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DESCRIPTION AND EVALUATION OF THE BENT IONOSPHERIC MODEL

Volume 1

October 1972

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VOLUME 1

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FOREWORD

This report was prepared by DBA Systems of Melbourne, Florida, for the Air Force Space and Missile Systems Organization (SAMSO), System 621B under contract number F04701-72-C-0380. The report is assigned the USAF Report No. SAMSO TR-72-239 and is published in three volumes. Volume 1 contains the report proper and analysis of the results, whereas the individual results are listed in Volumes 2 and 3.

Captain L. J. Plotkin and Major R. H. Jesson served as Project Officers of this program. Appreciation is also due to Mr. J. Klobuchar of AFCRL and Mr. K. Kretcher of Aerospace Corporation who also monitored the progress of this contract. The Faraday rotation data used in this study were provided by the Air Force Cambridge Research Laboratories, Stanford Electronics Laboratories, the University of Hawaii and the University of Illinois.

The principal investigators involved in this work were Rodney B. Bent, and Sigrid K. Llewellyn. Margaret K. Walloch developed the software for the statistical analysis and Tom L. Lewis prepared the data organization.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

JACK L. PRICE, Colonel, USAF
Chief, General Purpose Systems Division

ABSTRACT

This study is directed towards evaluating a world-wide empirical ionospheric model by comparing it with total electron content data obtained from Faraday rotation measurements. The results are intended to assist in the design and implementation of a satellite navigational system which depends on signal ranging and hence the delay effects due to the ionosphere. The world-wide ionospheric model is evaluated in detail and the mean, standard deviation and root mean square of the residuals are computed along with correlation coefficients and cumulative probability distributions. Model update procedures and results are discussed where the update data is obtained from 1 to 9 hours prior to evaluation. The results show the capability of the model to remove a high proportion of the ionospheric effects but the conclusions indicate that caution is needed in reading too much optimism into these overall values and imply that diurnal trends should be reviewed in detail. Certain update procedures considerably improve the ionospheric residual during periods of high ionospheric density. Recommendations for future study and implementation of a model into the system are discussed.

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1.0 INTRODUCTION

For several years scientists have investigated many different approaches to modeling the ionospheric profile on a theoretical basis. The names and types of these methods are well known and will not be discussed here, but it is obvious after all the years that a good theoretical ionospheric profile still does not exist.

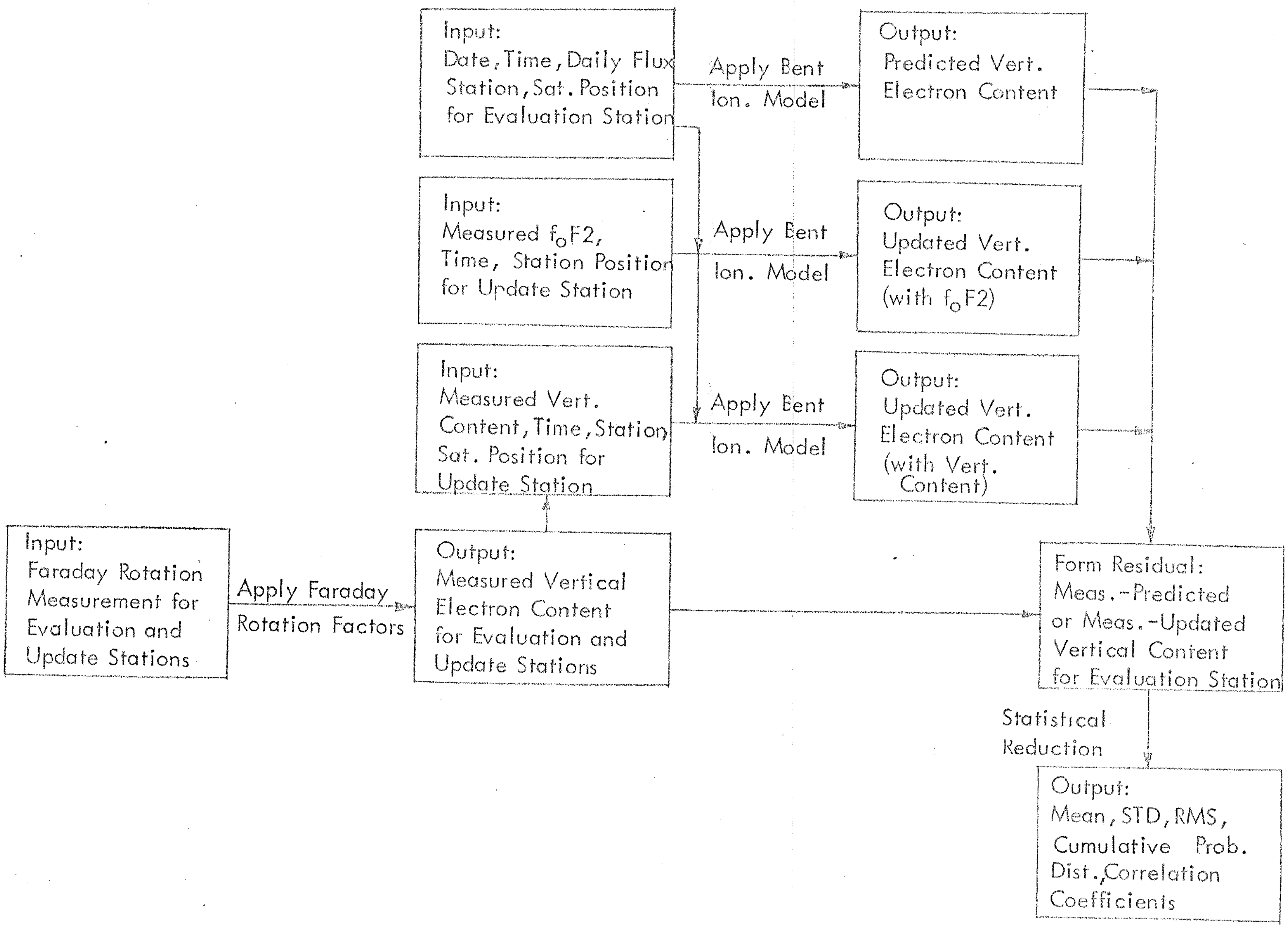
The object of DBA's past investigations was to come up with an ionospheric profile that could give much improved results for refraction corrections in satellite communications to ground or to another satellite than had been obtained with the Chapman and many other theoretical profiles. It would have been pointless for us to sit down and investigate another theoretical approach when so many more competent scientists are working on this problem. For this reason we decided that, in this present time of computers, an empirical model taken from a vast data base may provide us with the profile we were looking for.

It was our intention to acquire ionospheric data of any kind that helped us build up a data base covering minimum to maximum of a solar cycle and providing information up to 1000km. The lower layers of the ionosphere were neglected in terms of their irregularities although their electron content was added into the larger F layer; this was done to simplify the approach and as the prime objective was to obtain refraction corrections through the ionosphere, or at least to a point above 150 km, such an elimination would not be very detrimental.

Data from bottom side ionospheric sounders was obtained over the years 1962 through 1969 covering 14 stations approximately along the American longitudes having geographic latitudes 76 degrees to -12 degrees or magnetic latitudes 85 degrees to 0 degrees. This data was in the form of hourly profiles of the ionosphere up to the $f_o F2$ peak. Topside soundings were acquired for the years 1962 to 1966 covering the magnetic latitude range 85 degrees to -75 degrees and providing electron density profiles from about 1,000km down to a height just above maximum electron density. As the topside data was not available near to solar maximum, electron density probe data was obtained from the Ariel 3 satellite over the period May 1967 to April 1968 from 70 degrees north to 70 degrees south geographic latitude and linked in real time to f_oF2 values obtained from 13 stations on the ground.

To satisfy military needs for precise navigation of many different vehicle types, operating over wide ranges of speeds and environments, the Air Force Space and Missile Systems Organization is investigating a new navigation satellite system concept (System 621B). An area of prime consideration is the navigation error resulting from radio signal propagation through the ionosphere. The total navigation system must be capable of predicting and correcting for the excess group delay associated with ranging signal propagation through the ionosphere. Accordingly, as a part of the System 621B development program, an operationally useful ionospheric model must be developed to predict these ionospheric delays. The objective of this study is to assess the prediction accuracy of one such model under specific evaluation conditions.

The following diagram shows the flow and the separate steps of the data reduction for the ionospheric model evaluation.


Input:
Date, Time, Daily Flux
Station, Sat. Position
for Evaluation Station
Apply Bent
Ion. Model
Output:
Predicted Vert.
Electron Content
Input:
Measured f_oF2,
Time, Station Position
for Update Station
Apply Bent
Ion. Model
Output:
Updated Vert.
Electron Content
(with f_oF2)
Input:
Measured Vert.
Content, Time, Station
Sat. Position for
Update Station
Apply Bent
Ion. Model
Output:
Updated Vert.
Electron Content
(with Vert.
Content)
Input:
Faraday Rotation
Measurement for
Evaluation and
Update Stations
Apply Faraday
Rotation Factors
Output:
Measured Vertical
Electron Content
for Evaluation and
Update Stations
Form Residual:
Meas.-Predicted
or Meas.-Updated
Vertical Content
for Evaluation Station
Statistical
Reduction
Output:
Mean, STD, RMS,
Cumulative Prob.
Dist., Correlation
Coefficients

2.0 DESCRIPTION OF THE BENT IONOSPHERIC PREDICTION MODEL

In order to analyze the vast amount of data that was obtained a number of assumptions had to be made. In the first case the topside sounding data did not geographically cover the entire globe and the bottom side data was only available for land masses and not over the oceans; however, as a local time effect is far more significant than a longitude effect, the data was analyzed as a function of latitude and local time. Geographic longitude was, however, taken into account for the determination of maximum electron density by using the ITS coefficients for f_oF2 which are a function of latitude, longitude, time and solar activity. Secondly a theoretical profile was determined to which the data would fit. This profile which is used in the evaluation discussed later, is shown in Figure 1 and is the result of earlier work by Kazantsev (1956) and unpublished work of Bent (1967) while at the Radio & Space Research Station in England and requires the knowledge of the parameters k_1, k_2, k_3, y_t, y_m, f_oF2, and h_m. The equation of the upper topside is exponential, namely,

$$N = N_o e^{-ka},$$

the lower ionosphere is a bi-parabola,

$$N = N_m \left(1 - \frac{b_2^2}{y_m^2}\right)^2,$$

and the top and bottom side are fit together with a parabola,

$$N = N_m \left(1 - \frac{b_1^2}{y_t^2}\right),$$

where,

- N is the electron density
- N_m is the maximum value of electron density
- N_o is the maximum electron density for each exponential layer
- a and b are vertical distances
- y_m is the half thickness of the lower layer
- y_t is the half thickness of the upper parabolic layer
- k is the decay constant for an exponential profile.

The upper parabola extends from the height of the maximum electron density up to the point where the slope of the parabola matches the slope of the exponential layer. The data investigated included over 50,000 topside soundings, 6,000 satellite electron density and related f_oF2 measurements, and over 400,000 bottom side soundings.

2.1 Topside Ionosphere

The initial approach was to take the topside soundings and break them down into zones 5 degrees of latitude by 40 minutes of local time eliminating data in the same zones that have similar times and profiles, and therefore are duplicated. This resulted in over 1,200 different areas in the northern and southern hemisphere with a reasonably constant density of data in each area. By these means it was possible to investigate the decay constant k in the exponential topside profile as a function of local time, latitude, solar flux, sunspot number and season. One of the major concerns was whether the decay constant k would be uniform for each sounding over the range 1,000 km to the minimum height, and investigations showed that such an exponential profile does not exist. The layer was therefore divided into three equal height sections from 1,000 km to the minimum recorded height and the exponent k computed for the center point in each section. Figure 1 shows such a division where the values under investigation are the decay constants k_1, k_2, k_3. In most cases the topside soundings do not reach the height of maximum electron density and therefore the gradient at this lower point was mathematically equated to the point where the gradient of the 'nose' parabola was the same. Extensive analysis of the acquired data showed these gradients to be similar, on average, at a height $y_m/4$ above the maximum electron density. At this point the value of f_kF2, which defines the lowest point of the topside sounding, is 0.93 f_oF2. (N_o in Figure 1 is the equivalent electron density to the frequency f_kF2).

For an initial test the decay constants k for each of the three layers, upper, middle and lower topside were plotted as a function of magnetic latitude and f_kF2. Values from the northern and southern hemispheres were treated independently at first, but the analysis showed that there was excellent correlation between the two. Figure 2 shows the relationship between the three decay constants k and magnetic latitude for all local times, solar activity and season. The equatorial anomaly and a 40 degree trough show in the lower topside layer. The 65 degree trough is not as evident as it is when the same analysis is doen for various local times which suggests the physical variances of these anomalies should be investigated in more detail.

It was found that correlations in k for specific $f_k F2$ did not bear any further local time correlation, but bore a significant variation with solar activity and magnetic latitude. However, the correlation with solar flux was considerably better than that with sunspot number, even allowing for the delay in the effect reaching the ionosphere, so all further correlations were with the Ottawa 10.7 cm solar flux. All these correlations were then plotted in graphical form to enable final interpolation.

Unfortunately the Alouette data did not cover the period at the peak of the solar cycle, but the Director of the U.K. Radio & Space Research Station made available electron density data from the Ariel 3 satellite to cover this period. The data had already been reduced thoroughly and the satellite electron density at about 550km was provided with the sub-satellite $f_o F2$ value obtained from 13 stations around the world. If the satellite was not directly over an ionosonde at the time of observation, the $f_o F2$ values from two or three transmitters in the general area had been interpolated in time and position to give the sub-satellite value. These interpolations had been carried out taking care to modify the values for uneven ionospheric gradients. Data that was in doubt was eliminated. While these values did not give the three exponential decay constants at each point, it was found that for similar conditions of solar flux and position, the Ariel 3 data fit very closely to the profiles deduced from Alouette 1. The profile equations developed for the lower solar activity period related to the topside sounders could therefore be extended to the larger solar flux values and still be in good agreement with the Ariel 3 data. Typical results from this analysis are shown in the graphs of Figure 3. The original data curves were less regular, and since the variations were mainly caused by the relatively low data density in each group after division of the large data base, the data was smoothed by the fitting of straight lines. In order to interpret these graphs and obtain a profile, we need the value of $f_o F2$

and the magnetic latitude position. These values will indicate which graph relates the 10.7 cm flux to the decay constants k for the upper, middle and lower portions of the topside ionosphere. Figure 3, therefore, shows the basis of obtaining the 3 independent slopes of the topside ionosphere as a function of f_oF2, latitude and solar flux.

A further correlation to investigate the seasonal effects on k was carried out with some 15,000 totally different Alouette soundings and fluctuations in the k values of ±15% were noted from the average spring and autumn values. The seasonal variation is monitored by observing the change in the daily maximum solar zenith angle from the equinoctial mid-day value. Figure 4 shows the seasonal fluctuation in k for each of the three layers in the topside profile. There is considerable evidence that this seasonal relationship has an added local time factor and this point will shortly be under investigation.

Examination of the upper part of the 'nose' of the N-h profile is difficult because topside sounding information rarely gives any values in this region. Evidence from many leading scientists also implies that the topside profiles have about a +4% error in the effective distance from the sounding satellite indicating the obtained topside profiles are too low near the peak. This evidence is based on comparisons with two-frequency data, backscatter results, Faraday rotation and overlap tests, etc. Preliminary results in this empirical model showed that a parabola in this region gave the better comparison with integrated total electron content when compared with two-frequency and Faraday rotation data. A simple parabola having a half thickness y_t was fitted between the bi-parabola and the exponential layer. Upon initial tests y_t was set equal to the half-thickness of the bi-parabola y_m for f_oF2 values below 10.5 Mhz, and y_t increases with f_oF2 values rising above 10.5 Mhz. Further investigations of this problem are planned in future work.

The final step in predicting the shape of the ionosphere is arranging for the gradient in the upper parabolic layer to be the same as the gradient in the lowest part of the topside exponential layer. This is the case at a distance $d = 1/k\,[(1 + y_t^2 k^2)^{\frac{1}{2}} - 1]$ above the height of the maximum electron density.

2.2 Bottom Side Ionosphere

Modeling the bottom side ionospheric profile was a somewhat easier task because for each profile the value of f_oF2 was known and the electron density versus height profile from h_{min} to h_{max} was also known. Once more the geographic effect of longitude was eliminated and replaced with the more simple local time correlation. From Figure 1 we see that the equation of the lower layer is a parabola squared or a bi-parabola. This was found in general to fit the real profile somewhat better than a simple parabola. The unknown in this equation is the half thickness of the layer y_m and in the reduction of the data the y_m value was treated in a similar way to a topside k value.

The irregularities in the ionosonde data due to the lower layers of the ionosphere were smoothed out because the prime objective of the work was to simplify the model but keep the total content as accurate as possible. The sounding data was therefore integrated up to the peak electron density (N_m) and forced to fit the bi-parabolic equation along with the value of N_m obtained from the sounding. In each instance the value of y_m was computed ready for further correlation.

A number of real profiles from various stations at different local times were compared with the computed profile and excellent agreement found. A further 12,000 soundings from all 14 stations were analyzed and the computed value of y_m compared to the actual measured value. These results are shown in Figure 5 along with the RMS errors. The two tests indicate that the bi-parabolic profile is, on average, in close agreement to the real profile. Investigations, similar to those carried out for the topside decay constants, correlated y_m with solar flux, f_o F2, local time and season. Surprisingly, no direct correlation was found between y_m and solar flux, but a definite correlation existed in local time and also in the solar zenith angle at local noon which represents the season. Earlier work by Becker (1971) showed significant correlation between the product of solar flux and cosine of the solar zenith angle with the half layer thickness, but it appeared that no attempt had been made to separate these. Carrying out such tests on our vast data bank we showed beyond any doubt that there was almost no correlation with solar flux and that all the effect was in the solar zenith angle.

Figure 6 indicates how y_m can be determined from local time and f_oF2, and Figure 7 shows the seasonal update as a function of local time for the sunrise, sunset, night and daytime period. In the cases where f_oF2 was larger than 10 Mhz the local time curve fluctuated very little from the 10 Mhz curve. All of the curves displayed have not been hand smoothed; due to the large data base the average of all values taken every hour fit precisely on the lines shown.

The remaining unknowns which are needed to compute the profile are f_oF2 and the height of that value; by far the most important of these being the value of f_oF2.

2.3 Predicting f_oF2

Severe horizontal gradients in f_oF2 exist within the ionosphere as can be seen by examining Figure 8. In fact even if the value of f_oF2 is known directly above a station, it can change considerably over the whole 'visible' ionosphere from that site. Figure 8 is a predicted status of f_oF2 over the world at 6.0am during August 1968 and two types of severe gradients are immediately noticeable, one due to sunrise causes rapid changes in f_oF2 in an east to west direction and the other situated around the equatorial anomaly occurs primarily during the afternoon and early evening and causes severe gradients in the north to south direction. Two hypothetical stations, A and B, are marked on Figure 8 along with the ionosphere 'visible' from those sites. In case A the value of f_oF2 changes from 11.5Mhz directly overhead to 5Mhz on the southern horizon. This change must be squared when converting to electron content hence a difference of a factor of over 5 in the vertical content arises before correcting for elevation angle effects. Similar gradients exist over half the earth's surface at some time of the day and it is therefore imperative to model these gradients in any ionosphere model.

For many years NOAA (formerly CRPL and ITSA) have been engaged in the development of numerical methods and computer programs for mapping and predicting characteristics of the ionosphere used in telecommunications. The most advanced method for producing an f_oF2 model undoubtedly comes from their work. Jones, Graham & Leftin (1969) describe their techniques on how a monthly median of the F2 layer critical frequency (f_oF2) was developed from an extremely large worldwide data base. In fact the gradient map shown in Figure 8 is a result of this work. We have already shown that it is important to include the horizontal gradients of f_oF2 in any analysis and the work by Jones et al is undoubtedly the only satisfactory approach to this problem.

The document by Jones et al describing this work includes a Fortran program which, with monthly coefficients obtainable from NOAA, enables the monthly median value of f_oF2 to be computed above any point in the world at any time. This program was primarily written to accept monthly coefficients using an average sunspot number, but more recent work by Jones & Obitts (1970) has described a more generalized set of coefficients which provide more annual continuity and uses more extensive analysis. These generalized coefficients can be obtained from the Ionospheric Prediction Services, NOAA, Boulder for a sunspot number or a solar flux approach. The value of a monthly median f_oF2 can be computed on a worldwide basis centralized around the specific day in question rather than the 15th of the month; it can also be based on a 12-month running average of solar flux or sunspot number. Private communication with Mrs. Leftin at NOAA indicates that the solar flux approach is likely to provide more accurate values of f_oF2 than the use of the sunspot number.

For the ionospheric profile under discussion it was decided to use the generalized f_oF2 coefficients from NOAA incorporating solar flux thereby eliminating any need to purchase monthly data from them. The program was made self-contained and enabled a monthly median f_oF2 to be produced above any surface position for any time of day or season and any twelve month running average of solar flux.

The question now arises as to how good these monthly median values are and how much error is introduced by day to day fluctuations. Many daily soundings were analyzed and the monthly median value computed; these were compared with the monthly median predicted values and the actual day to day fluctuations. Some typical results are shown in Figure 9. It is seen that the monthly median predicted values are indeed very close to the actual measured value, but the day to day fluctuations can be as large as ± 75%. A technique therefore had to be derived to bring the computed monthly median value closer to the actual value.

It would be pointless to use the daily value of solar flux in the generalized coefficient set which had been built up using a twelve month running average, but it was thought possible that there may be a relation between the difference in f_oF2 from monthly median to daily value and the difference in the 12 month running average of solar flux to the daily value.

Approximately 6,000 real values of f_oF2 from 13 stations widely spread in latitude, longitude and solar cycle were compared with the predicted values using the NOAA solar flux method. A very surprising result emerged and can be explained by referring to Figure 10. Eliminating the data from stations close to the magnetic poles which did not quite follow the trend of the other stations a comparison between the difference in daily and 12 month flux value and the percentage difference of computed and measured f_oF2 showed all stations having a very similar bias. Figure 10 shows this comparison where the stations having similar latitude were averaged quoting their mean magnetic latitude. The fact that the lines did not pass through the zero points in the graph undoubtedly indicates an erroneous bias in the NOAA predictions, but results help one to update substantially the monthly median f_oF2 value on a daily basis. Further comparisons were carried out with two years of hourly f_oF2 values obtained near solar maximum from Hawaii and the results fit perfectly in the latitude position expected in Figure 10. By these means it is possible to come somewhat nearer the actual daily value of f_oF2. Further accuracy can be derived by update from stations within the general area if this is available and the investigation of this approach will now be explained.

In order to investigate the size of an area from which ionospheric values would show similar deviations from normal, many comparisons of three or more stations were investigated for random dates. It is well known that magnetic disturbances can affect the ionosphere above one station in one direction and a nearby station in an opposite direction. For this reason investigations of disturbances were not carried out near to the magnetic poles. Over 100 groups of stations from various continents and having similar longitudes were compared in similar ways. Figure 11 is a typical result of such a test and shows f_oF2 disturbances being recorded simultaneously at sites 1,000km apart. The percentage error in the predicted $f_o F2$ value when compared to the real value was noted to be similar in 90% of the cases where stations were within 2,000km of one another in a longitudinal direction and investigations over the 'quiet' North American continent show improvement in 9 out of 10 cases when f_oF2 was updated with information from across the continent; or 3,000 to 4,000km. However, in general the update procedure is restricted to information from within 2,000km of the evaluating station.

2.4 Predicting the Height of the Maximum Layer

In order to predict the real height of $f_o F2$ the M(3000)F2 predictions from NOAA were used. To explain the terminology:

$$M(3000)F2 = M\ FACTOR = MUF(3000)F2 \div f_o F2,$$

where MUF(3000)F2 is the maximum usable frequency to propagate by reflection from the F2 layer a distance of 3,000km. The M(3000)F2 predictions can be calculated on a monthly basis from a generalized set issued by NOAA and provide the monthly median value as a function of sunspot number.

Knowledge of this factor along with the $f_o F2$ value enables the height of the layer to be calculated using the equations of Appleton & Beynon (1940). If M is the M(3000)F2 factor and one assumes that y_m divided by the height of the bottom edge of the lower layer is greater than 0.4, then it is possible to derive the following polynomial,

$$h_m = 1346.92 - 526.40M + 59.825M^2,$$

where h_m is the required height.

(Text continues on page 24)

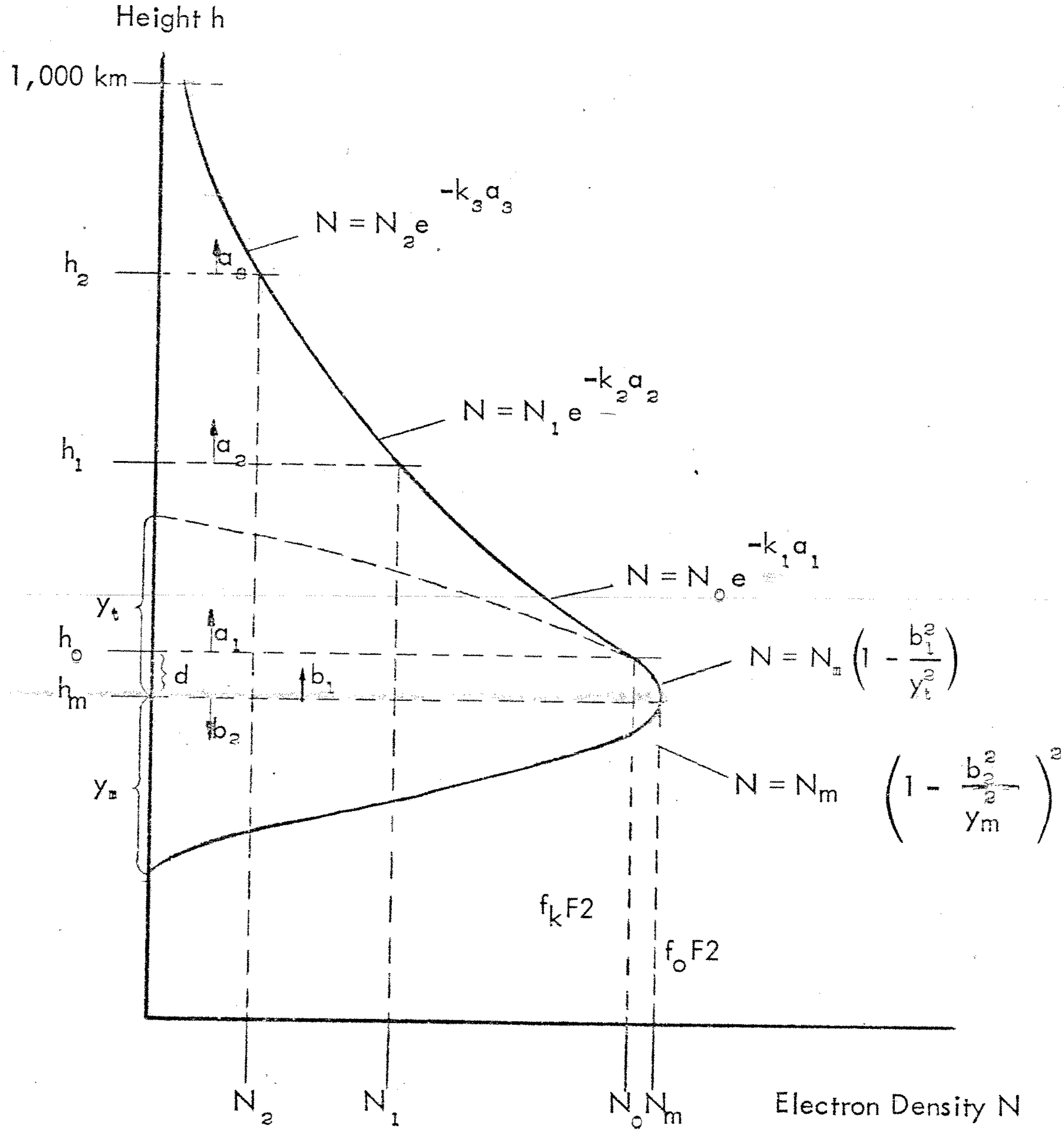


Fig. 1 The Exponential Parabolic & Bi-parabolic Profile

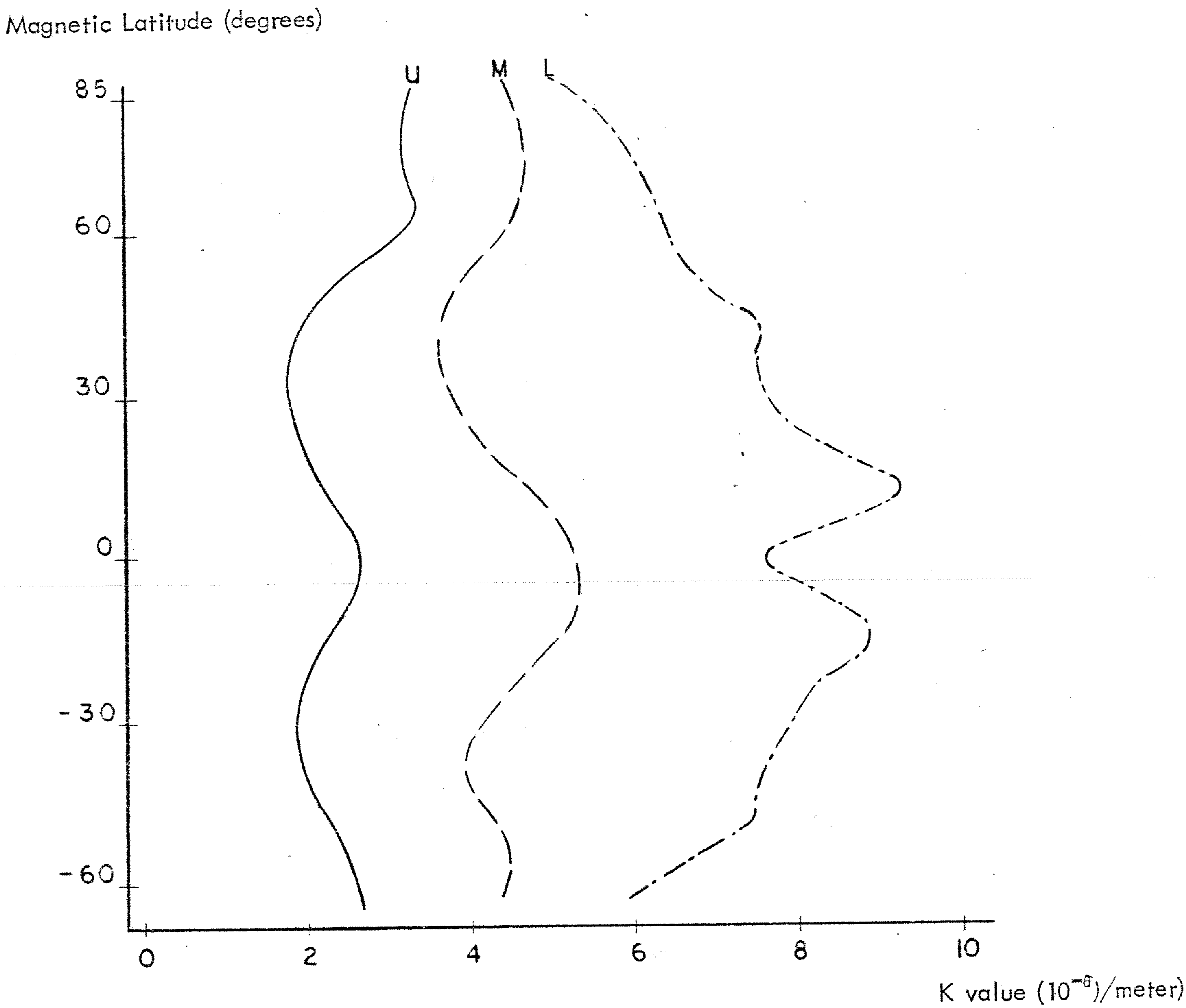


Fig. 2 The mean fluctuation of the decay constant k with magnetic latitude for the upper (U), middle (M) and lower (L) portions of the topside ionosphere.

