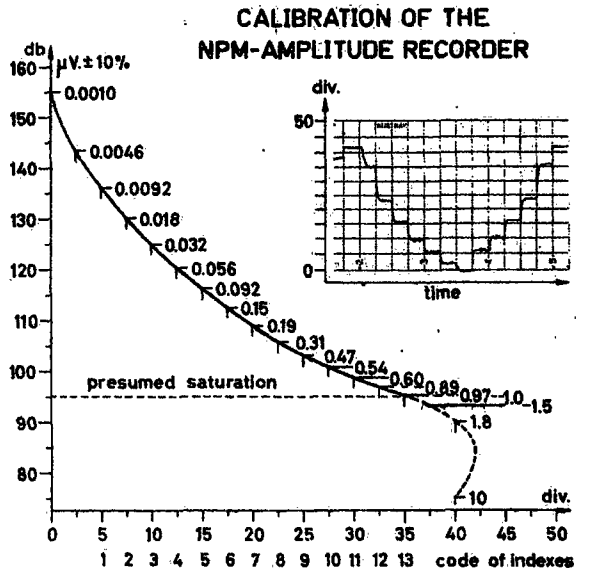

Fig. 3

Microvolts are expressed in terms of decibels and divisions of the roll chart paper.

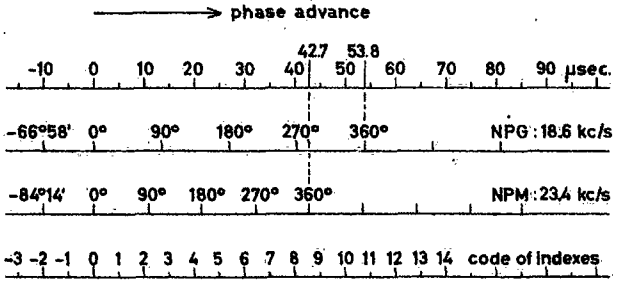

Fig.4. NPG- and NPM-relative phase scales.

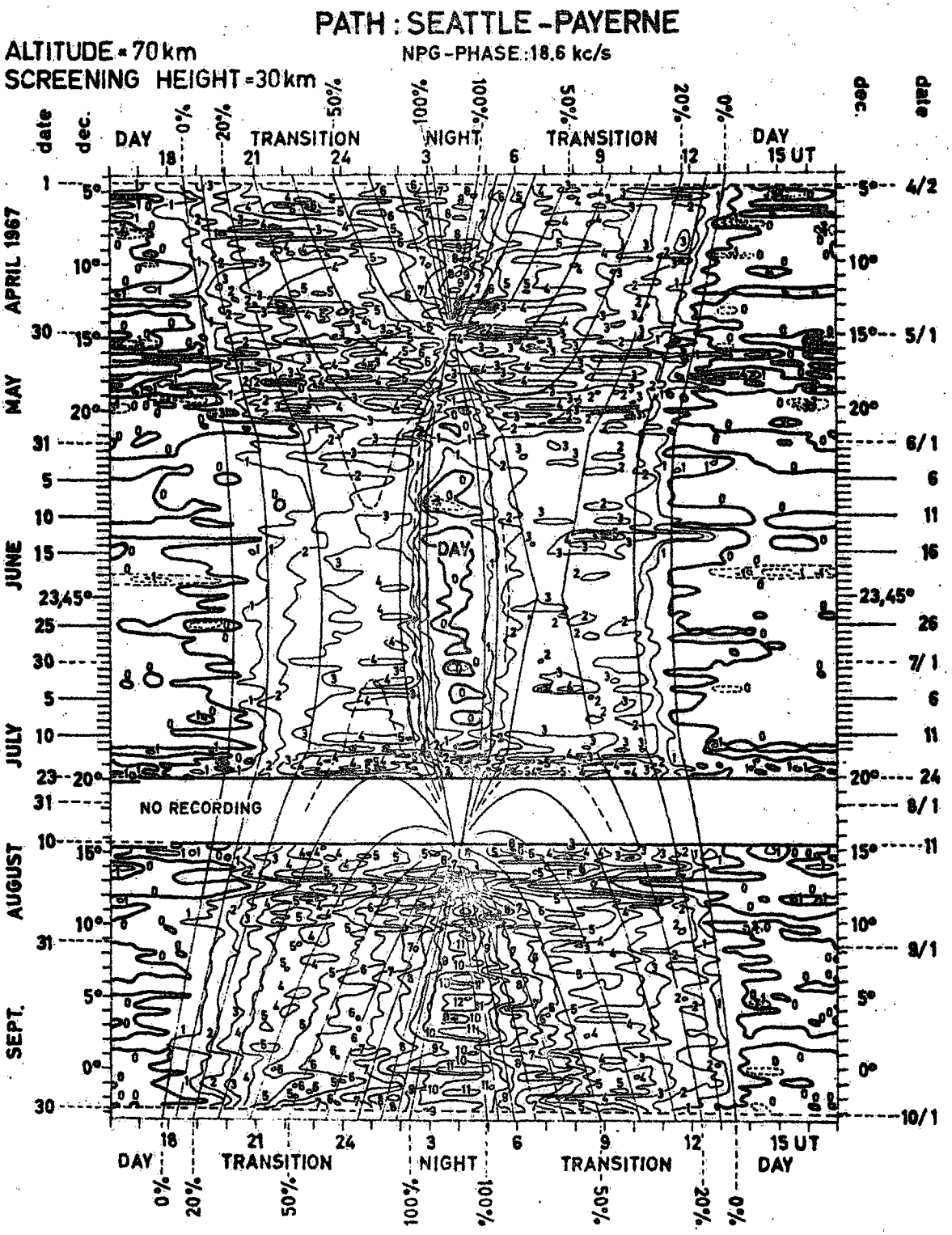

Figure 5. Relative phase representation of NPG-signal from April 1, 1967 to October 1, 1967, expressed after the code of indexes (figure 4), is presented in a system of rectangular coordinates: in ordinate the sun declination, in abscissa the interval of a 24 hours day in UT. The transition lines are expressed in percentage of the dark portion of the path by the total path.

