NsG-174-61

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Stanford U.

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

UNPUBLISHED PRELIMINARY DATA [redacted]

A NEW VLF PHENOMENON: WHISTLERS TRAPPED BELOW THE PROTONOSPHERE

[redacted]

D. L. Carpenter, N. Dunckel, J. F. Walkup

29461

ABSTRACT

A new whistler phenomenon has been identified through measurements at ground stations, on an Aerobee rocket between 100 and 200 km, and on the Alouette satellite at 1000 km. The new phenomenon is called the "sub-protonospheric" or "SP" whistler, since most of its path appears to be restricted to the region below about 1000 km. The first reported example of an SP whistler was shown by Barrington and Belrose [1963]. In the present report a large number of observations are summarized and the basic characteristics of the new phenomenon are described. Experimental results are presented which suggest that the whistler ray path is confined to the region between roughly 100 km and 1000 km altitude, and that the whistler energy can echo back and forth between these levels. The SP phenomenon occurs mostly at night, typically within a few hours after sunset. SP events are often observed over a period of one or two hours in duration and, for a single Alouette pass, have been observed over a north-south range as great as 2000 km in extent. The evidence suggests that the SP phenomenon occurs mostly near sunspot minimum and at dipole latitudes greater than 45 degrees.

author

INTRODUCTION

Most reported whistler observations support a propagation model in which the whistler energy penetrates the ionosphere and propagates along approximately field-aligned paths to the opposite hemisphere. Travel times over the paths are typically on the order of 1 sec. Recently however, whistlers with travel times on the order of 0.1 sec have been found. Various properties of these events suggest that the ray paths are confined to some ionospheric region near the point of observation. An example

N65-29461 (ACCESSION NUMBER)	1 (THRU)
26 (PAGES)	(CODE)
CR 58255 (NASA CR OR TMX OR AD NUMBER)	07 (CATEGORY)

FACILITY FORM 602

REPORTS CONTROL No. 8

of this type of whistler was first reported by Barrington and Belrose [1963], who showed Alouette satellite records of a whistler with two components. The first component was identified as a conventional fractional hop whistler, with travel time corresponding to propagation once through the ionosphere to 1000 km. The travel time of the second component was approximately three times that of the first, and it was suggested that this component had propagated three times through the ionosphere, having followed a sequence of partial reflection of the original whistler energy near 1000 km, re-reflection below the ionosphere, and subsequent repeated observation at the satellite.

We have recently examined many examples of this new phenomenon, and find that it occurs frequently and has certain well defined characteristics. It is the purpose of this paper to describe these characteristics and to discuss certain aspects of the whistler propagation path. Because most of the postulated path lies below that portion of the magnetosphere in which hydrogen is the principal ionic constituent, we shall for convenience call the new phenomena "sub-protonospheric" or "SP" whistlers.

Recordings of SP whistlers have been made at ground stations, in the Alouette satellite near 1000 km, and on board an Aerobee rocket in the height range roughly 100 to 200 km. The observations bear out the suggestion of Barrington and Belrose that the whistler propagates through the ionosphere to a height of roughly 1000 km and is then reflected back to the lower ionosphere or ground. Frequently there are repeated echoes of

[redacted]

the whistler, suggesting reflection back and forth between the bottom of the ionosphere and the upper region. Figure 1 shows a diagram of this interpretation and indicates the altitudes at which SP whistlers have been observed. Numbers indicate the successive order of observations. In a case involving repeated reflections, the even-order appearances of the whistler energy are recorded near the lower boundary of the ionosphere or on the ground, and the odd-order hops are observed well above the peak of the F layer.

It should not be thought that the actual ray path of an SP whistler is as simple as Figure 1 suggests. While the experimental data support a model in which propagation over most of the path is in the conventional right-handed circularly polarized whistler mode and travel time of a given component is approximately proportional to the number of traversals of the ionosphere, the data also suggest that certain details of the ray path may be quite complex.

Some of the experimental results on SP whistlers will be described in the following paragraphs. The extent to which the data support a simple propagation model will be indicated. Since we are dealing with a new class of phenomena, a relatively wide variety of detail will be presented. At the end of the paper, the experimental observations will be summarized, and some comments on the propagation model will be made. In a companion paper, R. L. Smith presents a possible theoretical explanation of the mechanism by which the whistler energy is reflected from the upper ionosphere.

EXPERIMENTAL RESULTS

Observations Between 100 and 200 km. A large number of SP whistlers were received on an Aerobee rocket fired from Wallops Island (50°N dipole latitude) on July 9, 1963 at 2146 EST. A purpose of the firing was to test the performance of the broadband (0.2 - 12.5 kc/s) receiver developed for use by Stanford University in the EOGO satellite. The antenna consisted of a loop mounted vertically inside the nose-cone section. The rocket reached a peak altitude of 204 km and made broadband VLF observations for approximately 7 minutes after launch. The first whistler event was recorded at about 108 km, at the approximate height of a pronounced sporadic-E layer. From this point to peak altitude and back down to 102 km where the final event was recorded, the observed whistler rate was relatively uniform at about 15 per minute, with a single burst of relatively high activity in the vicinity of 200 km. Ground recordings at Greenbank, West Virginia, roughly 500 km from Wallops Island, revealed no detectable whistler events during the entire rocket flight.