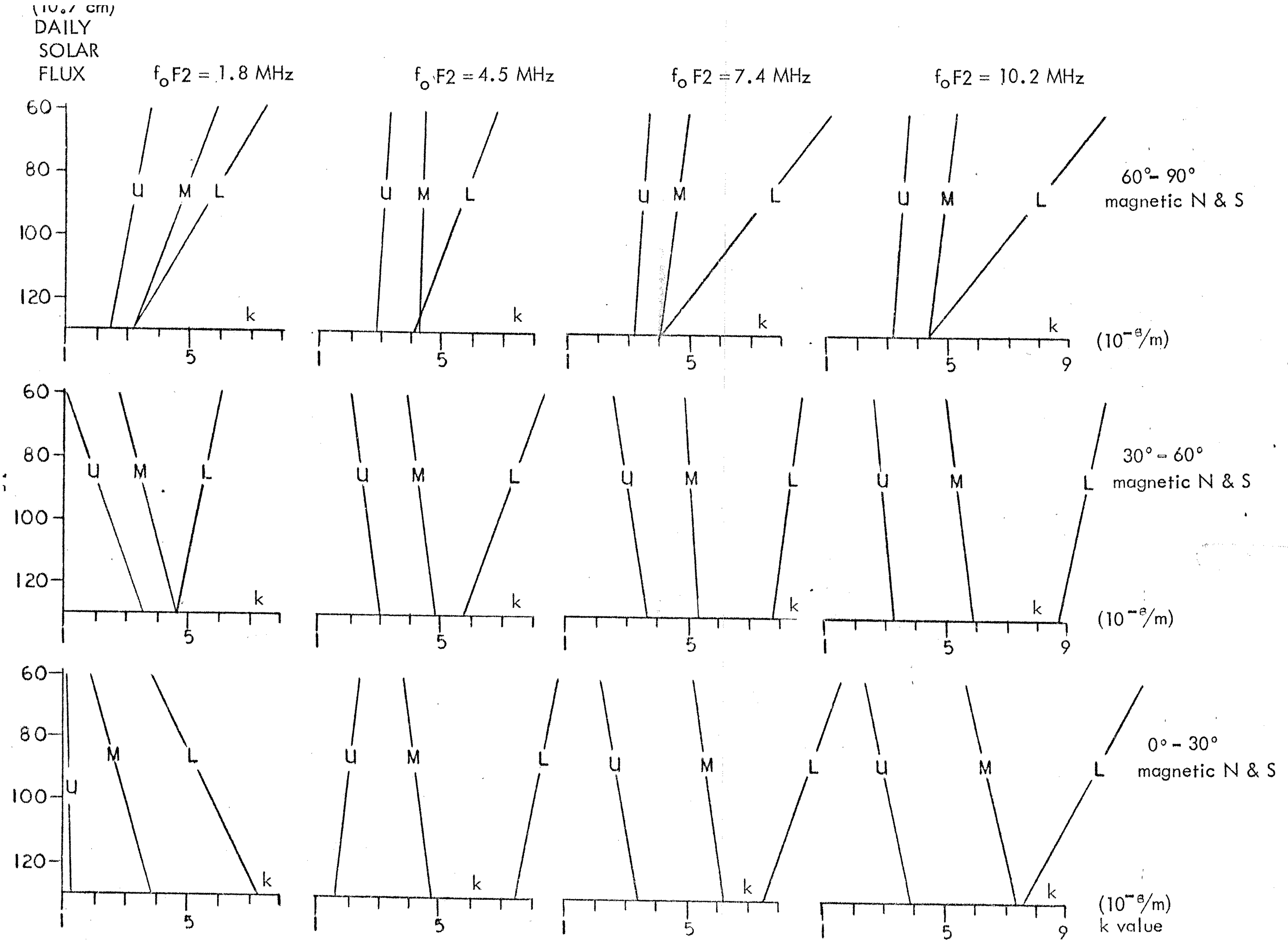


Fig. 3 Variation of k for the upper (U), middle (M) and lower (L) topside profile due to solar flux, f_oF2 and magnetic latitude.

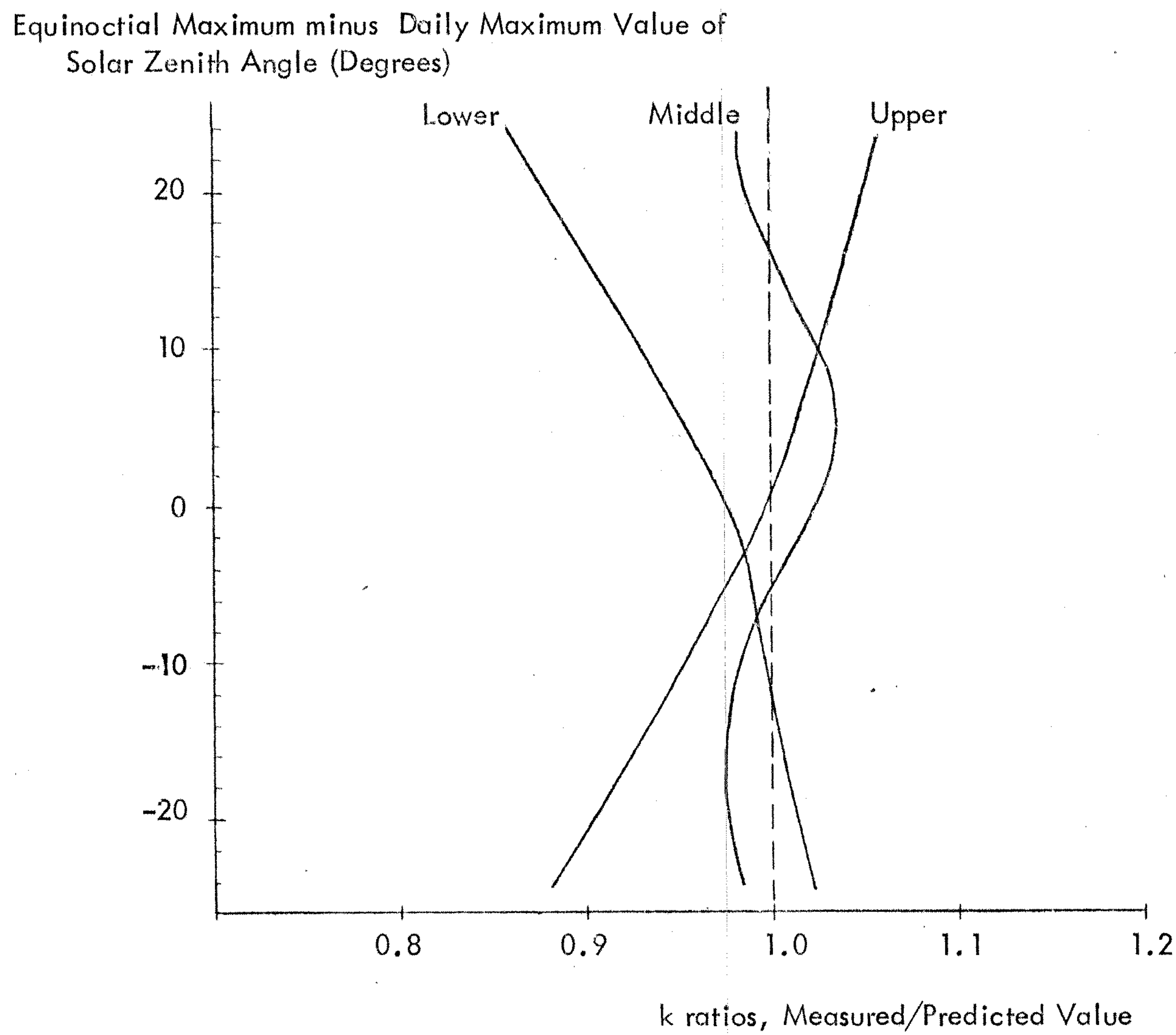


Fig. 4 The seasonal variation in the predicted k values

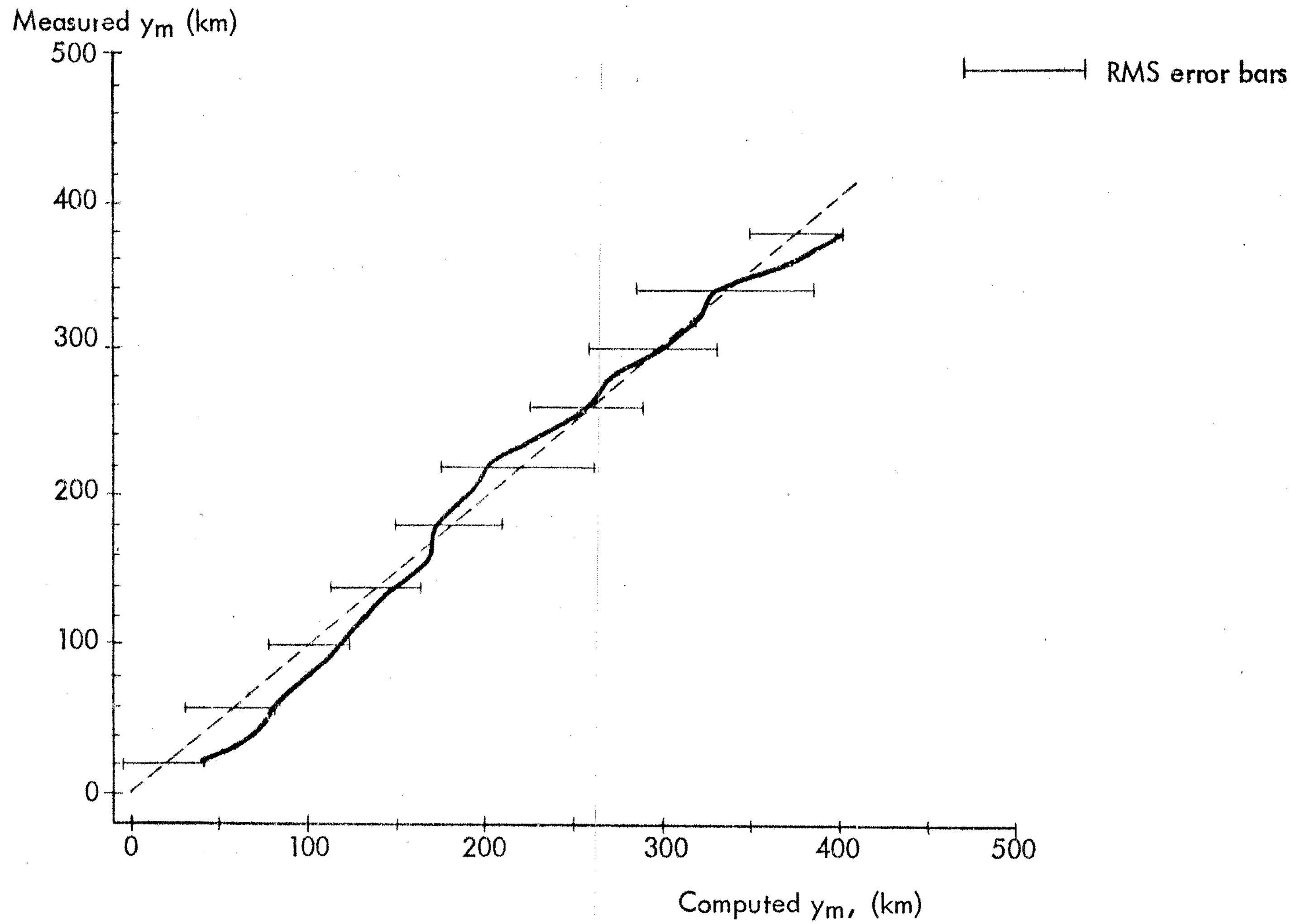


Fig. 5 The comparison of measured and predicted y_m for 12,000 profiles showing RMS error bars.

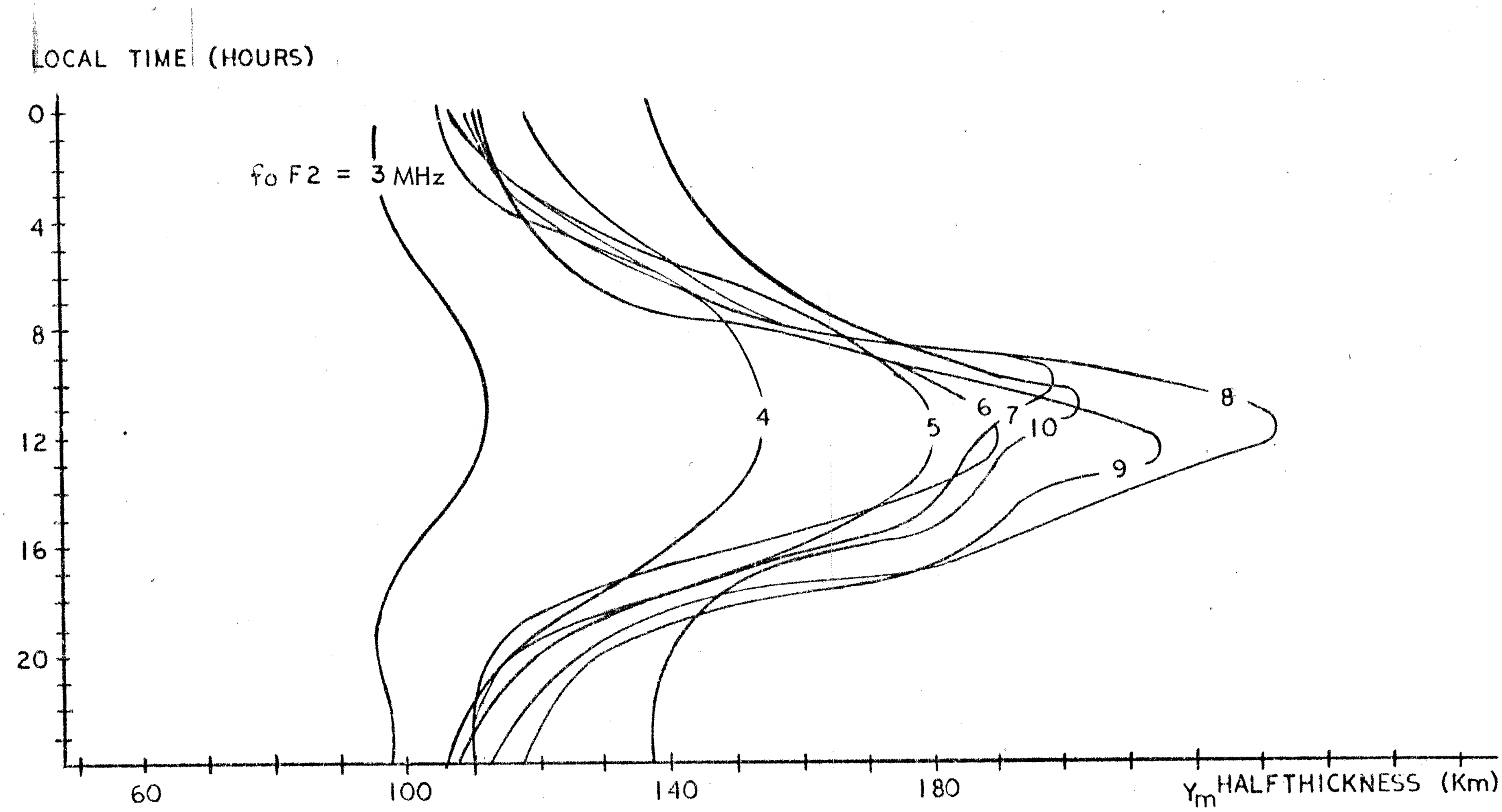


Fig. 6 Variation of y_m as a function of f_oF2 and local time.

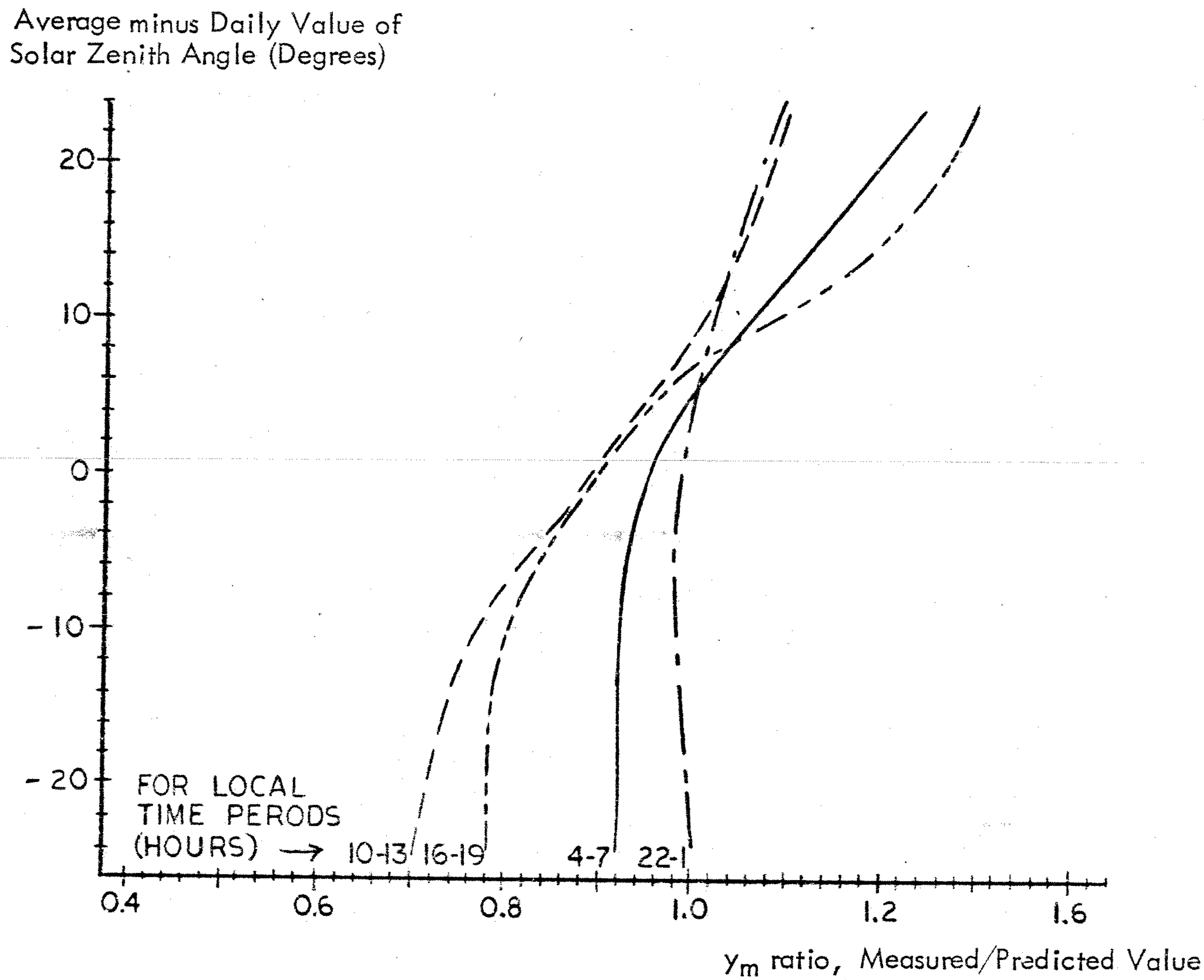


Fig. 7 The seasonal variation of predicted y_m as a function of local time.

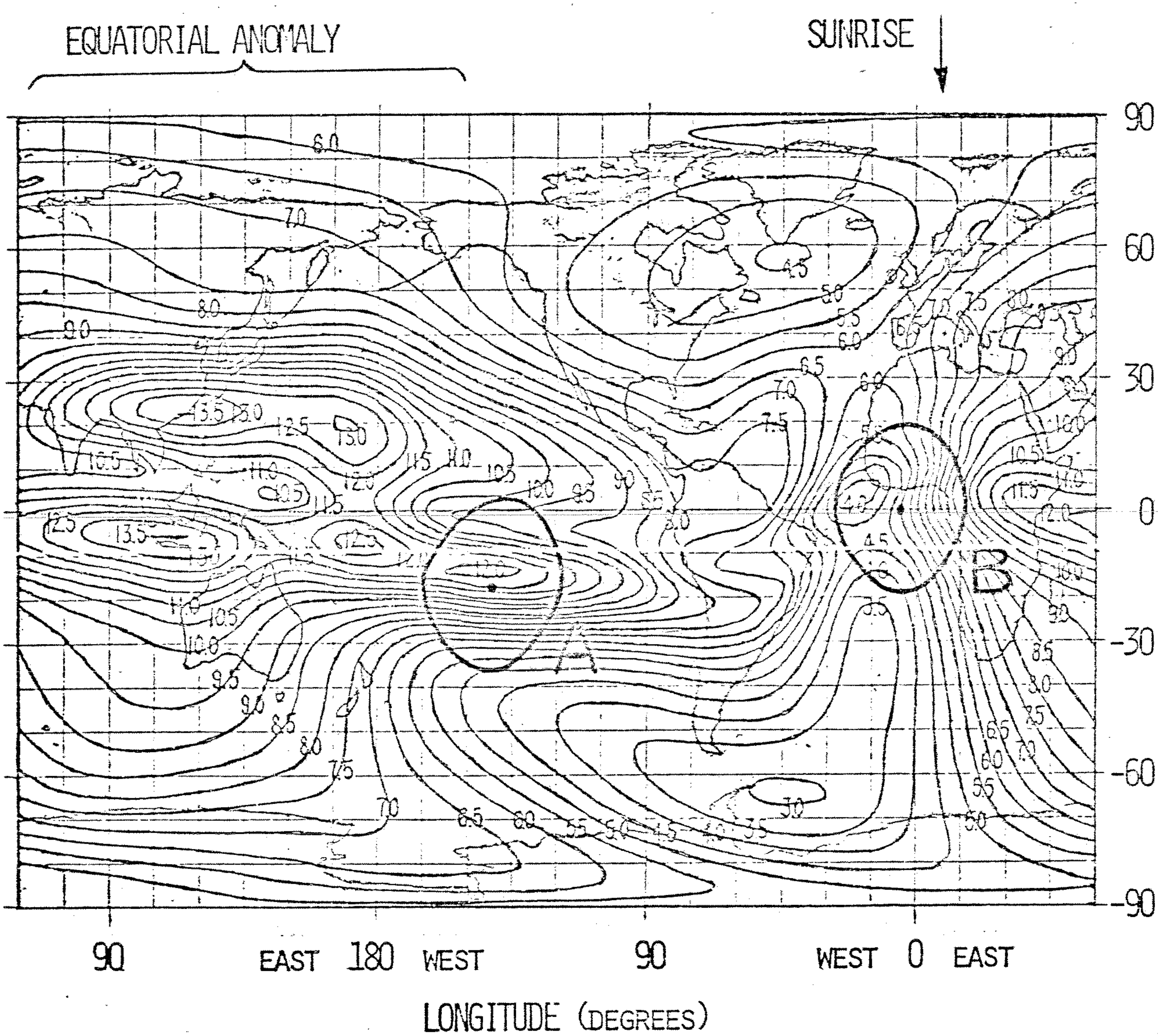


Fig. 8 The predicted global status of a monthly median f_xF2 at 6.0 a.m. UT August 1968 showing areas of visibility for two hypothetical ground stations.

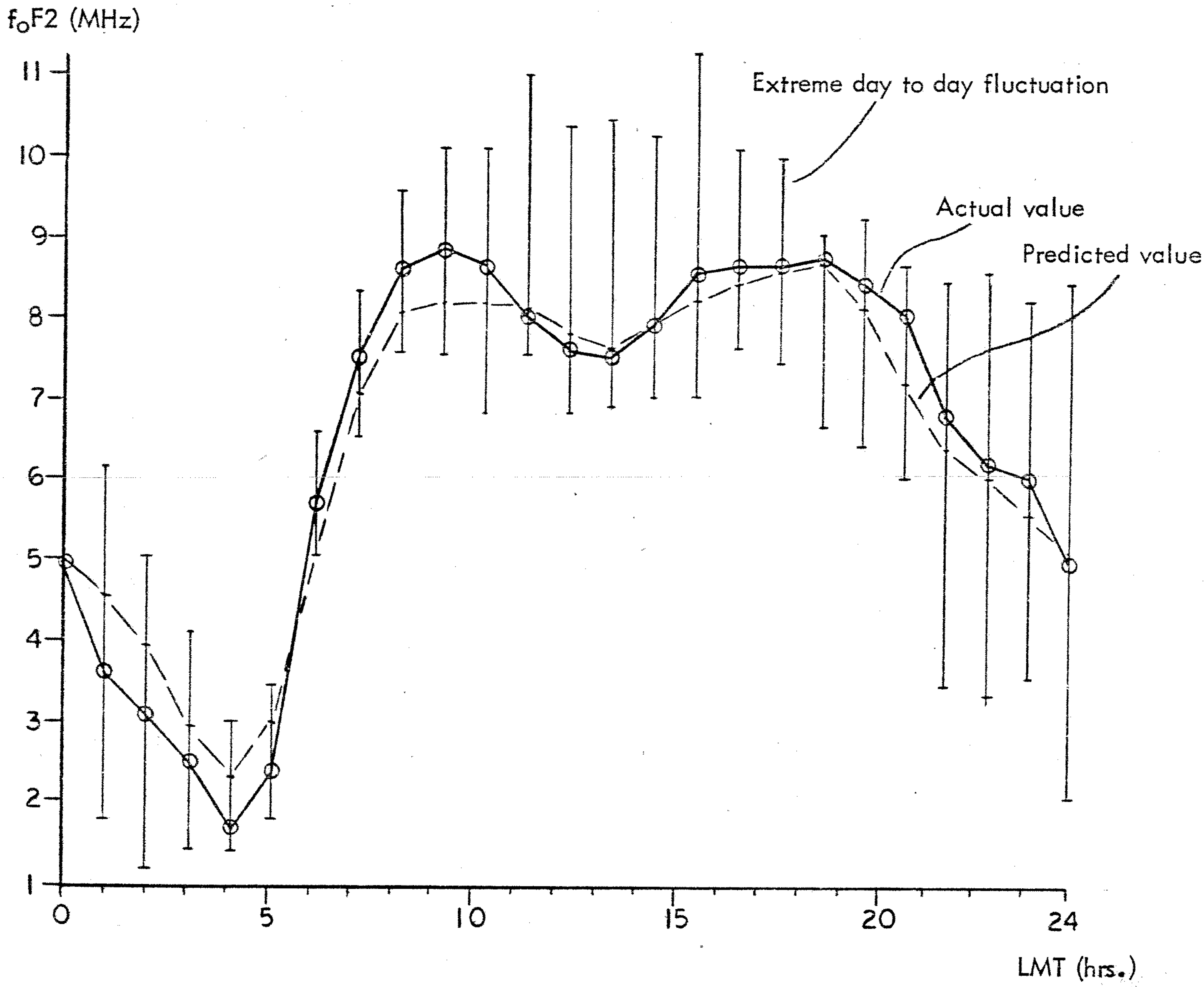


Fig. 9 The predicted and actual monthly median values of f_oF2 for Ibadan June 1962 showing the extreme day to day fluctuations.

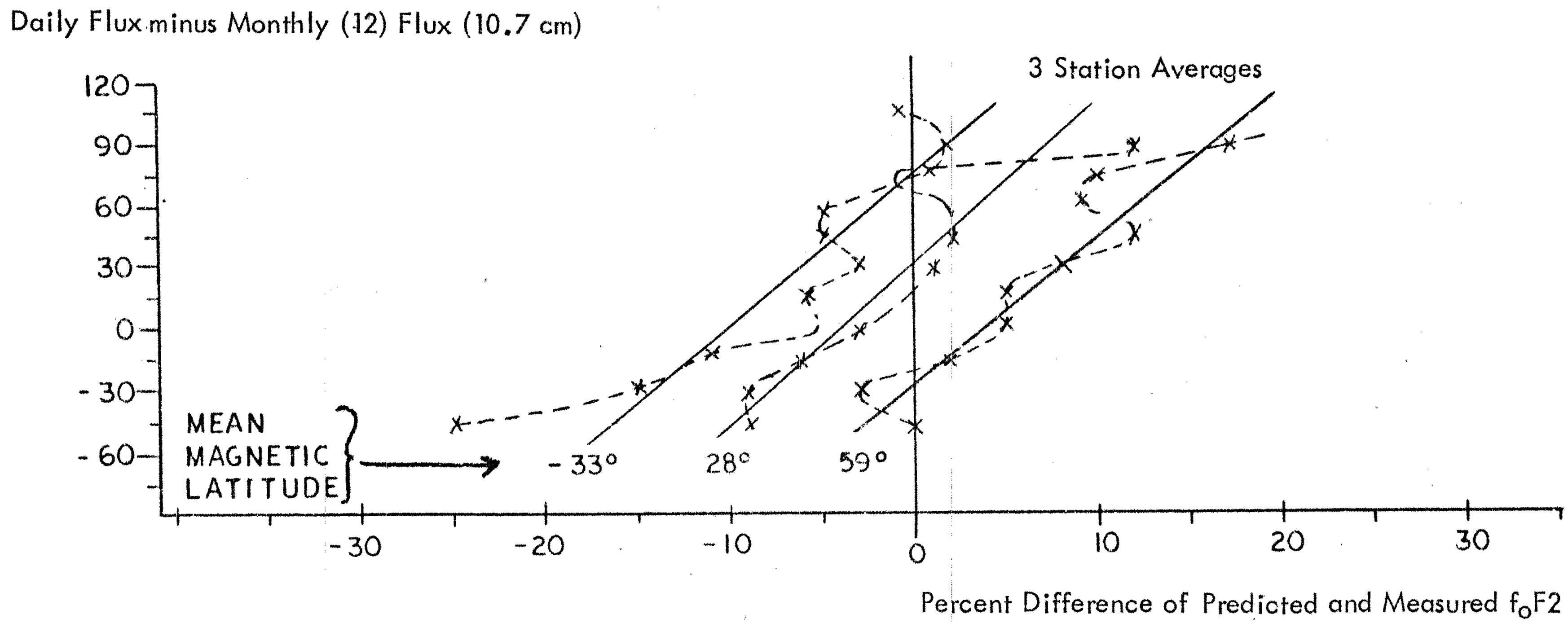


Fig. 10 An error in the NOAA f_oF2 predictions as a function of magnetic latitude and daily solar flux minus the 12 month running average.