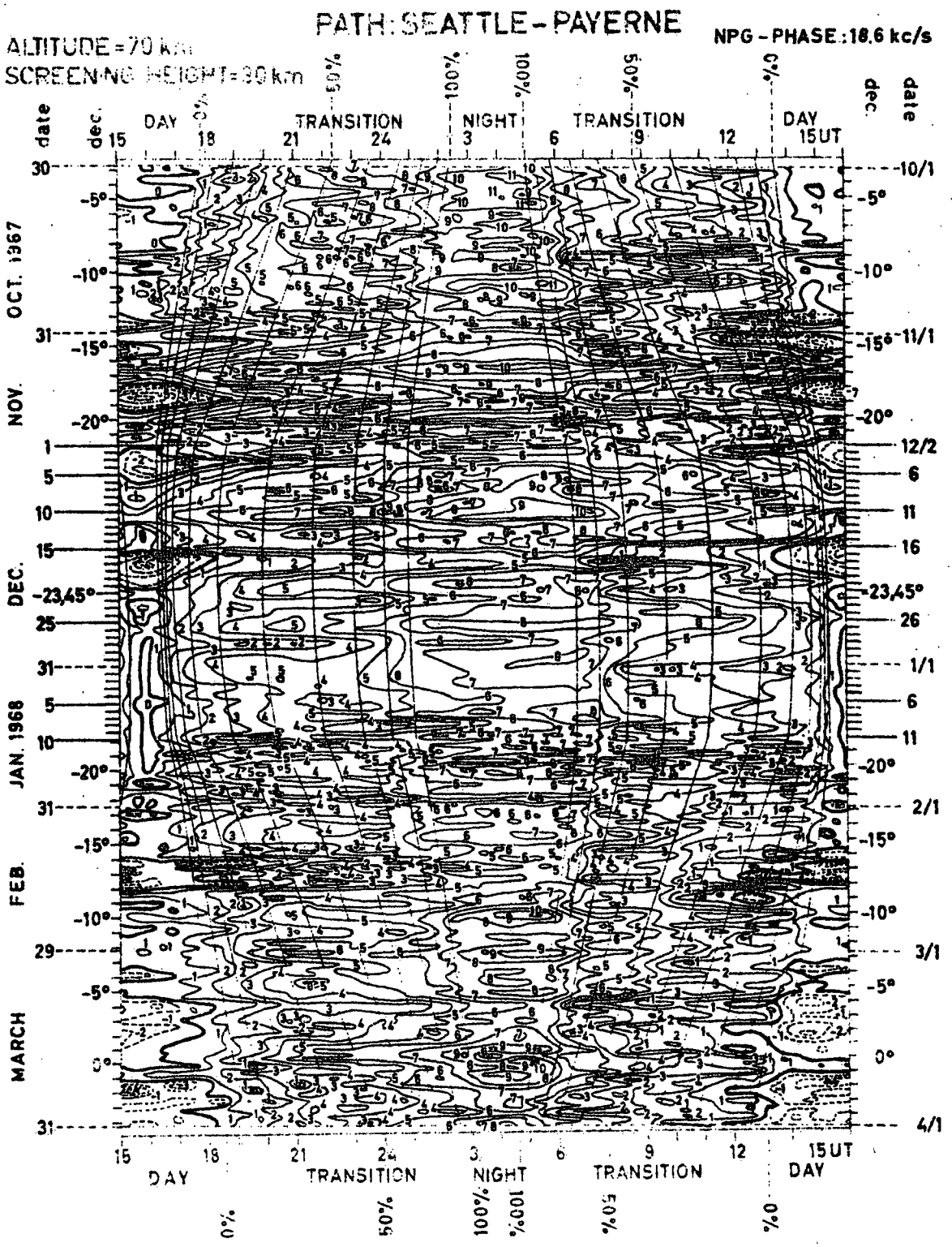

Figure 6. Relative phase representation of NPG-signal from September 30, 1967 to April 1, 1968 is shown; for explanations see text figure 5.

