SCINTILLATION OBSERVATIONS AT MEDIUM LATITUDE GEOMAGNETICALLY CONJUGATE STATIONS

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ABSTRACT

This work is based on one year's scintillation observations of satellite BE-B on 40 MHz at Adak and Wellington. Approximately, Adak and Wellington stations form a geomagnetic conjugate pair. The nighttime scintillation shows a semi-annual variation especially the equatorward of Adak and Wellington.

Cross-correlation studies indicate that conjugate effect is statistically significant at night but not in daytime.

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1. Introduction

The study of scintillation phenomenon has been carried out over a two-decade period by observing radio stars and more lately also by observing radio satellites. It is believed that scintillation is produced when radio waves pass through an ionosphere containing irregularities in electron density. These irregularities tend to focus or defocus radio energy, resulting in a change of amplitude on the ground. This changing amplitude pattern is sometimes referred to as the diffraction pattern. The diffraction pattern will move on the ground if there is ionospheric wind or motion of the (satellite) radio source. For a fixed observer the moving diffraction pattern is observed as a fluctuating amplitude, known as scintillation.

At present there is not an experimentally proven theory to explain the cause for these irregularities in the F region at temperate latitudes. Due to complexity of the phenomenon there may be more than one causative mechanism. One possible test of interest is to investigate if the geomagnetic field plays a role in the production of these irregularities. Such a test requires observations of the phenomenon at geomagnetically conjugate stations. The conjugacy test has been carried out for a number of geophysical phenomena such as polar cap absorption, auroral events and magnetic variations, but not much has been done in regard to the scintillation phenomenon. To the authors' knowledge the only publication in this area is one by Brenan (1960) who studied radio star scintillation at Halley Bay and Jodrell Bank. This pair of stations is not ideal for conjugate study since Jodrell Bank is approximately 2000 km from the conjugate point of Halley Bay. Nevertheless, a significant correlation coefficient of 0.37 was obtained for 388 pairs of observations. Similar studies between a temperate latitude station and equatorial station yielded an insignificant correlation.

The present investigation is concerned with scintillation observations of radio signals at 40 MHz from satellite BE-B recorded at Adak, Alaska and at Wellington, New Zealand. The geographic coordinates of the receivers, the coordinates of their geomagnetic conjugate points as well as other pertinent parameters computed by Roederer, et. al. (1965) are listed in Table 1.

From a comparison of spread F and radio star scintillation Briggs (1958) has suggested that the irregularities causing nighttime scintillation at mid-latitudes, occur in patches with dimensions of order 500 km in a N-S direction, and considerably greater in the E-W direction. More recent satellite scintillation observations are in agreement with this suggestion. The point conjugate to Adak is approximately 1000 km west of Wellington. Therefore, Adak and Wellington are sufficiently close to being a conjugate pair to permit a meaningful correlation of scintillation study.

The paper starts with a discussion of the method of analysis in Section 2. The behavior of scintillation at each station is studied separately first and the results are given in Section 3. From other related studies it has been found that scintillations in the daytime behave differently from those at night. Therefore in cross-station correlation studies data have been divided into daytime and nighttime. These are presented respectively in Section 4a and 4b. Finally a conclusion is given in Section 5.

2. Method of Analysis

The satellite BE-B was launched in October, 1964. Its approximate orbital parameters are listed in Table 2. Regularly there are at least

TABLE 1

Coordinates and Other Pertinent Parameters

	Latitude	Longitude	B	L
Adak	51.90° N	176.65° W	0.427	2.21
Adak Conjugate	39.0° S	164.7° E	0.509	2.21
Wellington	41.28° S	174.77° E	0.503	2.26
Wellington Conjugate	50.1° N	162.5° W	0.431	2.26

TABLE 2

Approximate Orbital Elements of Satellite BE-B

Nodal Period	104.81 min.
Eccentricity	0.0136
Inclination	79.69°
Perigee Height	880 km
Apogee Height	1080 km

one good south-bound pass and one good north-bound pass per day. On occasions there may be three or four good passes per day. The orbit is such that it takes about three months for the south-bound and north-bound passes together to go through a diurnal cycle. In Figure 1 is shown a map which depicts two sample sub-satellite tracks and their relations with respect to the observing stations and L-shells. The corresponding sub-ionospheric paths are also shown by connecting them to the sub-satellite paths by dashed lines. The present study covers the period from October, 1964 through October, 1965, one year of observations.

For each one-quarter minute length of the record a scintillation index 0, or 1 or 2 is assigned by visual inspection. Examples of different degrees of scintillation and the corresponding scintillation indices are shown in Figure 2. The rectified quasi-sinusoidal behavior in the absence of scintillation is caused by the Faraday effect. The scintillation index is roughly proportional to the intensity of rapid and random fluctuations. This method of scaling has been used before and proven to be useful (Yeh and Swenson, 1964). For the present analysis each pass is divided into 5 L-shell ranges on the basis of the sub-ionospheric position at 350 km (see Figure 1). This height is typical for irregularities producing nighttime scintillation at mid-latitudes (McClure 1964). The five ranges are

Range 1: L = 1.5 to 1.75
Range 2: L = 1.75 to 2.0
Range 3: L = 2.0 to 2.5
Range 4: L = 2.5 to 3.0
Range 5: L = 3.0 to 4.0

These ranges were chosen to give about equal geographic range to each L-shell range. Both Adak and Wellington fall in about the center of range 3. For each pass the quarter minute scintillation indices are then averaged over each L range as well as over the pass as a whole. The data were