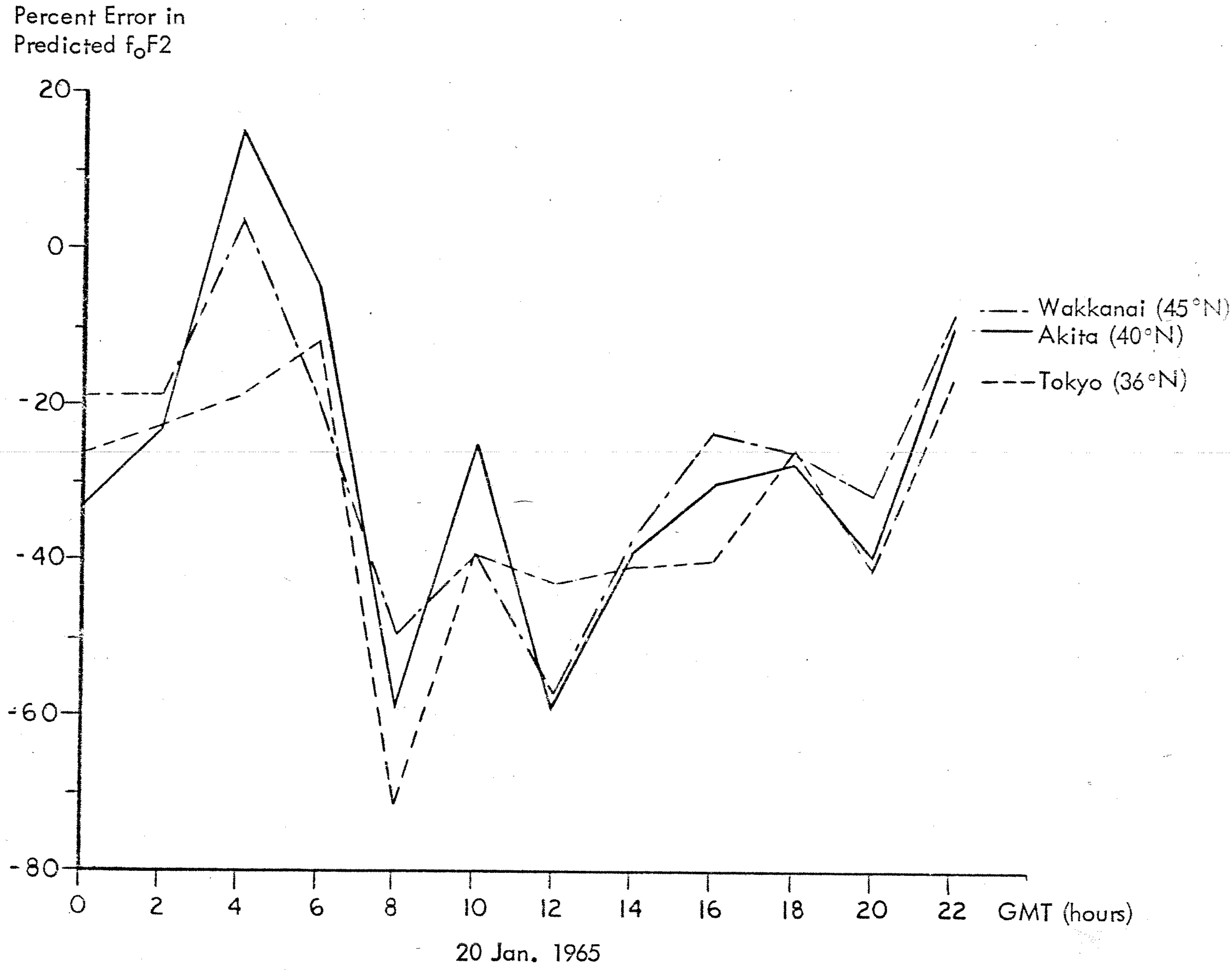


Fig. 11 Deviations in f_oF2 evident over a distance of 1,000 km

3.0 PROGRAMMED MODEL EQUATIONS

The units in the equation of this section are all kept in meter, radians, seconds and Mhz.

3.1 Sub-ionospheric Point

The vertical electron content is obtained by integrating through the electron density N versus height h profile. The N-h profile is computed for that latitude ϕ and longitude λ at which the radiowave from the observing station to the satellite penetrates the ionosphere. This is called the sub-ionospheric point and is computed as a function of the station latitude ϕ_s, longitude λ_s, elevation ($E\ell$) and azimuth (Az) to the satellite:

$$\phi = \arcsin\,(\sin\phi_s \cos\alpha + \cos\phi_s \sin\alpha \cos Az)$$

$$\lambda = \lambda_s + \arcsin\left(\frac{\sin Az \sin\alpha}{\cos\phi}\right),$$

where α is the earth central angle between the station and the sub-ionospheric point,

$$\alpha = \frac{\pi}{2} - E\ell - \arcsin\left(\frac{R_e}{R_e + h_m} \cos E\ell\right),$$

R_e is the earth radius and h_m is the height of the ionosphere at the maximum electron density above the surface of the earth. On first try for this calculation the assumption $h_m = 300$ km is made. After the h_m computation in Section 3.3, the difference between the computed h_m and its first estimate of 300 km is calculated. If the difference is less than 50 km its effect is negligible, if it is greater than or equal to 50 km, equations in Sections 3.1 through 3.3 are iterated upon for the new value of h_m.

3.2 f_oF2 and M(3000)F2

The critical frequency f_oF2 and the M-factor M(3000)F2, required for the profile calculation, are computed from monthly $U_{s,k}$ coefficient sets for f_oF2 and M(3000)F2 using equations based on Fourier series expansions and spherical harmonics analysis, which were developed by ITS in Boulder (now NOAA, Boulder).

The values of f_oF2 and M(3000)F2 are functions $\Omega(\phi, \lambda, T)$ of geographic latitude ϕ, longitude λ, and time T. The function $\Omega(\phi, \lambda, T)$ can be expressed by a series of products of time dependent functions D(T) and position dependent geographic functions $G(\phi, \lambda)$:

$$\Omega(\phi, \lambda, T) = \Omega[D(T), G(\phi, \lambda)] = \sum_{k=0}^{K} D_k(T)\, G_k(\phi, \lambda),$$

where K is the cutoff point for the approximate representation of Ω. K = 75 when $\Omega = f_oF2$, and K = 48 when Ω = M(3000)F2; these cutoff points were originally determined using a Student's t test.

The time dependent functions can be expanded in their Fourier series representation with the coefficients $A_j^{(k)}$ and $B_j^{(k)}$:

$$D_k(T) = A_0^{(k)} + \sum_{j=1}^{H} (A_j^{(k)} \cos jT + B_j^{(k)} \sin jT) .$$

The number of harmonics retained in the series is H, higher harmonics are not considered since they are produced more by noise than by real physical variation. For the f_oF2 computation H = 6 and for the M(3000)F2 computation H = 4 are sufficient.

The Fourier coefficients $A_j^{(k)}$ and $B_j^{(k)}$ are numerically mapped as predicted or final coefficients $U_{s,k}$, which are the f_oF2 or M(3000)F2 coefficient sets to be used for the f_oF2 or M(3000)F2 computation respectively,

$$A_j^{(k)} = U_{2j,k} \quad j = 0,1,\ldots H$$

$$B_j^{(k)} = U_{2j-1,k} \quad j = 1,2,\ldots H.$$

Thus we get for the function Ω:

$$\Omega(\phi,\lambda,T) = \sum_{k=0}^{K} U_{0,k}\, G_k(\phi,\lambda) + \sum_{j=1}^{H} \left[\cos jT \cdot \sum_{k=0}^{K} U_{2j,k}\, G_k(\phi,\lambda) + \sin jT \cdot \sum_{k=0}^{K} U_{2j-1,k}\, G_k(\phi,\lambda) \right].$$

The geographic functions $G_k(\phi,\lambda)$ are linear combinations of the surface spherical harmonics. Extensive investigations to find the best arguments for the harmonic functions resulted in the use of the modified magnetic dip $x = x(\phi,\lambda)$, since for this case smaller residuals between the measured and computed test data values for f_0F2 were obtained than for any other case. Thus $G_k(\phi,\lambda)$ is an explicit and implicit function of latitude ϕ and longitude λ:

$$G_0(\phi,\lambda) = \sin^{q_0} x$$

$$G_k(\phi,\lambda) = \sin^{q_k} x \cdot \cos^k \phi \cdot \sin k\lambda, \qquad k = 1,2,\ldots K.$$

q_k, $k = 0,1,\ldots K$ denotes the highest power of $\sin x$ for the kth order harmonic in longitude.

The modified magnetic dip x is an explicit function of latitude and the magnetic dip I. I is computed from the magnetic field components $X(\phi,\lambda)$, $Y(\phi,\lambda)$, $Z(\phi,\lambda)$:

$$\sin x = \frac{I}{\sqrt{I^2 + \cos\phi}}, \qquad I = \tan^{-1}\left[\frac{-Z}{\sqrt{X^2+Y^2}}\right].$$

X, Y, Z are the north, east and vertical components of the magnetic field vector. They are computed following the spherical harmonic analysis of the magnetic field by Chapman and Bartels, as discussed in detail in the report by Jones, Graham and Leftin (1969).

Defining $\varphi = 90° - \phi$ and $R = \frac{R_e}{R_e + h_m}$;

R_e = earth radius

h_m = height of F2 layer

$$X = \sum_{n=1}^{6} \sum_{m=0}^{n} \frac{d}{d\varphi} P_{n,m} (\cos \varphi) [g_n^m \cos m\lambda + h_n^m \sin m\lambda] R^{n+2}$$

$$Y = \sum_{n=1}^{6} \sum_{m=0}^{n} \frac{m P_{n,m} (\cos \varphi)}{\sin \varphi} [g_n^m \sin m\lambda - h_n^m \cos m\lambda] R^{n+2}$$

$$Z = \sum_{n=1}^{6} \sum_{m=0}^{n} -(n+1) P_{n,m} (\cos \varphi) [g_n^m \cos m\lambda + h_n^m \sin m\lambda] R^{n+2} .$$

Values tabulated from the analysis of the magnetic field for Epoch 1960 are used for the coefficients g_n^m and h_n^m. $P_{n,m} (\cos \varphi)$ is a multiple of the associated Legendre function.

3.3 Profile Parameters

The N-h profile at each sub-ionospheric point (ϕ, λ) is modeled as having a bi-parabolic bottom side layer and 3 sections to a topside exponential layer, as shown in Figure 1. The bottom side and topside are fit together with a parabolic layer extending from the height of the maximum electron density up to the point where the slopes of the parabola and the lower exponential layer are equal. Thus the profile is defined by the following parameters: the critical frequency f_cF2, the height at the maximum electron density h_m, the half thickness of the bottom side layer y_m, the half thickness of the topside parabolic layer y_t, and the decay constants k_i for the lower, middle and upper third of the topside exponential layer.

The predicted value of the critical frequency is updated for day to day fluctuations using the daily solar flux and the 12 month running average of the solar flux for the particular month on which the computation of the coefficient set for f_oF2 was based.

The height at the maximum electron density is a function of the M-factor M(3000)F2 and computed as a second order polynomial,

$$h_m = [1346.92 - 526.40 \times (\text{M-factor}) + 59.825 \times (\text{M-factor})^2] \times 10^3 .$$

The half thickness of the bottom layer y_m is interpolated from tables in which y_m is modeled as function of f_oF2, local time and season. The half thickness of the topside parabolic layer y_t is derived from y_m and f_oF2.

The three topside decay constants k_i vary with f_oF2, magnetic latitude, daily solar flux and season, and are also obtained by interpolating constant tables. The magnetic latitude of the sub-ionospheric point is given by,

$$\phi_m = \arcsin (\sin\phi \sin\phi_p + \cos\phi \cos\phi_p \cos (\lambda - \lambda_p)),$$

where (ϕ_p, λ_p) are the latitude and longitude of the magnetic north pole.

3.4 Integrated Electron Content

The maximum electron density N_m is given by:

$$N_m = 1.24 \times 10^{10} \times (f_oF2)^2 .$$

The total vertical electron content N_T is obtained by integrating the electron density profile from zero to the height of the satellite h_s. For a satellite below the bi-parabolic layer of the ionosphere:

$$N_T = 0.$$

For a satellite in the bi-parabolic layer:

$$N_T = N_m \left\{ \frac{8}{15} y_m - (h_m - h_s) + \frac{2}{3} \frac{(h_m - h_s)^3}{y_m^2} - \frac{1}{5} \frac{(h_m - h_s)^5}{y_m^4} \right\} .$$

For a satellite in the parabolic layer:

$$N_T = N_m \left\{ \frac{8}{15} y_m - (h_m - h_s) + \frac{1}{3} \frac{(h_m - h_s)^3}{y_t^2} \right\} .$$

For a satellite in the lower exponential layer of the topside with decay constant k_1:

$$N_T = \left(1 - \frac{d^2}{y_t^2}\right) N_m \left\{ \frac{1}{k_1} \left(1 - e^{-k_1 (h_s - h_0)}\right) \right\} + N_B ,$$

and the height of the bottom of the lower exponential layer where the slopes of the exponential and parabolic layer are equal is determined as:

$$h_0 = h_m + d, \qquad d = \frac{1}{k_1} \left[(1 - y_t^2 k_1^2)^{\frac{1}{2}} - 1 \right] ,$$

$$N_B = N_m \left\{ \frac{8}{15} y_m - (h_m - h_0) + \frac{1}{3} \frac{(h_m - h_0)^3}{y_t^2} \right\} .$$

For a satellite in the middle exponential layer of the topside with decay constant k_2:

$$N_T = \left(1 - \frac{d^2}{y_t^2}\right) N_m \left\{ \frac{1}{k_1} + e^{-k_1 (h_1 - h_0)} \left[-\frac{1}{k_1} + \frac{1}{k_2} \left(1 - e^{-k_2 (h_s - h_1)}\right) \right] \right\} + N_B ,$$

and the height of the bottom of the middle exponential layer is,

$$h_1 = h_0 + \frac{1}{3}\,(1.012 \times 10^6 - h_0).$$

For a satellite in the upper exponential layer of the topside with decay constant k_3:

$$N_T = \left(1 - \frac{d^2}{y_t^2}\right) N_m \left\{ \frac{1}{k_1} + e^{-k_1(h_1 - h_0)} \left[-\frac{1}{k_1} + \frac{1}{k_2} + e^{-k_2(h_2 - h_1)} \left(-\frac{1}{k_2} + \frac{1}{k_3} - \frac{1}{k_3}\, e^{-k_3(h_s - h_2)} \right) \right] \right\} + N_e\,;$$

and the height of the bottom of the upper exponential layer is,

$$h_2 = h_0 + \frac{2}{3}\,(1.012 \times 10^6 - h_0).$$

In the data reduction the upper integration limit was set to h_s=2000 km to yield electron content comparable to the Faraday rotation measurements.

3.5 Update Process

DBA's program has the option of updating the predicted electron content at any evaluation station with observations of critical frequency f_0 F2 or with electron content N_T reduced from Faraday rotation measurements from other stations. Several measurement entries separated by different amounts in time and space from the evaluation time and station can be accepted. The predictions for N_T or f_0 F2 are computed according to the observation type, and the ratios r of measured/predicted N_T or f_0F2 are formed for each update condition. A weighted mean technique combines all n ratios r_i to a final ratio R, using as weights the time differences Δt_i between observation and evaluation times and the earth central angles α_i between observation and evaluation stations.

$$R = \frac{\sum_{i=1}^{n} \frac{r_i}{\Delta t_i\, \alpha_i}}{\sum_{i=1}^{n} \frac{1}{\Delta t_i\, \alpha_i}}\,,$$

where $\Delta t = |t - t_o|$, and $\cos\alpha = \sin\phi \sin\phi_o + \cos\phi \cos\phi_o \cos(\lambda-\lambda_o)$, t, ϕ, λ; t_o, ϕ_o, λ_o are time, latitude and longitude for evaluation and observation condition respectively. The final ratio R indicates the overall percentage by which the predictions deviate from the ionospheric observations. If measured electron content values are available at the update stations, the predicted electron content at the evaluation station is multiplied by the final ratio, giving an updated value for N_T. In the case of $f_o F2$ observations at the update stations, the predicted f_oF2 value at the evaluation station is multiplied by the final ratio. The resulting updated f_oF2 is used in the reevaluation of the profile parameters of the half thickness of the bottom layer y_m and the topside decay constants k_i. Integration through this new profile yields the updated electron content for the evaluation station.

4.0 GENERAL BACKGROUND

The proposed navigation system employs constellations of earth-synchronous (but not stationary) satellites with altitudes varying from 10,000 - 30,000 nautical miles. The satellites transmit synchronized UHF ranging signals, which the user analyzes to determine his position and velocity in three dimensions. The user must receive signals from at least four satellites in order to make his position fix. System accuracy is projected to be on the order of tens of feet in position and less than a foot per second in velocity.

The UHF ranging signals will also transfer information to system users at a low data rate (10 bits per second). This information will consist of satellite ephemeris data, ranging signal time synchronization data, and input or update information for estimating the ionospheric group delay. A master ground station, located in the central continental United States (CONUS) will transmit this information to the satellites for retransmission to the users.

The master station and three signal monitor stations, all located on United States territory, will provide ionospheric input/update information for the prediction model. These stations will actually measure the ionospheric group delay using dual frequency transmissions from those System 621B satellites which are within their field of view. Other sources of ionospheric information may also be used for updating if required.

5.0 EVALUATION REQUIREMENTS

This effort consists of describing a way of incorporating the Bent Ionospheric Prediction Model into System 621B and evaluating the model to determine its accuracy in predicting total electron content (N_T).

DBA was asked to evaluate the Bent Ionospheric Prediction Model to determine the accuracy with which it can predict group delay at 1600Mhz. The model was used to predict group delay at certain locations (evaluation stations) and for certain time periods. These predictions were compared with the actual group delay as computed from Faraday rotation data. The residuals, or differences between the predicted and observed values of the group delay, were then statistically analyzed as specified below.

5.1 Evaluation Schemes (see Table 1)

The model was evaluated using each of the following updating schemes. The geographic locations of the stations used in the reduction are marked in Figure 12.

5.1.1 No Updating

The Bent model initially generated predictions using no inputs other than position, time and 10.7 cm solar flux values. This scheme applied to all five evaluation conditions.

5.1.2 With Updating

For the update situations Faraday rotation data was obtained for various stations through SAMSO and ionospheric critical frequency measured by ionosonde techniques was purchased from NOAA, Boulder. Single, double and triple station update was performed for the total electron content data and single station update from the critical frequency data. Table 1 summarizes all these conditions. The time of the update observation was at least one hour prior to the prediction, and for certain evaluation conditions the prediction was determined using update information 2, 3, 5, and 9 hours prior. Table 1 summarizes all these situations and shows that a total of 81 update conditions were applied to the original 11 cases.

5.2 Residual Statistics

For the evaluation stations listed in Table 1 and the updating schemes described above, DBA determined, to the extent permitted by the availability of update data, the quantities described below.

A. The mean, standard deviation, and root mean square (RMS) value of the residuals for the entire evaluation period, the number of residuals used in computing these values, and the cumulative probability distribution of the residuals.

B. The mean, standard deviation, and RMS value of the daytime-only residuals at the evaluation station (sunrise to sunset) for the entire evaluation period, the number of residuals used in computing these values, and the cumulative probability distribution of the residuals.

C. The mean, standard deviation, and the RMS value of the residuals for each one-hour interval (UT) during the day for each calendar month of the evaluation period and the number of residuals used in computing these values.

5.3 Correlation Coefficients

For each evaluation station pair listed in Table 2, DBA computed the correlation coefficient for the entire evaluation period and the number of residual pairs used in computing this value. Residuals separated by time intervals of up to 10 minutes were used when residuals computed for the same universal time were not available. However, no residual was used in more than one residual pair for a specific evaluation pair.

TABLE 1. Data Conditions for Monthly and Overall Statistics

Conditions	Period	Evaluation Station	Update Conditions: 1 Station f_oF2 Update	1 Station N_T Update	2 Station N_T Update	3 Station N_T Update	Time Delay in Applying Update	Number of Updates
1 & 2	8 Dec '67 --- 18 Apr '68	Stanford ATS1	Pt. Arguello	Hono. ATS1	Arec. ATS3 & Hono. ATS1 (rows 1–4)	Arec. ATS3 & Hono. ATS1 & Saga. ATS3 (rows 1–3)	1 hour	4
		Stanford ATS3	Pt. Arguello	Saga. ATS3			1 hour	4
		Urbana ATS3	Wallops Is.	Saga. ATS3			1 hour	4
		Sagamore ATS3	Wallops Is.	Arec. ATS3			1 hour	3
3	1 Jan '65 --- 31 Dec '65	Honolulu SYN3	---	Stan. SYN3	---	---	1 hour	1
4	1 Jan '68 --- 31 Dec '68	Honolulu ATS1	Maui/ Pt. Arguello	Stan. ATS1	---	---	1,2,3,5 & 9 hours	15
		Sagamore ATS3	Wallops Is./ Pt. Arguello	Stan. ATS1	---	---	1,2,3,5 & 9 hours	15
5	1 Dec '68 --- 13 Nov '69	Stanford ATS1	Pt. Arguello	Edmo. ATS1	---	Edmo. ATS1 & Saga. ATS3 & Hono. ATS1 (rows 1–4)	1,2,3,5 & 9 hours	15
		Stanford ATS3	Pt. Arguello	Edmo. ATS1	---		1 hour	3
		Cold Bay ATS1		Edmo. ATS1	---		1 hour	2
		Urbana ATS3	Wallops Is.	Saga. ATS3	---		1,2,3,5 & 9 hours	15

TABLE 2. Data Conditions for Correlation Coefficients

Condition	Period	Station Pair	Update Conditions: 1 Station f_oF2 Update	1 Station N_T Update	2 Station N_T Update	3 Station N_T Update
1 & 2	8 Dec '67 --- 18 Apr '68	Stanford ATS1/Stanford ATS3	Pt. Arguello	---	Arec.ATS3 & Hono.ATS1 (rows 1–3)	Arec.ATS3 & Hono.ATS1 & Saga.ATS3 (rows 1–2)
		Stanford ATS3/Urbana ATS3	---	Saga.ATS3		
		Urbana ATS3/Sagamore ATS3	Wallops Is.	---		---
5	1 Dec '68 --- 13 Nov '69	Stanford ATS1/Stanford ATS3	Pt. Arguello	Edmo.ATS1	---	Edmo. ATS1 & Hono.ATS1 & Saga.ATS3 (rows 1–2)
		Stanford ATS3/Urbana ATS3	---	---	---	

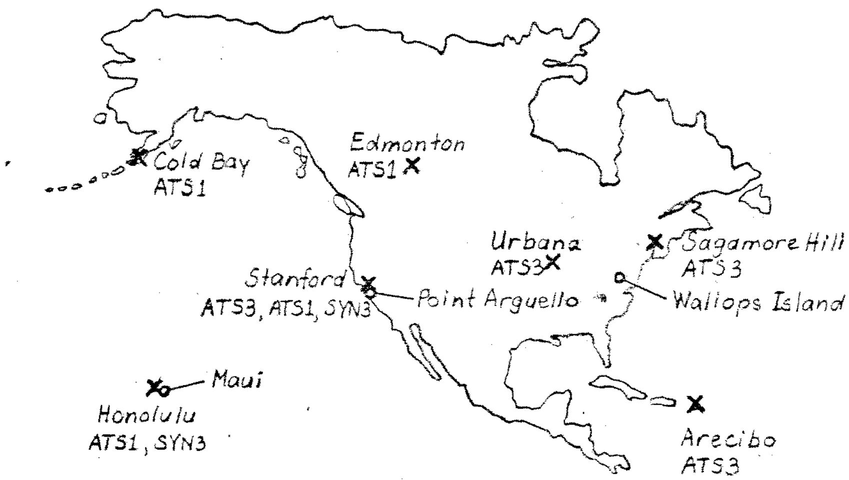


Figure 12. Geographic Location of (x) Faraday Rotation Observing Stations, Listed with Station Name and Satellites Being Observed, and of (o) f_oF2 Observing Stations Used in Study.

6.0 RESULTS

6.1 Theoretical Approach

Preliminary tests were conducted to determine what effect the frequency of the data samples would have on the statistical reduction of the Faraday rotation data. Sets of Honolulu data for January, March, and December 1968 were evaluated for samples taken every 15 minutes and for samples every 60 minutes. The differences between each of the two data cases for each month proved to be negligible and in general, less than 1% of the resultant values. For example all of the December data resulted in the following mean, standard deviation and RMS value of the vertical content residuals (10^{16} e/m^2): Mean (15)= 4.45, Mean (60) = 4.48, STD (15) = 15.47, STD (60) = 15.51, RMS (15) = 16.10, RMS (60) = 16.13. For this reason it was decided to base the entire statistical reduction on hourly data samples alone.

The only time the results of the 2 tested sample frequencies would show significant differences is when frequent data point dropouts occur such that the hourly distribution of the overall 60 minute data contains considerably less values during certain hours than during others, while the 15 minute data distribution might still be quite even throughout the days. Upon closer examination of the Faraday rotation data from different stations over the entire evaluation periods it was found that sometimes during certain hours significantly more observations existed than during the remaining hours. Since the objective of the task was to evaluate the performance of the Bent ionospheric model under general conditions representing the diurnal variation of the ionosphere, the results for each hour of the entire evaluation period were weighed evenly for the computation of the overall values. Table 3 demonstrates the differences between the percent errors based on even and uneven data distribution. For many of the cases evaluated though, the hourly distribution was quite even and the results for both distributions essentially the same.

The quantities mean, standard deviation, root mean square and correlation coefficients are evaluated separately for each hour using the standard formulas, and are then combined as shown in the working equations below giving equal weight to the values of each hour. The residual of each entry is defined as R_k = measured-predicted quantity, n is the number of data points for each hour **i**.

$$\text{Mean} = \frac{1}{24} \sum_{i=1}^{24} \left(\frac{\sum_{k=1}^{n} R_k}{n} \right)_i$$

$$\text{Standard Deviation} = \left[\frac{1}{24} \sum_{i=1}^{24} \left(\frac{\sum_{k=1}^{n} R_k^2 - \left(\sum_{k=1}^{n} R_k \right)^2 / n}{n-1} \right)_i \right]^{\frac{1}{2}}$$

$$\text{RMS} = \left[\frac{1}{24} \sum_{i=1}^{24} \left(\frac{\sum_{k=1}^{n} R_k^2}{n} \right)_i \right]^{\frac{1}{2}} .$$

In the correlation coefficient computation for the station pair A/B, X is the residual (measured-predicted quantity) for station A, and Y is the residual for station B. The intermediate sums S_{xx}, S_{yy}, S_{xy} are computed individually for each hour and are then combined to hourly and total correlation coefficients,

$$S_{xx} = n \sum_{k=1}^{n} X_k^2 - \left(\sum_{k=1}^{n} X_k \right)^2$$

$$S_{yy} = n \sum_{k=1}^{n} Y_k^2 - \left(\sum_{k=1}^{n} Y_k \right)^2$$

$$S_{xy} = n \sum_{k=1}^{n} X_k Y_k - \left(\sum_{k=1}^{n} X_k \right) \left(\sum_{k=1}^{n} Y_k \right) .$$

$$\text{Hourly correlation coefficient } r_i = \frac{S_{xy}}{\sqrt{S_{xx} \cdot S_{yy}}} .$$

Correlation coefficient for entire period,

$$r = \frac{\sum_{i=1}^{24} \left(\frac{S_{xy}}{n}\right)_i}{\left[\sum_{i=1}^{24} \left(\frac{S_{xx}}{n}\right)_i \cdot \sum_{i=1}^{24} \left(\frac{S_{yy}}{n}\right)_i\right]^{\frac{1}{2}}} .$$

In addition, correlation coefficients were computed for the daytime periods by summing only over the hours for which the local time at both stations A and B lies between 9 and 16 hours.

Mean, standard deviation and RMS are expressed in electron content as well as group delay. In addition percent errors are computed for each individual data entry. The mean, standard deviation and RMS of the percent error are computed by setting percent error = R = 100 (measured-predicted)/measured values in the above equations and by summing over the daytime period only, defined as 7-18 hours local time. Combining the nighttime and daytime percent errors does not give any useful information, since negligible small prediction errors in the low nighttime electron content result in large percent errors. The actual point of interest lies in the daytime percent errors, expressing how accurate the ionosphere can be predicted for the worst conditions, the daytime peaks.

Range errors, ΔR, for a particular observing station can be reduced from the vertical electron content, N_T, if the elevation angle, $E\ell$, is known. To obtain range rate errors, $\Delta\dot{R}$, the elevation rate, $\dot{E}$, must also be known.

For 1600mhz frequency:

$$\Delta R = \frac{1.57 \times 10^{-5} N_T}{\sqrt{1 - .905 \cos^2 E\ell}}$$, where, ΔR is in meters, N_T is in electrons/meter^2

$$\Delta\dot{R} = \frac{.905 \, \Delta R \, \dot{E} \sin E\ell \cos E\ell}{1 - .905 \cos^2 E\ell}$$, where, $\Delta\dot{R}$ is in meters/second, $\dot{E}$ is in radians/second.

Both terms are expressed for an average height of the ionosphere, $h_m = 325$ km and $\left(\frac{R}{R+h_m}\right)^2 = .905$. The corrections ΔR and $\Delta\dot{R}$ are along the angular path and are reduced from their vertical components; the horizontal gradients in the ionosphere are taken into account by computing the vertical electron content for the location where the ray passes through the densest part of the ionosphere.