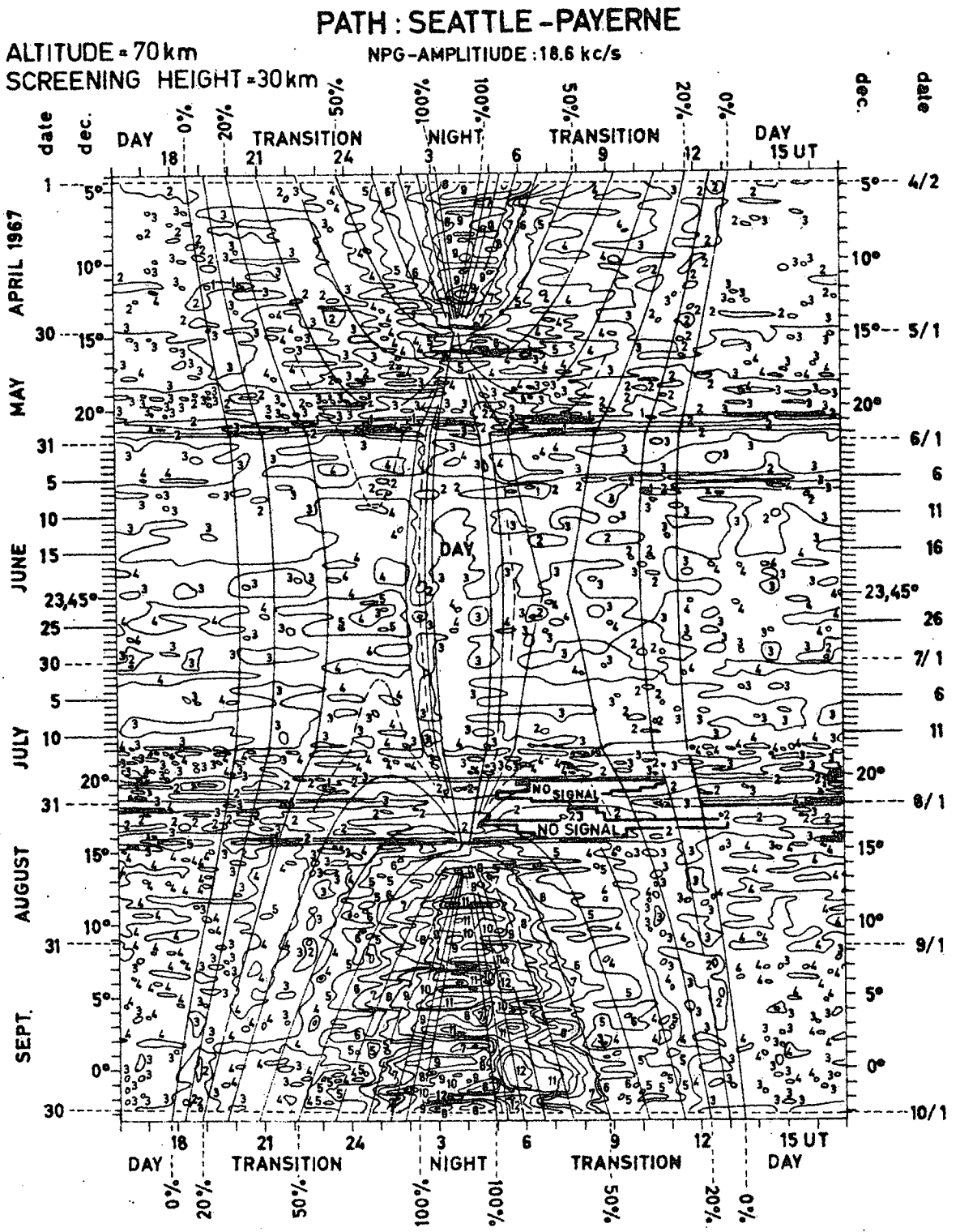

Figure 7. Amplitude representation of NPG-signal from April 1, 1967 to October 1, 1967 is expressed after the code of indexes (figure 2); for explanations see text figure 5.

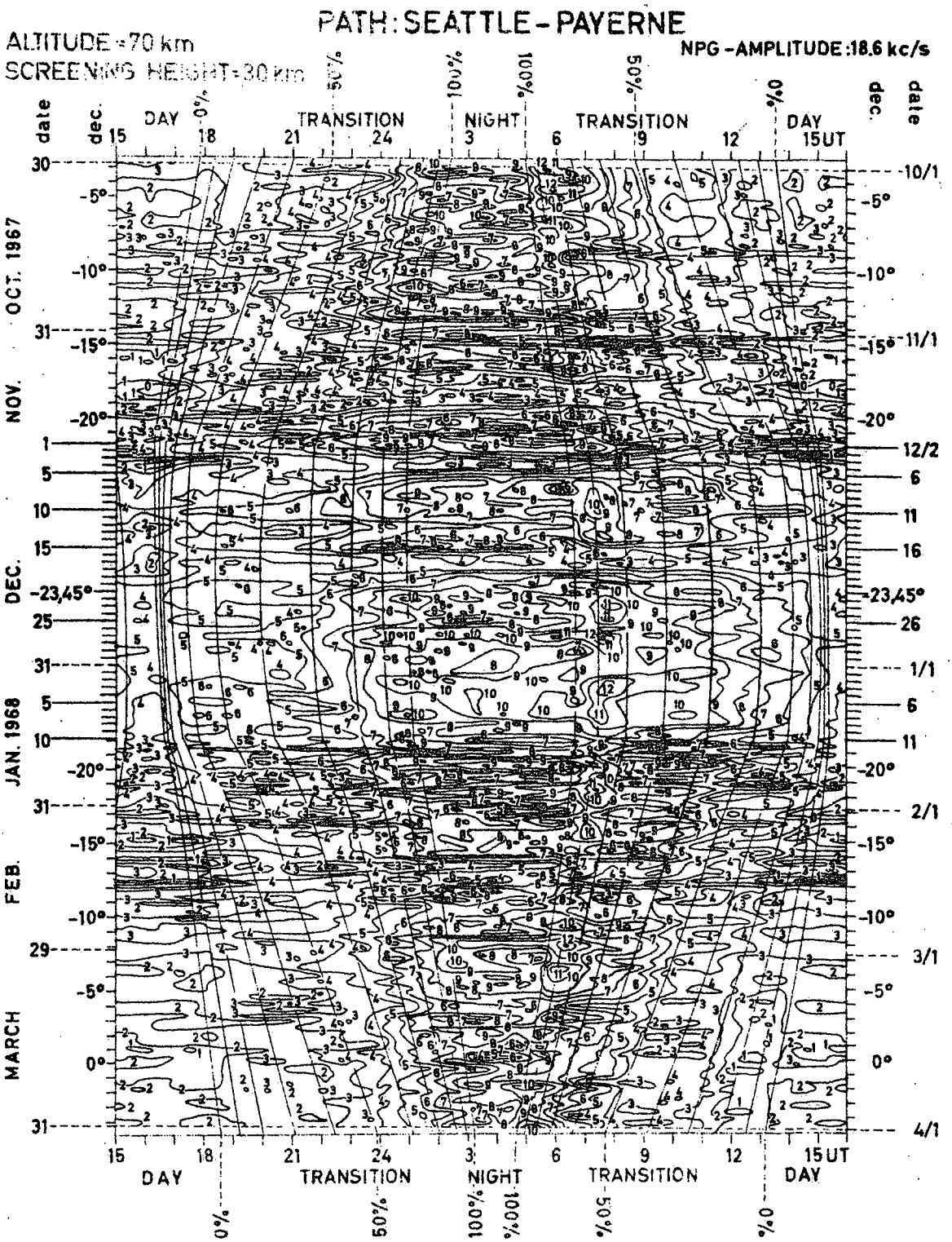

Figure 8. Amplitude representation of NPG-signal from September 30, 1967 to April 1, 1968, is expressed after the code of indexes (figure 2); for explanations see text figure 5.