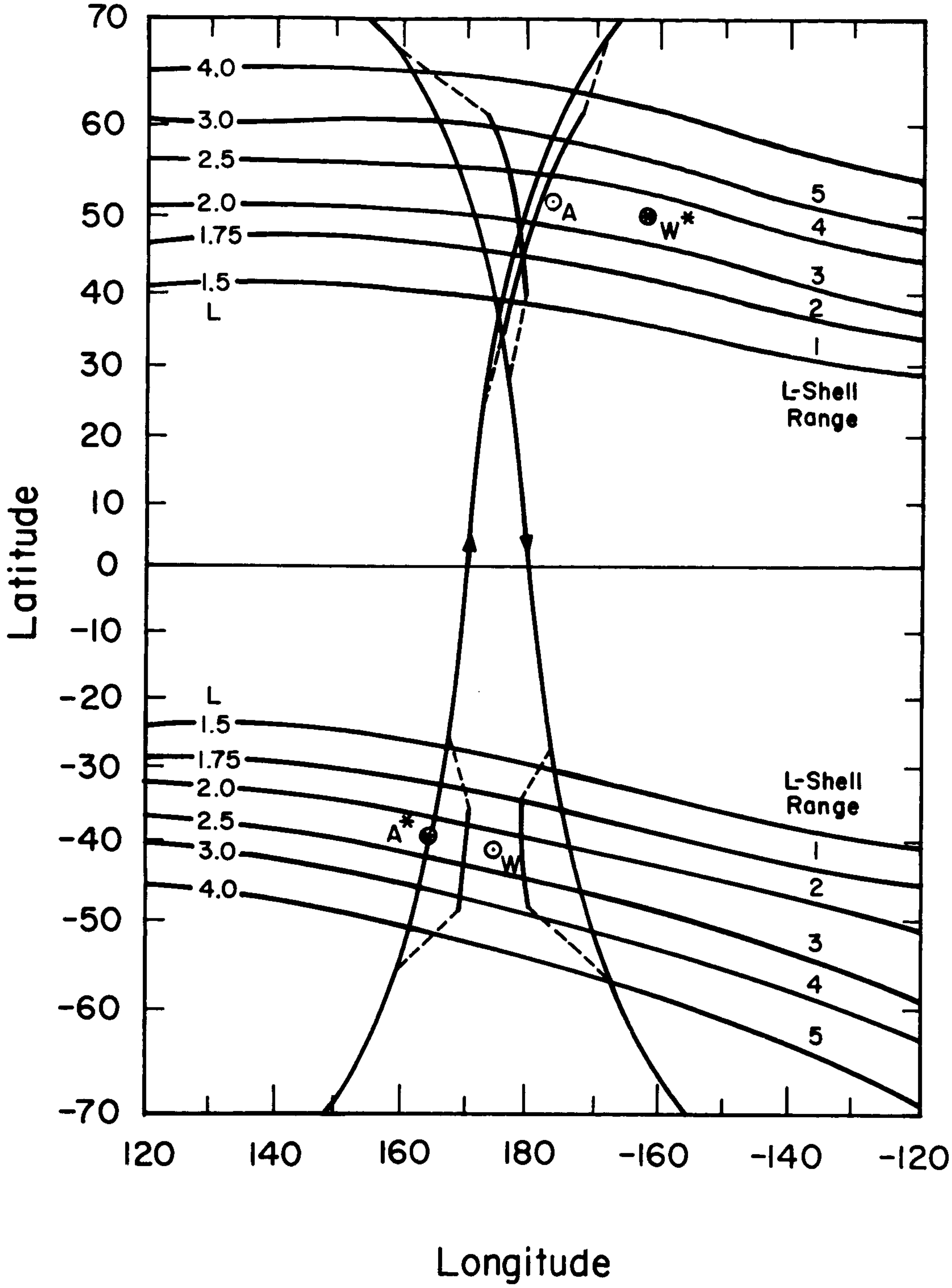


Figure 1. Map showing locations of Adak (A) and Wellington (W) and their geomagnetic conjugates (A* and W* respectively). Also shown are L-shells and sub-satellite tracks.