For the statistical reduction all Faraday rotation angle data was converted to vertical electron content using the Faraday rotation factors listed in Table 4. These conversion factors were obtained using ionospheric profile predictions and earth magnetic field computations. The equations relating the Faraday rotation angle Ω to the vertical total electron content N_T is,

$$\Omega = \frac{K}{f^2} \int_0^{h_u} B \cos\theta \sec X N\, dh = \frac{K}{f^2} \bar{M} \int_0^{h_u} N\, dh = \frac{K}{f^2} \bar{M} N_T = F N_T$$

Ω = rotation angle in radians

K = 2.36 = constant

f = frequency in hertz

B = magnetic field strength in gauss

θ = angle between directionof propagation and magnetic field

X = zenith angle

N = electron density in e/m^3

h = height above surface of earth in m

$\bar{M}$ = mean value of $(B \cos\theta \sec X)$

N_T = vertical total electron content in e/m^2 column

F = Faraday rotation factor in m^2 radians

The upper limit of the integral corresponds to the height above which the remaining amount of rotation is less than the absolute experimental error, and was used as $h_u = 1000$ km.

$$F = \frac{K}{f^2} \bar{M} = \frac{K}{f^2} \frac{\int_0^{h_u} B \cos\theta \sec X\, N\, dh}{\int_0^{h_u} N\, dh} .$$

The frequency for the Faraday rotation date was f = 137 MHz. The integrals were evaluated by generating the electron density N and the function ($B \cos \theta \sec \chi N$) at small height increments between 0 and 1000 km and integrating numerically. The electron density at each height h was computed by the Bent ionospheric profile model. The components of the magnetic field strength were obtained by the spherical harmonic analysis as described in Section 3.2. The zenith angle at each height h is a function of the ground elevation angle, and the angle θ was calculated using station and satellite positions and the direction of the magnetic field. For each station observing the ATS1 or Syncom 3 satellites monthly conversion factors were calculated as the diurnal means of monthly average ionospheric conditions. This method though was not sufficient for the stations observing the ATS3 satellite, since its position frequently shifted rapidly between 90° west and 45° west longitude during the two years under investigation. For these stations the conversion factors were re-evaluated as the diurnal mean on a daily basis whenever the satellite shifted by more than 3 degrees in longitude from its last evaluated position.

6.2 Comparison with Other Results

Care should be exercised when comparing the residuals described here with those of the earlier contractors because of different update conditions. For the update conditions in this report, the update is considered for the whole of the 24 hours and not for a short daytime only period, as was done by Stanford University.

6.3 Model Weaknesses

During these investigations it became evident that certain weaknesses existed in the model but the resulting improvements have not yet been incorporated. The model used was the latest model that existed prior to the contract commencement and the same model was used throughout. The real weakness of the model is in the immediate layer above the height of maximum electron density where the topside sounding data was insufficient. One of the better ways to model this region is by integration and comparison with total content data from Faraday rotation or two frequency data. Evidence from linking topside and bottom side profiles, taking account of the probable 4% distance error from topside sounders, indicates that a slightly thicker layer exists immediately above the peak than below it. Supposing that a bias in the mean residuals obtained in this present analysis comes mainly from this assumed parabolic region above the peak, the results strongly indicate that the constant of this parabola is a function of magnetic latitude, time and solar flux, and not a simple number as used in this analysis. It is safe to assume that any large difference that exists between standard deviation and root mean square values listed here will shortly be removed by improved modeling of this narrow region. Experiments have already shown this to be the case and that the parabolic constant needed to eliminate the mean residual bias has definite relationships for different stations as functions of time and solar flux. Further weaknesses of the model showing large update problems for a brief period in the local morning also occurred. This problem is not yet completely understood but its characteristics indicate it can easily be tracked down.

6.4 Discussion of Analysis of Residuals

It is impossible in the few days allowed for investigating the results and writing the report to cover all significant aspects of the analysis, but it must be emphasized that conclusions cannot safely be drawn from the summary for the entire evaluation periods. Thorough investigations of the monthly and hourly residuals are very necessary. An example of this data will later be examined in detail as an indication of the problems needing further thought. A summary of the residuals for the entire evaluation period is shown in Table 5. In these tables the mean, standard deviation and RMS values of the residuals are given for each evaluation and update condition, for the entire period of evaluation and for the daytime only period. These results also show the update conditions based on 1,2,3,5 and 9 hours prior to the evaluation time and give the residuals in terms of group delay time and electron content. It is emphasized once more that these results can be extremely misleading and reference to the more complete tables is necessary.

A further summary of these results is given in Table 6 where the RMS residual and standard deviation are quoted for the whole period of evaluation. The largest RMS taken from the monthly-diurnal (1 hour) tables are also given and indicate the problems that the 621B system has to contend with. The value of the updated RMS residual is given but without deeper investigation this number is deceptive. The most striking feature may be that on average the RMS and standard deviation agree reasonably well, indicating little bias from the mean in the model. However, on investigating some of the larger residuals a considerable reduction in the standard deviation over the RMS value is shown. This mean bias indicates a model weakness that undoubtedly can be improved. Before proceeding further into what these numbers mean it will be worthwhile studying one of the periods in more detail in order to bring out any significant features. This same reasoning should then be applied to all the data. For such an investigation, it is wise to choose probably one of the most unpredictable periods of the analyzed data and discuss the problems in more detail. The data from Honolulu in January, 1968, is by far the most erratic analyzed under this contract and Table 7a–e shows the average diurnal values for this period. This evaluation station is situated near the equatorial anomaly and in 1968 the solar cycle was at its peak. January is also the most ionospherically 'unstable' month for such a station. It is seen from Table 7a that the RMS values for the residuals in the prediction alone vary from 19.55 nanoseconds in the local afternoon to 0.45 nanoseconds just before sunrise. The standard deviation ranges from 11.61 to 0.36 nanoseconds and shows very little bias in the model from the mean except during the hours 22.00 to 02.00UT when considerable, and hopefully, temporary bias occurs. During these periods in the local afternoon the vertical electron content rose often to values greater than 10^{18} electrons/m^2 column, and the results show that about 34% (17 nanoseconds) of RMS residual remain unpredicted, but only about 19% (10 nanoseconds) in standard deviation remain.

Considering update circumstances with Stanford ATS-1 data (1 hour prior) in Table 7b, the RMS value is reduced a significant amount during these afternoon hours (17 to 13 nanoseconds) but the standard deviation changes little. This implies the update has removed a considerable portion of the bias in the model but not improved the overall standard deviation very much. The update method often makes the nighttime values much worse and really should not have been used this way. The method suggested in the Stanford report would probably have produced better results here; namely updating for all the nighttime values with the update conditions recorded just prior to sunset. Assuming that the model can be easily improved in terms of the bias from the mean, update from Stanford does not appear to improve the overall accuracy of the model. In fact during the summer months such an update gives a deterioration. Now considering Table 7c showing f_0F2 update from Maui (1 hour prior) a considerable improvement all-around is noticed. The predicted model RMS residuals for the local afternoon period are reduced from 17 to 7.7 nanoseconds and the standard deviation from 10 to 6.5 nanoseconds. The improvement is maintained during the summer months, particularly in standard deviation. Maui is some 121 km distant from the sub-ionospheric point looking at ATS-1 from Honolulu. One question to be raised here is over what distance will this considerable improvement in the predicted 'disturbed' ionosphere be maintained? We will see later that such great improvements are not typical for the more stable U.S. region but perhaps the large improvement in model predictions over equatorial zones will be maintained elsewhere in the world. Tables 7d and 7e show the predictions using Stanford and Maui data 2 hours prior to evaluation time. Comparing these with the original predictions still shows an improvement in the RMS value during the local afternoon from the Stanford data and, as expected, still an extremely good improvement using the Maui data. The overall statistics imply that no update improvement can be made during this evaluation condition. However, by scrutinizing the data in more detail it appears that useful improvements can be made during the times of the day when it really matters, and these improvements can be as great as 12 nanoseconds in the average residual for an hour during one bad month.

This brief discussion on a small part of the data indicates the close scrutiny that must be applied to the following results. Such a scrutiny, that is impossible in the time allowed in this contract, should help formulate ideas on whether a simple model would be sufficient for the more 'quiet' zones of the world, even without update. It should also indicate to what level, and at what times and seasons, update is necessary for the equatorial zones. Further analysis of the model for other equatorial and disturbed zones is probably necessary, however, before final conclusions could be made.

Table 8 gives a brief summary of the overall statistics for updating certain cases with data 1,2,3,5 and 9 hours prior to evaluation time. Again this data is deceptive and it can often be shown from diurnal curves that considerable improvement occurs, during the times when the ionosphere is dense, with update data taken from 3 to 5 hours prior to evaluation time.

As we have pointed out earlier the fine structure of the data must be investigated in detail. A halfway approach to this problem is to analyze the diurnal results averaged over the whole evaluation period. Figures 13a to 13v show the RMS and standard deviation of the residuals as a function of UT for the entire evaluation period, for the basic prediction and for updating with data from various stations taken 1 hour prior. The curves marked '0' indicate the predicted values. Any curves to the 'left' of this '0' curve therefore indicates a situation where the update has improved the predicted value. Nighttime is indicated by the 10 or so hours where the '0' curve is low; during this time update improvement is difficult but not as important because of the low values. Much greater success is apparent during the afternoon period when the 621B project requires more accurate predictions due to the denser ionosphere. During these times improvements of 20-50% in the RMS of the residuals is not uncommon. Again, however, close examination of the comprehensive results show a strong seasonal trend in all this data, indicating update is better where the ionosphere is thicker.

Examination of Figures 13a,b,c,d,l,m,n,o indicates very large residuals between 14 and 18 hours UT when Honolulu is included in the update condition. These discrepancies are due to erratic nighttime values of total content observed at Honolulu on February 4th and 11th, 1968. At 14 hours UT on these days (4a.m. LT) the observed total content was about 7 times larger than average. These large enhancements were also observed in the f_oF2 data recorded at Maui. At these times it was already daytime at the evaluation stations and the update procedure we used weighted the predicted content at the evaluation station by the enormous percentage at the update station, causing large excursions in the residuals at these times. These two Honolulu values alone will also considerably effect the overall residual for these update conditions again pointing to the caution required in analyzing the residuals. A better update solution may have been to use the last daytime update value throughout the nighttime periods, thereby, eleminating these large nighttime excursions affecting daytime updates some thousands of Kilometers distant.

Examination of these curves indicates a weakness in the model with update for a brief period during the first hours of daylight. The error causes high values of RMS residual during this time which rapidly changes to a reduction in RMS residual during the denser afternoon ionosphere. No great difficulty is expected in correcting this error and the abundance of data analyzed here will be used towards achieving this goal. In order to point out problems in the update capability, reference should be made to Figures 14a,b. The first of these figures shows good update capability for the whole of May, 1969. It is seen that the measured value of f_0F2 was higher than predicted and the updated value of total content agrees extremely well with the measured value. The next figure shows similar monthly mean diurnal curves for December, 1968, where the measured and predicted values of f_0F2 are in close agreement. However, the predicted and updated total content has large errors during local morning conditions. Further investigation of the RMS and standard deviation of the residuals for this month, shown in Figures 15a and b, also indicate a large bias in the mean residual at that time. It appears that further study of the seasonal-local time update routine is necessary.

6.5 Update with Data Taken 1,2,3,5 and 9 Hours Prior to Evaluation

Four cases were investigated with update capability from data taken up to 9 hours prior to evaluation time and whereas the overall residuals were not necessarily greatly improved the diurnal trend showed certain interesting results. Figures 16a to 16h give the RMS and standard deviation of the residuals as a function of time for the four evaluation periods. The numbers on the curves are the same as the delay time in hours of the update data. One of the cases also indicates the residuals where the model is updated with zero hours delay. Comparison with the basic prediction ('0' curve) from Figures 13a to 13v shows over what periods of time of day improvement to the predictions occurs and also by how many hours previous the update data shows such an improvement. In general 3 to 5 hours delay means the updated model and predicted model give similar results particularly in local afternoon. In evaluation condition 5, however, a significant improvement in the RMS residual is obtained for a long period of the day with update from Wallops f_0F2 taken 9 hours earlier.

When the existing model update problem has been cured it will be advisable to investigate curves such as these in detail and devise a scheme which would indicate when and where a significant and necessary improvement in the model would be given by updating with data from a specific number of hours earlier.

6.6 Summary of Findings from Analysis of Residuals

The RMS and standard deviation of the residual group delay for the entire period and the percentage of the daytime ionosphere eliminated by the Bent model are graphically displayed in Figures 17 and 18 for each of the evaluation conditions. The RMS values for the predictions alone and the standard deviations for the predictions and for the best update condition are presented. Some of the updates give worse results than the predictions alone because of weak update station configurations or large distances between update and evaluation station. The graphs should be viewed with caution though, since it was found that by eliminating a single disturbed day out of the entire evaluation period, the total results could show significant improvement. On 24 March 1969, Stanford observed a daytime ionosphere a factor of 2 higher than on adjacent days; excluding these few hours from the reduction resulted in a 4.2% improvement of the overall RMS value.

Some important conclusions drawn from briefly investigating the residuals obtained during the contract analysis are now summarized.

a) Daytime residuals are higher than nighttime values.

b) Diurnal curves indicate a very wide range of residuals.

c) Seasonal trends are very large and may increase or decrease the maximum residual by a factor of 5. This can be validated by examining the data in volumes 2 and 3.

d) The diurnal data shows large differences in RMS and standard deviation of the residuals whereas the full data summary hides this fact. See Figure 19.

e) During local afternoon at an equatorial station under maximum solar cycle conditions, 17 nanoseconds (34%) in RMS residual remain or 10 nanoseconds (19%) in standard deviation from the mean. (Evaluation condition 4, Honolulu).

f) These high values are seasonally and diurnally dependent.

g) The Stanford ATS-1 and Stanford ATS-3 predictions give very similar results indicating a stable model.

h) Update of the model often gives significant improvement during local afternoon with dense ionospheres. This could assist in improving dense equatorial ionospheric predictions. Such an example is shown in Figure 19.

i) Update at night in general gives little improvement and often gives larger residuals than direct prediction. See Figure 13s.

j) Little advantage of updating with total electron content is shown over updating with f_oF2; the most significant feature being distance. See Figure 19 for nearby update.

k) In general, improvement in prediction is obtained by updating with data up to 3 or 5 hours old, but mainly this occurs during afternoon conditions. At times data 9 hours old give an improvement; such as local afternoon between 22 and 1 hours UT condition 5, Urbana ATS3. Comparison of Figures 13v and 16h demonstrate this point.

l) Nighttime update is reasonable only for nearby stations. See Figure 15a.

m) If the update stations are close to the evaluation station, the RMS and standard deviation are similar. However, if the update stations are far away, the RMS value is much larger than the standard deviation.

n) In 1969 the Wallops and Point Arguello f_oF2 update is good. In 1968 the Maui and Point Arguello update is also good, but that from Wallops is bad during local morning hours probably due to the weakness in the model update as mentioned in the text.

o) If one update station is close then single station update is better than multiple station update. See Figure 13t.

p) If the update stations are far away in a triangle with good N-S and E-W coverage then multiple update is better than the predictions or a single station update. See Figure 13v.

6.7 Probability Distributions

The cumulative probability distributions were computed for all the cases listed in Table 1. This included the update cases obtained with data up to 9 hours prior as well as for the entire period and the daytime only period. A typical distribution is shown in Table 9. This table indicates very little skewness in the model but other cases indicate varying degrees of bias. These results need no explanation and will not be discussed further in this report.

6.8 Correlation Coefficients

The evaluation station pairs discussed earlier and listed in Table 2 were used in computing the correlation coefficients. The results of this analysis are shown in Table 10. These numbers are extremely deceptive particularly for cases where the stations differ in local time, as the correlation has been performed, as requested, in terms of universal time. In other words the rapid sunrise changes occurring at Urbana 2 hours prior to Stanford, inject large errors into achieving good correlation. The daytime only (9-16 hours LT) correlation is therefore likely to be of more interest for the 621B system as no erratic changes occur during these hours.

Figures 20a to 20e indicate the diurnal correlation and show that the sunrise period is often denoted by a large reduction in the correlation coefficient. Once more these curves need little discussion and visual investigation shows immediately the diurnal pattern of correlation.

(Text continues on page 126)

TABLE 3. Comparison of Percent Errors for Even and Uneven Hourly Data Distribution

CONDITION NUMBER = 1 EVALUATION STATION = Stanford ATS-1

PERCENT ERROR STATISTICS FOR DAYTIME ONLY

Update Stations:	NR	EVEN DISTRIBUTION MEAN	EVEN DISTRIBUTION ST.DEV	EVEN DISTRIBUTION RMS	NON-EVEN DISTRIBUTION MEAN	NON-EVEN DISTRIBUTION ST.DEV	NON-EVEN DISTRIBUTION RMS
None	1411	2.880	23.322	24.894	3.306	26.834	27.028
Arec/Hono./Saga.	684	-5.426	35.731	36.868	-7.700	41.363	42.044
Arec./Hono.	828	-10.346	41.538	43.934	-13.633	47.208	49.110
Hono.	1194	-6.169	51.310	52.662	-8.364	56.640	57.230
Pt. Arguello	1293	-5.297	26.195	27.059	-6.348	28.798	29.479

TABLE 4. FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION	SATELLITE	MONTH / YEAR	1	2	3	4	5	6	7	8	9	10	11	12
HONO	SYN3	65	4453	4478	4493	4507	4532	4557	4557	4557	4527	4497	4480	4463
STAN	SYN3	65	2112	2124	2150	2177	2177	2177	2177	2178	2157	2137	2128	2118
HONO	ATS1	67												4979
STAN	ATS1	67												2448
HONO	ATS1	68	4993	5006	5039	5073	5109	5145	5124	5103	5068	5033	5012	4992
STAN	ATS1	68	2455	2461	2489	2516	2523	2530	2523	2516	2497	2479	2467	2456
EDMO	ATS1	68												1967
COLD	ATS1	68												2274
HONO	ATS1	69	5004	5016	5044	5072	5108	5144	5125	5106	5065	5025	4992	
STAN	ATS1	69	2461	2466	2491	2516	2522	2529	2523	2518	2496	2474	2445	
EDMO	ATS1	69	1969	1971	1988	2004	2006	2009	2007	2006	1992	1978	1960	
COLD	ATS1	69	2279	2283	2305	2326	2332	2339	2335	2332	2308	2283	2267	

TABLE 4 CONTINUED. FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION STAN   SATELLITE ATS3

YEAR	67	68	68	68	68	68	69	69	69	69	69	69	69	69	69	69	69
MONTH	12	1	2	3	4	12	1	2	3	4	5	6	7	8	9	10	11
DAY																	
1		2769	2779	2828	2864	2932	2964	2911	2908	2933	2957	2960	2936	2918	2928	2929	2893
2		2769	2779	2828	2864	2932	2964	2911	2908	2933	2957	2960	2936	2918	2928	2929	2893
3		2769	2779	2828	2864	2932	2960	2911	2908	2933	2957	2979	2936	2918	2928	2929	2893
4		2769	2779	2828	2864	2932	2960	2911	2908	2933	2957	2979	2936	2918	2928	2929	2893
5		2769	2805	2828	2864	2932	2960	2911	2908	2933	2957	2979	2936	2918	2928	2929	2893
6		2769	2805	2828	2864	2932	2960	2911	2908	2933	2957	2979	2936	2918	2928	2929	2893
7	2793	2769	2805	2828	2864	2932	2960	2911	2908	2933	2957	2993	2936	2918	2928	2929	2893
8	2793	2769	2825	2828	2864	2932	2960	2911	2908	2933	2957	2993	2936	2918	2928	2929	2893
9	2793	2769	2825	2828	2864	2932	2946	2911	2908	2933	2957	2993	2936	2918	2928	2929	2893
10	2769	2769	2825	2828	2864	2932	2946	2911	2908	2933	2957	2993	2936	2918	2928	2929	2893
11	2769	2779	2828	2864	2898	2937	2940	2908	2933	2957	2960	3006	2918	2928	2929	2893	2847
12	2769	2779	2828	2864	2898	2937	2940	2908	2933	2957	2960	3006	2918	2928	2929	2893	2845
13	2769	2779	2828	2864	2898	2937	2940	2908	2933	2957	2960	3006	2918	2928	2929	2893	2845
14	2769	2779	2828	2864	2898	2937	2940	2908	2933	2957	2960	3006	2918	2928	2929	2893	
15	2769	2779	2828	2864	2898	2937	2928	2908	2933	2957	2960	3012	2918	2928	2929	2893	
16	2769	2779	2828	2864	2898	2956	2928	2908	2933	2957	2960	3012	2918	2928	2929	2893	
17	2769	2779	2828	2864	2898	2956	2928	2908	2933	2957	2960	3012	2918	2928	2929	2893	
18	2769	2779	2828	2864	2898	2956	2928	2908	2933	2957	2960	3012	2918	2928	2929	2893	
19	2769	2779	2828	2864		2956	2928	2908	2933	2957	2960	3011	2918	2928	2929	2893	
20	2769	2779	2828	2864		2956	2928	2908	2933	2957	2960	3011	2918	2928	2929	2893	
21	2769	2779	2828	2864		2956	2928	2908	2933	2957	2960	3011	2918	2928	2929	2893	
22	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	3011	2918	2928	2929	2893	
23	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	3000	2918	2928	2929	2893	
24	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	3000	2918	2928	2929	2893	
25	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	3000	2918	2928	2929	2893	
26	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	3000	2918	2928	2929	2893	
27	2769	2779	2828	2864		2966	2928	2908	2933	2957	2960	2976	2918	2928	2929	2893	
28	2769	2779	2828	2864		2964	2928	2908	2933	2957	2960	2976	2918	2928	2929	2893	
29	2769	2779	2828	2864		2964	2911		2933	2957	2960	2976	2918	2928	2929	2893	
30	2769	2779		2864		2964	2911		2933	2957	2960	2976	2918	2928	2929	2893	
31	2769	2779		2864		2964	2911		2933		2960		2918	2928		2893	

TABLE 4 CONTINUED. FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION URBA SATELLITE ATS3

YEAR	67	68	68	68	68	68	69	69	69	69	69	69	69	69	69	69	69
MONTH	12	1	2	3	4	12	1	2	3	4	5	6	7	8	9	10	11
DAY																	
1		2360	2365	2379	2409	2354	2375	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
2		2360	2365	2379	2409	2354	2375	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
3		2360	2365	2379	2409	2354	2384	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
4		2360	2365	2379	2409	2354	2384	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
5		2360	2376	2379	2409	2354	2384	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
6		2360	2376	2379	2409	2354	2384	2389	2390	2416	2434	2439	2398	2394	2392	2383	2364
7	2366	2360	2376	2379	2409	2354	2384	2389	2390	2416	2434	2438	2398	2394	2392	2383	2364
8	2366	2360	2380	2379	2409	2354	2384	2389	2390	2416	2434	2438	2398	2394	2392	2383	2364
9	2366	2360	2380	2379	2409	2354	2387	2389	2390	2416	2434	2438	2398	2394	2392	2383	2364
10	2360	2360	2380	2379	2409	2354	2387	2389	2390	2416	2434	2438	2398	2394	2392	2383	2364
11	2360	2365	2379	2409	2431	2356	2387	2390	2416	2434	2439	2436	2394	2392	2383	2364	2335
12	2360	2365	2379	2409	2431	2356	2387	2390	2416	2434	2439	2436	2394	2392	2383	2364	2334
13	2360	2365	2379	2409	2431	2356	2387	2390	2416	2434	2439	2436	2394	2392	2383	2364	2334
14	2360	2365	2379	2409	2431	2356	2387	2390	2416	2434	2439	2436	2394	2392	2383	2364	
15	2360	2365	2379	2409	2431	2356	2389	2390	2416	2434	2439	2432	2394	2392	2383	2364	
16	2360	2365	2379	2409	2431	2363	2389	2390	2416	2434	2439	2432	2394	2392	2383	2364	
17	2360	2365	2379	2409	2431	2363	2389	2390	2416	2434	2439	2432	2394	2392	2383	2364	
18	2360	2365	2379	2409	2431	2363	2389	2390	2416	2434	2439	2432	2394	2392	2383	2364	
19	2360	2365	2379	2409		2363	2389	2390	2416	2434	2439	2427	2394	2392	2383	2364	
20	2360	2365	2379	2409		2363	2389	2390	2416	2434	2439	2427	2394	2392	2383	2364	
21	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2427	2394	2392	2383	2364	
22	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2427	2394	2392	2383	2364	
23	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2421	2394	2392	2383	2364	
24	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2421	2394	2392	2383	2364	
25	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2421	2394	2392	2383	2364	
26	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2421	2394	2392	2383	2364	
27	2360	2365	2379	2409		2369	2389	2390	2416	2434	2439	2412	2394	2392	2383	2364	
28	2360	2365	2379	2409		2375	2389	2390	2416	2434	2439	2412	2394	2392	2383	2364	
29	2360	2365	2379	2409		2375	2389		2416	2434	2439	2412	2394	2392	2383	2364	
30	2360	2365		2409		2375	2389		2416	2434	2439	2412	2394	2392	2383	2364	
31	2360	2365		2409		2375	2389		2416		2439		2394	2392		2364	

TABLE 4 CONTINUED, FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION AREC SATELLITE ATS3

YEAR	67	68	68	68	68
MONTH	12	1	2	3	4
DAY					
1		3956	3975	3947	3981
2		3956	3975	3947	3981
3		3956	3975	3947	3981
4		3956	3975	3947	3981
5		3956	3959	3947	3981
6		3956	3959	3947	3981
7	3946	3956	3959	3947	3981
8	3946.	3956	3951	3947	3981
9	3946	3956	3951	3947	3981
10	3955	3956	3951	3947	3981
11	3956	3975	3947	3981	4025
12	3956	3975	3947	3981	4025
13	3956	3975	3947	3981	4025
14	3956	3975	3947	3981	4025
15	3956	3975	3947	3981	4025
16	3956	3975	3947	3981	4025
17	3956	3975	3947	3981	4025
18	3956	3975	3947	3981	4025
19	3956	3975	3947	3981	
20	3956	3975	3947	3981	
21	3956	3975	3947	3981	
22	3956	3975	3947	3981	
23	3956	3975	3947	3981	
24	3956	3975	3947	3981	
25	3956	3975	3947	3981	
26	3956	3975	3947	3981	
27	3956	3975	3947	3981	
28	3956	3975	3947	3981	
29	3956	3975	3947	3981	
30	3956	3975		3981	
31	3956	3975		3981	

TABLE 4 CONTINUED. FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION SAGH SATELLITE ATS3

YEAR	67	68	68	68	68	68	68	68	68	68	68	68	68
MONTH	12	1	2	3	4	5	6	7	8	9	10	11	12
DAY													
1		2424	2431	2425	2445	2464	2421	2382	2354	2361	2357	2339	2319
2		2424	2431	2425	2445	2464	2421	2382	2354	2361	2357	2339	2319
3		2424	2431	2425	2445	2464	2421	2382	2354	2361	2357	2339	2319
4		2424	2431	2425	2445	2464	2421	2382	2354	2361	2357	2339	2319
5		2424	2430	2425	2445	2459	2421	2382	2354	2361	2357	2339	2319
6		2424	2430	2425	2445	2459	2421	2382	2354	2361	2357	2339	2319
7	2421	2424	2430	2425	2445	2450	2421	2382	2354	2361	2357	2339	2319
8	2421	2424	2428	2425	2445	2450	2421	2382	2354	2361	2357	2339	2319
9	2421	2424	2428	2425	2445	2440	2421	2368	2354	2361	2357	2339	2319
10	2423	2424	2428	2425	2445	2440	2421	2368	2354	2361	2357	2339	2329
11	2424	2431	2425	2445	2464	2430	2418	2365	2361	2346	2341	2319	2333
12	2424	2431	2425	2445	2464	2430	2418	2365	2361	2357	2341	2319	2333
13	2424	2431	2425	2445	2464	2421	2418	2365	2361	2357	2341	2319	2333
14	2424	2431	2425	2445	2464	2421	2418	2365	2361	2357	2341	2319	2333
15	2424	2431	2425	2445	2464	2421	2418	2354	2361	2357	2341	2319	2333
16	2424	2431	2425	2445	2464	2421	2418	2354	2361	2357	2339	2319	2344
17	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2344
18	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2344
19	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2344
20	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2344
21	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2344
22	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2357
23	2424	2431	2425	2445	2464	2421	2410	2354	2361	2357	2339	2319	2357
24	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2357
25	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2357
26	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2357
27	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2368
28	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2368
29	2424	2431	2425	2445	2464	2421	2400	2354	2361	2357	2339	2319	2368
30	2424	2431		2445	2464	2421	2400	2354	2361	2357	2339	2319	2368
31	2424	2431		2445		2421		2354	2361		2339		2368

TABLE 4 CONTINUED. FARADAY ROTATION FACTORS (1.E11/(DEG*M**2))

STATION SAGH SATELLITE ATS3

YEAR	69	69	69	69	69	69	69	69	69	69	69
MONTH	1	2	3	4	5	6	7	8	9	10	11
DAY											
1	2368	2409	2408	2428	2445	2449	2361	2356	2358	2350	2334
2	2368	2409	2408	2428	2445	2449	2361	2356	2358	2350	2334
3	2384	2409	2408	2428	2445	2441	2361	2356	2358	2350	2334
4	2384	2409	2408	2428	2445	2441	2361	2356	2358	2350	2334
5	2384	2409	2408	2428	2445	2441	2361	2356	2358	2350	2334
6	2384	2409	2408	2428	2445	2441	2361	2356	2358	2350	2334
7	2384	2409	2408	2428	2445	2433	2361	2356	2358	2350	2334
8	2384	2409	2408	2428	2445	2433	2361	2356	2358	2350	2334
9	2394	2409	2408	2428	2445	2433	2361	2356	2358	2350	2334
10	2394	2409	2408	2428	2445	2433	2361	2356	2358	2350	2334
11	2397	2408	2428	2445	2449	2425	2356	2358	2350	2334	2305
12	2397	2408	2428	2445	2449	2425	2356	2358	2350	2334	2305
13	2397	2408	2428	2445	2449	2425	2356	2358	2350	2334	2305
14	2397	2408	2428	2445	2449	2425	2356	2358	2350	2334	
15	2402	2408	2428	2445	2449	2415	2356	2358	2350	2334	
16	2402	2408	2428	2445	2449	2415	2356	2358	2350	2334	
17	2402	2408	2428	2445	2449	2415	2356	2358	2350	2334	
18	2402	2408	2428	2445	2449	2415	2356	2358	2350	2334	
19	2402	2408	2428	2445	2449	2404	2356	2358	2350	2334	
20	2402	2408	2428	2445	2449	2404	2356	2358	2350	2334	
21	2402	2408	2428	2445	2449	2404	2356	2358	2350	2334	
22	2402	2408	2428	2445	2449	2404	2356	2358	2350	2334	
23	2402	2408	2428	2445	2449	2393	2356	2358	2350	2334	
24	2402	2408	2428	2445	2449	2393	2356	2358	2350	2334	
25	2402	2408	2428	2445	2449	2393	2356	2358	2350	2334	
26	2402	2408	2428	2445	2449	2393	2356	2358	2350	2334	
27	2402	2408	2428	2445	2449	2380	2356	2358	2350	2334	
28	2409	2408	2428	2445	2449	2380	2356	2358	2350	2334	
29	2409		2428	2445	2449	2380	2356	2358	2350	2334	
30	2409		2428	2445	2449	2380	2356	2358	2350	2334	
31	2409		2428		2449		2356	2358		2334	

TABLE 5a

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR <u>CONDITION 1</u>, 8 DECEMBER 1967 TO 18 APRIL 1968