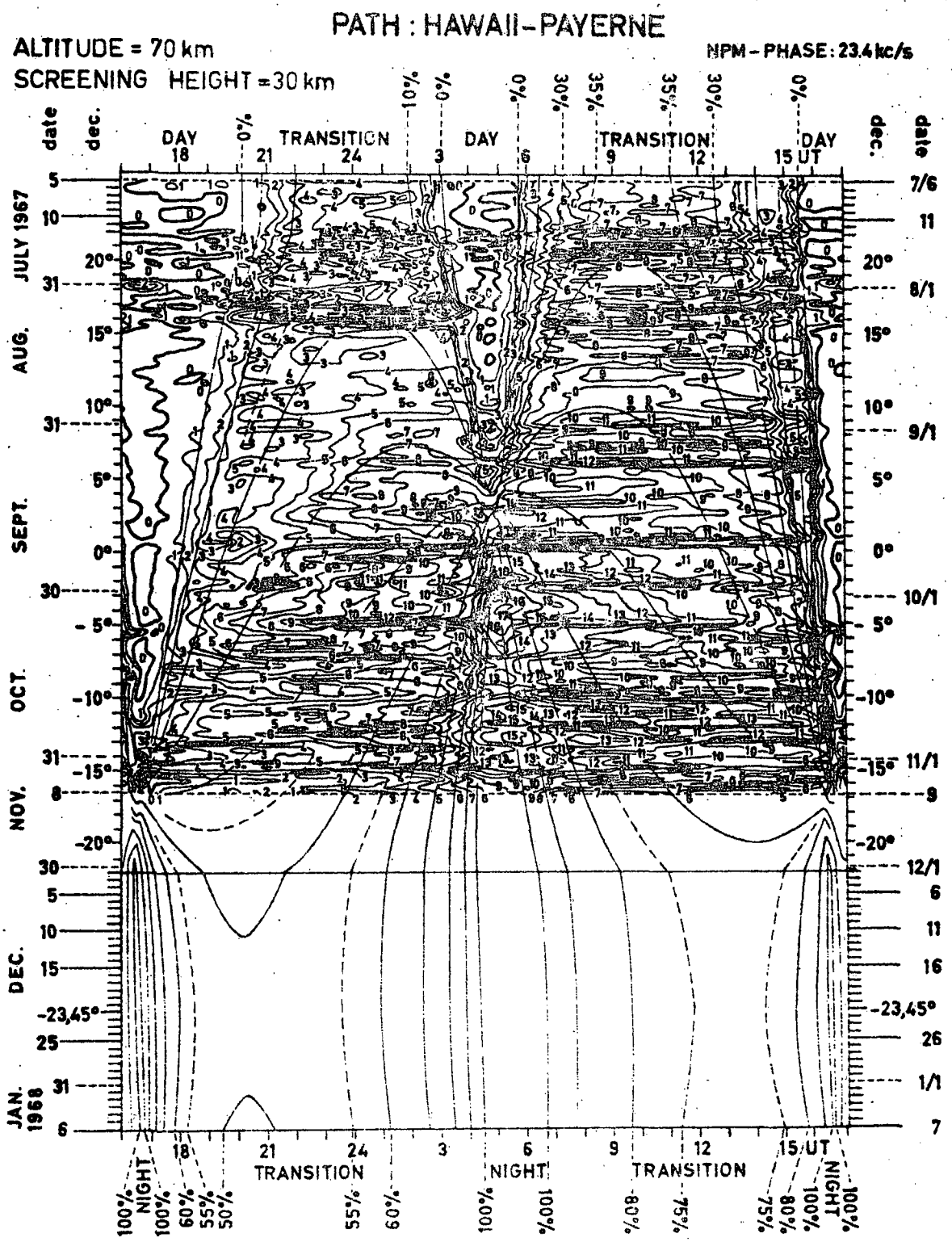

Figure 9. Relative phase representation of NPM-signal from July 5, 1967 to November 9, 1967 is shown; for explanations see text figure 5. From November 9, 1967 to January 25, 1968, recordings are not available.

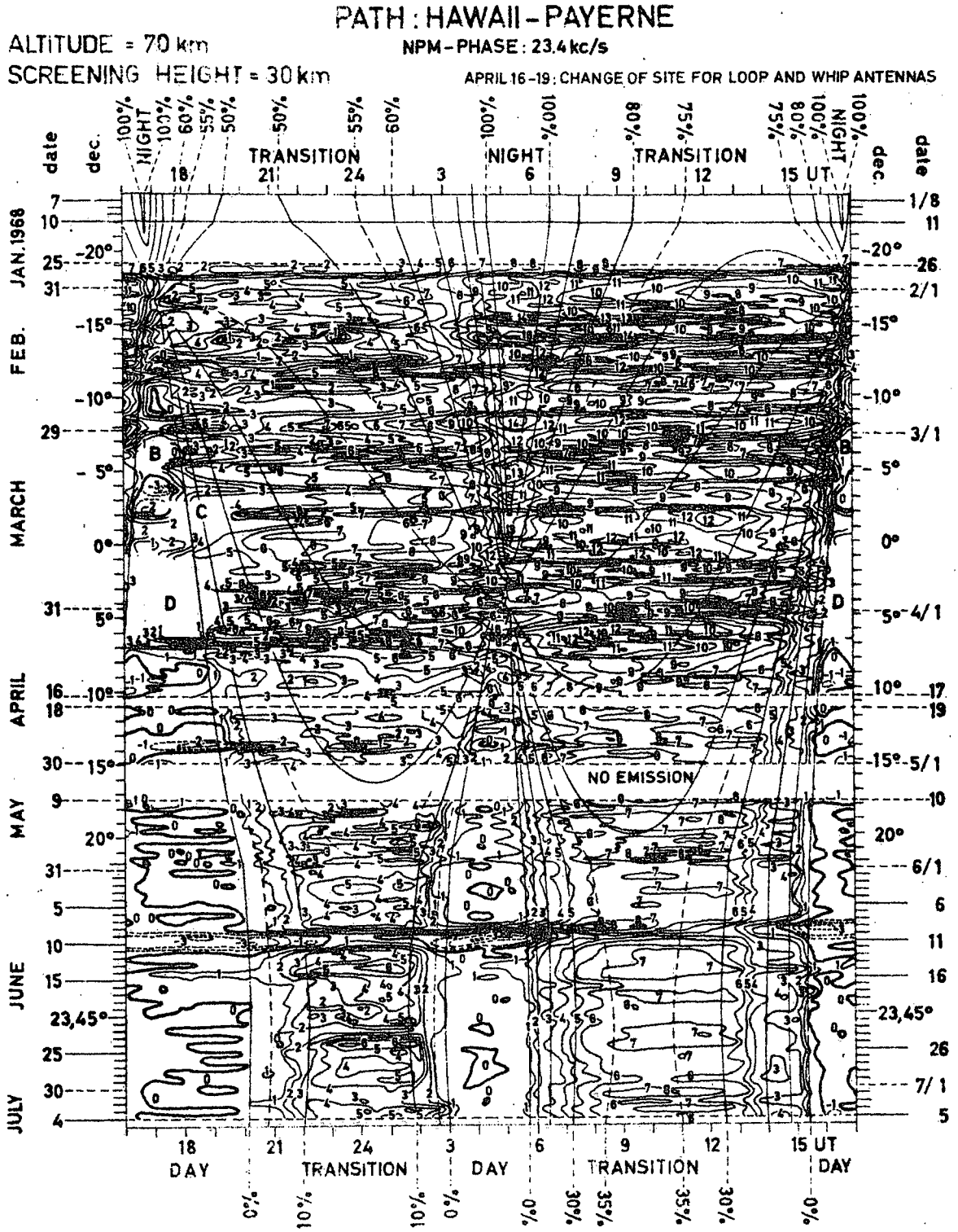

Figure 10. Relative phase representation of NPM-signal from January 25, 1968 to July 5, 1968 is shown; for explanations see text figure 5. From November 9, 1967 to January 25, 1968 recordings are not available. Because of absorption no signal is received in B-, C- and D-areas.