Nearly all of the 75 whistlers observed on the rocket exhibited the type of component structure illustrated in Figure 2. The upper left spectrogram, with frequency range 0 - 8 kc/s, shows a whistler event recorded at an altitude of 201 km. The two right-hand records, with frequency range 0 - 16 kc/s, show the early part of the same event as recorded on the rocket and on the ground at Greenbank. On each record the origin of the time scale indicates the leading edge of the essentially impulsive first signal, or 0th hop of the whistler. Following this impulsive signal are two dispersed traces with travel times at 3 kc/s of approximately 0.09 seconds and 0.18 seconds, respectively. These are the 2nd and 4th hops indicated in Figure 1. Note that while these components are well defined in the lower ionosphere, they are not detected on the ground recording. The ground recording may conveniently be compared to the Aerobee record above it by noting the presence on both spectrograms of NAA signals at 14.7 kc/s.

The lower left-hand record in Figure 2, with frequency range 0 - 8 kc/s, shows a whistler event recorded at an altitude of 204 km. In this case the SP traces are well defined, and two later components may also be seen, with travel times at 5 kc/s of about 1.0 sec and 1.7 sec. (These later traces should not be confused with the two additional SP events identified by the arrows in the lower margin of the record. The arrows indicate the position of the 0th hop for these SP events). The later traces, produced by the lightning source that initiated the first SP event, represent portions of the energy that followed magnetospheric paths extending from hemisphere to hemisphere.

All but one or two of the 75 Aerobee whistler events exhibited at least one SP component, but there was great variation in the definition of the later traces. This is illustrated by a comparison of the two left-hand records in Figure 2. In the upper record the SP components are intense, but the later traces are only faintly indicated near 4 kc/s.

A detailed study has been made of the frequency-versus-time properties of eleven of the best defined Aerobee whistlers. In addition, certain basic properties of all the events have been investigated through examination of real-time Rayspan records. In the following summary of the results, travel-time measurements are expressed in terms of dispersion $D = tf^{1/2}$ $sec^{1/2}$, where t is the travel time at frequency f. For convenience we shall indicate measurements on a specific SP component by using the hop number as a subscript, that is, D_2 and D_4 will represent measurements on the 2nd and 4th-hop components. Most travel time measurements were made with respect to a fixed time at the leading edge of the 0th hop.

1. Within the experimental error of about ± 5 percent, the dispersion $D = tf^{1/2}$ of the SP components is constant as a function of frequency. This is the expected dispersion law for propagation in the right-handed circularly polarized whistler-mode when wave frequency is well below the electron plasma frequency and gyrofrequency and when the wave normal is within a relatively large range of angles with the geomagnetic field. Most of the dispersion measurements were made in the frequency range between about 1.5 kc/s and 4 kc/s. Below 1.5 kc/s there is some indication of an increase in dispersion with decreasing frequency, but this point is not yet well established.

2. For 11 cases, the value of D_2 ranged from 4.4 $sec^{1/2}$ to 5.4 $sec^{1/2}$. (The value of D_2 for an event was determined by averaging the results of measurements at several frequencies).

The scatter of $\pm$ 10 percent around $D_2 = 4.9 \sec^{1/2}$ is probably attributable to experimental uncertainty in identifying the leading edge of a trace or impulse.

3. There is no apparent systematic variation in D_2 throughout the flight. The electron-density profile obtained at the time of the shot shows that electron density increased quite rapidly only above 175 km. The systematic dispersion variations that might be present under these conditions are approximately of the order of some of the experimental uncertainties involved.

4. The travel time at a given frequency between the 2nd and 4th hops is approximately the same as that between the 0th and 2nd hops. The ratio of D_4 to D_2, averaged for each event, remained within $\pm$ 10 percent of 2.0 throughout the flight. This uncertainty is approximately the same as that associated with experimental error.

5. The upper cutoff frequency of the 2d-hop, or 1st dispersed SP component, is about 6.5 kc/s. Most values are in the range 6 - 8 kc/s. The upper cutoff frequency appeared to be somewhat higher near peak altitude. The cutoff of the 4th-hop SP component is about 5.5 kc/s, and the range throughout the flight is roughly 5 - 6 kc/s.

6. The lower cutoff frequencies of both the 2d-hop and 4th-hop SP components lie between about 700 and 750 c/s throughout the flight.

A number of other aspects of the results may be mentioned.

One interesting point is the lack of VLF activity on the ground. A corresponding lack of VLF activity on the ground during a rocket flight at 0030 LT was noted by Cartwright [1964]. It appears likely that a factor contributing to the absence of ground activity was the observed sporadic E layer. In addition to causing the sub-protonospheric components to be re-reflected upward, this layer may have provided a means of reflecting conventional downcoming whistlers. The lack of activity on the ground at Greenbank, some 500 km from Wallops Island, is supported by the rocket experiment itself, which produced records during the sub-ionospheric segments of the flight. During these periods no whistler events were observed.

Although primary attention here is devoted to the SP components, a few comments should be made about the higher-dispersion traces illustrated in the lower left-hand part of Figure 2. The propagation path of these events has not been studied in detail, but an examination of their dispersion properties and a comparison with the known properties of ground-observed whistlers suggests that the first component, with dispersion at 5 kc/s of about 68 $sec^{1/2}$, made a single south-to-north traversal of a magnetospheric path. The path of the first was probably excited by an impulse which reached the southern hemisphere by trans-equatorial subionospheric propagation from the source. This "hybrid" mode of excitation has been previously observed on ground records [Helliwell, 1959; Helliwell and Carpenter, 1963], and it appears to be relatively common in observations made in the ionosphere. The second component, with dispersion of about 118, appears to be a two-hop whistler, with path entrance in the northern hemisphere.