HOURS PRIOR TO EVALUATION TIME: <u>1</u>

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	MEAN %ER	MEAN REC	MEAN RGD	STANDARD DEVIATION %ER	STANDARD DEVIATION REC	STANDARD DEVIATION RGD	ROOT MEAN SQUARE %ER	ROOT MEAN SQUARE REC	ROOT MEAN SQUARE RGD	NUMBER OF RESIDUALS
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		1.21	.63		4.75	2.49		5.43	2.85	2800
*	2.88	2.74	1.44	23.32	5.87	3.08	24.89	6.74	3.54	1411
ARECIBO ATS-3		-2.48	-1.30		6.40	3.36		7.32	3.84	1643
*HONOLULU ATS-1	-10.35	-2.55	-1.34	41.54	7.97	4.18	43.93	8.86	4.65	828
HONOLULU ATS-1		-1.05	-.55		8.81	4.62		9.23	4.85	2403
*	-6.17	-1.09	-.57	51.31	10.97	5.76	52.66	11.40	5.99	1194
POINT ARGUELLO		-.77	-.40		4.47	2.34		4.76	2.50	2282
*	-5.30	-1.21	-.63	26.20	5.61	2.94	27.06	5.95	3.12	1293
FOR EVALUATION STATION: STANFORD ATS-3										
NONE		1.17	.61		4.80	2.52		5.49	2.88	2884
*	4.32	2.81	1.47	18.16	5.95	3.12	19.26	6.83	3.59	1495
ARECIBO ATS-3		-2.33	-1.23		6.24	3.28		7.17	3.77	1680
*HONOLULU ATS-1	-8.53	-2.27	-1.19	28.27	7.87	4.13	31.32	8.75	4.59	885
SAG HILL ATS-3		1.19	.62		5.76	3.03		6.48	3.40	2324
*	5.84	2.59	1.36	20.99	7.03	3.69	23.04	7.98	4.19	1189
POINT ARGUELLO		-.91	-.48		4.88	2.56		5.15	2.70	2337
*	-4.09	-1.15	-.60	17.91	6.03	3.17	19.11	6.33	3.32	1353

TABLE 5b

UPDATE CONDITION	<------ MEAN %ER	REC	RGD ------->	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER RESIDU
FOR EVALUATION STATION: URBANA ATS-3										
NONE		-.24	-.13		4.87	2.56		5.15	2.70	24
*	-5.26	-.01	-.01	20.80	5.85	3.07	24.02	6.21	3.26	12
ARECIBO ATS-3		-4.47	-2.35		6.28	3.30		8.29	4.35	15
*HONOLULU ATS-1	-15.80	-4.61	-2.42	25.78	7.79	4.09	32.68	9.86	5.18	7
SAG HILL ATS-3		.88	.46		3.33	1.75		3.76	1.97	19
*	3.90	1.69	.88	10.80	3.81	2.00	12.35	4.40	2.31	9
WALLOPS ISLAND		-2.86	-1.50		4.31	2.26		5.44	2.86	19
*	-13.23	-3.19	-1.67	18.00	5.12	2.69	24.84	6.46	3.39	10
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-.89	-.47		4.59	2.41		5.40	2.84	25
*	-11.47	-1.80	-.94	22.30	5.68	2.98	28.83	6.88	3.61	12
ARECIBO ATS-3		-4.48	-2.35		6.46	3.39		8.07	4.24	15
*HONOLULU ATS-1	-20.64	-5.32	-2.79	31.06	8.61	4.52	38.25	10.36	5.44	7
ARECIBO ATS-3		-5.16	-2.71		5.37	2.82		7.76	4.07	18
*	-23.43	-6.02	-3.16	26.07	6.89	3.62	36.55	9.57	5.02	9
WALLOPS ISLAND		-3.40	-1.78		4.41	2.32		6.45	3.39	18
*	-21.04	-5.15	-2.71	25.19	5.69	2.99	37.48	8.53	4.48	9

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 2, 8 DECEMBER 1967 TO 18 APRIL 1968

HOURS PRIOR TO EVALUATION TIME: 1

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

	<------ MEAN	------->		STANDARD DEVIATION			ROOT MEAN SQUARE			NUMBER OF
UPDATE CONDITION	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUALS
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		1.21	.63		4.75	2.49		5.43	2.85	2800
	2.88	2.74	1.44	23.32	5.87	3.08	24.89	6.74	3.54	1411
ARECIBO ATS-3		-1.35	-.71		5.05	2.65		5.57	2.92	1357
HONOLULU ATS-1	-5.43	-.95	-.50	35.73	6.23	3.27	36.87	6.63	3.48	684
SAG HILL ATS-3										
HONOLULU ATS-1		-1.05	-.55		8.81	4.62		9.23	4.85	2403
	-6.17	-1.09	-.57	51.31	10.97	5.76	52.66	11.40	5.99	1194
POINT ARGUELLO		-.77	-.40		4.47	2.34		4.76	2.50	2282
	-5.30	-1.21	-.63	26.20	5.61	2.94	27.06	5.95	3.12	1293
FOR EVALUATION STATION: STANFORD ATS-3										
NONE		1.17	.61		4.80	2.52		5.49	2.88	2884
	4.32	2.81	1.47	18.16	5.95	3.12	19.26	6.83	3.59	1495
ARECIBO ATS-3		-.98	-.51		4.83	2.54		5.38	2.83	1382
HONOLULU ATS-1	-2.52	-.39	-.20	20.64	6.03	3.16	22.03	6.47	3.40	718
SAG HILL ATS-3										
SAG HILL ATS-3		1.19	.62		5.76	3.03		6.48	3.40	2324
	5.84	2.59	1.36	20.99	7.03	3.69	23.04	7.98	4.19	1189
POINT ARGUELLO		-.91	-.48		4.88	2.56		5.15	2.70	2337
	-4.09	-1.15	-.60	17.91	6.03	3.17	19.11	6.33	3.32	1353

TABLE 5d

UPDATE CONDITION	<------- MEAN -------> %ER	REC	RGD	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER O[illegible] RESIDUA[illegible]
FOR EVALUATION STATION: URBANA ATS-3										
NONE		-.24	-.13		4.87	2.56		5.15	2.70	242[illegible]
*	-5.26	-.01	-.01	20.80	5.85	3.07	24.02	6.21	3.26	120[illegible]
ARECIBO ATS-3		-1.71	-.90		3.60	1.89		4.27	2.24	124[illegible]
*HONOLULU ATS-1	-5.39	-1.33	-.70	14.26	4.31	2.26	16.67	4.85	2.55	57[illegible]
SAG HILL ATS-3										
SAG HILL ATS-3		.88	.46		3.33	1.75		3.76	1.97	192[illegible]
*	3.90	1.69	.88	10.80	3.81	2.00	12.35	4.40	2.31	92[illegible]
WALLOPS ISLAND		-2.86	-1.50		4.31	2.26		5.44	2.86	192[illegible]
*	-13.23	-3.19	-1.67	18.00	5.12	2.69	24.84	6.46	3.39	100[illegible]

TABLE 5e

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 3, 1 JANUARY 1965 TO 31 DECEMBER 1965

HOURS PRIOR TO EVALUATION TIME: 1

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

	<------ MEAN ------>			STANDARD DEVIATION			ROOT MEAN SQUARE			NUMBER OF
UPDATE CONDITION	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUAL
FOR EVALUATION STATION: HONOLULU SYN-3										
NONE		.59	.31		4.97	2.61		5.38	2.83	8241
*	-2.34	-.00	-.00	25.71	6.08	3.19	29.78	6.55	3.44	419
STANFORD SYN-3		1.09	.57		5.71	3.00		5.92	3.11	602
*	2.81	.99	.52	25.57	6.84	3.59	27.05	7.07	3.71	314

TABLE 5f

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR <u>CONDITION 4</u>, 1 JANUARY 1968 TO 31 DECEMBER 1968

HOURS PRIOR TO EVALUATION TIME: 1

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN %ER	REC	RGD ------>	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER OF RESIDUAL[S]
FOR EVALUATION STATION: HONOLULU ATS-1										
NONE		2.90	1.52		11.99	6.29		13.07	6.86	820
*	5.02	5.45	2.86	24.59	14.00	7.35	25.68	15.48	8.13	424
STANFORD ATS-1		1.93	1.02		12.88	6.76		13.23	6.94	743
*	1.06	2.58	1.35	26.01	15.01	7.88	26.24	15.42	8.10	388
MAUI		-1.95	-1.02		7.77	4.08		8.35	4.38	6941
*	-4.37	-2.44	-1.28	20.16	9.38	4.92	22.48	10.10	5.30	381
POINT ARGUELLO		-.16	-.09		16.50	8.66		16.66	8.75	700
*	-5.95	-.80	-.42	36.52	19.70	10.34	37.34	19.85	10.42	398
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-1.08	-.57		4.24	2.23		4.96	2.60	778
*	-12.47	-2.03	-1.07	22.93	5.22	2.74	28.62	6.29	3.30	389
STANFORD ATS-1		-.93	-.49		5.72	3.00		6.07	3.19	706
*	-10.41	-1.88	-.99	31.55	7.41	3.89	34.18	7.93	4.17	352
WALLOPS ISLAND		-2.70	-1.42		4.30	2.26		5.64	2.96	6085
*	-15.90	-3.69	-1.94	23.57	5.55	2.91	31.49	7.32	3.84	3237
POINT ARGUELLO		-1.93	-1.01		6.67	3.50		7.51	3.94	6625
*	-16.33	-3.68	-1.93	34.96	8.77	4.60	39.75	10.02	5.26	3354

TABLE 5g

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR <u>CONDITION 4,</u> 1 JANUARY 1968 TO 31 DECEMBER 1968

HOURS PRIOR TO EVALUATION TIME: <u>2</u>

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

	<------ MEAN ------->			STANDARD DEVIATION			ROOT MEAN SQUARE			NUMBER O[illegible]
UPDATE CONDITION	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUA[illegible]
FOR EVALUATION STATION: HONOLULU ATS-1										
NONE		2.90	1.52		11.99	6.29		13.07	6.86	82[illegible]
*	5.02	5.45	2.86	24.59	14.00	7.35	25.68	15.48	8.13	42[illegible]
STANFORD ATS-1		1.77	.93		12.67	6.65		12.98	6.81	74[illegible]
*	1.32	2.50	1.31	25.39	14.82	7.78	25.85	15.21	7.98	38[illegible]
MAUI		-1.86	-.98		10.34	5.43		10.91	5.73	69[illegible]
*	-4.58	-2.05	-1.07	28.11	12.57	6.60	30.30	13.27	6.97	37[illegible]
POINT ARGUELLO		-.40	-.21		16.40	8.61		16.53	8.68	70
*	-5.75	-.86	-.45	35.79	19.65	10.32	36.71	19.81	10.40	39
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-1.08	-.57		4.24	2.23		4.96	2.60	77
*	-12.47	-2.03	-1.07	22.93	5.22	2.74	28.62	6.29	3.30	38
STANFORD ATS-1		-.68	-.36		5.97	3.13		6.16	3.23	70
*	-8.25	-1.21	-.64	31.74	7.75	4.07	33.39	8.04	4.22	35
WALLOPS ISLAND		-2.82	-1.48		5.04	2.65		6.45	3.39	60
*	-18.46	-3.99	-2.09	30.81	6.57	3.45	40.19	8.44	4.43	31[illegible]
POINT ARGUELLO		-1.68	-.88		6.78	3.56		7.38	3.88	66
*	-13.94	-2.99	-1.57	34.95	8.90	4.67	38.46	9.79	5.14	32

TABLE 5h

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

HOURS PRIOR TO EVALUATION TIME: 3

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN		------->	STANDARD DEVIATION			ROOT MEAN SQUARE			NUMBER
	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDU
FOR EVALUATION STATION: HONOLULU ATS-1										
NONE		2.90	1.52		11.99	6.29		13.07	6.86	82
*	5.02	5.45	2.26	24.59	14.00	7.35	25.68	15.48	8.13	42
STANFORD ATS-1		1.70	.89		12.77	6.71		13.07	6.86	74
*	1.99	2.75	1.44	26.67	15.03	7.89	27.34	15.45	8.11	38
MAUI		-1.59	-.83		12.38	6.50		12.99	6.82	69
*	-3.32	-1.42	-.75	34.26	15.16	7.96	37.01	15.90	8.35	37
POINT ARGUELLO		-.55	-.29		16.43	8.62		16.54	8.69	70
*	-4.48	-.66	-.35	35.54	19.83	10.41	36.76	19.98	10.49	39
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-1.08	-.57		4.24	2.23		4.96	2.60	77
*	-12.47	-2.03	-1.07	22.93	5.22	2.74	28.62	6.29	3.30	38
STANFORD ATS-1		-.43	-.22		6.23	3.27		6.32	3.32	70
*	-6.74	-.58	-.31	32.29	8.12	4.26	33.30	8.24	4.32	35
WALLOPS ISLAND		-3.07	-1.61		6.00	3.15		7.60	3.99	60
*	-21.90	-4.68	-2.46	34.18	7.98	4.19	46.29	10.16	5.34	31
POINT ARGUELLO		-1.34	-.70		6.82	3.58		7.17	3.76	66
*	-11.58	-2.15	-1.13	34.83	8.92	4.68	37.14	9.42	4.95	31

TABLE 5i

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

HOURS PRIOR TO EVALUATION TIME: 5

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------- MEAN %ER	REC	RGD ------->	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER RESIDU
FOR EVALUATION STATION: HONOLULU ATS-1										
NONE		2.90	1.57		11.99	6.29		13.07	6.86	82
*	5.02	5.45	2.86	24.59	14.00	7.35	25.68	15.48	8.13	42
STANFORD ATS-1		1.73	.91		13.66	7.17		14.07	7.39	74
*	3.38	3.44	1.81	28.25	16.37	8.59	29.60	16.93	8.89	38
MAUI		-.82	-.43		16.68	8.76		17.40	9.14	69
*	-1.12	.28	.15	43.68	20.82	10.93	46.79	21.68	11.38	37
POINT ARGUELLO		-.58	-.31		16.65	8.74		16.87	8.85	69
*	-2.15	.10	.05	35.66	20.28	10.65	37.31	20.52	10.77	37
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-1.08	-.57		4.24	2.23		4.96	2.60	77
*	-12.47	-2.03	-1.07	22.93	5.22	2.74	28.62	6.29	3.30	38
STANFORD ATS-1		-.05	-.02		6.55	3.44		6.67	3.50	7[illegible]
*	-3.39	.50	.26	32.15	8.55	4.49	32.67	8.70	4.57	3[illegible]
WALLOPS ISLAND		-3.76	-1.98		8.43	4.42		10.68	5.61	6[illegible]
*	-27.02	-6.40	-3.36	38.98	11.53	6.05	54.05	14.70	7.72	3[illegible]
POINT ARGUELLO		-.71	-.37		6.86	3.60		6.97	3.66	6[illegible]
*	-6.99	-.56	-.29	34.26	8.89	4.67	35.18	9.01	4.73	3[illegible]

TABLE 5j

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

HOURS PRIOR TO EVALUATION TIME: 9

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN %ER	REC	RGD ------->	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER RESIDU
FOR EVALUATION STATION: HONOLULU ATS-1										
NONE		2.90	1.52		11.99	6.29		13.07	6.86	82
*	5.02	5.45	2.86	24.59	14.00	7.35	25.68	15.48	8.13	42
STANFORD ATS-1		2.92	1.53		15.36	8.06		16.88	8.86	74
*	7.96	6.35	3.33	31.01	18.68	9.80	34.69	20.70	10.87	38
MAUI		1.42	.75		22.87	12.01		24.11	12.66	69
*	4.44	5.00	2.62	50.26	28.91	15.18	52.51	30.42	15.97	34
POINT ARGUELLO		1.17	.62		16.57	8.70		17.95	9.42	69
*	4.51	4.07	2.14	35.35	20.00	10.50	39.24	21.77	11.43	34
FOR EVALUATION STATION: SAG HILL ATS-3										
NONE		-1.08	-.57		4.24	2.23		4.96	2.60	778
*	-12.47	-2.03	-1.07	22.93	5.22	2.74	28.62	6.29	3.30	389
STANFORD ATS-1		.52	.27		6.71	3.52		7.23	3.79	706
*	.66	1.87	.98	34.30	8.77	4.61	36.23	9.45	4.96	34
WALLOPS ISLAND		-4.63	-2.43		9.88	5.19		12.50	6.56	607
*	-33.93	-8.56	-4.49	45.22	13.63	7.16	60.43	17.36	9.11	282
POINT ARGUELLO		.10	.05		8.00	4.20		8.37	4.40	662
*	-2.10	1.32	.69	39.84	10.63	5.58	41.75	11.11	5.83	300

TABLE 5k

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 5, 1 DECEMBER 1968 TO 13 NOVEMBER 1969

HOURS PRIOR TO EVALUATION TIME: 1

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN %ER	REC	RGD ------>	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER OF RESIDUALS
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		.89	.46		5.81	3.05		6.00	3.15	8008
*	-.57	1.70	.89	27.05	7.12	3.74	27.24	7.36	3.87	4003
EDMONTON ATS-1		-1.85	-.97		4.14	2.17		4.59	2.41	6598
*SAG HILL ATS-3	-7.95	-1.28	-.67	19.94	4.95	2.60	22.08	5.19	2.72	3341
HONOLULU ATS-1										
EDMONTON ATS-1		-3.22	-1.69		5.29	2.78		6.39	3.36	7251
*	-11.22	-2.08	-1.09	23.75	6.37	3.34	29.21	6.91	3.63	3705
POINT ARGUELLO		.11	.06		4.14	2.17		4.17	2.19	7406
*	-1.28	.03	.02	19.04	5.12	2.69	19.25	5.16	2.71	3819
FOR EVALUATION STATION: STANFORD ATS-3										
NONE		1.28	.67		6.02	3.16		6.44	3.38	2856
*	3.02	2.64	1.39	24.36	7.25	3.81	24.56	7.79	4.09	1412
EDMONTON ATS-1		-2.65	-1.39		4.82	2.53		5.54	2.91	2494
*SAG HILL ATS-3	-9.59	-2.05	-1.08	20.43	5.71	3.00	22.88	6.15	3.23	1254
HONOLULU ATS-1										
EDMONTON ATS-1		-4.51	-2.37		6.09	3.20		7.67	4.03	2645
*	-14.64	-3.70	-1.94	23.80	7.28	3.82	29.14	8.36	4.39	1333
POINT ARGUELLO		-.15	-.08		4.61	2.42		4.79	2.52	2612
*	.56	-.03	-.02	15.34	5.57	2.92	16.18	5.78	3.03	1334

TABLE 5ℓ

UPDATE CONDITION	<------ MEAN %ER	REC	RGD ------>	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER RESID
FOR EVALUATION STATION: COLD BAY ATS-1										
NONE		.69	.36		4.94	2.59		5.14	2.70	54
*	-.03	1.32	.69	24.35	5.99	3.14	24.57	6.20	3.25	26
EDMONTON ATS-1		-2.38	-1.25		4.81	2.52		5.46	2.87	46
*SAG HILL ATS-3	-12.47	-2.20	-1.15	25.32	5.46	2.87	28.98	6.09	3.19	23
HONOLULU ATS-1										
EDMONTON ATS-1		-3.50	-1.84		5.50	2.89		6.65	3.49	50
*	-13.80	-2.17	-1.14	28.51	6.02	3.16	32.40	6.49	3.41	25
FOR EVALUATION STATION: URBANA ATS-3										
NONE		2.12	1.11		5.48	2.88		5.95	3.12	79
*	2.85	1.67	.88	21.27	6.38	3.35	21.75	6.72	3.53	39
EDMONTON ATS-1		.60	.32		3.59	1.89		3.66	1.92	67
*SAG HILL ATS-3	-.64	.46	.24	14.01	3.95	2.08	14.15	4.00	2.10	33
HONOLULU ATS-1										
SAG HILL ATS-3		1.81	.95		3.59	1.88		4.24	2.23	76
*	6.95	2.32	1.22	11.70	3.90	2.05	14.76	4.79	2.52	38
WALLOPS ISLAND		.61	.32		4.41	2.31		4.56	2.40	59
*	.22	.27	.14	16.82	5.11	2.68	17.24	5.26	2.76	32

TABLE 5m

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 5, 1 DECEMBER 1968 TO 13 NOVEMBER 1969

HOURS PRIOR TO EVALUATION TIME: 2

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN -------> %ER	REC	RGD	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER O[F] RESIDUA[LS]
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		.89	.46		5.81	3.05		6.00	3.15	800
*	-.57	1.70	.89	27.05	7.12	3.74	27.24	7.36	3.87	400
EDMONTON ATS-1		-1.85	-.97		4.50	2.36		4.90	2.57	66[illegible]
*SAG HILL ATS-3	-9.10	-1.33	-.70	22.89	5.41	2.84	25.59	5.64	2.96	33[illegible]
HONOLULU ATS-1										
EDMONTON ATS-1		-3.47	-1.82		5.62	2.95		6.85	3.60	725
*	-15.25	-2.82	-1.48	29.36	6.79	3.56	38.36	7.73	4.06	36[illegible]
POINT ARGUELLO		.14	.07		4.99	2.62		5.08	2.67	74[illegible]
*	-1.09	.26	.13	23.01	6.16	3.23	23.47	6.29	3.30	38[illegible]
FOR EVALUATION STATION: URBANA ATS-3										
NONE		2.12	1.11		5.48	2.88		5.95	3.12	794
*	2.85	1.67	.88	21.27	6.38	3.35	21.75	6.72	3.53	396
EDMONTON ATS-1		.65	.34		3.89	2.04		4.00	2.10	672
*SAG HILL ATS-3	-.31	.57	.30	15.23	4.38	2.30	15.53	4.50	2.36	331
HONOLULU ATS-1										
SAG HILL ATS-3		2.05	1.08		3.89	2.04		4.65	2.44	76[illegible]
*	8.33	2.85	1.50	13.05	4.29	2.25	16.17	5.36	2.82	38[illegible]
WALLOPS ISLAND		.61	.32		4.97	2.61		5.17	2.72	59[illegible]
*	-.20	.24	.13	19.90	5.78	3.04	20.45	5.99	3.15	32[illegible]

TABLE 5n

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 5, 1 DECEMBER 1968 TO 13 NOVEMBER 1969

HOURS PRIOR TO EVALUATION TIME: 3

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------- MEAN -------> %ER	REC	RGD	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER RESIDL
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		.89	.46		5.81	3.05		6.00	3.15	80
*	-.57	1.70	.89	27.05	7.12	3.74	27.24	7.36	3.87	40
EDMONTON ATS-1		-1.86	-.98		4.92	2.58		5.30	2.78	65
*SAG HILL ATS-3	-9.58	-1.40	-.74	23.62	6.00	3.15	26.22	6.22	3.27	33
HONOLULU ATS-1										
EDMONTON ATS-1		-3.84	-2.02		6.14	3.22		7.62	4.00	72
*	-18.26	-3.76	-1.97	29.60	7.51	3.94	39.42	8.98	4.72	36
POINT ARGUELLO		.24	.12		5.46	2.86		5.62	2.95	74
*	-.16	.53	.28	23.26	6.74	3.54	23.91	6.95	3.65	37
FOR EVALUATION STATION: URBANA ATS-3										
NONE		2.12	1.11		5.48	2.88		5.95	3.12	79
*	2.85	1.67	.88	21.27	6.38	3.35	21.75	6.72	3.53	39
EDMONTON ATS-1		.66	.35		4.26	2.23		4.41	2.32	67
*SAG HILL ATS-3	-.71	.57	.30	16.82	4.83	2.54	17.35	5.01	2.63	32
HONOLULU ATS-1										
SAG HILL ATS-3		2.19	1.15		4.40	2.31		5.22	2.74	76
*	8.10	3.13	1.64	17.17	4.95	2.60	19.73	6.10	3.20	38
WALLOPS ISLAND		.48	.25		5.60	2.94		5.84	3.07	59
*	-1.87	-.04	-.02	25.06	6.63	3.48	26.04	6.89	3.62	32

TABLE 5o

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 5, 1 DECEMBER 1968 TO 13 NOVEMBER 1969

HOURS PRIOR TO EVALUATION TIME: 5

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

	<------ MEAN ------->			STANDARD DEVIATION			ROOT MEAN SQUARE			NUMBER OF
UPDATE CONDITION	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUALS
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		.89	.46		5.81	3.05		6.00	3.15	8008
*	-.57	1.70	.89	27.05	7.12	3.74	27.24	7.36	3.87	4003
EDMONTON ATS-1		-1.93	-1.01		5.58	2.93		5.94	3.12	6604
*SAG HILL ATS-3	-9.91	-1.58	-.83	25.05	6.88	3.61	27.54	7.14	3.75	3230
HONOLULU ATS-1										
EDMONTON ATS-1		-4.73	-2.48		7.09	3.72		9.31	4.89	7255
*	-23.28	-5.71	-3.00	33.24	8.84	4.64	44.42	11.53	6.05	3638
POINT ARGUELLO		.57	.30		5.87	3.08		6.21	3.26	7409
*	2.06	1.30	.68	23.75	7.22	3.79	25.03	7.67	4.03	3713
FOR EVALUATION STATION: URBANA ATS-3										
NONE		2.12	1.11		5.48	2.88		5.95	3.12	7947
*	2.85	1.67	.88	21.27	6.38	3.35	21.75	6.72	3.53	3963
EDMONTON ATS-1		.52	.27		5.08	2.67		5.33	2.80	6731
*SAG HILL ATS-3	-2.56	.20	.10	20.82	5.98	3.14	22.17	6.27	3.29	3204
HONOLULU ATS-1										
SAG HILL ATS-3		2.14	1.13		5.55	2.92		6.41	3.37	7692
*	6.30	2.92	1.53	23.09	6.60	3.47	25.85	7.76	4.08	3837
WALLOPS ISLAND		-.12	-.06		7.56	3.97		8.11	4.26	5961
*	-5.96	-1.32	-.69	32.51	9.38	4.93	35.27	10.05	5.28	3087

TABLE 5p

RESIDUAL (MEASURED - PREDICTED/UPDATED) ANALYSIS FOR ENTIRE PERIOD
AND FOR DAYTIME ONLY FOR CONDITION 5, 1 DECEMBER 1968 TO 13 NOVEMBER 1969

HOURS PRIOR TO EVALUATION TIME: 9

%ER = PERCENT ERROR OF OBSERVED ELECTRON CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS
LINE 1, FOR ENTIRE PERIOD, LINE 2, (*) FOR DAYTIME ONLY

UPDATE CONDITION	<------ MEAN ------> %ER	REC	RGD	STANDARD DEVIATION %ER	REC	RGD	ROOT MEAN SQUARE %ER	REC	RGD	NUMBER [illegible] RESIDUA[illegible]
FOR EVALUATION STATION: STANFORD ATS-1										
NONE		.89	.46		5.81	3.05		6.00	3.15	800[illegible]
*	-.57	1.70	.89	27.05	7.12	3.74	27.24	7.36	3.87	400[illegible]
EDMONTON ATS-1 *SAG HILL ATS-3 HONOLULU ATS-1		-2.19	-1.15		6.85	3.60		7.22	3.79	660[illegible]
*	-12.64	-2.20	-1.15	30.82	8.66	4.54	33.94	9.00	4.72	316[illegible]
EDMONTON ATS-1		-6.00	-3.15		9.03	4.74		11.98	6.29	726
*	-32.49	-8.36	-4.39	44.07	11.48	6.03	57.42	15.28	8.02	355
POINT ARGUELLO		1.55	.81		6.83	3.59		7.65	4.02	741
*	6.35	3.35	1.76	26.42	8.46	4.44	28.28	9.55	5.01	360
FOR EVALUATION STATION: URBANA ATS-3										
NONE		2.12	1.11		5.48	2.88		5.95	3.12	794
*	2.85	1.67	.88	21.27	6.38	3.35	21.75	6.72	3.53	396
EDMONTON ATS-1 *SAG HILL ATS-3 HONOLULU ATS-1		-.03	-.01		6.09	3.20		6.53	3.43	673
*	-6.16	-1.14	-.60	23.62	7.31	3.84	25.85	7.83	4.11	330
SAG HILL ATS-3		1.44	.75		7.15	3.75		7.92	4.16	769[illegible]
*	1.15	1.02	.54	26.95	8.80	4.62	29.67	9.68	5.08	3831
WALLOPS ISLAND		-1.08	-.57		9.75	5.12		10.90	5.72	596[illegible]
*	-11.35	-3.39	-1.78	36.56	12.33	6.47	40.74	13.77	7.23	279[illegible]

TABLE 6a. Summary of RMS and Standard Deviation of Residuals in Group Delay (nanoseconds) for the Entire Evaluation Period and for Update Conditions 1 Hour Prior to Evaluation Time

Condition	Period	Evaluation Station	Update Stations	RMS	Standard Deviation	Maximum RMS*
1 & 2	12/8/67 --- 4/18/68	Stanford ATS1	none	2.85	2.49	5.73
			Arec.ATS3, Hono.ATS1, Saga.ATS3	2.92	2.65	3.81
			Arec.ATS3, Hono.ATS1	3.84	3.36	5.56
			Hono.ATS1	4.85	4.62	5.49
			Pt. Arguello	2.50	2.34	2.19
		Stanford ATS3	none	2.88	2.52	5.71
			Arec.ATS3, Hono.ATS1, Saga.ATS3	2.83	2.54	3.34
			Arec.ATS3, Hono.ATS1	3.77	3.28	2.92
			Saga.ATS3	3.40	3.03	4.94
			Pt. Arguello	2.70	2.56	4.96
		Urbana ATS3	none	2.70	2.56	5.61
			Arec.ATS3, Hono.ATS1, Saga.ATS3	2.24	1.89	4.97
			Arec.ATS3, Hono.ATS1	4.35	3.30	10.14
			Saga.ATS3	1.97	1.75	1.89
			Wallops Island	2.86	2.26	4.80
		Sagamore ATS3	none	2.84	2.41	6.70
			Arec.ATS3, Hono.ATS1	4.24	3.39	--
			Arec.ATS3	4.07	2.82	6.18
			Wallops Island	3.39	2.32	4.61

* The maximum RMS residual was chosen from the hourly variation of the monthly averages of the prediction alone and the values corresponding to the same hour and month are filled in for the update conditions.