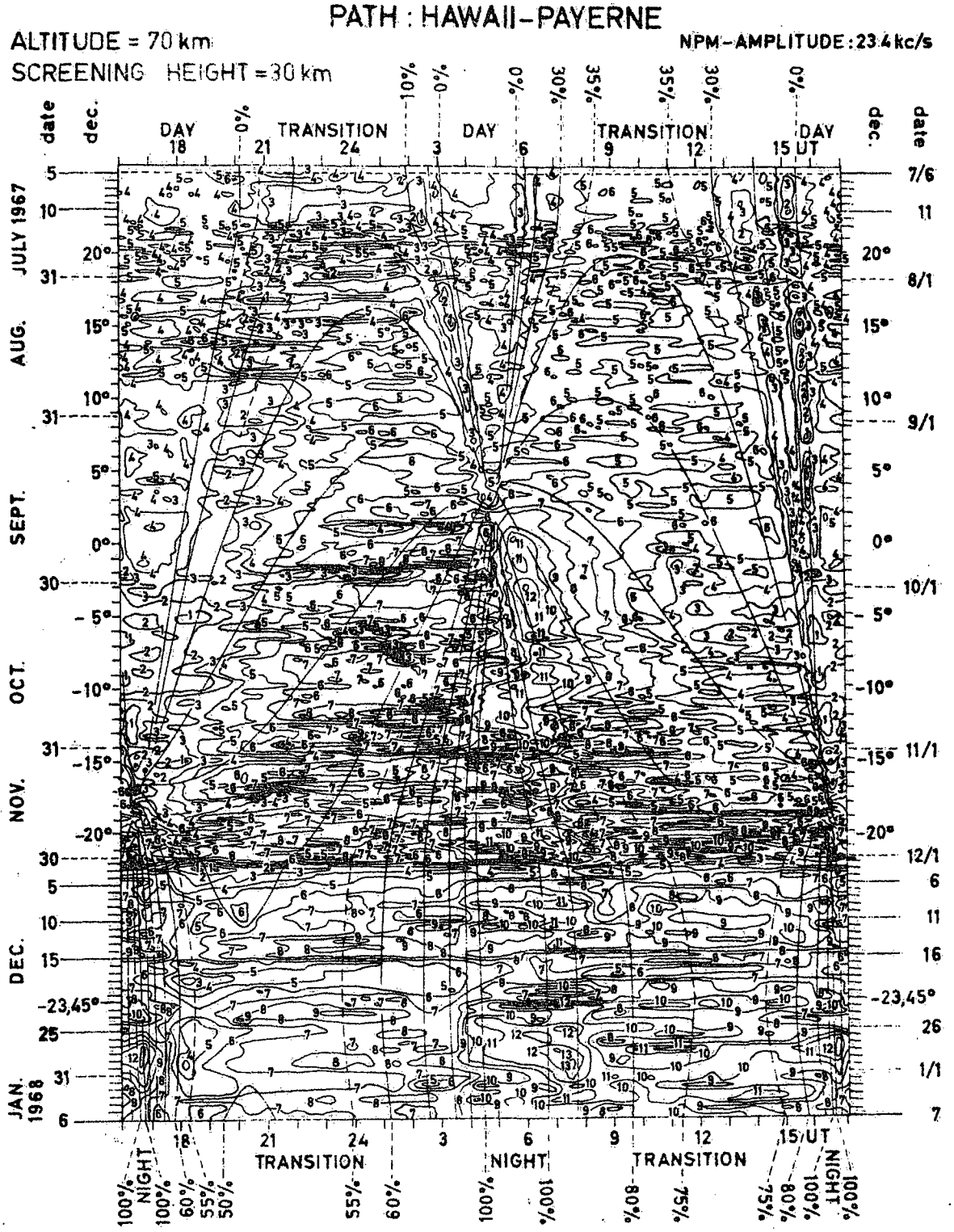

Figure 11. Amplitude representation of NPM-signal from July 5, 1967 to January 7, 1968 is expressed after the code of indexes (figure 3); for explanations see text figure 5.