Ground observations. A relatively large number of sub-protonospheric whistlers were observed at ground stations in 1962 and 1963. Observing stations at which they have been detected are Suffield Experimental Station (58°N dipole latitude) and Great Whale River (70°N dipole latitude). Figure 3 shows a graph, based on aural monitoring of hourly two-minute recordings, of the number of recording periods containing SP whistlers versus local time at the observing station. On the graph are represented 55 two-minute runs from 26 recording days during 28 station months of operation. The number of cases exhibits an abrupt rise at about 2100 LT, and after remaining at a high value for several hours, decreases gradually and then falls rapidly near dawn. It should be pointed out that on most of the days represented in Figure 3, examples were found during only one or perhaps two successive runs. On a few occasions SP whistlers were detected for as many as four or five hours in succession.

The ground observations appear to be limited by the nature of source activity. More than one half of the events were seen in local summer, when lightning activity in neighboring areas is relatively high. In many of the runs containing SP whistlers, only one or perhaps two faint examples were observed following one or more of the loudest impulsive atmospherics in the run. On some occasions, however, many SP events were detected, and a few included 4th hops, as in the case of the Aerobee recordings.

When SP events were observed on the ground, other forms of whistler activity were seldom detected. On a few rare occasions, the SP whistler was followed by a faint two-hop long whistler.

A preliminary study shows that the ground records and Aerobee records are similar in several respects. The even-order hops are observed on the ground (see Figure 1), and travel times are frequently such that $D_2 \approx 5\ sec^{1/2}$ and D_4 (when observed) $\approx 10\ sec^{1/2}$. Most of the ground-observed dispersion values fall in the range $D = 3 - 6\ sec^{1/2}$, a distribution to be expected if the corresponding spatial and temporal range of variation in ionospheric electron density is within a factor of about 4. The frequency range of the ground observations is usually relatively limited as compared to the range observed on the Aerobee. In many cases the detectable energy in the SP components is limited to the band from about 700 c/s to about 2000 c/s.

On the basis of ground observations, it appears that the sub-protonospheric whistler is associated with sunspot minimum. An extensive amount of experimental work has been done with whistler records made since early in the IGY, and as yet wo examples of SP events from this early period have been reported. A careful sampling of certain IGY records should be carried out to clarify this situation.

Observations at 1000 km. The broadband VLF experiment on the Alouette satellite provides a valuable source of information on the spatial distribution of SP whistlers, and on the general properties of SP events as observed at 1000 km. The first report on what appears to be an SP whistler recorded on the Alouette was made by Barrington and Belrose [1963]. These authors showed a spectrogram of two low-dispersion traces, apparently corresponding to the 1st and 3rd hops of a sub-protonospheric whistler. The value of D_3 was reported to be three times the value of D_1.

A relatively large number of observations of SP whistlers have been made through telemetry of the Alouette receptions to a ground station at Stanford University, California. What appear to be SP whistlers have been observed on several passes during the hours after local sunset and on at least one pass near dawn. A particularly interesting set of records was obtained on April 19, 1963 at approximately 1920 local time at the satellite. The track was approximately north to south near the 105°West geographic meridian. During a 5-minute observing period, 7 well-defined examples of SP whistlers were recorded, the first being seen at 53°N geographic (62°N dipole) latitude, and the last at approximately 37°N geographic (46°N dipole) latitude. Thus the north-south range of observations was on the order of 2000 km on this occasion. It is noteworthy that while a substantial number of SP whistlers were observed over the range from about 53° to about 37°N geographic, no SP events were observed over the range from 37°N to the end of the pass at about 10°N. On this low-latitude segment there was a significant amount of source activity available, as evidenced by the presence on the Alouette records of a number of conventional low-dispersion whistlers with $D = 3 - 4\ sec^{1/2}$.

Figure 4 shows spectrograms of SP whistlers recorded on the

April 19, 1963 pass at 53°, 50°, 38° and 37°N geographic latitude. (The event at 33°N will be discussed in a later paragraph.) Each of the four examples shows several odd-order SP components. The event at 38° exhibits 6 well defined traces, corresponding to the 1st, 3rd, 5th, 7th, 9th and 11th hops. This event also exhibits conventional whistler traces, with travel times of 2 sec or greater. There are actually three whistler events at 38°, although only the first exhibits well defined dispersion properties. Arrows mark the approximate time of origin of the second and third flashes, while the origin of the time scale indicates the approximate time of origin of the principal whistler event. The horizontal lines were introduced by instrumentation on the satellite.

The results of a preliminary survey of the dispersion properties of the SP events illustrated in Figure 4 may be summarized as follows:

1. The dispersion D_1 of the 1st-hop component is approximately $3\ sec^{1/2}$. This value is consistent with previous nighttime observations of 1-hop propagation through the ionosphere to 1000 km [Barrington and Belrose, 1963]. It is also consistent with theoretical predictions of whistler dispersion for 1-hop propagation through a nighttime ionosphere [Smith, 1961; Pope, 1961]. The value of D_1 is very nearly the same for all of the events.