TABLE 6b. Summary of RMS and Standard Deviation of Residuals in Group Delay (nanoseconds) for the Entire Evaluation Period and for Update Conditions 1 Hour Prior to Evaluation Time

Condition	Period	Evaluation Station	Update Stations	RMS	Standard Deviation	Maximum RMS
3	1/1/65 – 12/31/65	Honolulu SYN3	none	2.83	2.61	7.59
			Stan. SYN3	3.11	3.00	4.59
4	1/1/68 – 12/31/68	Honolulu ATS1	none	6.86	6.29	20.49
			Stan. ATS1	6.94	6.76	19.44
			Maui	4.38	4.08	6.34
			Pt. Arguello	8.75	8.66	21.70
		Sagamore ATS3	none	2.60	2.23	6.16
			Stan. ATS1	3.19	3.00	6.64
			Wallops Island	2.96	2.26	6.55
			Pt. Arguello	3.94	3.50	7.78
5	12/1/68 – 11/13/69	Stanford ATS1	none	3.15	3.05	7.91
			Edmo. ATS1, Saga. ATS3, Hono. ATS1	2.41	2.17	3.74
			Edmo. ATS1	3.36	2.78	3.12
			Pt. Arguello	2.19	2.17	5.65
		Stanford ATS3	none	3.38	3.16	7.09
			Edmo. ATS1, Saga. ATS3, Hono. ATS1	2.91	2.53	3.70
			Edmo. ATS1	4.03	3.20	3.24
			Pt. Arguello	2.52	2.42	5.26
		Cold Bay ATS1	none	2.70	2.59	6.81
			Edmo. ATS1, SAGA. ATS3, Hono. ATS1	2.87	2.52	5.16
			Edmo. ATS1	3.49	2.89	6.22
		Urbana ATS3	none	3.12	2.88	6.94
			Edmo. ATS1, Saga. ATS3, Hono. ATS1	1.92	1.89	3.25
			Saga. ATS3	2.23	1.88	3.09
			Wallops Island	2.40	2.31	5.43

TABLE 7a

HOURLY VARIATION OF RESIDUALS (MEASURED - PREDICTED/UPDATED) EVALUATED FOR
CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

EVALUATION STATION: HONOLULU ATS-1 LCT = UT -10 HRS TIME INTERVAL: 1 JAN 68 - 31 JAN 68
UPDATE CONDITION: NONE

%ER = PERCENT ERROR OF OBSERVED CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS

UNIVERSAL	<------- MEAN ------->			<-STANDARD DEVIATION->			<--ROOT MEAN SQUARE-->			NUMBER OF
HOUR	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUALS
0	29.74	29.04	15.24	19.43	22.12	11.61	35.36	36.29	19.05	31
1	26.35	25.09	13.17	20.93	21.67	11.38	33.45	32.92	17.28	31
2	17.87	17.62	9.25	26.01	21.99	11.54	31.20	27.89	14.64	30
3	10.02	11.32	5.94	32.82	19.18	10.07	33.80	22.00	11.55	31
4	2.37	5.99	3.15	35.79	15.31	8.04	35.27	16.21	8.51	30
5	N	1.36	.71	N	13.81	7.25	N	13.65	7.16	30
6	N	1.66	.87	N	14.02	7.36	N	13.87	7.28	29
7	N	3.88	2.04	N	13.83	7.26	N	14.13	7.42	29
8	N	1.41	.74	N	9.06	4.76	N	9.02	4.73	29
9	N	-.79	-.42	N	5.37	2.82	N	5.33	2.80	28
10	N	-1.35	-.71	N	3.27	1.72	N	3.49	1.83	28
11	N	-1.30	-.68	N	2.69	1.41	N	2.95	1.55	28
12	N	-1.81	-.95	N	2.59	1.36	N	3.13	1.64	29
13	N	-2.11	-1.11	N	2.11	1.11	N	2.96	1.55	29
14	N	-1.07	-.56	N	1.54	.81	N	1.85	.97	27
15	N	.01	.01	N	.91	.48	N	.89	.47	28
16	N	-.52	-.27	N	.69	.36	N	.85	.45	28
17	-26.14	-1.54	-.81	17.27	1.03	.54	31.15	1.84	.97	27
18	1.12	.59	.31	17.41	3.88	2.03	17.13	3.85	2.02	28
19	-3.10	.11	.06	23.84	8.24	4.33	23.60	8.09	4.24	27
20	2.43	2.43	1.28	20.64	10.35	5.44	20.43	10.47	5.49	30
21	18.66	12.63	6.63	15.93	12.04	6.32	24.35	17.30	9.08	28
22	31.23	25.26	13.26	16.05	17.28	9.07	34.98	30.44	15.98	28
23	33.62	31.22	16.39	16.53	20.64	10.83	37.34	37.23	19.55	29

TABLE 7b

HOURLY VARIATION OF RESIDUALS (MEASURED - PREDICTED/UPDATED) EVALUATED FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

EVALUATION STATION: HONOLULU ATS-1 LCT = UT -10 HRS TIME INTERVAL: 1 JAN 68 - 31 JAN 68
UPDATE CONDITION: UPDATED WITH ELECTRON CONTENT (1 HOURS PRIOR TO EVALUATION TIME)
FOR STANFORD ATS-1

%ER = PERCENT ERROR OF OBSERVED CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS

UNIVERSAL	<------- MEAN ------->			<-STANDARD DEVIATION->			<--ROOT MEAN SQUARE-->			NUMBER OF
HOUR	%ER	REC	RGD	%ER	REC	RGD	%ER	REC	RGD	RESIDUALS
0	17.86	18.67	9.80	21.52	21.16	11.11	27.63	27.90	14.65	25
1	18.23	18.27	9.59	24.94	21.95	11.53	30.52	28.25	14.83	27
2	7.01	9.01	4.73	29.48	20.08	10.54	29.77	21.66	11.37	27
3	-3.96	2.43	1.28	28.90	14.38	7.55	28.61	14.31	7.51	26
4	4.55	5.35	2.81	30.59	14.22	7.47	30.32	14.93	7.84	25
5	N	8.83	4.64	N	13.33	7.00	N	15.78	8.28	26
6	N	10.01	5.26	N	14.44	7.58	N	17.34	9.10	25
7	N	8.31	4.36	N	13.64	7.16	N	15.72	8.26	24
8	N	2.68	1.41	N	9.62	5.05	N	9.79	5.14	24
9	N	-.69	-.36	N	6.19	3.25	N	6.10	3.20	25
10	N	-1.02	-.54	N	4.36	2.29	N	4.38	2.30	22
11	N	.00	.00	N	3.57	1.87	N	3.49	1.83	22
12	N	.09	.05	N	3.46	1.82	N	3.39	1.78	26
13	N	-1.11	-.58	N	2.61	1.37	N	2.79	1.46	26
14	N	-1.76	-.93	N	1.58	.83	N	2.35	1.23	23
15	N	-.31	-.16	N	.86	.45	N	.90	.47	23
16	N	.29	.15	N	.72	.38	N	.77	.40	25
17	-25.11	-1.51	-.79	20.90	1.28	.67	32.39	1.96	1.03	24
18	-3.42	-.69	-.36	13.55	3.03	1.59	13.70	3.04	1.60	24
19	-5.19	-1.51	-.79	18.29	5.74	3.01	18.64	5.82	3.05	24
20	-7.81	-3.52	-1.85	17.58	8.17	4.29	18.95	8.76	4.60	28
21	6.10	4.86	2.55	17.49	10.92	5.73	18.20	11.76	6.17	26
22	20.56	17.47	9.17	18.03	16.21	8.51	27.10	23.60	12.39	24
23	22.98	22.72	11.93	19.70	20.96	11.00	30.02	30.64	16.09	26

TABLE 7c

HOURLY VARIATION OF RESIDUALS (MEASURED - PREDICTED/UPDATED) EVALUATED FOR
CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

EVALUATION STATION: HONOLULU ATS-1 LCT = UT -10 HRS TIME INTERVAL; 1 JAN 68 - 31 JAN 68
UPDATE CONDITION: UPDATED WITH FOF2 (1 HOURS PRIOR TO EVALUATION TIME)
FOR MAUI

%ER = PERCENT ERROR OF OBSERVED CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS.

UNIVERSAL HOUR	<------- MEAN -------> %ER	REC	RGD	<-STANDARD DEVIATION-> %ER	REC	RGD	<--ROOT MEAN SQUARE--> %ER	REC	RGD	NUMBER OF RESIDUALS
0	5.30	5.58	2.93	13.39	12.19	6.40	14.13	13.17	6.91	23
1	7.02	6.64	3.48	14.02	11.82	6.20	15.40	13.32	6.99	22
2	-2.47	.68	.36	21.18	11.62	6.10	20.92	11.41	5.99	26
3	-6.23	-.96	-.51	25.04	10.10	5.30	25.38	9.97	5.23	29
4	-11.07	-2.68	-1.41	16.06	3.84	2.01	19.20	4.61	2.42	22
5	N	-.57	-.30	N	9.35	4.91	N	9.20	4.83	29
6	N	2.06	1.08	N	6.88	3.61	N	7.05	3.70	26
7	N	2.65	1.39	N	4.80	2.52	N	5.40	2.83	25
8	N	-2.47	-1.30	N	5.39	2.83	N	5.84	3.06	26
9	N	-3.91	-2.05	N	4.11	2.16	N	5.61	2.95	26
10	N	-3.20	-1.68	N	3.58	1.88	N	4.74	2.49	21
11	N	-2.59	-1.36	N	3.01	1.58	N	3.92	2.06	24
12	N	-3.86	-2.03	N	3.55	1.86	N	5.20	2.73	28
13	N	-2.21	-1.16	N	3.42	1.79	N	4.02	2.11	26
14	N	.08	.04	N	1.63	.86	N	1.59	.84	22
15	N	.52	.27	N	.96	.50	N	1.07	.56	23
16	N	-.37	-.19	N	1.19	.63	N	1.22	.64	22
17	29.01	1.63	.86	25.74	1.64	.86	38.39	2.29	1.20	22
18	7.63	2.32	1.22	29.97	6.10	3.20	30.31	6.41	3.36	24
19	-24.88	-8.05	-4.23	31.82	10.21	5.36	39.93	12.85	6.75	27
20	-14.23	-7.17	-3.76	21.81	11.27	5.92	25.74	13.20	6.93	30
21	4.16	3.72	1.95	23.55	12.38	6.50	23.46	12.70	6.67	26
22	16.38	13.77	7.23	16.78	14.58	7.65	23.24	19.86	10.43	28
23	13.75	11.97	6.28	13.25	11.91	6.25	18.90	16.70	8.77	23

TABLE 7d

HOURLY VARIATION OF RESIDUALS (MEASURED - PREDICTED/UPDATED) EVALUATED FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

EVALUATION STATION: HONOLULU ATS-1 LCT = UT -10 HRS TIME INTERVAL: 1 JAN 68 - 31 JAN 68
UPDATE CONDITION: UPDATED WITH ELECTRON CONTENT (2 HOURS PRIOR TO EVALUATION TIME) FOR STANFORD ATS-1

%ER = PERCENT ERROR OF OBSERVED CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS

UNIVERSAL HOUR	MEAN %ER	MEAN REC	MEAN RGD	STANDARD DEVIATION %ER	STANDARD DEVIATION REC	STANDARD DEVIATION RGD	ROOT MEAN SQUARE %ER	ROOT MEAN SQUARE REC	ROOT MEAN SQUARE RGD	NUMBER OF RESIDUALS
0	17.73	18.91	9.93	22.61	22.57	11.85	28.41	29.14	15.30	28
1	14.54	14.84	7.79	21.32	18.99	9.97	25.46	23.80	12.50	25
2	10.50	12.18	6.40	30.95	21.21	11.13	32.11	24.10	12.65	26
3	-.11	4.45	2.34	34.80	16.48	8.65	34.17	16.78	8.81	28
4	-10.80	-.52	-.27	29.25	10.78	5.66	30.63	10.57	5.55	25
5	N	1.47	.77	N	12.73	6.68	N	12.56	6.60	25
6	N	8.13	4.27	N	14.33	7.52	N	16.22	8.52	25
7	N	10.74	5.64	N	13.72	7.20	N	17.22	9.04	26
8	N	5.39	2.83	N	9.25	4.86	N	10.54	5.53	24
9	N	.41	.21	N	6.06	3.18	N	5.94	3.12	23
10	N	-1.35	-.71	N	4.08	2.14	N	4.22	2.21	25
11	N	-1.08	-.56	N	3.49	1.83	N	3.57	1.88	22
12	N	-.62	-.33	N	3.51	1.84	N	3.49	1.83	23
13	N	-.51	-.27	N	2.68	1.41	N	2.68	1.41	26
14	N	-.43	-.23	N	1.66	.87	N	1.68	.88	24
15	N	-.39	-.20	N	.86	.45	N	.93	.49	24
16	N	-.89	-.47	N	.98	.52	N	1.31	.69	23
17	14.05	1.05	.55	19.46	1.46	.77	23.67	1.78	.93	24
18	1.79	.66	.35	13.22	3.13	1.64	13.07	3.13	1.64	25
19	-6.22	-1.66	-.87	17.30	5.57	2.92	18.02	5.69	2.99	23
20	-.21	.20	.10	18.18	8.31	4.36	17.85	8.16	4.28	27
21	9.63	6.58	3.46	17.16	10.23	5.37	19.39	12.00	6.30	26
22	21.09	17.97	9.44	19.20	16.56	8.70	28.27	24.22	12.72	26
23	22.64	21.98	11.54	18.95	19.82	10.41	29.28	29.33	15.40	25

TABLE 7e

HOURLY VARIATION OF RESIDUALS (MEASURED - PREDICTED/UPDATED) EVALUATED FOR CONDITION 4, 1 JANUARY 1968 TO 31 DECEMBER 1968

EVALUATION STATION: HONOLULU ATS-1 LCT = UT -10 HRS TIME INTERVAL: 1 JAN 68 - 31 JAN 68
UPDATE CONDITION: UPDATED WITH FOF2 (2 HOURS PRIOR TO EVALUATION TIME)
FOR MAUI

%ER = PERCENT ERROR OF OBSERVED CONTENT
REC = RESIDUAL ELECTRON CONTENT, 10** 16 E/M**2 COLUMN
RGD = RESIDUAL GROUP DELAY, NANOSECONDS.

UNIVERSAL HOUR	<------- MEAN -------> %ER	REC	RGD	<-STANDARD DEVIATION-> %ER	REC	RGD	<--ROOT MEAN SQUARE--> %ER	REC	RGD	NUMBER OF RESIDUALS
0	10.40	10.88	5.71	20.08	17.83	9.36	22.24	20.57	10.80	24
1	1.54	3.83	2.01	21.21	17.33	9.10	20.80	17.38	9.12	23
2	-.52	2.83	1.49	25.69	16.80	8.82	25.08	16.64	8.74	21
3	-15.13	-3.35	-1.76	38.90	13.18	6.92	41.06	13.36	7.01	27
4	-13.49	-1.90	-1.00	30.32	10.23	5.37	32.69	10.23	5.37	28
5	N	-4.86	-2.55	N	4.47	2.35	N	6.54	3.43	22
6	N	.16	.08	N	11.04	5.80	N	10.85	5.69	28
7	N	3.31	1.74	N	8.17	4.29	N	8.67	4.55	26
8	N	1.03	.54	N	6.39	3.35	N	6.34	3.33	25
9	N	-3.76	-1.97	N	6.17	3.24	N	7.12	3.74	25
10	N	-3.73	-1.96	N	4.33	2.27	N	5.65	2.97	26
11	N	-2.91	-1.53	N	4.33	2.27	N	5.13	2.69	21
12	N	-3.32	-1.74	N	3.63	1.91	N	4.87	2.56	25
13	N	-3.95	-2.07	N	3.82	2.00	N	5.44	2.86	28
14	N	-1.04	-.55	N	2.67	1.40	N	2.81	1.48	24
15	N	.44	.23	N	1.37	.72	N	1.40	.74	23
16	N	.06	.03	N	1.68	.88	N	1.64	.86	23
17	-2.38	-.61	-.32	50.53	3.62	1.90	49.42	3.59	1.89	22
18	35.95	7.31	3.84	22.62	4.80	2.52	42.21	8.69	4.56	23
19	1.26	2.49	1.31	39.88	13.08	6.87	39.02	13.04	6.84	23
20	-22.97	-9.95	-5.22	33.34	13.98	7.34	40.01	16.96	8.90	29
21	2.75	1.84	.97	20.08	12.02	6.31	19.91	11.95	6.27	28
22	17.21	15.61	8.20	27.50	20.22	10.62	31.99	25.23	13.25	26
23	18.31	18.38	9.65	20.80	20.59	10.81	27.44	27.34	14.35	29

TABLE 8 Summary of RMS Residuals in Group Delay (nanoseconds) for Entire Evaluation Period and for Update Conditions 1,2,3,5,9 Hours Prior to Evaluation Time

Condition	Evaluation Station	Update Stations	No Update	Time Delay in Applying Update 1 hour	2 hours	3 hours	5 hours	9 hours
4	Honolulu ATS1	none	6.86					
		Stan.ATS1		6.94	6.81	6.86	7.39	8.86
		Maui		4.38	5.73	6.82	9.14	12.66
		Pt. Arguello		8.75	8.68	8.69	8.85	9.42
	Sagamore ATS3	none	2.60					
		Stan. ATS1		3.19	3.23	3.32	3.50	3.97
		Wallops Island		2.96	3.39	3.99	5.61	6.56
		Pt. Arguello		3.94	3.88	3.76	3.66	4.40
5	Stanford ATS1	none	3.15					
		Edmo.ATS1, Saga.ATS3, Hono.ATS1		2.41	2.57	2.78	3.12	3.79
		Edmo.ATS1		3.36	3.60	4.00	4.89	6.29
		Pt. Arguello		2.19	2.67	2.95	3.26	4.02
	Urbana ATS3	none	3.12					
		Edmo.ATS1, Saga.ATS3, Hono.ATS1		1.92	2.10	2.32	2.80	3.43
		Saga.ATS3		2.23	2.44	2.74	3.37	4.16
		Wallops Island		2.40	2.72	3.07	4.26	5.72

CONDITION# 1-2 PERIOD 6712 8 TO 68 418   EVALUATION STATION= STAN ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HONO ATS1
3	1	NT	HONO ATS1
4	1	FOF2	ARGU ELLO

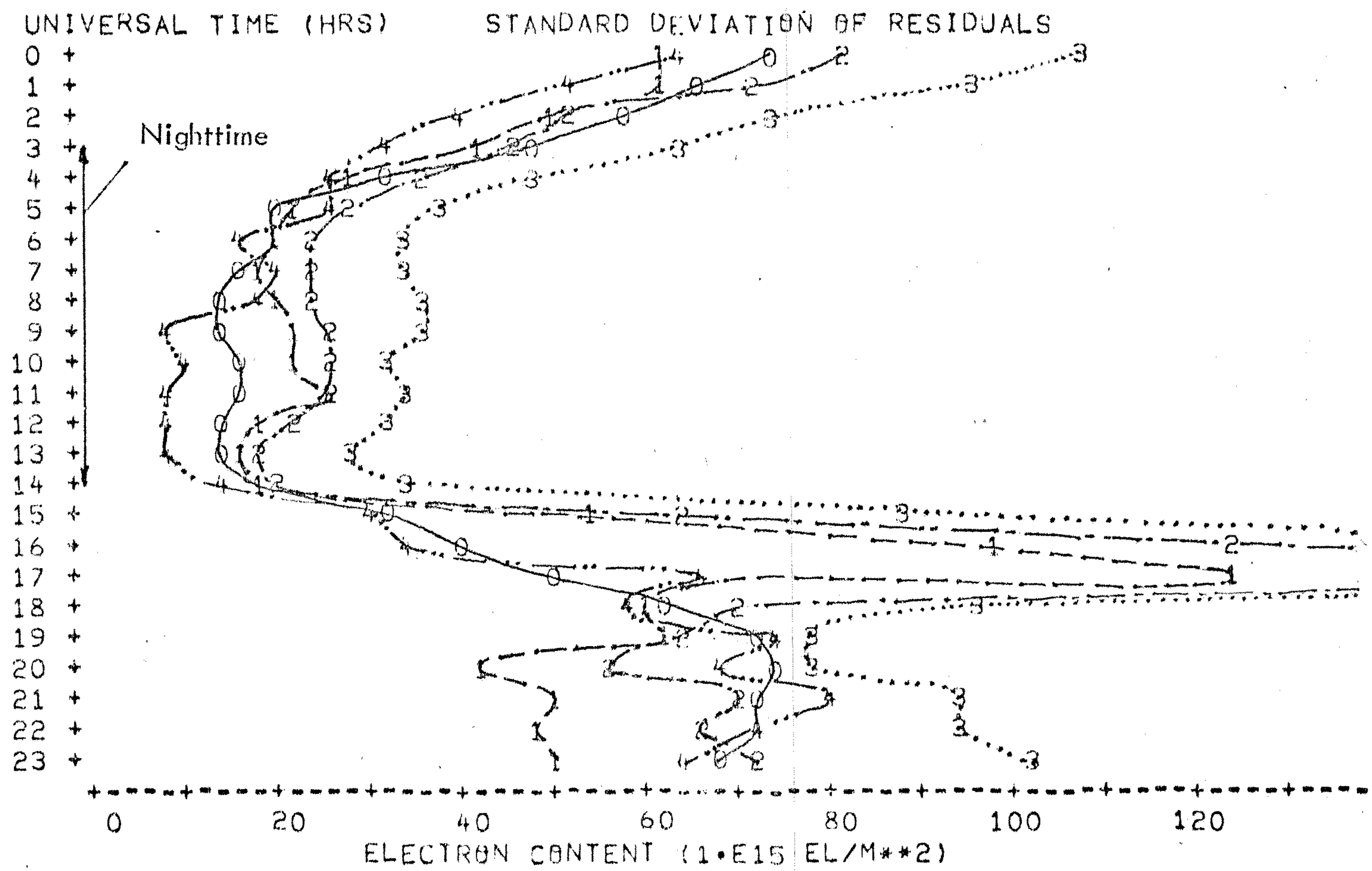


FIGURE 13a • HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1-2 PERIOD 6712 8 TO 68 418 EVALUATION STATION= STAN ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HONO ATS1
3	1	NT	SAGA ATS3
4	1	FOF2	ARGU ELLA

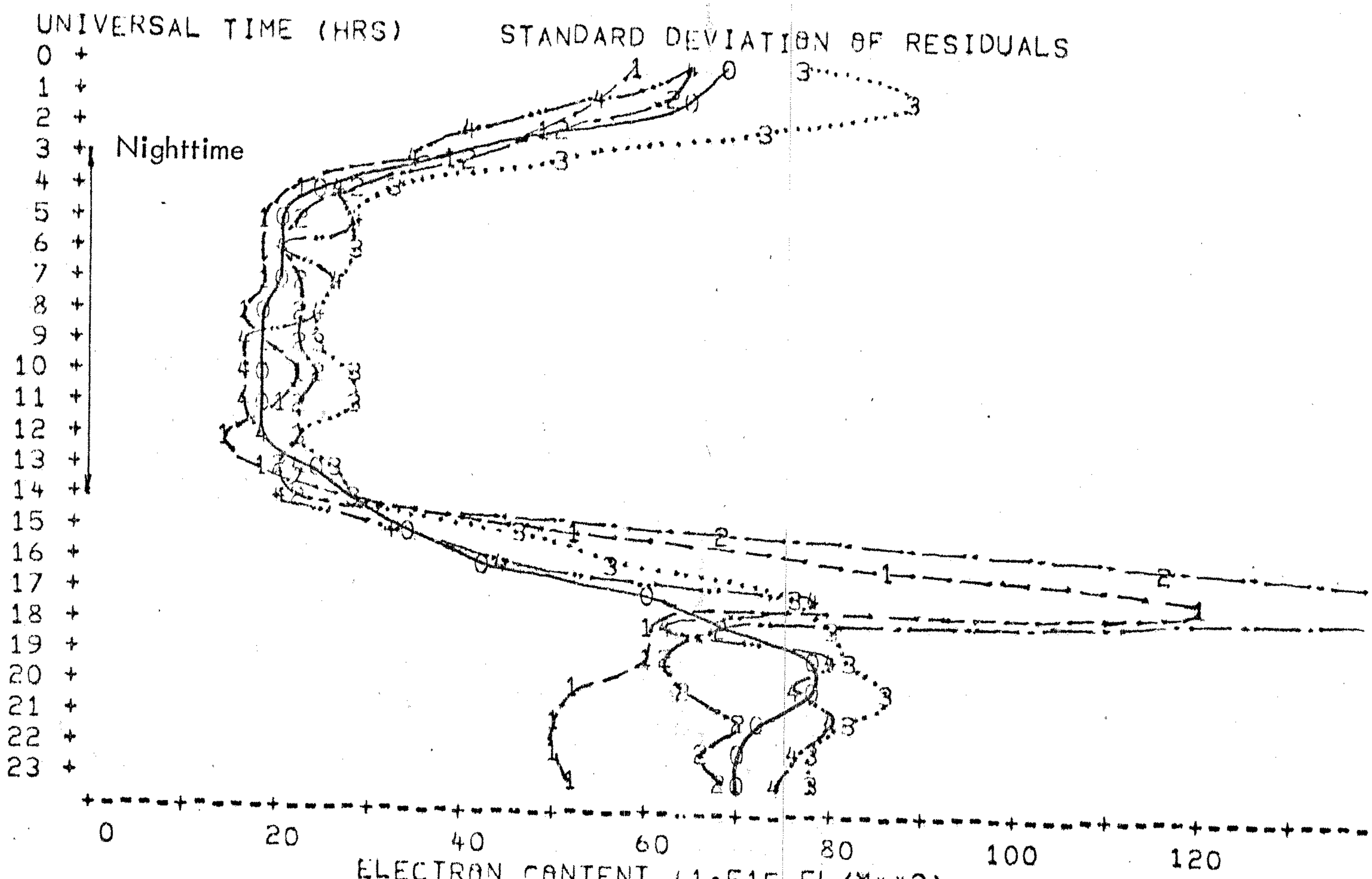


FIGURE 13b • HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1-2 PERIOD 6712 8 TO 68 418 EVALUATION STATION= URBA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HONO ATS1
3	1	NT	SAGA ATS3
4	1	FOF2	WALL OPS

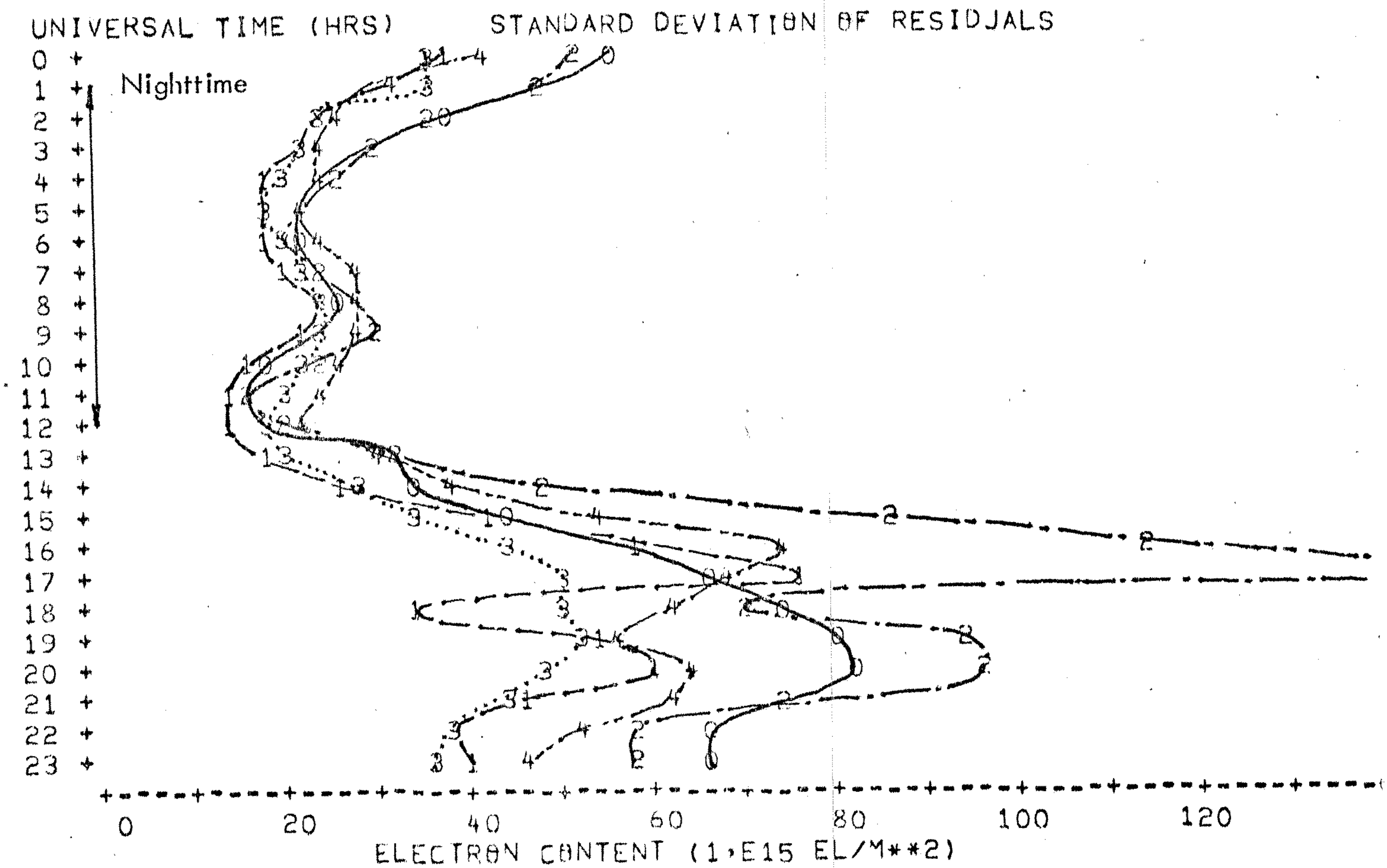


FIGURE 13c. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1   PERIOD 6712 8 TO 68 418   EVALUATION STATION= SAGA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HON9 ATS1
2	1	NT	AREC ATS3
3	1	FOF2	WALL OPS