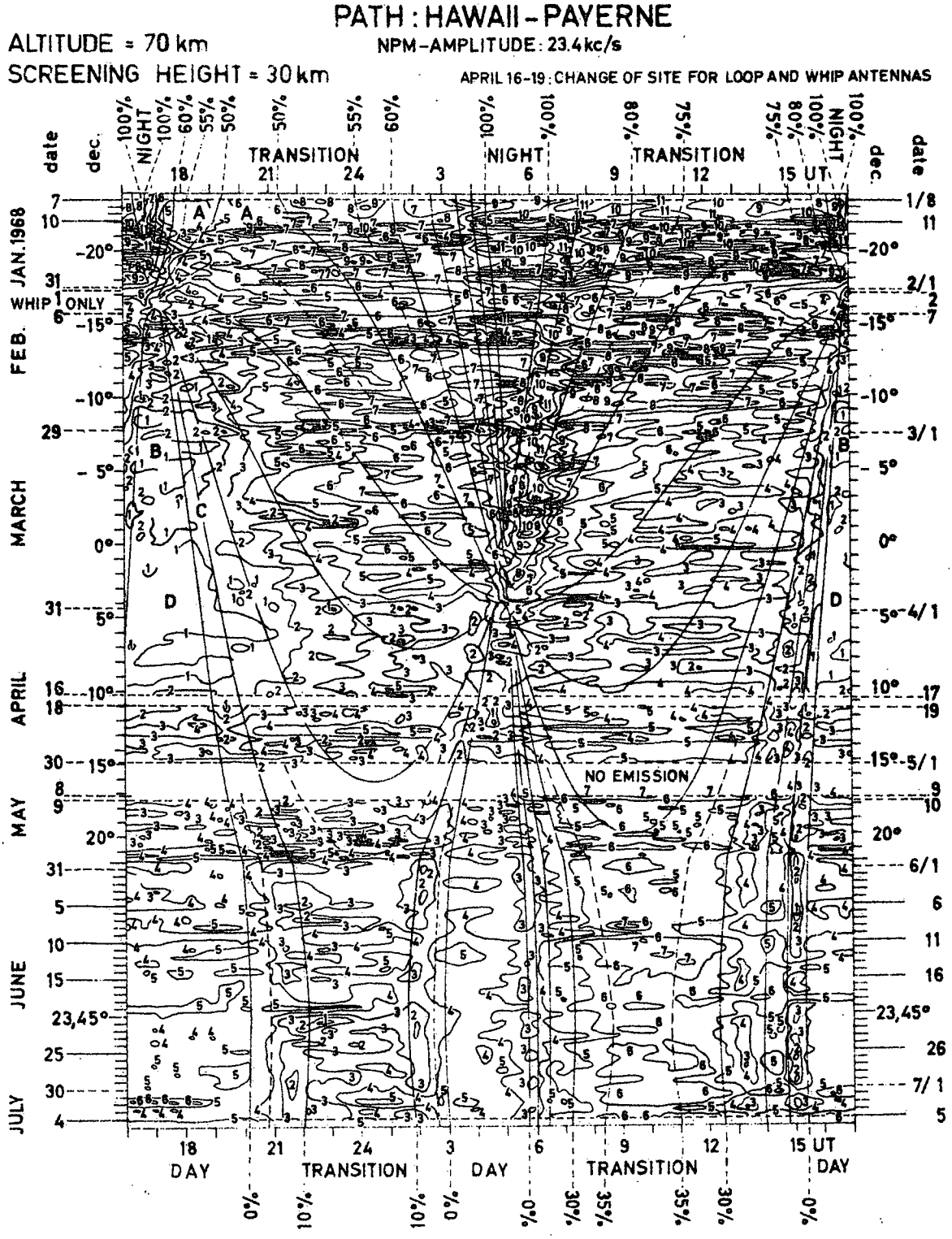

Figure 12. Amplitude representation of NPM-signal from January 7, 1968 to July 5, 1968 is expressed after the code of indexes (figure 3); for explanations see text figure 5. Because of absorption no signal is received in A-, B-, C- and D-areas.