2. To a first approximation, successive odd-order hops are separated by twice the travel time of the 1st hop. There do appear to be small departures from strict integral relations.

Preliminary measurements show that, to a degree depending somewhat upon the frequency of measurement, the interval between the 1st and 3rd-hop components tends to be on the order of 15 percent shorter than the intervals between the later traces. After the 3rd hop, the travel-time separation for most cases corresponds to a difference in dispersion of about $D = 5 - 6 \sec^{1/2}$.

3. To a first approximation, the dispersion of the components $D = tf^{1/2}$ is constant. However, as in the case of the Aerobee records, there appears to be a trend toward increasing dispersion with decreasing frequency, particularly below 1 kc/s. This trend is being investigated.

4. In several cases the upper cutoff frequency increases as hop number increases from 1 to 3 to 5. In all cases the upper cutoff frequency appears to increase from the 3rd to the 5th hop, and then remains roughly constant after the 5th hop at about 1500 c/s. Note that the upper cutoff frequency of the 5th hop is near the upper cutoff frequency of a faint noise band.

5. The lower cutoff frequency of the SP whistler increases with increasing trace order until the fifth hop.

6. In several of the events there appears to be a systematic variation in intensity from component to component. The most striking variation is the low intensity of the third hop and the apparent gradual increase in intensity from the 3d to the 5th and possibly to the 7th hop, after which the intensity appears to decrease again. In the case of the event at 37°N, the 3d hop is barely detected. Note that beginning with the event at about

$50^{\circ}N$, the relative intensity of the 3d hop decreases with decreasing latitude.

A number of the features of the Alouette records for April 19, 1963 (Figure 4) were repeated in a striking way on a recording made a year later on April 25, 1964, at roughly the same time and location. The satellite track was approximately north-south along the $122^{\circ}W$ geographic meridian at approximately 1855 local time, shortly after ground sunset. Figure 5 shows spectrographic records of two SP events, one recorded at $44^{\circ}N$ geographic ($50^{\circ}N$ dipole) latitude, and the other at about $36^{\circ}N$ geographic ($43^{\circ}N$ dipole) latitude. A comparison of Figures 4 and 5 reveals similarity both in the gross features and in several matters of detail. The simple model of reflection back and forth between an upper and lower region is supported. Once again the travel time between the 1st and 3d hops is slightly less than the interval between later hops. The 3d-hop component is again relatively faint and limited in frequency range, and its intensity decreases with decreasing latitude. In the upper record of Figure 5, the 3d hop is detected, while on the bottom record it is not observed.

It is tempting to speculate on some of the details of the propagation path as they might be deduced from the Alouette records, but it would seem preferable to await both further detailed measurements and theoretical studies of possible ray paths. It does seem reasonable to suggest that for observations by the Alouette, the effective area of the 3d hop can be relatively small. This is suggested by several forms of evidence, including the relatively limited frequency range of the 3d hop, as well as the tendency, on at least two occasions, for the 3d hop to disappear as the satellite moves southward.

Several additional remarks should be made about Figure 4. The event at 33°N deserves special attention, since it differs substantially from the usual SP configuration. The time of origin of the event has been determined only approximately, within about 50 msec. Two traces are in evidence, with travel-time separation corresponding to a difference in dispersion of about 5 $sec^{1/2}$. The lack of evidence of a 1st-hop component near $t = 0$ suggests that the originating flash was located at a considerable distance from the sub-satellite point. Because the other events in Figure 4 exhibit a decrease in 3d-hop intensity with decreasing latitude, it may be suggested that the two traces at 33°N are by analogy merely the late hops of an SP whistler, perhaps the 11th and 13th. Another possibility is that the traces are part of a conventional whistler propagating from an origin in the southern hemisphere. In this case the separation of the traces may be due to return of whistler energy to the satellite after reflection near the bottom of the ionosphere.

An additional note should be made in connection with the records for 53°N and 50°N. On both records a triggered rising tone appears at approximately the same place with respect to the SP traces. The riser begins at roughly 600 c/s, not far from the low-frequency tail of the 5th or 7th hop, and it rises in frequency by about 150 c/s over a period of about 0.5 sec. It is interesting that the confined nature of the whistler path makes it possible to conclude that the rising tone was triggered within the region between the lower ionosphere and roughly 1000 km.

CONCLUSIONS

Under certain conditions whistler energy can follow a ray path that is confined to the region between roughly 100 km and 1000 km altitude. The observations suggest that the energy echoes back and forth between these levels. The mechanism of lower reflection may probably be explained as reflection either from a sporadic E layer or reflection at the lower boundary of the ionosphere, in the manner of conventional whistler reflection as discussed by Helliwell [1962]. The unique aspects of the new phenomenon seem to lie in the mechanism of upper reflection and in the details of the ray path. In a companion paper, R. L. Smith, presents an explanation of the upper reflection involving refraction of the wave through the transverse region of propagation.

The altitude of upper reflection is not yet known precisely. The dispersion properties of many of the observed events, when compared to previous theoretical and experimental measurements, indicate that the upper reflection level is near 1000 km. Pending more detailed studies it may be estimated to be in the range 700 - 1300 km.