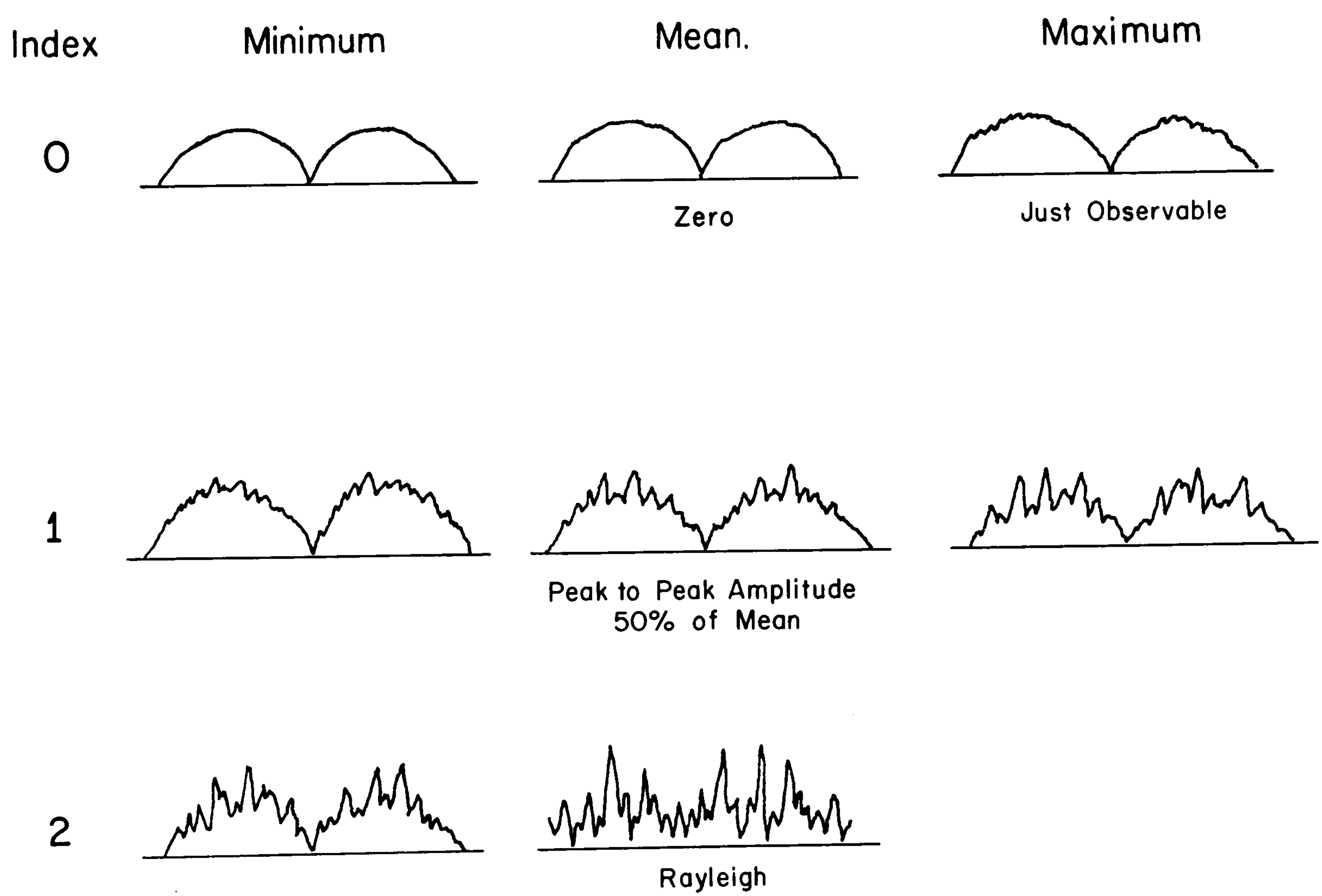


Figure 2. Scintillation index scale

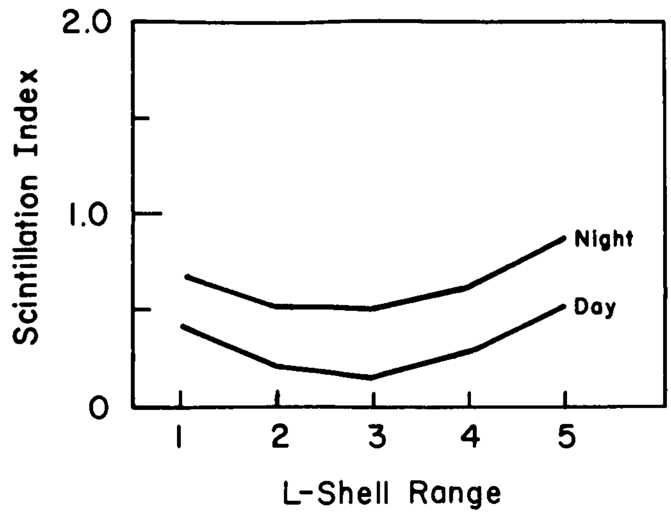
restricted in longitude by rejecting passes where the maximum satellite elevation was less than 30°. This corresponds to a sub-ionospheric longitude range of about 10° centered on the station.

3. Behavior of Scintillation at Each Station

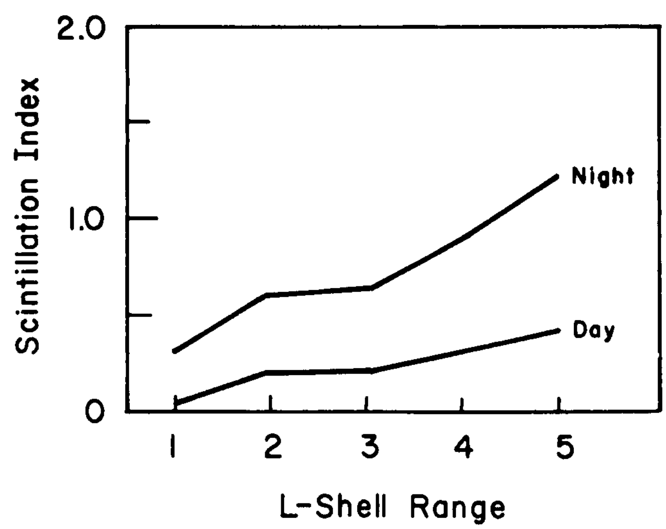
Before presenting results on conjugate correlation studies we first discuss results showing the behavior of scintillation at each station.

Height measurements indicate that the irregularities causing scintillation at mid-latitudes are predominately in E-region during daytime and F-region at night (McClure, 1964). We therefore divide the data into daytime data (0600-1800 local time) and nighttime data (the remaining local time). The average scintillation index in each L-shell range for both day and night at Adak is shown in Figure 3(a). Similar curves for Wellington are shown in Figure 3(b). The higher scintillation index at night than during the day is obvious for both stations. Zenith angle and latitude dependence are also apparent. Points for L-shell 1 at Wellington are unusual and receive further comment below.

Figure 4 shows plots of two-monthly mean values of scintillation index for the period 1000 to 1400 U.T. using two years data at Wellington and 15 months at Adak. (Local midnight at each station is within half an hour of 1200 U.T.). Poleward and equatorward observations have been considered separately for each station. Only indices corresponding to satellite elevations exceeding 15° have been used. The mean values are derived in most cases from at least 120 indices, equivalent to 30 minutes or more of recording time. There appears to be a semi-annual variation at night which is most noticeable in the equatorward data for both stations. The curves for Wellington and Adak are perhaps nearer to overlapping if that