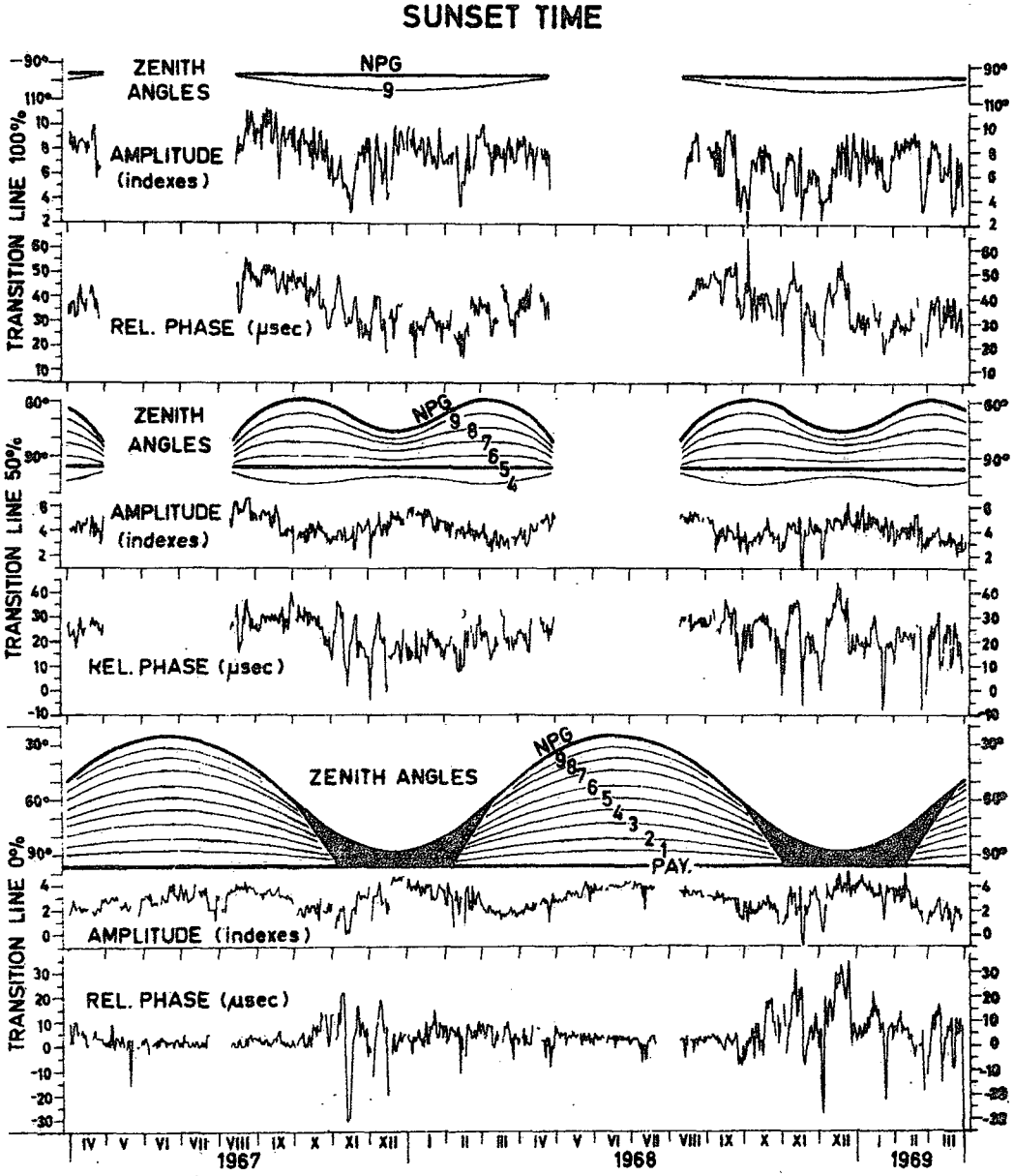

Fig. 13

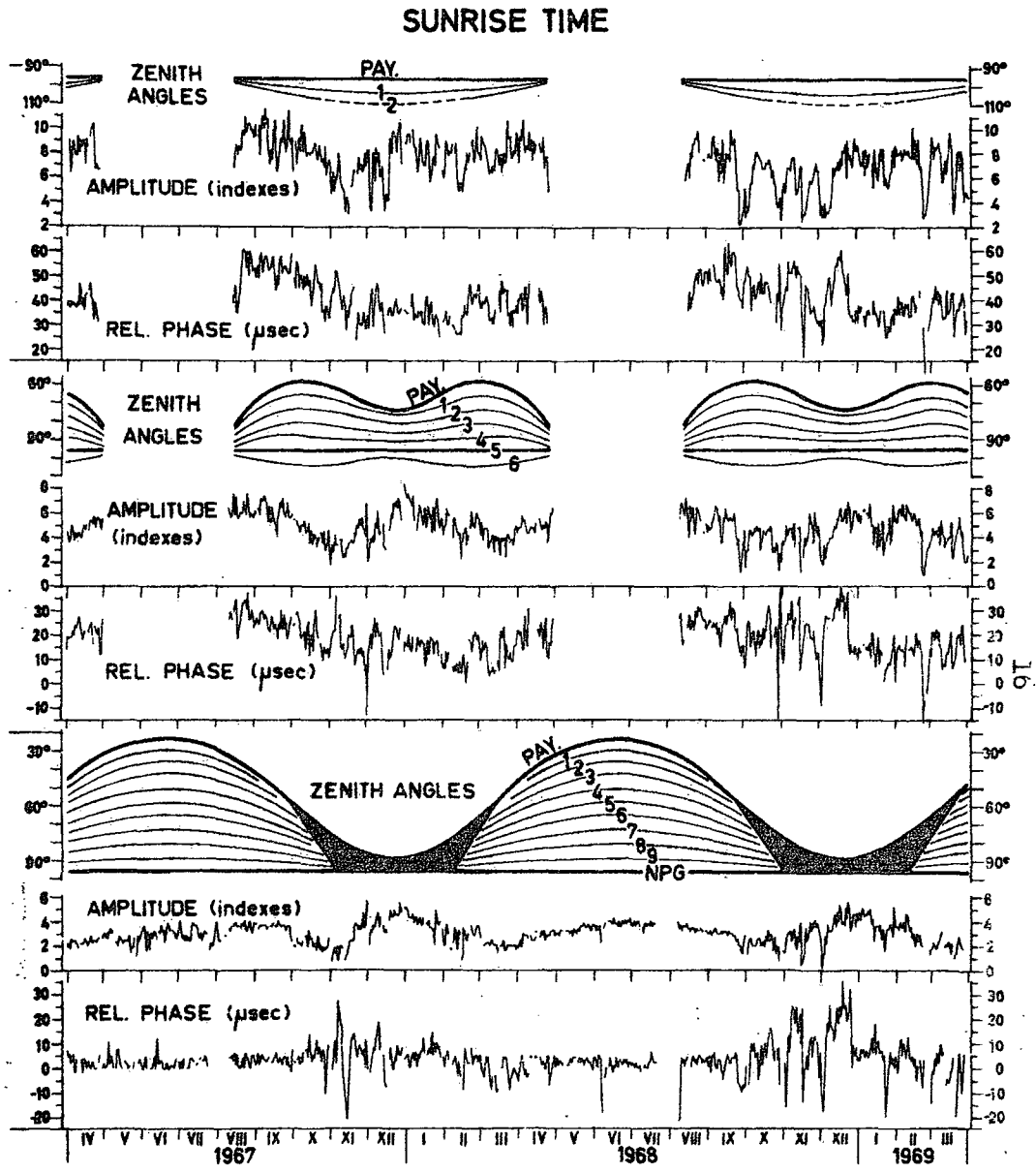

Fig. 14

Amplitude and relative phase profiles of NPG-signal along the 0%, 50% and 100% transition lines from April 1, 1967 to April 1, 1969 at sunset (fig.13) and at sunrise (fig.14), and sun zenith angles behaviour at the end of the 10 equal segments dividing the path [PAY., 1, 2, ...,9, 10 = NPG] (see fig.1) are shown. Amplitude, relative phase and sun zenith angles are respectively expressed in indexes (fig.2), and in angle degrees.