The probability of occurrence of the SP phenomenon, given suitable lightning source activity, is estimated to be on the order of 0.5 during the hours after sunset, near sunspot minimum, and at middle to high latitudes. SP events have been detected on approximately one-half of the Stanford recordings of Alouette whistlers made during the post-sunset hours. The ground observations do not show such a high rate of observation, but this is probably due to the strong blanketing effect of the ionosphere.

The data suggest that most of the propagation is in the right-handed circularly polarized whistler mode, and that each traversal of the path extends from roughly 100 to 1000 km. However, some of the Alouette results suggest that the ray path may show small but systematic departures from a simple model. An examples of this is the limited effective area of observation of the 3rd-hop SP component at 1000 km. The striking repeatability of the Alouette records on different passes suggests that a relatively complex descriptive picture of the SP phenomenon can be obtained from further study of spectrographic records.

An explanation of the SP phenomenon must account for the following observational details: 1) most of the examples have been found at nighttime, the majority within a few hours after sunset; 2) examples are often found during two consectuive hourly recording periods, and occasionally appear for as many as four or five hours in succession; 3) the north-south range over which SP whistlers have been found is as great as 2000 km (for a single Alouette pass); 4) no examples of SP whistlers observed on the ground have been reported for the period prior to 1962; 5) examples have thus far been limited to observations at dipole latitudes greater than about 45°.

BIBLIOGRAPHY

Barrington, R. E. and J. S. Belrose, Preliminary results from the very-low-frequency receiver aboard Canada's Alouette satellite, Nature, 198(4881), 651-656, May 18, 1963.

Cartwright, D. G., Rocket observations of very low frequency radio noise at night, Planet. and Space Sci., 12(1), 11-16, January 1964.

Helliwell, R. A., Whistler paths and electron densities in the outer ionosphere, Proc. of the Symposium on Physical Processes in the Sun-Earth Environment, Defence Res. Board, DRTE Pub. No. 1025, 165-175, July 20-21, 1959.

Helliwell, R. A., Coupling between the ionosphere and the earth-ionosphere waveguide at very low frequencies, Proc. Int'l. Conf. on the Ionosphere, London, July 1962, Inst. of Physics and Physical Soc., London, Bartholomew Press, Dorking, England, 452-460, 1963.

Helliwell, R. A. and D. L. Carpenter, Whistlers excited by nuclear explosions, J. Geophys. Res., 68(15), 4409-4420, 1963.

Pope, J. H., An estimate of electron densities in the exosphere using nose whistlers, J. Geophys. Res., 66(1), 67-75, 1961.

Smith, R. L., Properties of the outer ionosphere deduced from nose whistlers, J. Geophys. Res., 66(11), 3709-3716, 1961.

LIST OF ILLUSTRATIONS

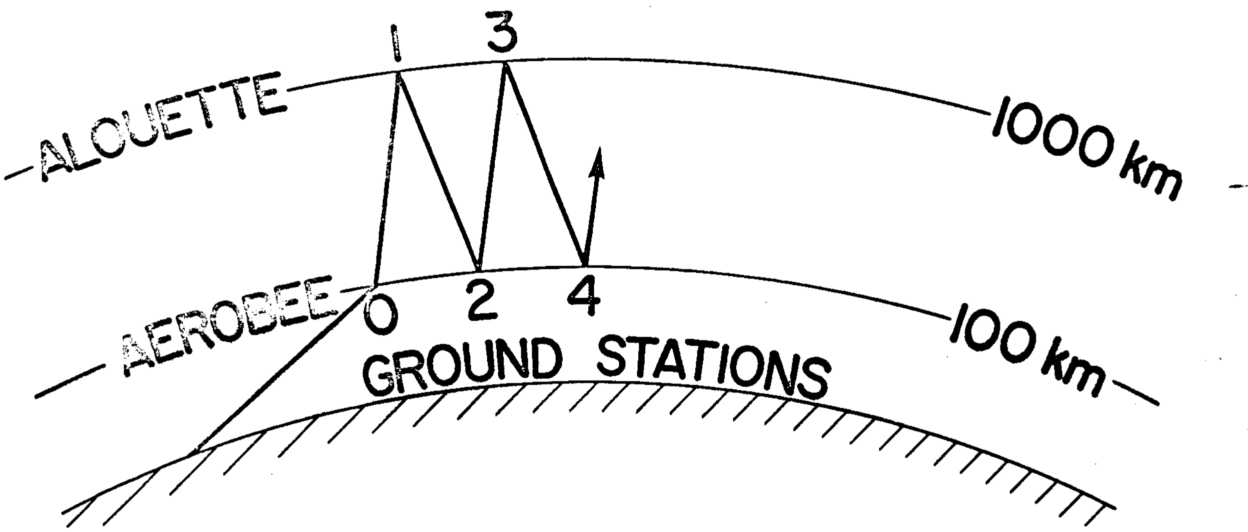
frequency near 2.6 kc s.

Figure 5. Spectrographic records of whistlers received on the Alouette satellite on April 25, 1964 at approximately 1850 local time at the satellite. The approximate geographic latitude of the satellite is indicated above the record. The horizontal lines and the wide vertical band at the upper right are of instrumental origin.