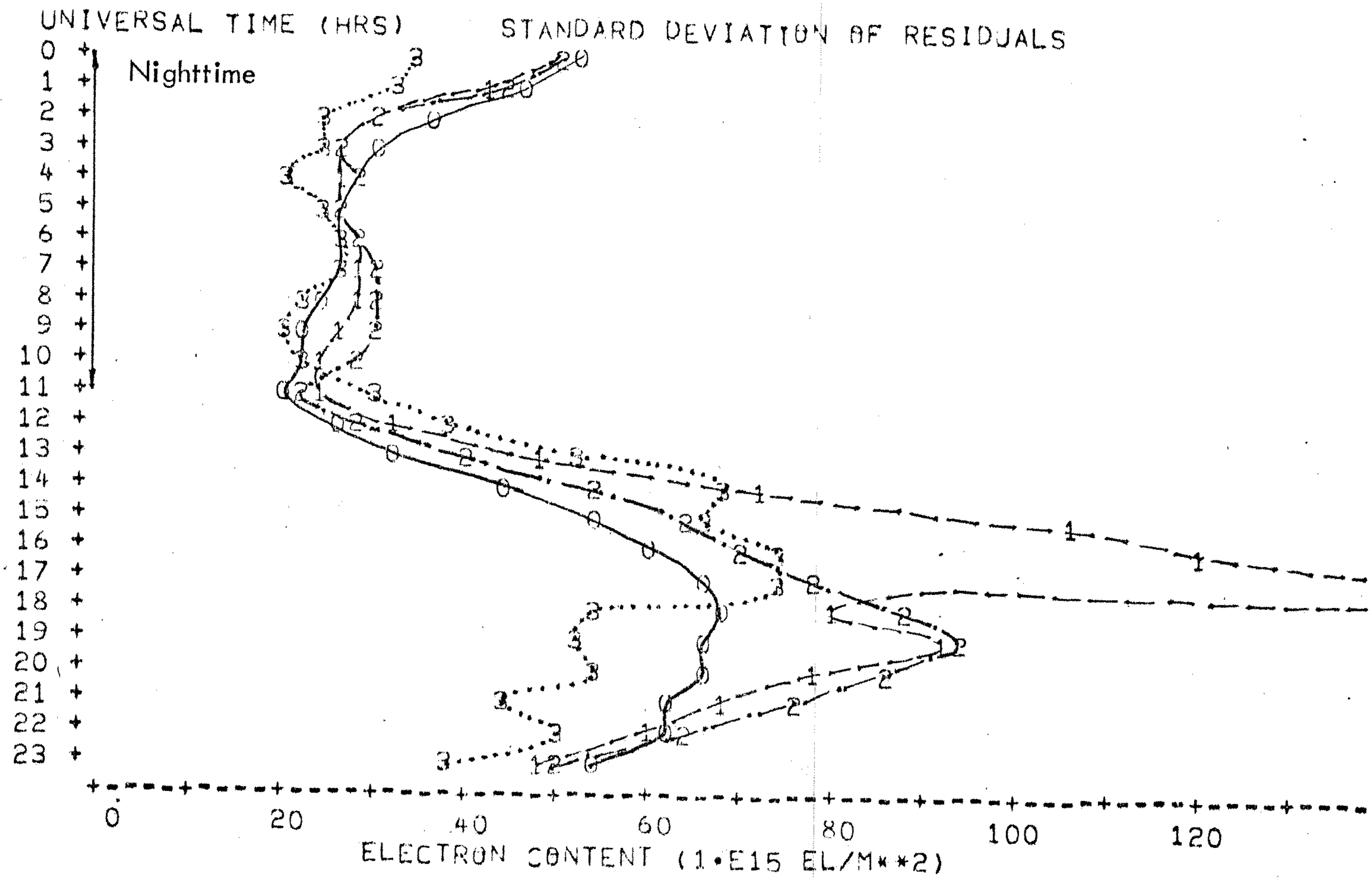


FIGURE 13d. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 3 PERIOD 65 1 1 TO 651231 EVALUATION STATION= HONO SYN3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN SYN3

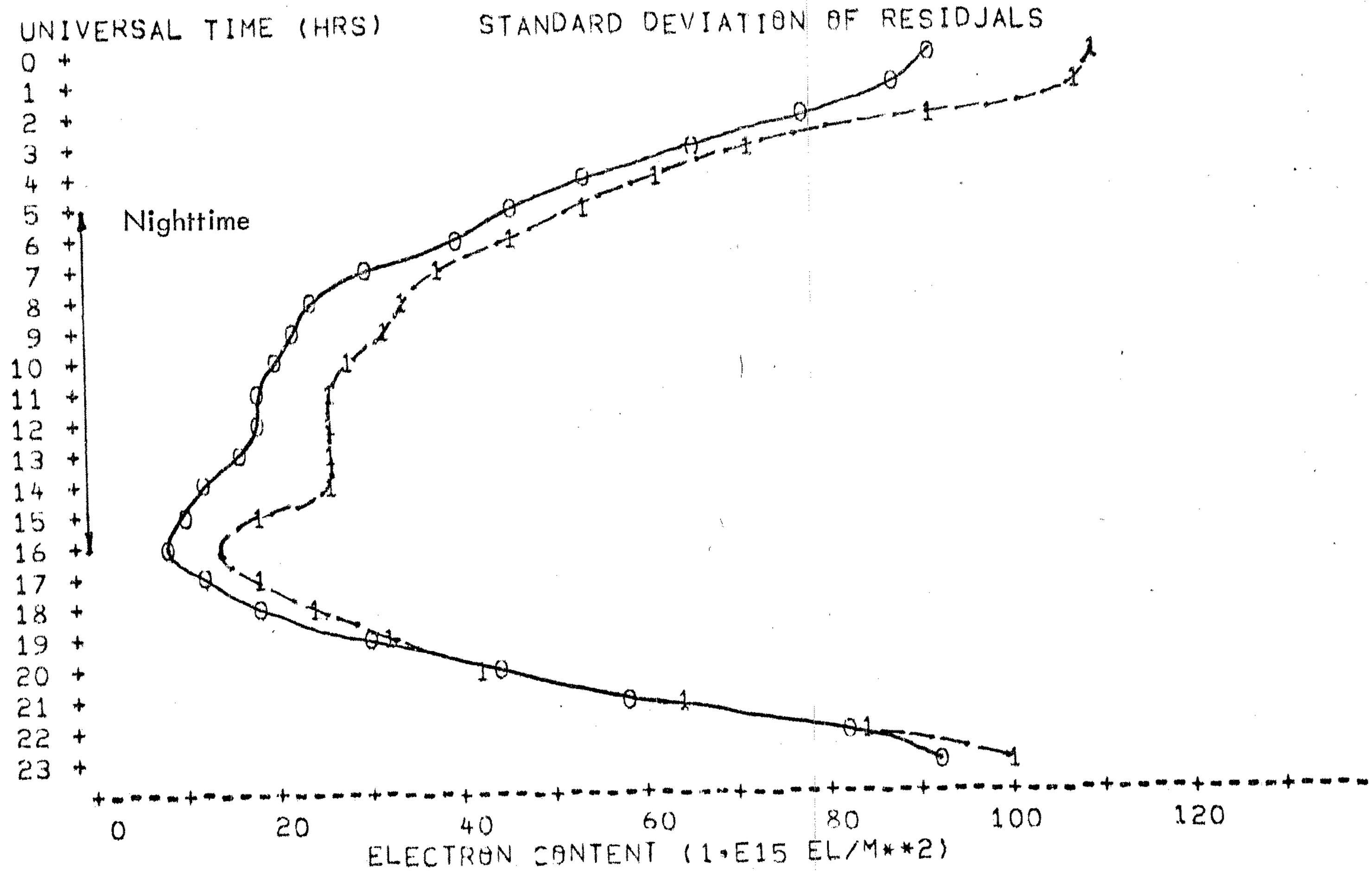


FIGURE 13e. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION= HONO ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN ATS1
2	1	FOF2	MAUI
3	1	FOF2	ARGU ELLO

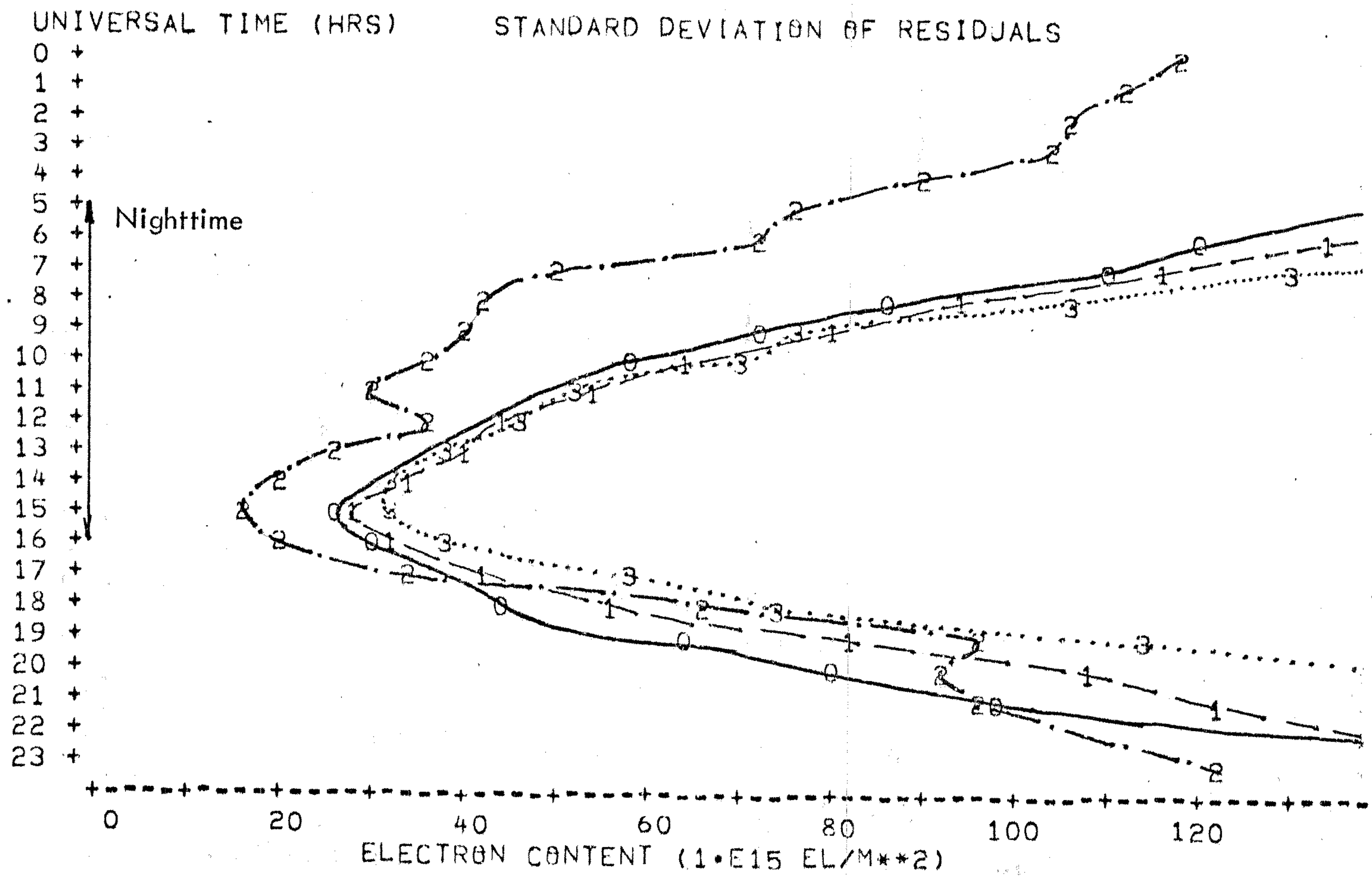


FIGURE 13f • HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4   PERIOD 68 1 1 TO 681231   EVALUATION STATION= SAGA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN ATS1
2	1	FOF2	WALL OPS
3	1	FOF2	ARGU ELLO

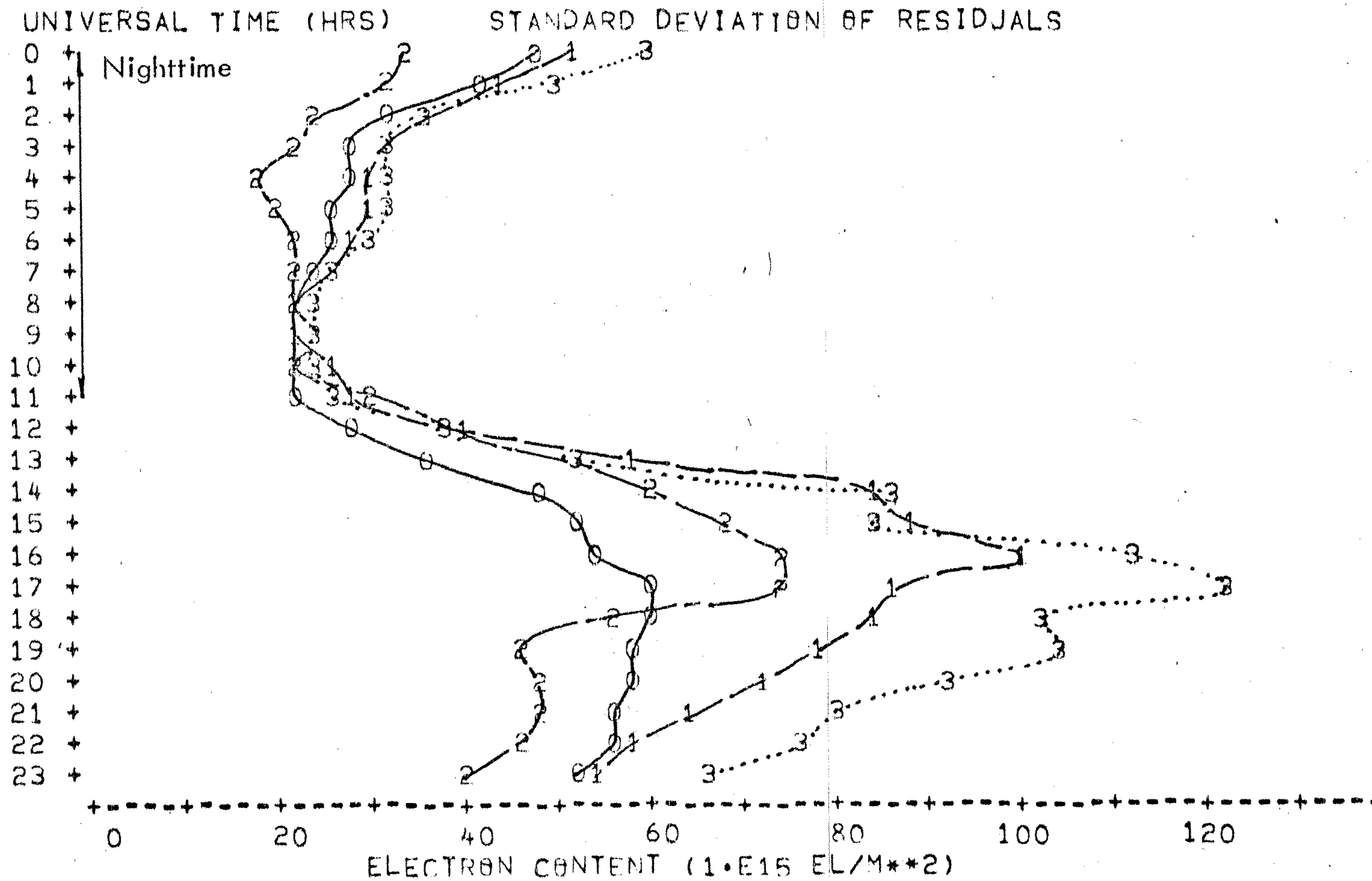


FIGURE 13g. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5   PERIOD 6812 1 TO 691113   EVALUATION STATION= STAN ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1
3	1	FOF2	ARGU ELLO

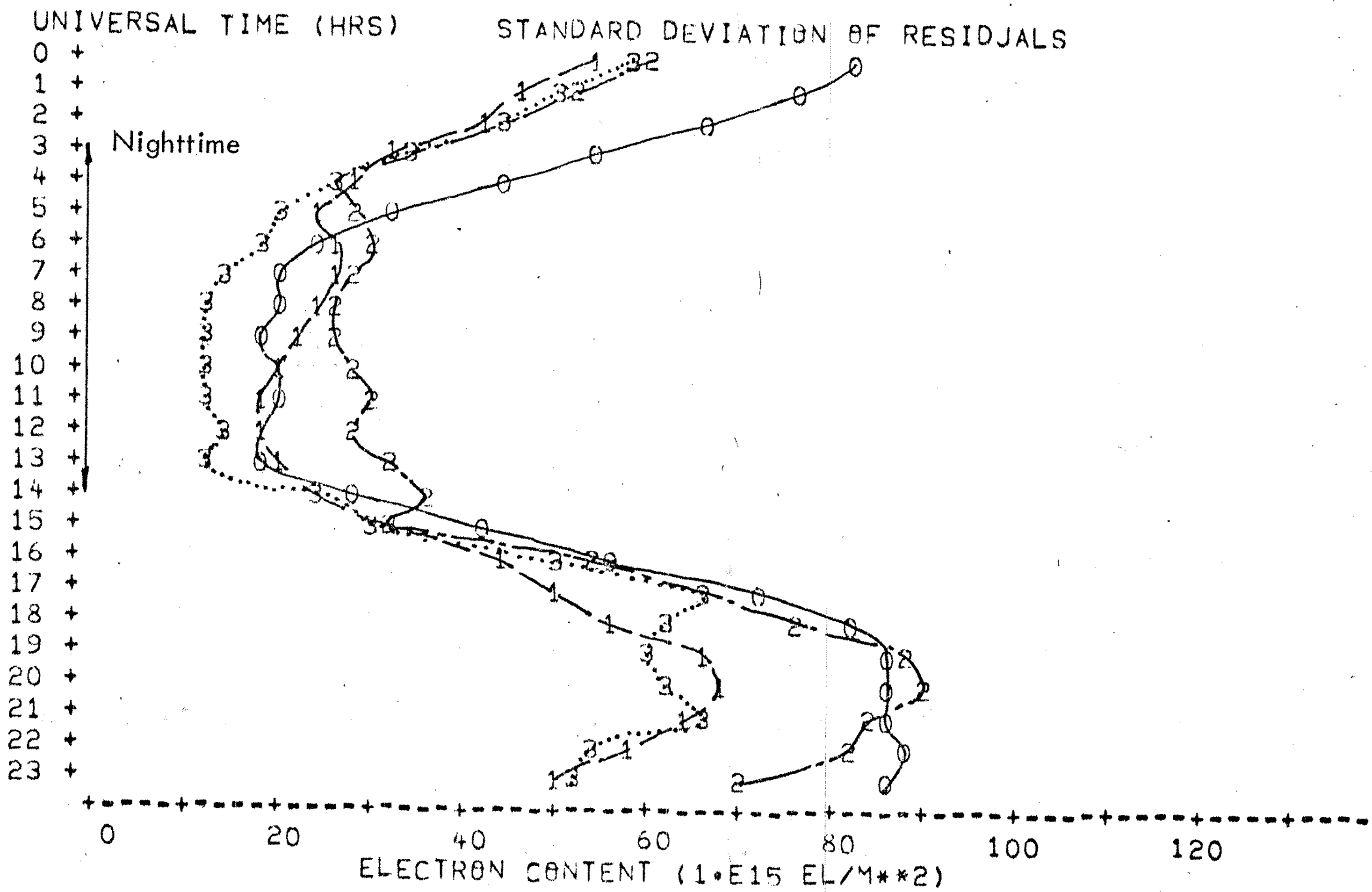


FIGURE 13h. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= STAN ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1
3	1	FOF2	ARGU ELLO

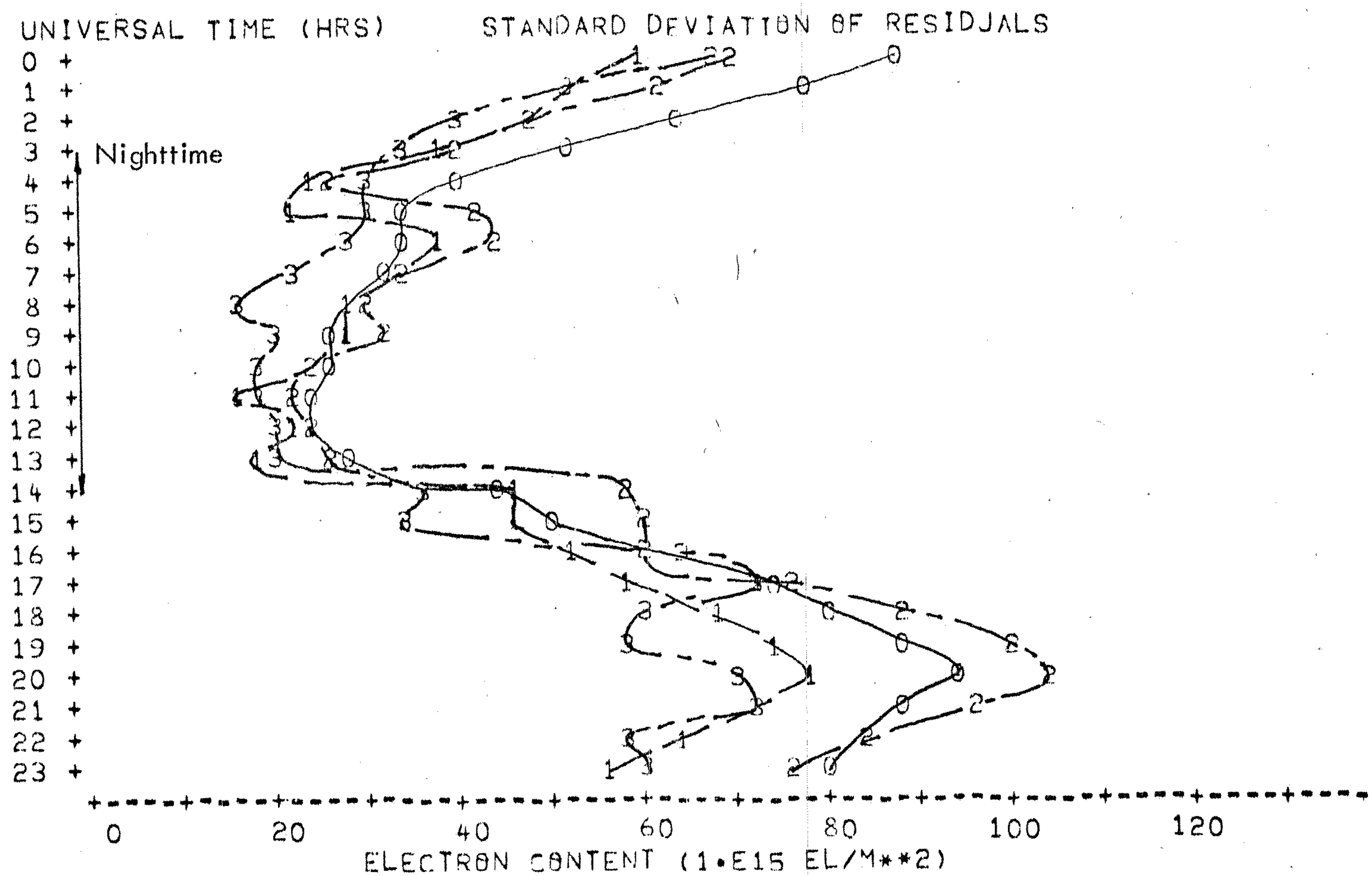


FIGURE 13i. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5   PERIOD 6812 1 TO 691113   EVALUATION STATION= COLD ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1

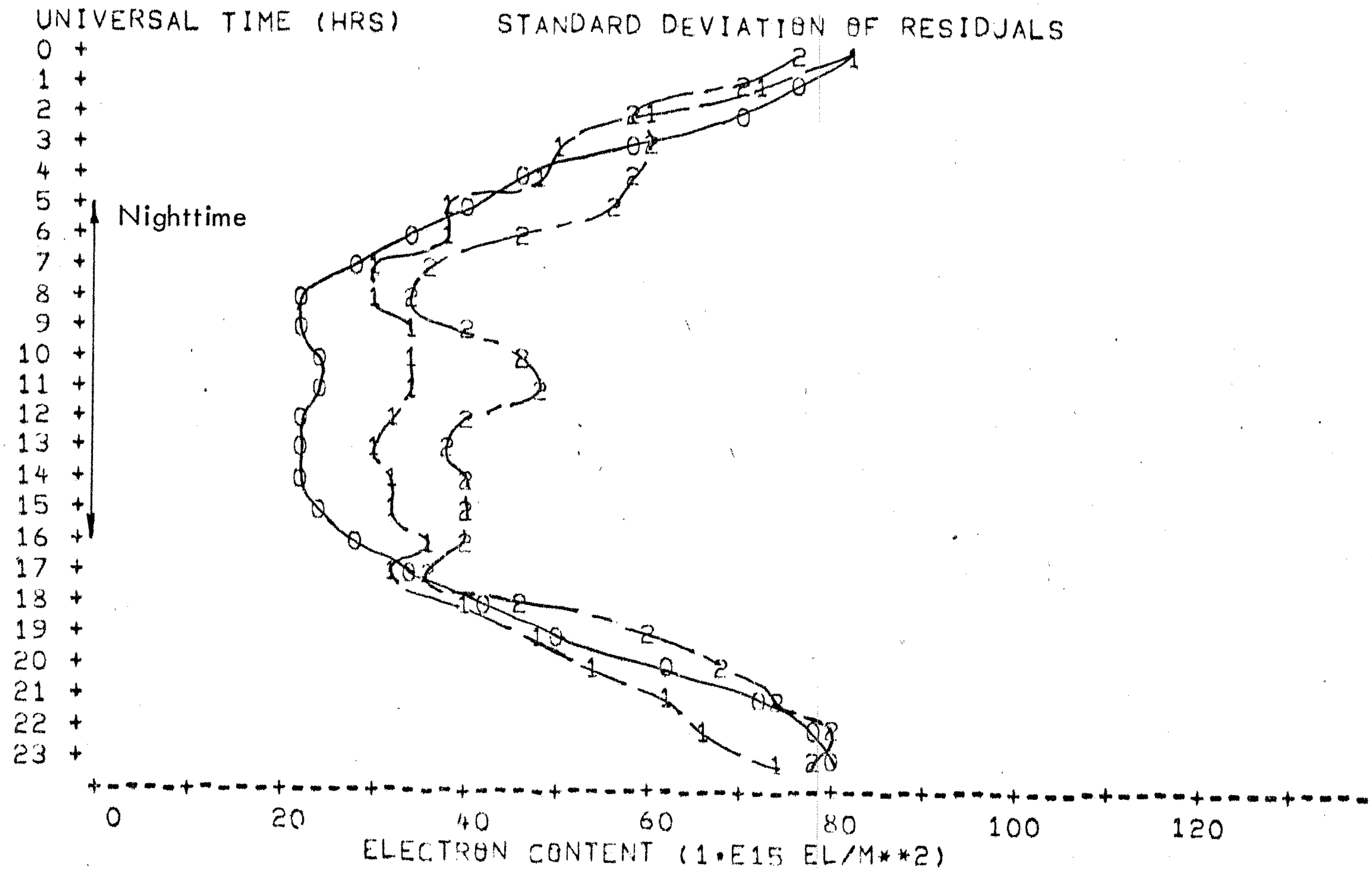


FIGURE 13j. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5   PERIOD 6812 1 TO 691113   EVALUATION STATION= URBA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	SAGA ATS3
3	1	FOF2	WALL OPS

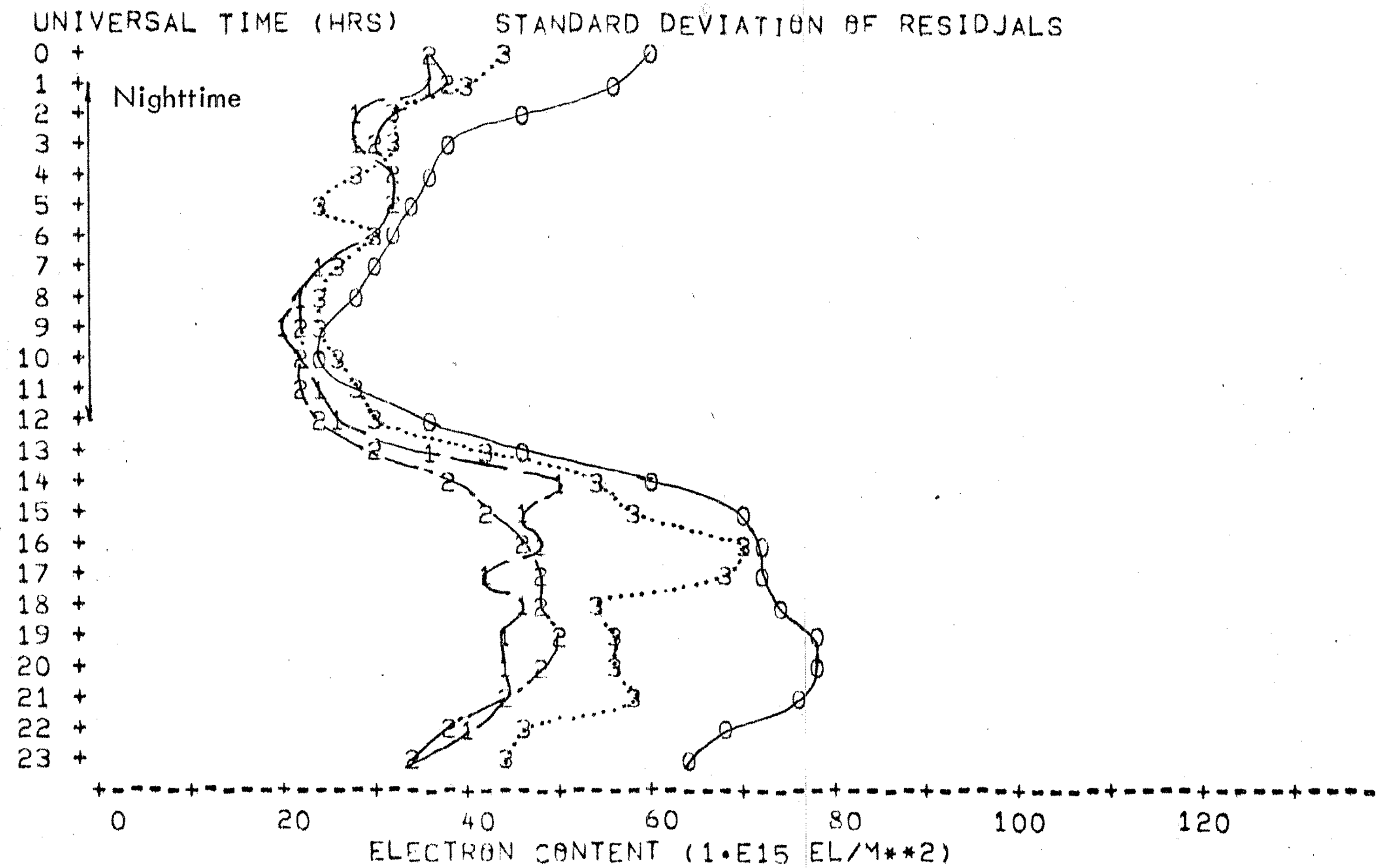


FIGURE 13k• HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1-2 PERIOD 6712 8 TO 68 418   EVALUATION STATION= STAN ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HONO ATS1
3	1	NT	HONO ATS1
4	1	FOF2	ARGU ELLO