a) Adak



b) Wellington

Figure 3. Average scintillation in each L-shell range
(a) Adak
(b) Wellington

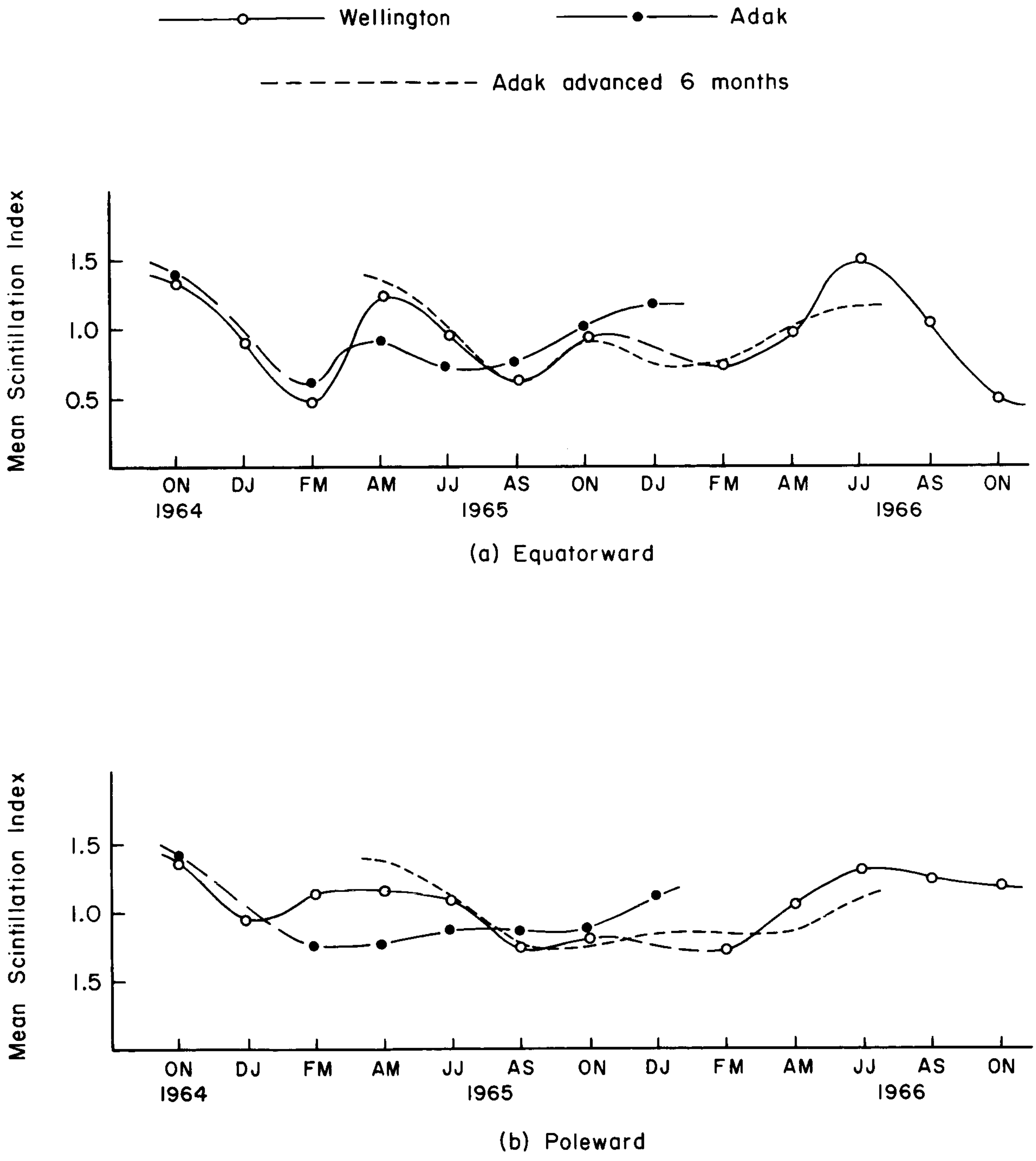


Figure 4. Two monthly mean values of scintillation index at Adak and at Wellington for the period 1000 to 1400 U.T.

for Adak is advanced by six months (dotted curves in Figure 4). However, no improvement in agreement is obtained if Adak curves are retarded by six months. The significance of this observation is discussed in Section 5.

4. Cross-Correlation Analysis

Time variability of the scintillation phenomenon is well known. For example, experience indicates that irregularities may occupy different regions geographically when observed on successive satellite passes. (We cannot, of course, use satellite BE-B to make simultaneous observations at conjugate stations.) In order to reduce the effect of time variability and yet have good statistical sampling, we cross-correlate records obtained at Adak and at Wellington if the passes are within 2 1/2 hours of each other. A total of 372 pairs of passes satisfy this requirement, 174 pairs of which are daytime passes and 198 pairs are nighttime passes. We first discuss the daytime results, then the nighttime results.

4.a. Daytime Results

Figure 5(a) shows the correlation coefficient for the scintillation index averaged over each pass as Adak (marked A) or Wellington (marked W) versus that for each L-shell range at Adak. Figure 5(b) is similar to Figure 5(a), but now we use Wellington L-shell averages. These figures show that the scintillation at a given L-shell range correlates with the average scintillation observed at the same station. The point for Wellington L-shell range 1 in Figure 5(b) is an exception. At Wellington we have tended to avoid using indices relating to satellite elevations below about 15°, where refractive effects may become important. There is also some horizon restriction on equatorward recording at low elevation. The scaled data for shell 1 are sufficient for correlation analysis at night, but not