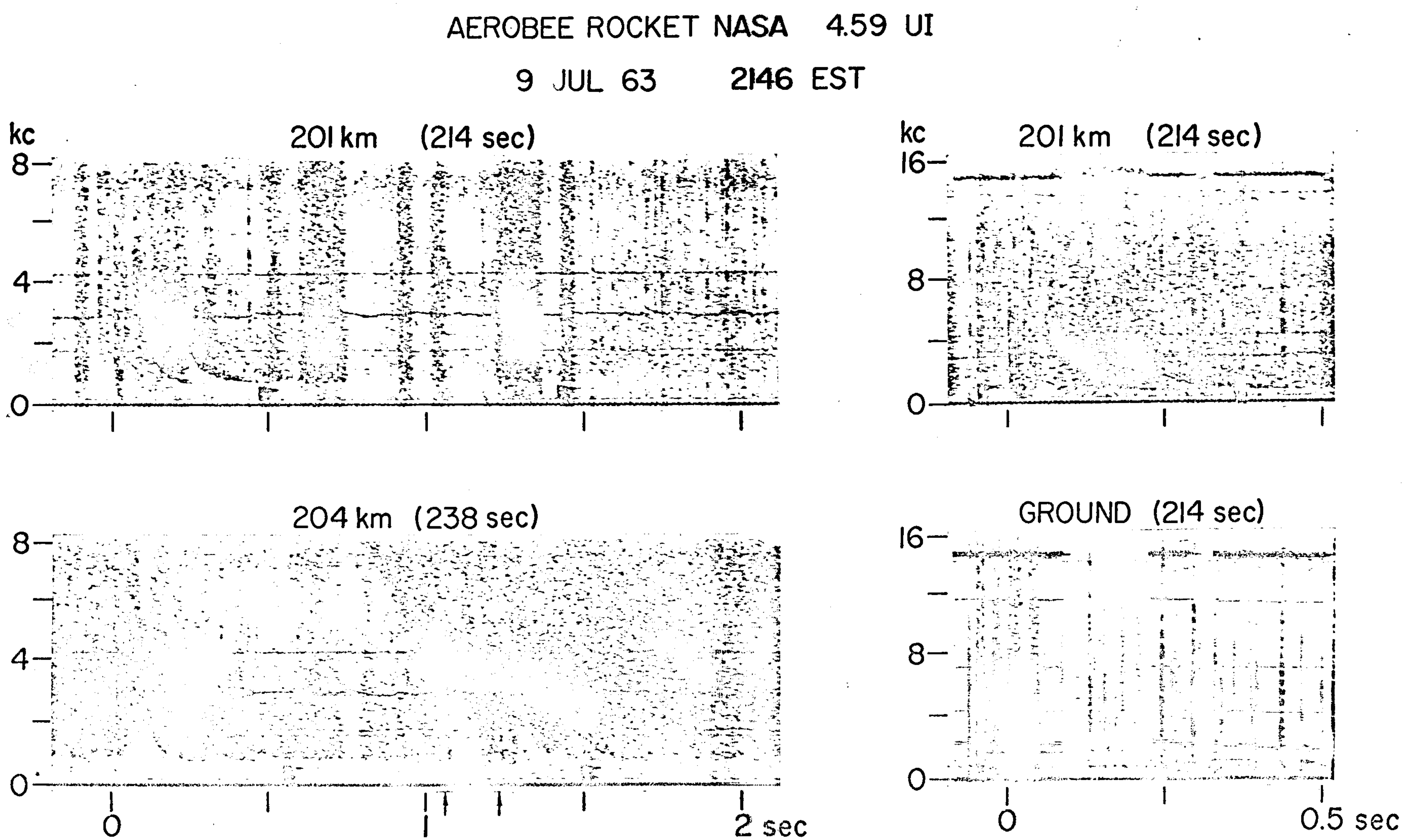
ACKNOWLEDGMENTS

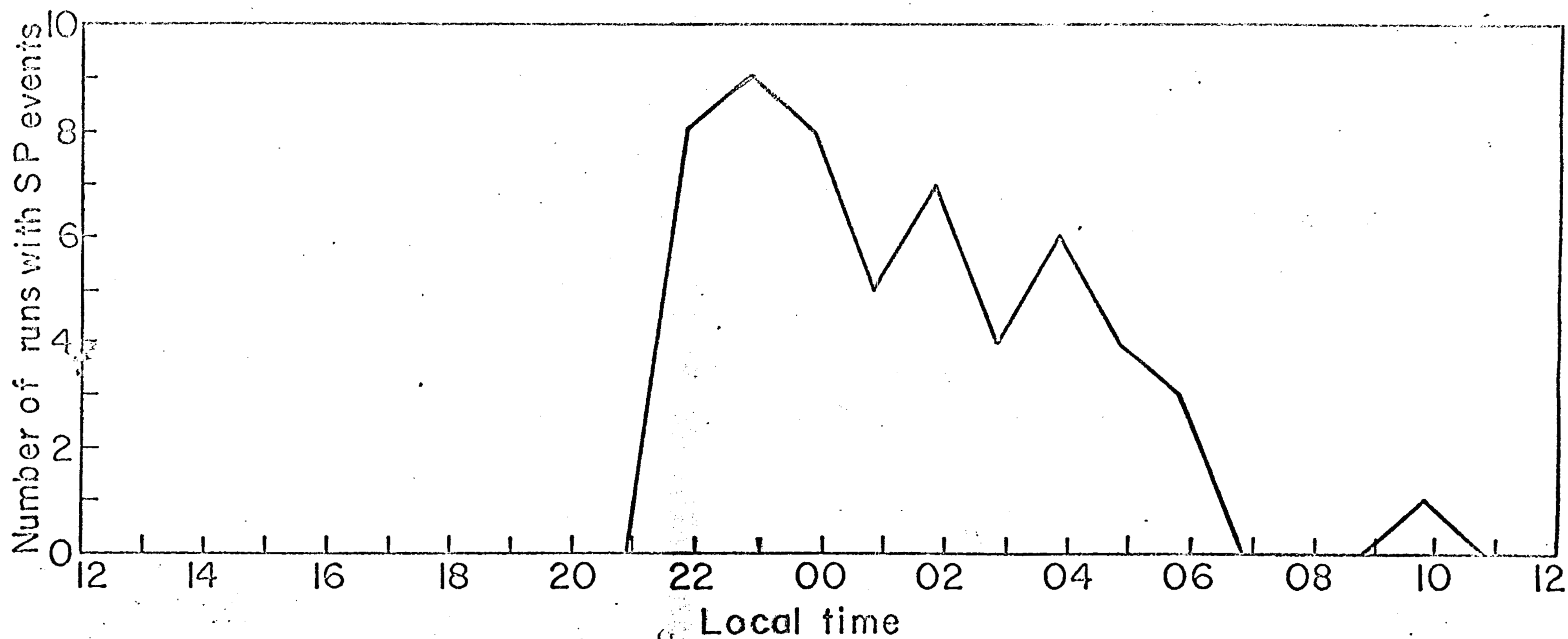
We acknowledge with thanks the cooperation of the Canadian Defence Research Telecommunications Establishment in making possible the telemetered recordings at Stanford of the Alouette VLF receptions. We thank Professor R. A. Helliwell for his comments upon the manuscript.