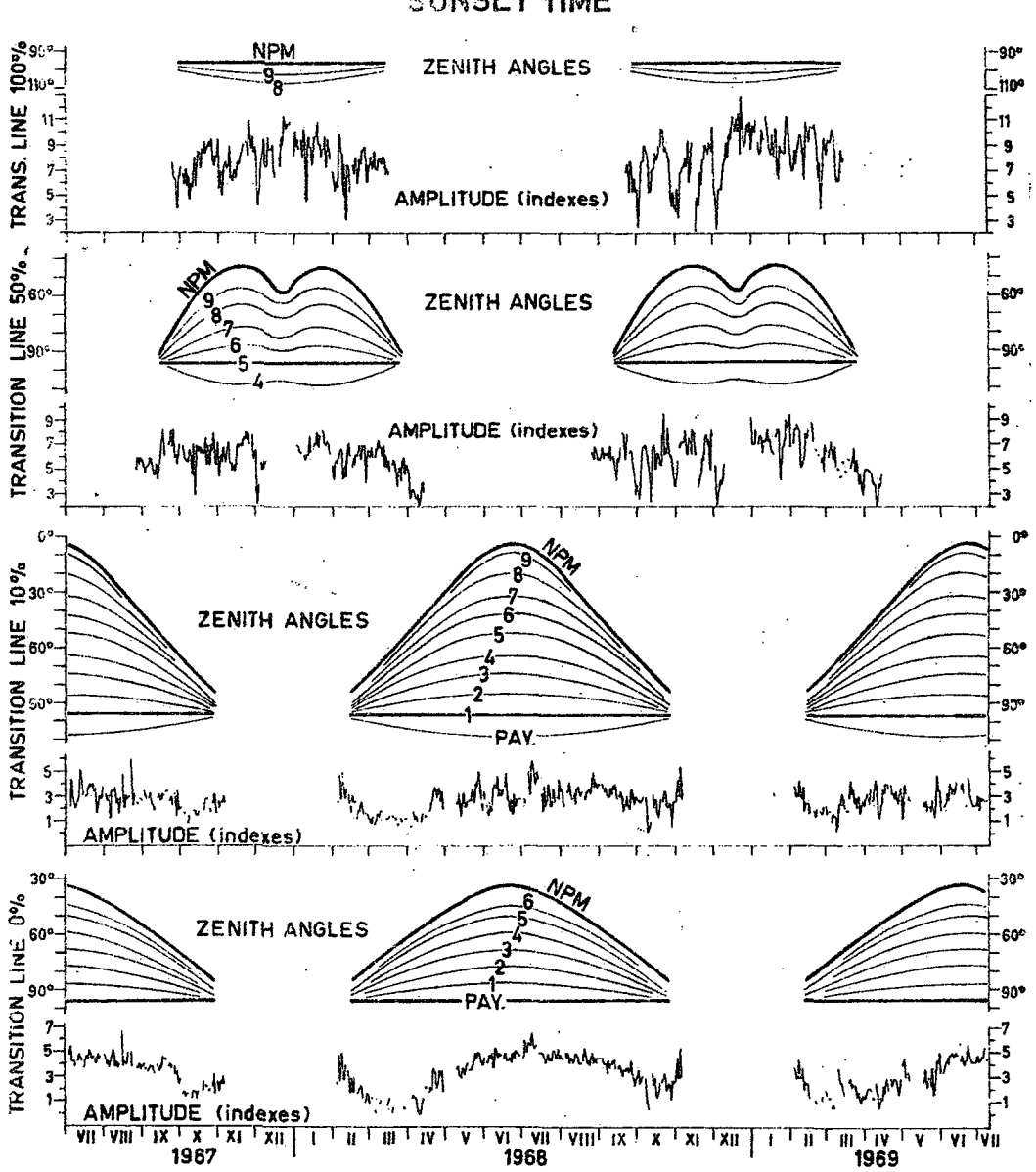

Fig. 15

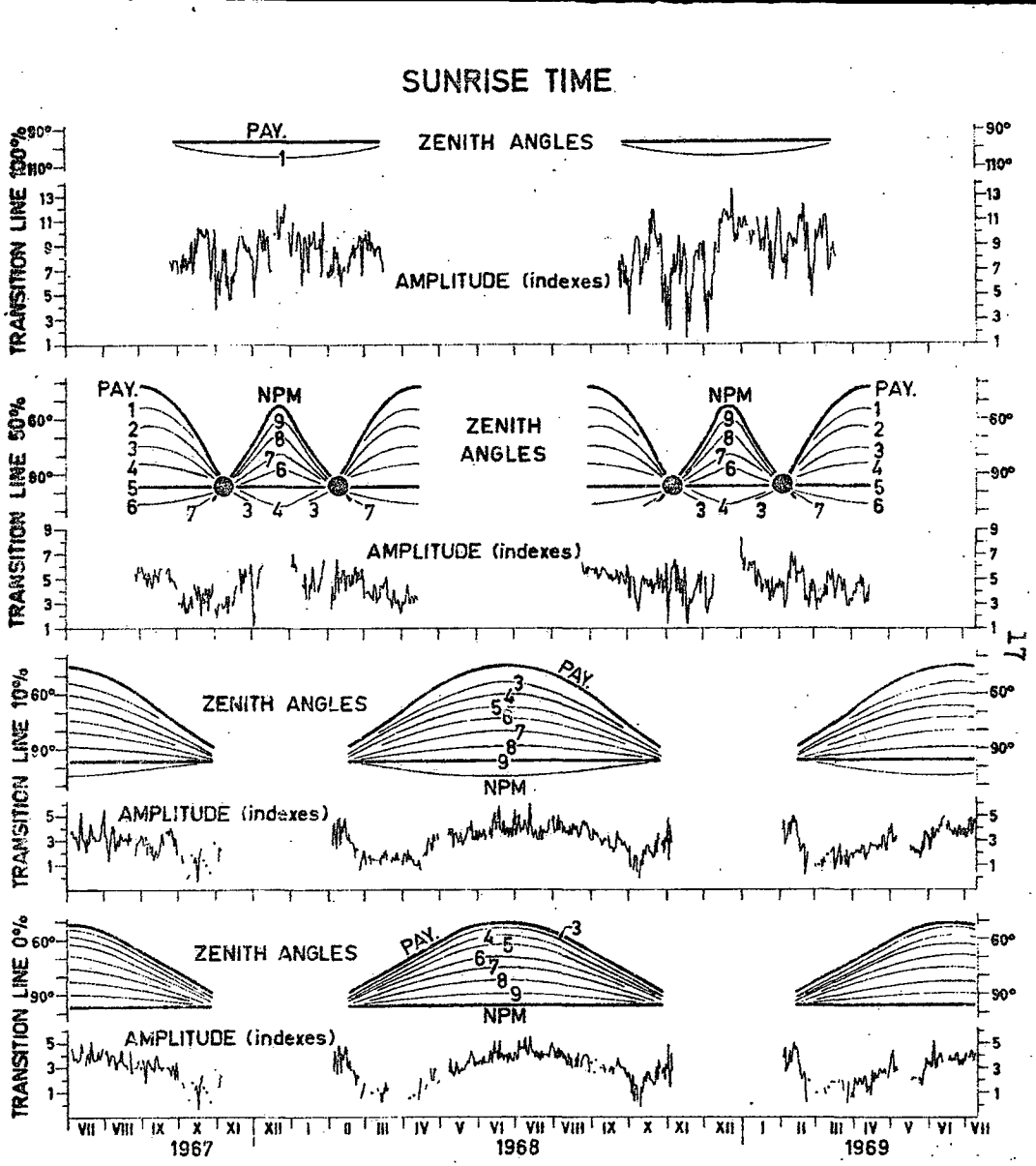

Fig. 16

Amplitude profiles of NPM-signal along the 0%, 10%, 50% and 100% transition lines from July 5, 1967 to July 6, 1969 at sunset (fig.15) and at sunrise (fig.16), and sun zenith angles behaviour at the end of the 10 equal segments dividing the path [PAY., 1, 2, ..., 9, 10 = NPM] (see fig.1) are shown. Amplitude, relative phase and sun zenith angles are respectively expressed in indexes (fig.3), in microseconds (fig.4) and in angle degrees.