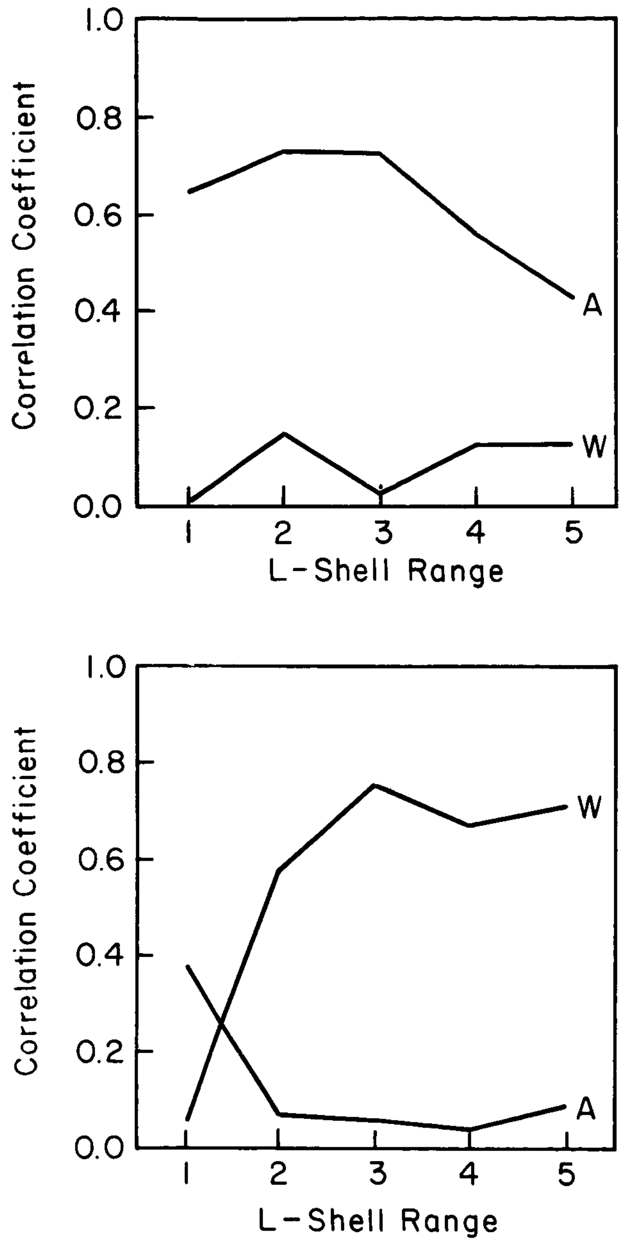


Figure 5. Correlation of pass average scintillation at each station with scintillation at each L-shell range for one station - daytime
(a) Adak average (A) and Wellington average (W) versus L-shell scintillation at Adak
(b) Adak average (A) and Wellington average (W) versus L-shell scintillation at Wellington

for daytime. The data are inadequate to obtain meaningful averages for shell 1 in Figure 3(b).

The results of correlation analysis of the scintillation index for L-shells at Adak with the scintillation index for L-shells at Wellington are shown in Figure 6. These curves show that there is essentially no significant correlation between L-shells at conjugate stations during the day. The absence of significant correlation is true even for corresponding L-shells. (The points for which the correlation coefficient reaches above 0.4 again correspond to L-shell range 1 observations at Wellington.)

Further cross-correlation studies are made by shifting the data according to the following scheme. When there is zero shift it means that data in the following L-shells are correlated.

Adak L-shell range	1	2	3	4	5
Wellington L-shell range	1	2	3	4	5

when the shift is +1, it means

Adak L-shell range	1	2	3	4
Wellington L-shell range	2	3	4	5

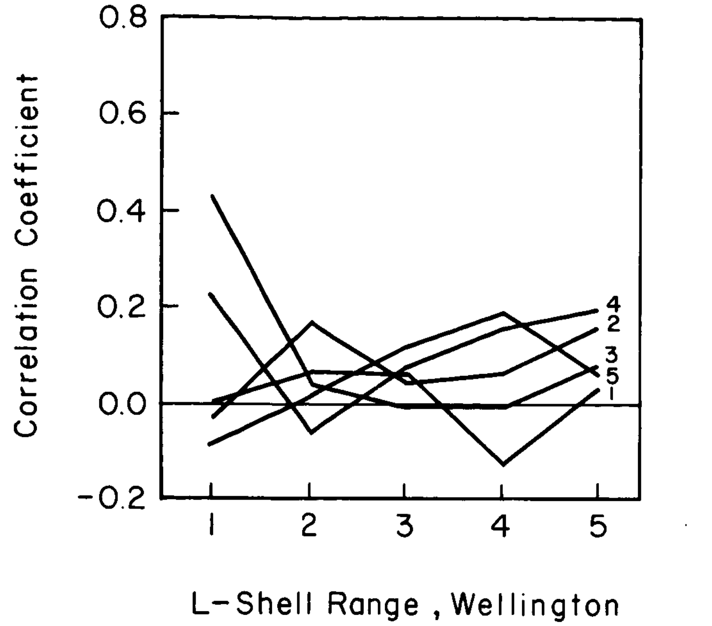
when the shift is -1, it means

Adak L-shell range	2	3	4	5
Wellington L-shell range	1	2	3	4

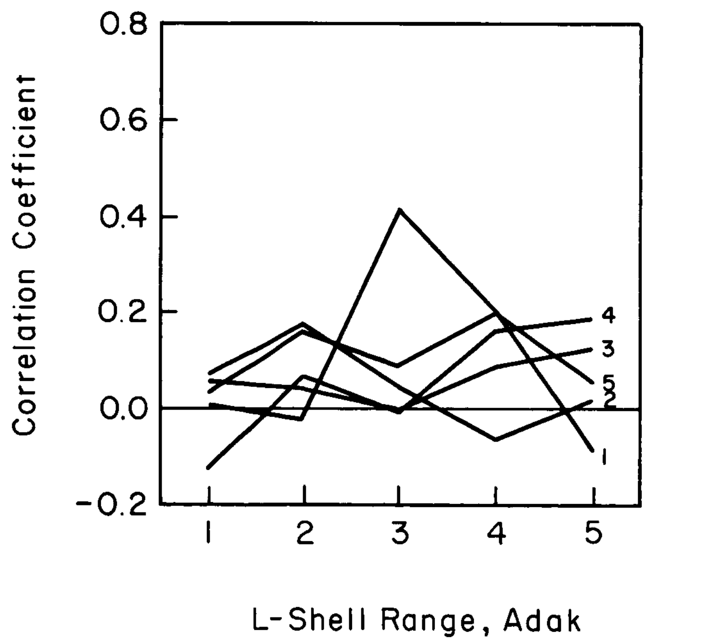
The cross-correlation function as a function of the shift in L-shell range is shown in Figure 7. No significant correlation and trend are revealed. Note that in obtaining Figure 7, only those passes with data in all five L-shell ranges at both stations and at the same time with an elevation angle near the point of closest approach larger than 30° are used. This includes a total of 32 passes.