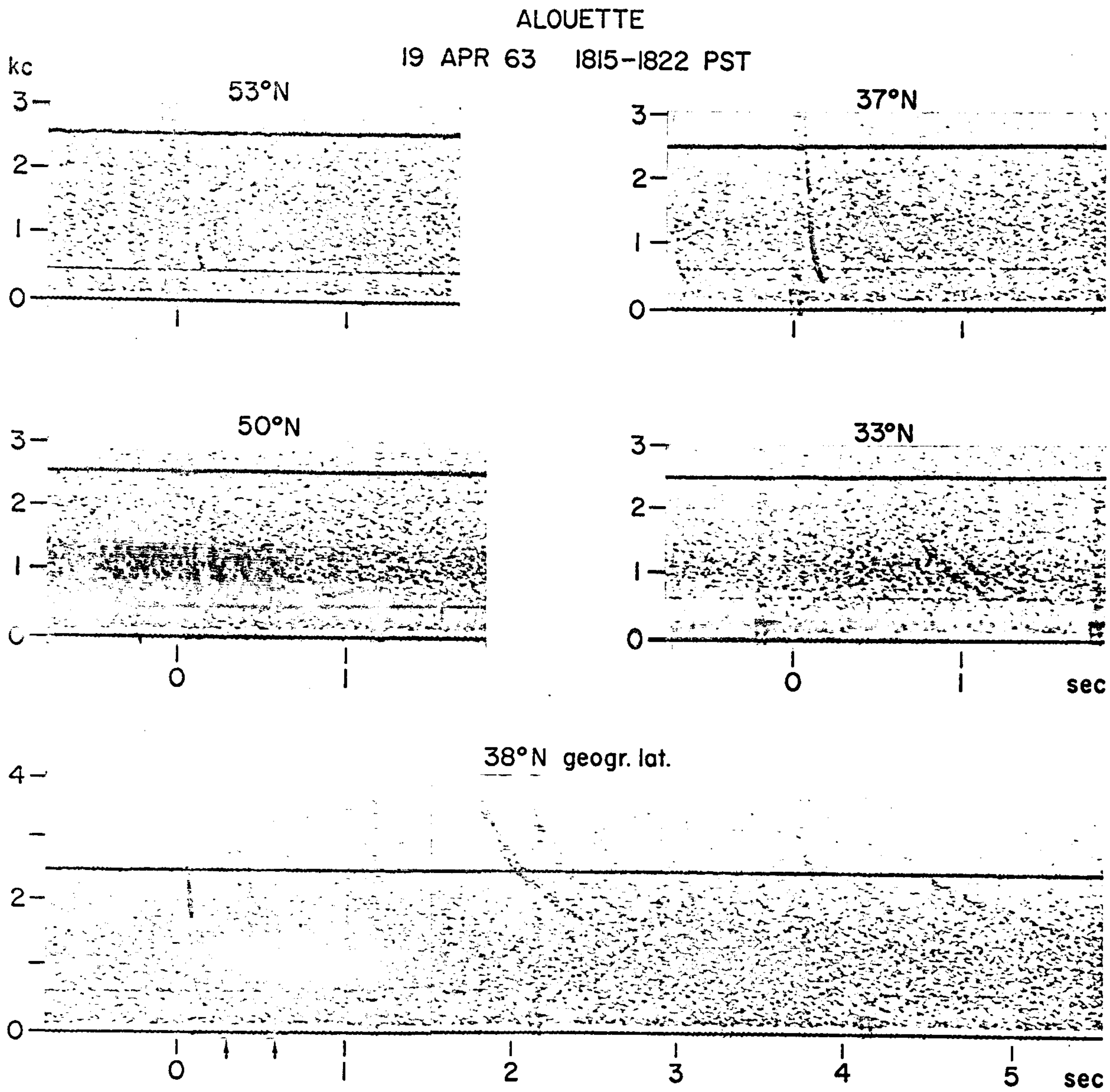
This research was supported by the National Aeronautics and Space Administration under Grant NSG 174-61 and Contract NAS 5-2131, and in part by the Atmospheric Sciences Section of the National Science Foundation under Grants NSF 17037 and GP-1191.