4.b. Nighttime Results

Nighttime correlation studies are similar to those made for daytime.



(a) Adak L-Shell as a Parameter



(b) Wellington L-Shell as a Parameter

Figure 6. Shell-to-shell correlations - daytime
(a) Adak L-shell as a parameter
(b) Wellington L-shell as a parameter

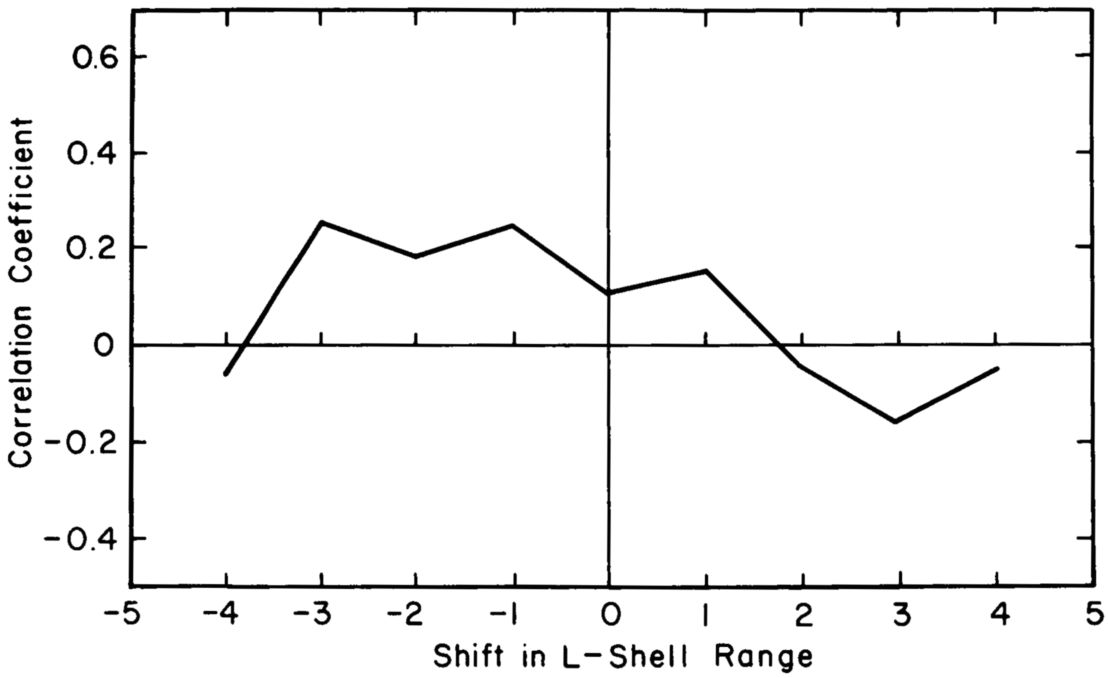


Figure 7. Cross-correlation of L-shell weighted averages - daytime

Figure 8 is similar to Figure 5 except that it is for nighttime data. This figure shows that the correlation between the average scintillation and L-shell scintillation at the same station is a little higher during the night than during the day. However the big difference is the large increase in correlation between the average at one station and L-shell scintillation at the conjugate station (compare Figure 8 with Figure 5). Although the increase is large it is still significantly less than the correlation with the L-shell scintillation at the same station, typically 0.3 lower. The increase in cross-station correlation suggests that there may exist conjugate effects.

The correlation between L-shells at Adak and L-shells at Wellington is shown in Figure 9. This figure shows that the best correlation is among ranges 2 and 3 as a group. It is not known whether the decrease in correlation at ranges 1 and 5 is genuine. Since both stations are in range 3, observations in ranges 1 and 5 may be affected by zenith angle variations. Figure 9 also shows that there is a tendency for Adak to correlate better with Wellington after a slight shift equatorward. This is illustrated clearly in the following. Let full rings be used for L-shell pairs of highest correlation (0.57 - 0.62 with a minimum 95% confidence interval greater than 0.40) and dashed rings be used for those of next highest correlation (0.37 - 0.49). Then we have

Adak	1	2	3	4	5		
Wellington			1	2	3	4	5
Adak	1	2	3	4	5		
Wellington		1	2	3	4	5	
Adak	1	2	3	4	5		
Wellington	1	2	3	4	5		
Adak		1	2	3	4	5	
Wellington	1	2	3	4	5		