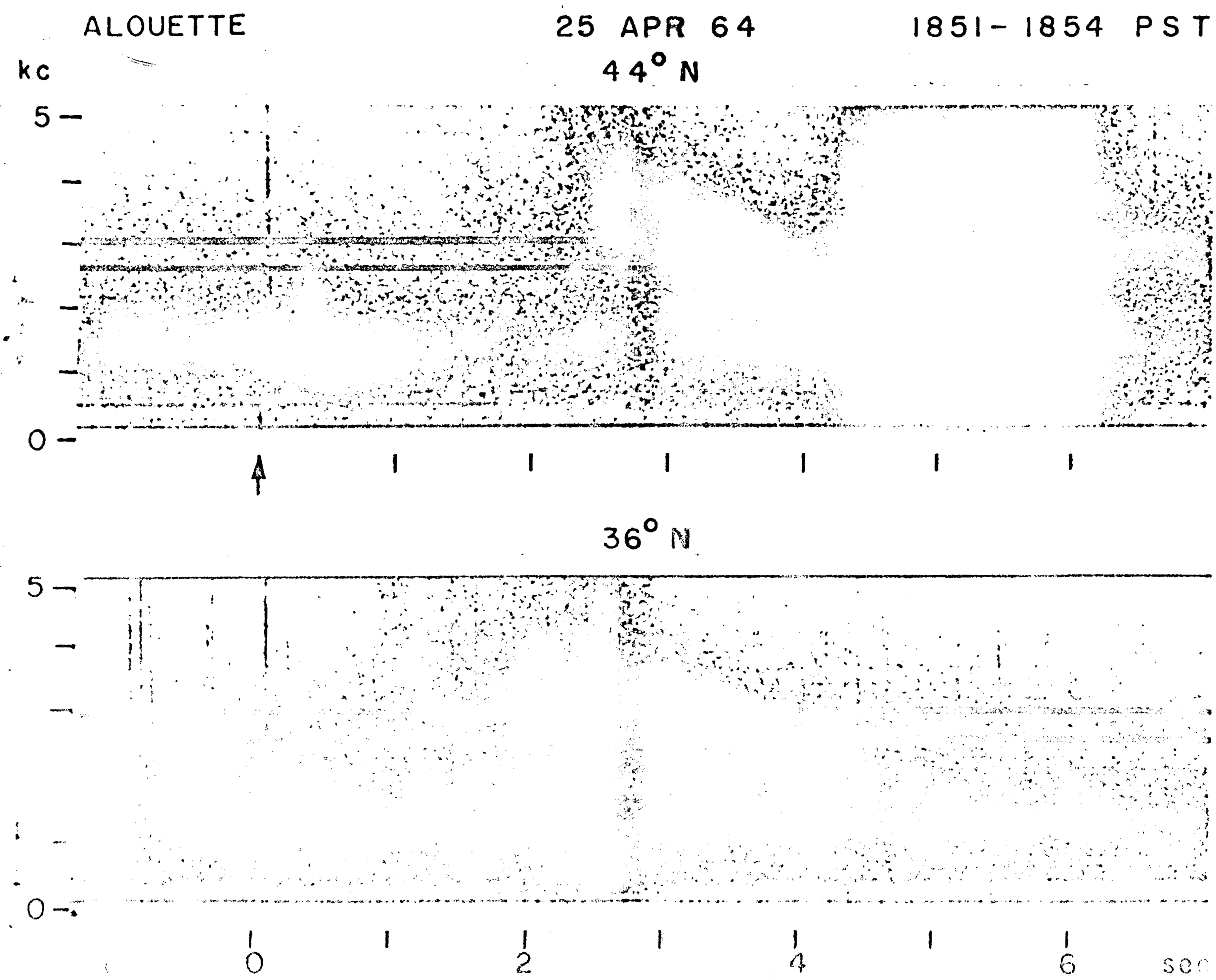


1
3
ALOUETTE
1000 km
AEROBEE
0
2
4
100 km
GROUND STATIONS


AEROBEE ROCKET NASA 4.59 UI
9 JUL 63 2146 EST
kc
201 km (214 sec)
8
4
0
201 km (214 sec)
16
8
0
204 km (238 sec)
8
4
0
0
1
2 sec
GROUND (214 sec)
16
8
0
0
0.5 sec


Number of runs with S P events
0
2
4
6
8
10
12
14
16
18
20
22
00
02
04
06
08
10
12
Local time


ALOUETTE
19 APR 63 1815-1822 PST
kc
53°N
37°N
50°N
33°N
38°N geogr. lat.
0
1
2
3
4
5
sec


ALOUETTE
25 APR 64
1851- 1854 PST
44° N
kc
5
0
36° N
5
0
0
2
4
6
sec