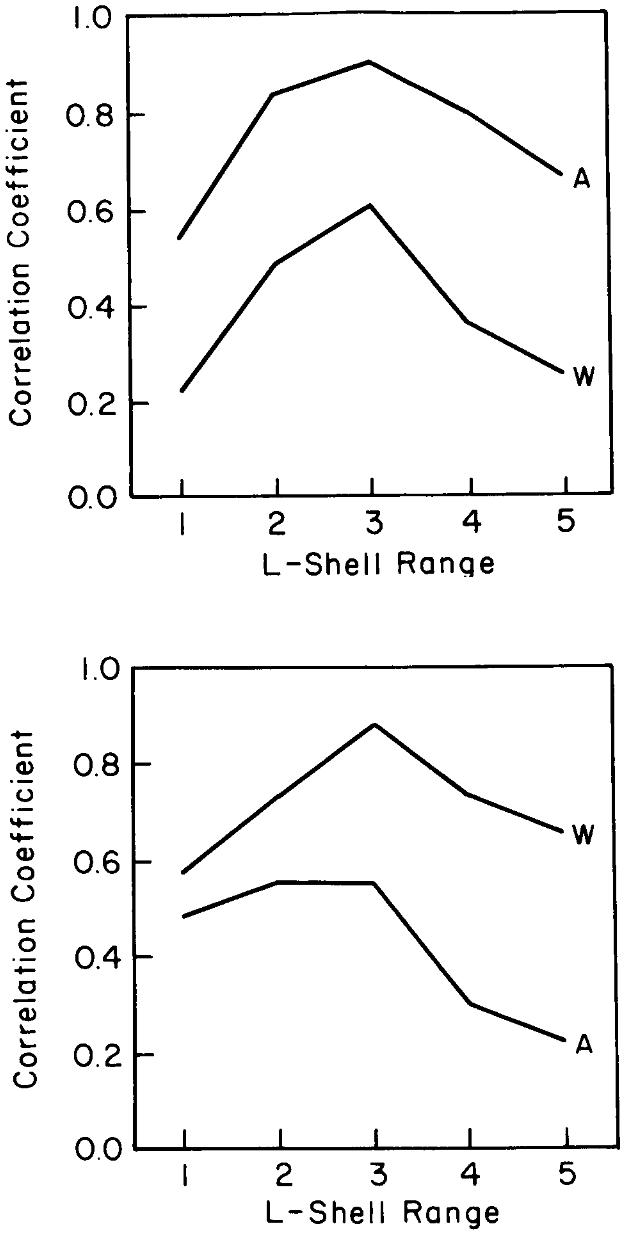


Figure 8. Correlation of pass average scintillation at each station with scintillation at each L-shell range for one station - nighttime

(a) Adak average (A) and Wellington average (W) versus L-shell scintillation at Adak

(b) Adak average (A) and Wellington average (W) versus L-shell scintillation at Wellington

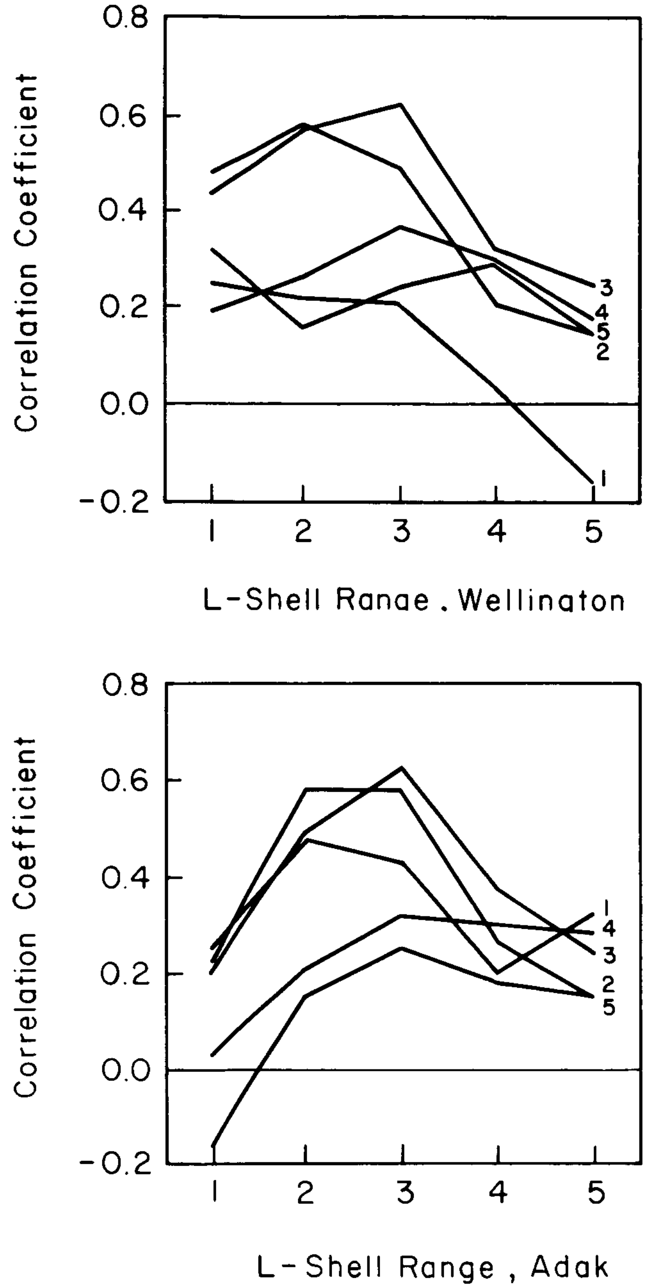


Figure 9. Shell-to-shell correlations - nighttime
(a) Adak L-shell as a parameter
(b) Wellington L-shell as a parameter

The asymmetry is apparent since the correlation tends to be maintained when the correlation coefficient is computed with an equatorward shift at Wellington. This point will be discussed again shortly.

Further cross-correlation studies are shown in Figure 10 where the scheme described in connection with Figure 7 is used again. The passes (15 in all) which were used to get the dashed curve have data in all five L-shell ranges and will be referred to as 5-shell passes. The passes (147 in all) which were used to get the solid curve have data in the center three ranges (2, 3 and 4) and will be referred to as 3-shell passes. The 5-shell passes all are south-bound with data first recorded at Adak and then recorded at Wellington after one complete orbit has elapsed. Both curves suggest that as far as the scintillation phenomenon is concerned, Wellington is perhaps associated with a slightly higher L-value than Adak. On the other hand, the time interval between observations might, conceivably, give rise to a slight asymmetry of this sort especially if the region of irregularities has a systematic direction of motion.

There are many variables which may affect the degree of correlation; among them are time and latitude. In order to test their effects we assemble the data by pairing up corresponding L-shells at Adak and Wellington to form a set of pairs which are then correlated in various groups. Table 3 shows the results of this procedure for a number of cases. If one considers the group using only the center 3 L-shell ranges there is indication of slight improvement. This suggests that the latitude effect is slight. If the data are restricted to those passes for which the two observations are only 1/2 hour apart (as opposed to the regular 2 1/2 hours), there is a noticeable increase in the correlation coefficient. Correlation is evidently reduced when the time interval between conjugate observations

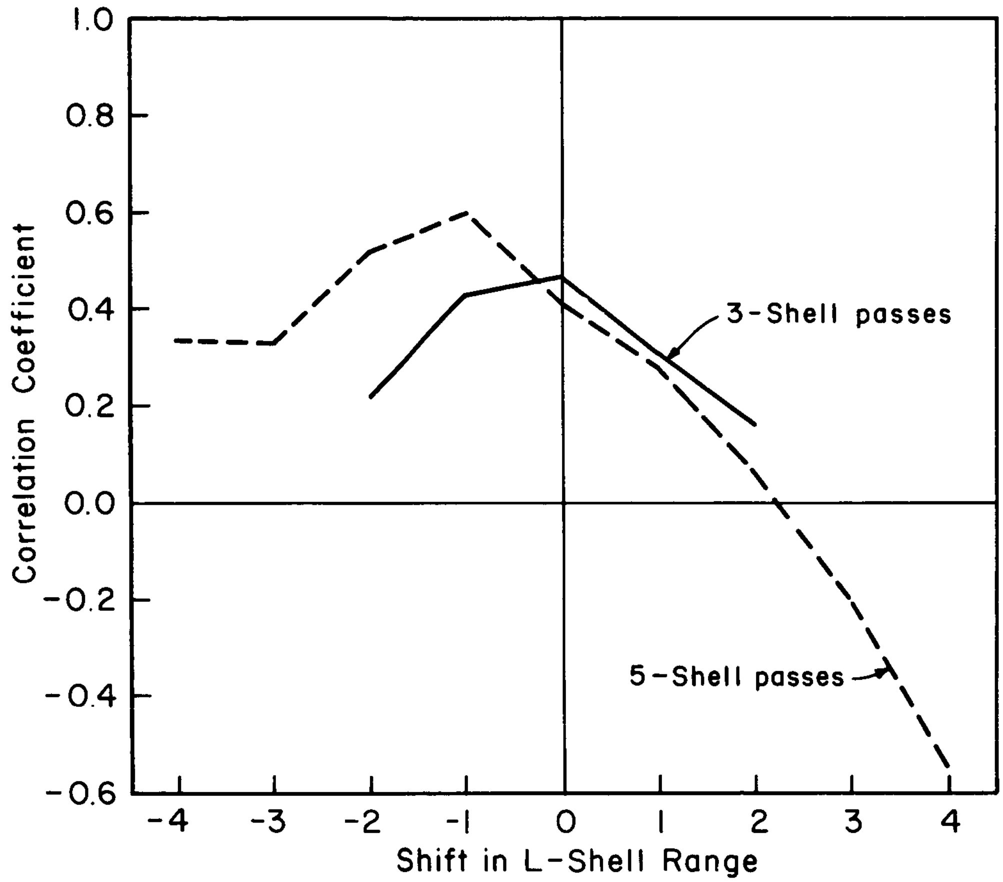


Figure 10. Cross-correlation of L-shell weighted averages - nighttime

TABLE 3

Correlation of L-shell Weighted Averages for a Number of Cases during the Night

(Time difference between observations is less than 2 1/2 hours unless otherwise stated.)

Case	# of points	Correlation coefficient	95% Confidence interval
all data	642	0.46	0.40-0.52
3 L-shell	441	0.47	0.41-0.54
5 L-shell	60	0.41	0.16-0.6
1/2 hr. between observations	226	0.56	0.45-0.65
10 hrs. about local midnight	512	0.47	0.41-0.54
8 hrs. about local midnight	415	0.45	0.37-0.53

is much in excess of half an hour. Table 3 also shows that there does not seem to be much diurnal influence in the correlation study since no appreciable change in correlation is observed when a change is made from 12 hours ("all data" in Table 3) to 10 hours to 8 hours about the local midnight. Indeed inspection of the data shows fluctuations between consecutive sample values large compared with the diurnal variation.

A straightforward check was also made in which the effects of these variables should be minimal. Seventeen northbound passes (observations at Adak within half an hour of corresponding observations at Wellington) were recorded with about 2 1/2 hours of midnight at both stations, in the period between mid-May and mid-June 1965. For each pass the quarter minute values of scintillation index were averaged separately for the regions "equatorward" and "poleward" of each station. Only indices corresponding to satellite elevations greater than 30° were used; thus excluding observations outside about the mid-points of L shells 2 and 4. In most cases this gave more than 5 minutes of useful record. The results are shown in Table 4. They are in good agreement with the more extensive analysis already described, even in respect of the suggested asymmetry.

5. Conclusion

The present report is based on one year's observations of satellite scintillations at Adak and Wellington, which are an approximately conjugate pair. Cross-station correlation studies show that conjugate effect on scintillations is significant at night but not in daytime. This shows a geomagnetic coupling effect in producing nighttime scintillation. The cross-correlation analysis of the nighttime data also reveals a slight asymmetry. It is of interest to note that earlier studies of 20 MHz

TABLE 4

Limited Sample Correlation for Wellington and Adak

(95% confidence interval bracketed)

Wellington	Adak	Correlation Coefficient
Poleward	Equatorward	0.16
Poleward	Poleward	0.56 (0.10-0.80)
Equatorward	Equatorward	0.88 (0.70-0.96)
Equatorward	Poleward	0.43

signals from the satellite Nora-Alice 1 show that sudden transitions from Faraday fading to scintillation occurs slightly poleward of auroral isochasm 5 in the northern hemisphere and slightly equatorward of auroral isochasm 5 in the southern hemisphere (Yeh and Swenson, 1964). Wellington has a slightly higher L value than Adak, and the trend of the present scintillation observations as well as those of Yeh and Swenson is in this direction. The scintillation observations appear to be more closely related to the L parameter than to the auroral isochasms.

The study of nighttime scintillation at each station shows that there is a semi-annual variation. Closer agreement on scintillation is obtained if Adak data is advanced by six months. This is suggestive of a true seasonal variation. In view of coupling between conjugate stations it is not known if the nighttime semi-annual variation is due to a single seasonal peak in each hemisphere "mapping over" into the other. More data, preferably from fixed source such as geostationary satellites, may be helpful in resolving this important question.

6. Acknowledgment

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