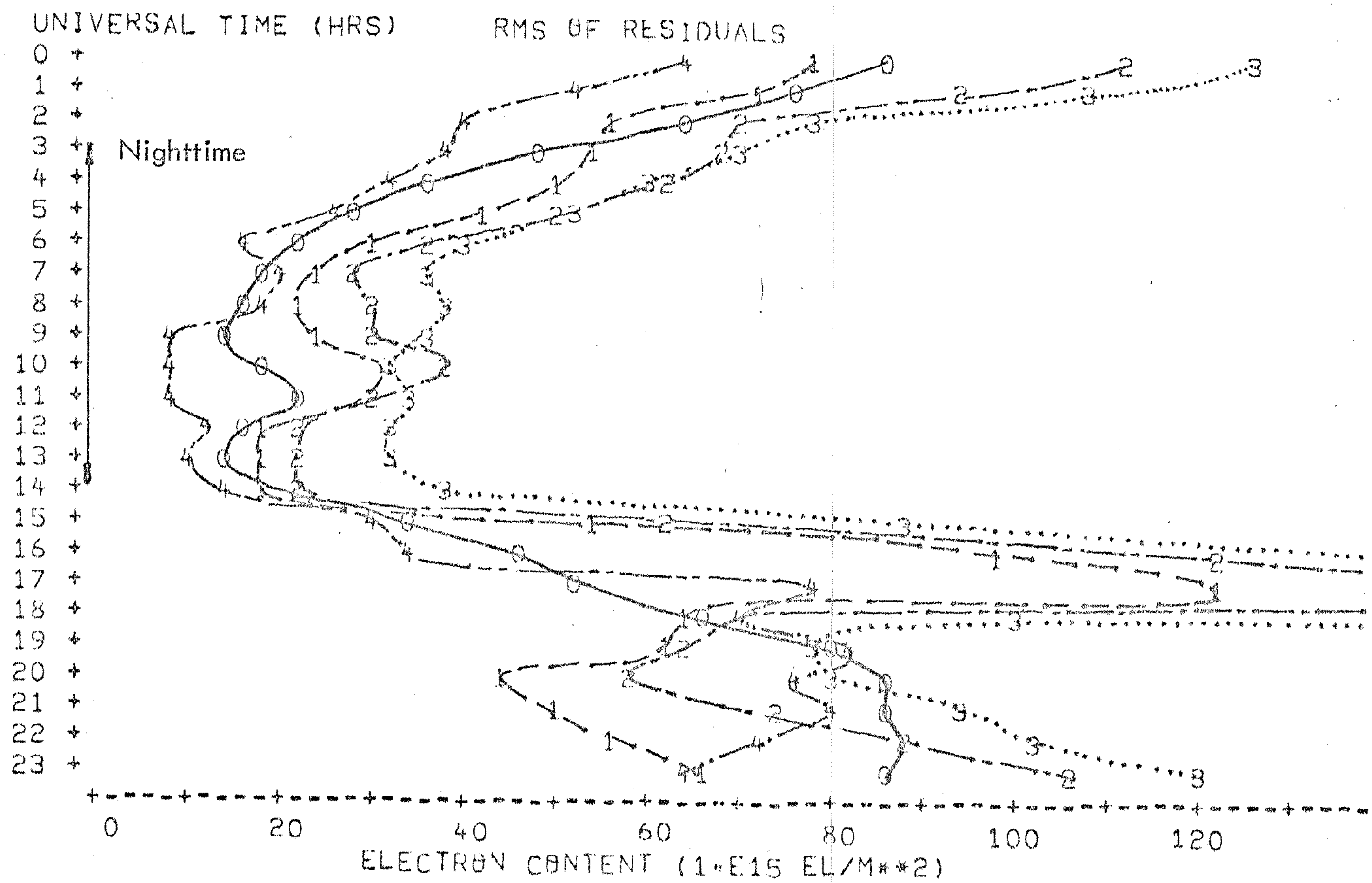


FIGURE 13l. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1-2 PERIOD 6712 8 TO 68 418 EVALUATION STATION= STAN ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HON9 ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HON9 ATS1
3	1	NT	SAGA ATS3
4	1	FOF2	ARGU ELLO

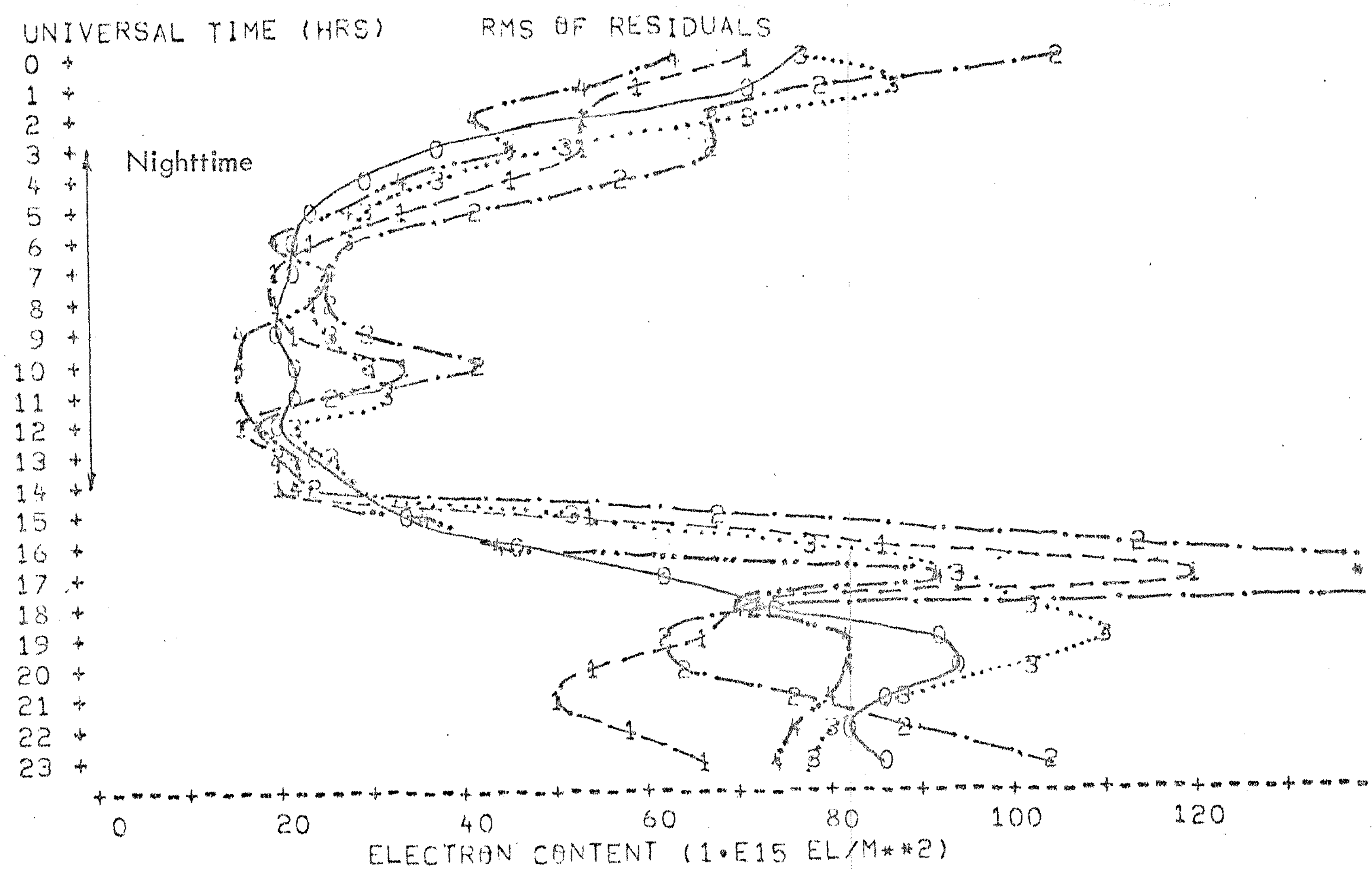


FIGURE 13m. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1-2 PERIOD 6712 8 TO 68 418 EVALUATION STATION= URBA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1 SAGA ATS3
2	1	NT	AREC ATS3 HONO ATS1
3	1	NT	SAGA ATS3
4	1	FOF2	WALL OPS

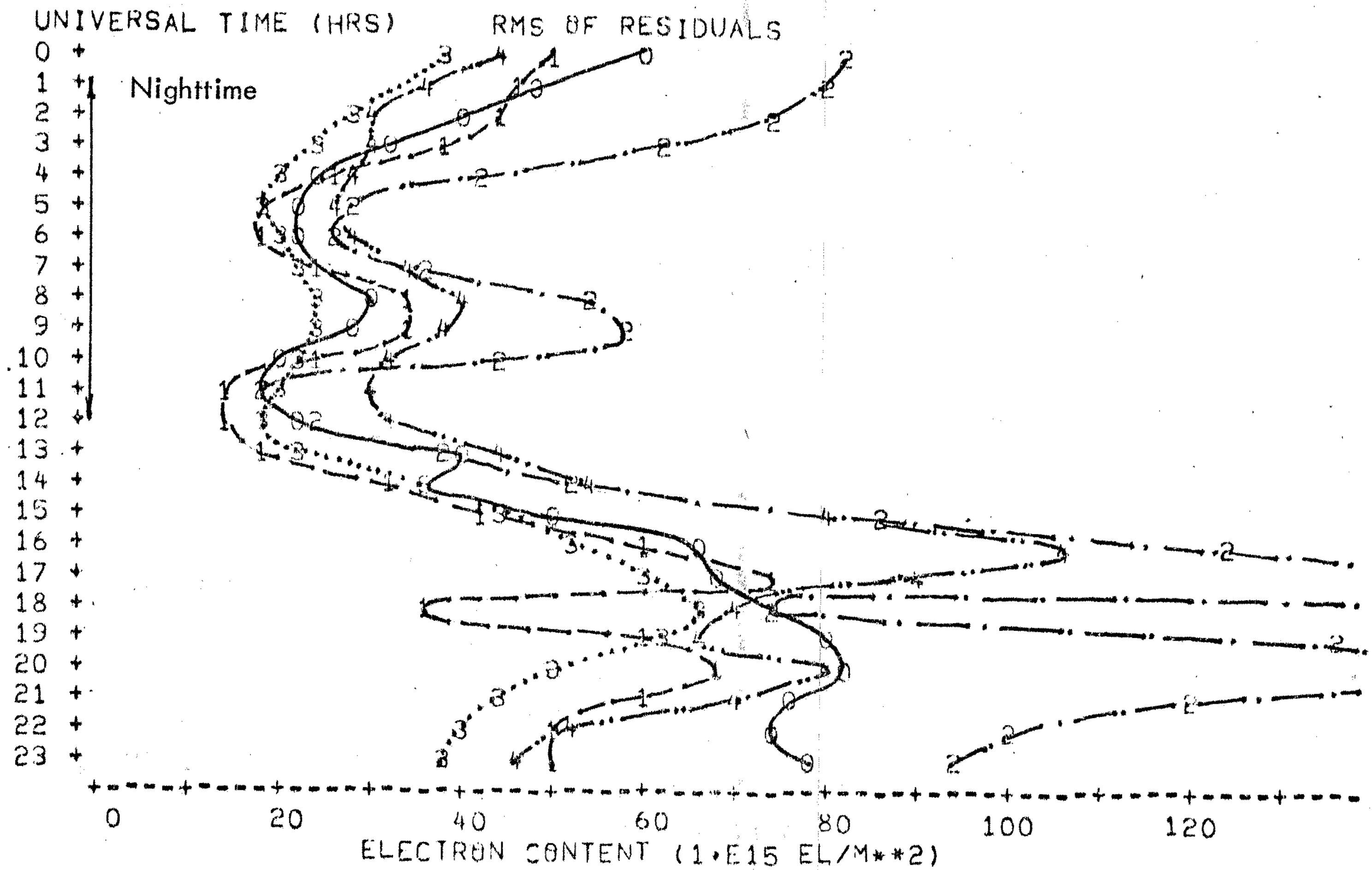


FIGURE 13n. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 1   PERIOD 6712 8 TO 68 418   EVALUATION STATION= SAGA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	AREC ATS3 HONO ATS1
2	1	NT	AREC ATS3
3	1	FOF2	WALL OPS

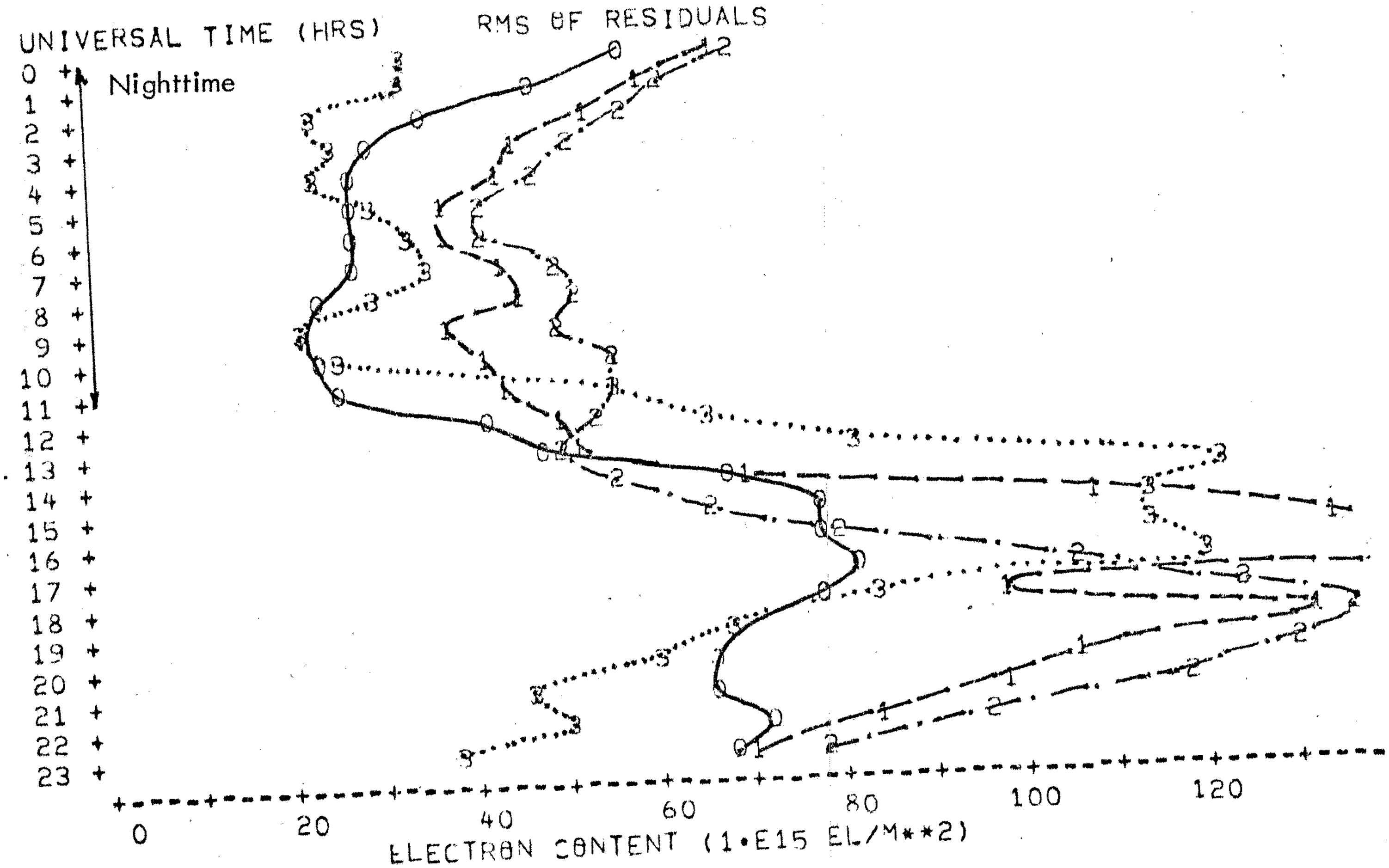


FIGURE 13o. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 3 PERIOD 65 1 1 TO 651231 EVALUATION STATION= HONO SYN3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN SYN3

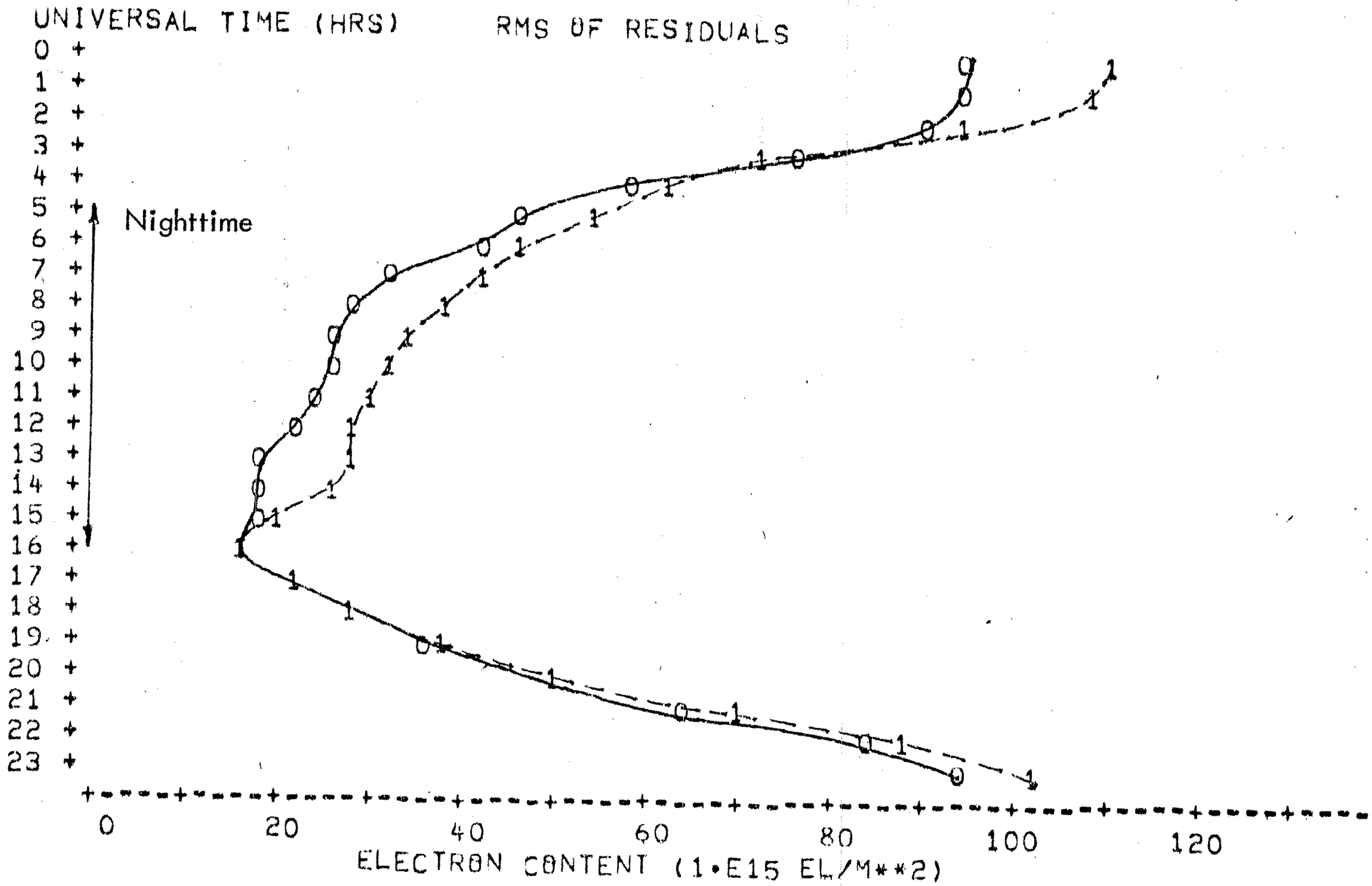


FIGURE 13p • HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION= HONO ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN ATS1
2	1	FOF2	MAUI
3	1	FOF2	ARGU ELLG

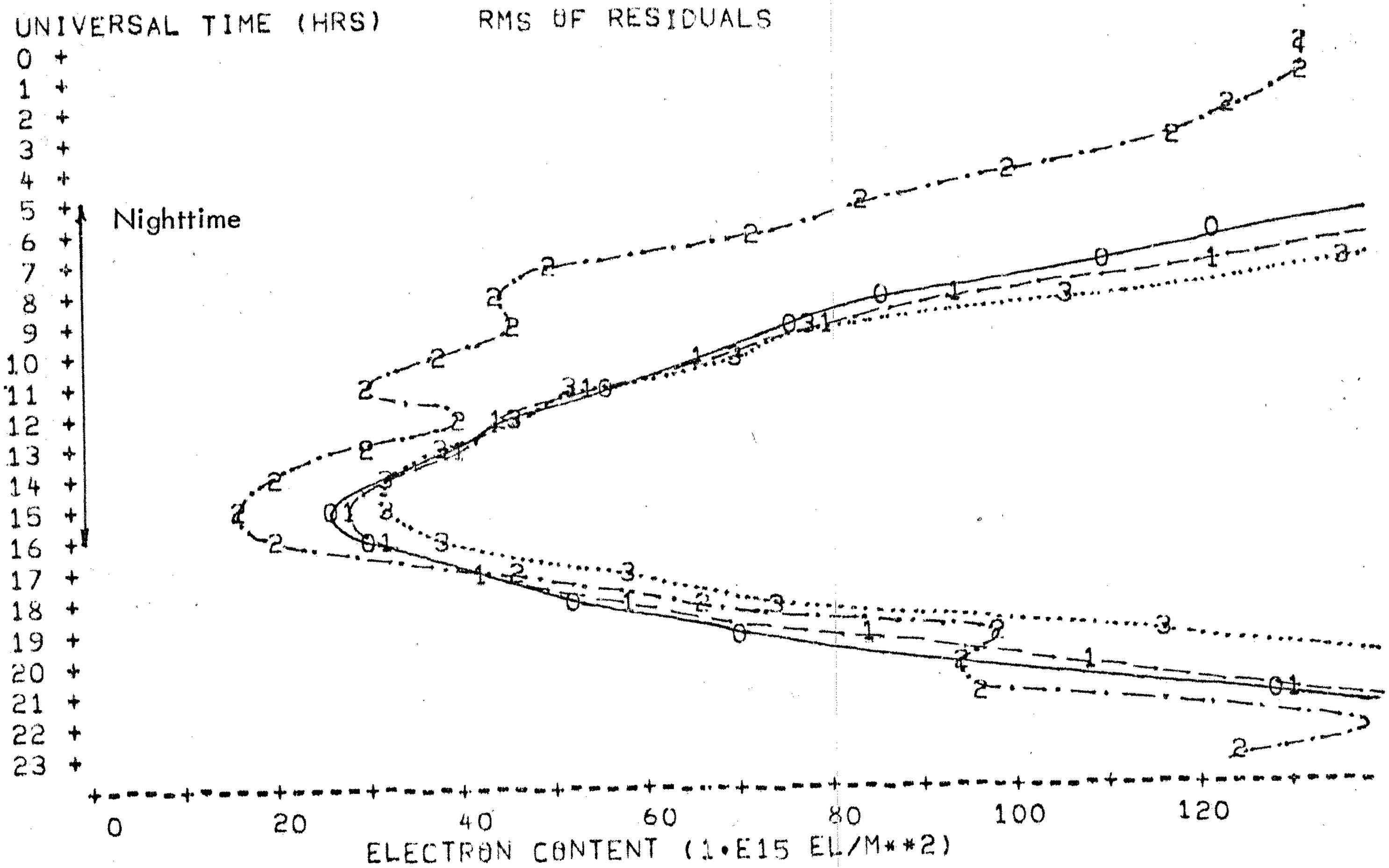


FIGURE 13q. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4   PERIOD 68 1 1 TO 681231   EVALUATION STATION= SAGA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	STAN ATS1
2	1	FOF2	WALL OPS
3	1	FOF2	ARGU ELLO

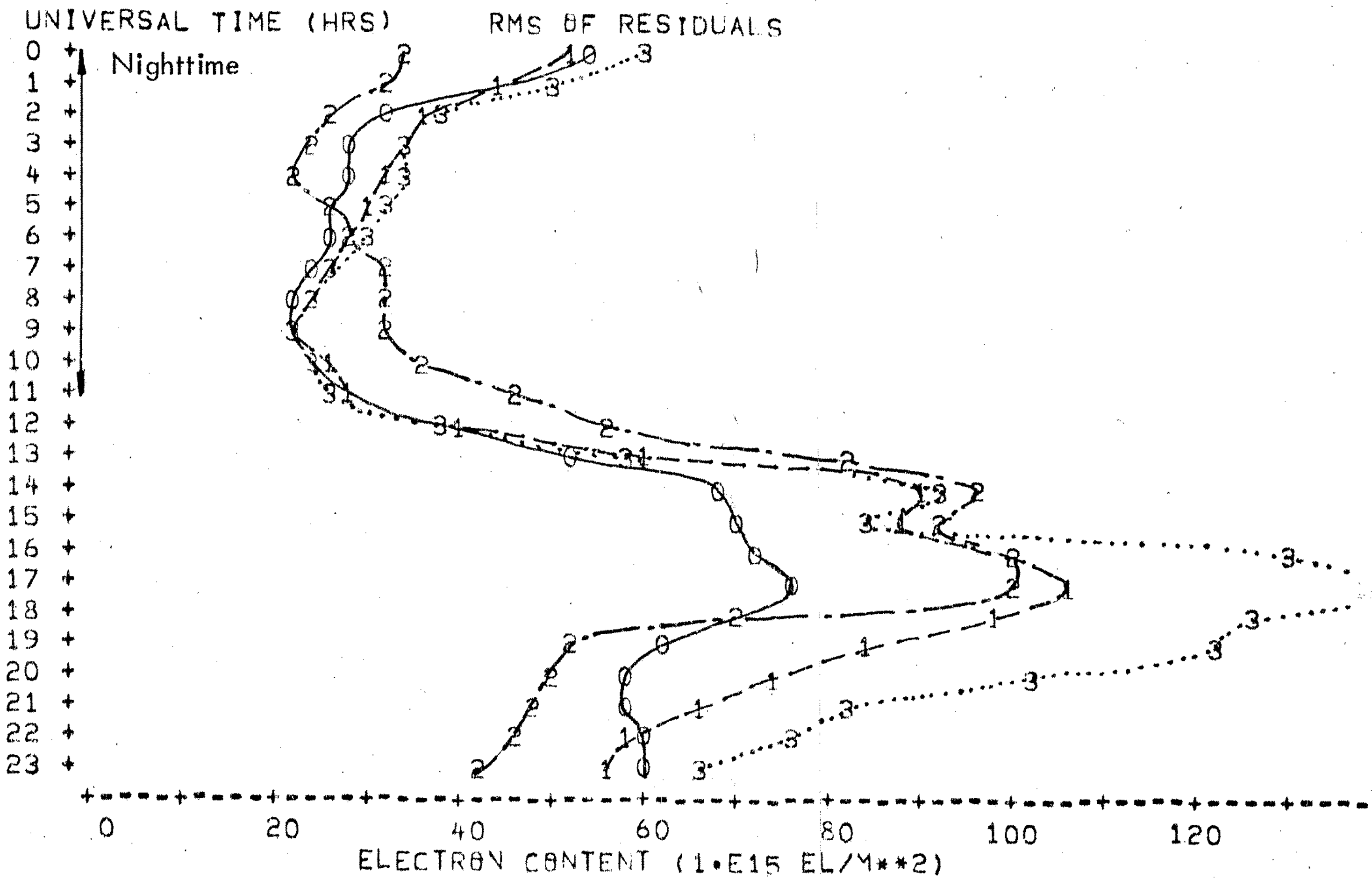


FIGURE 13r. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= STAN ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1
3	1	FOF2	ARGU ELLO

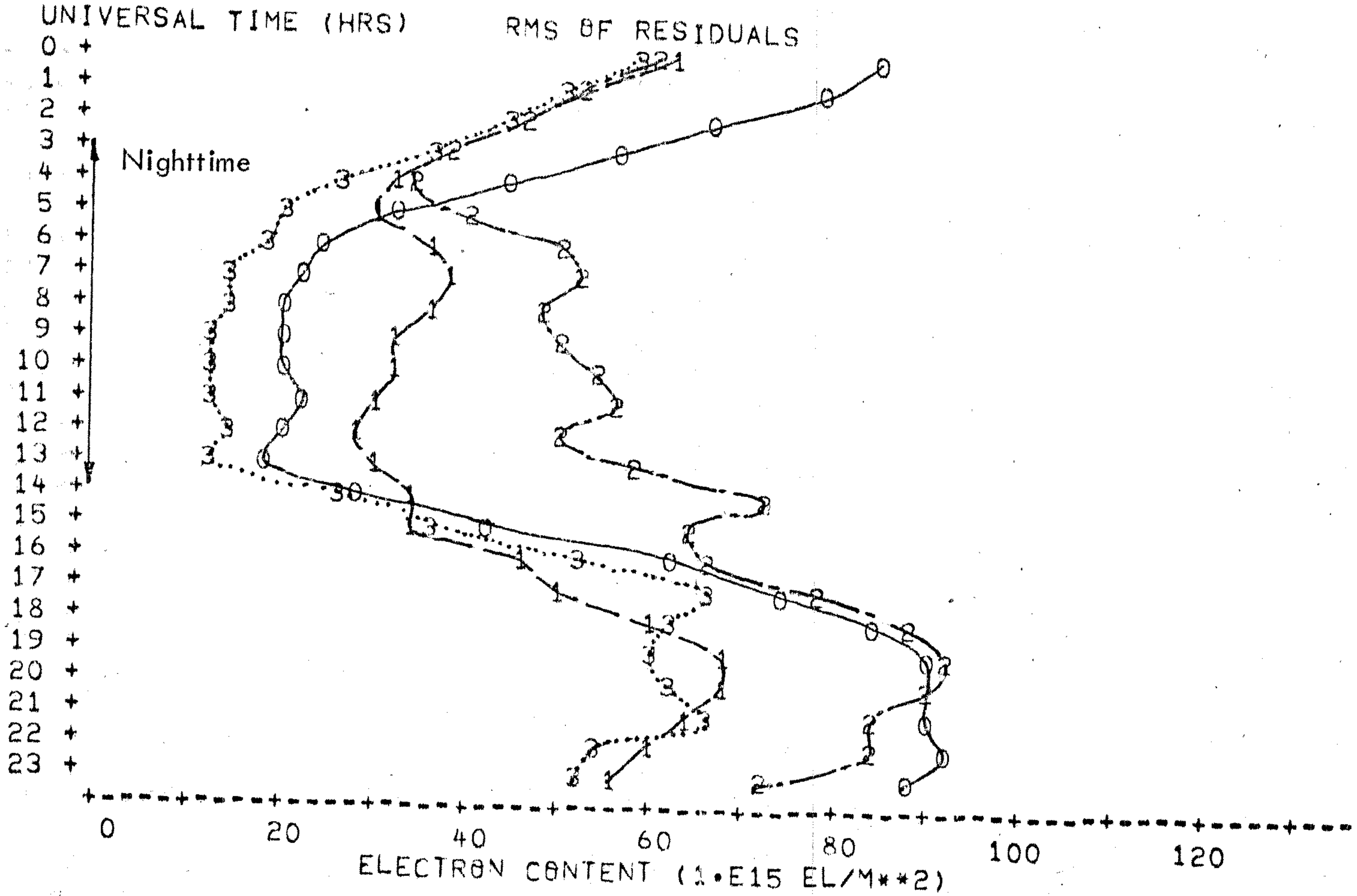


FIGURE 13s. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= STAN ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1
3	1	FOF2	ARGU ELLO

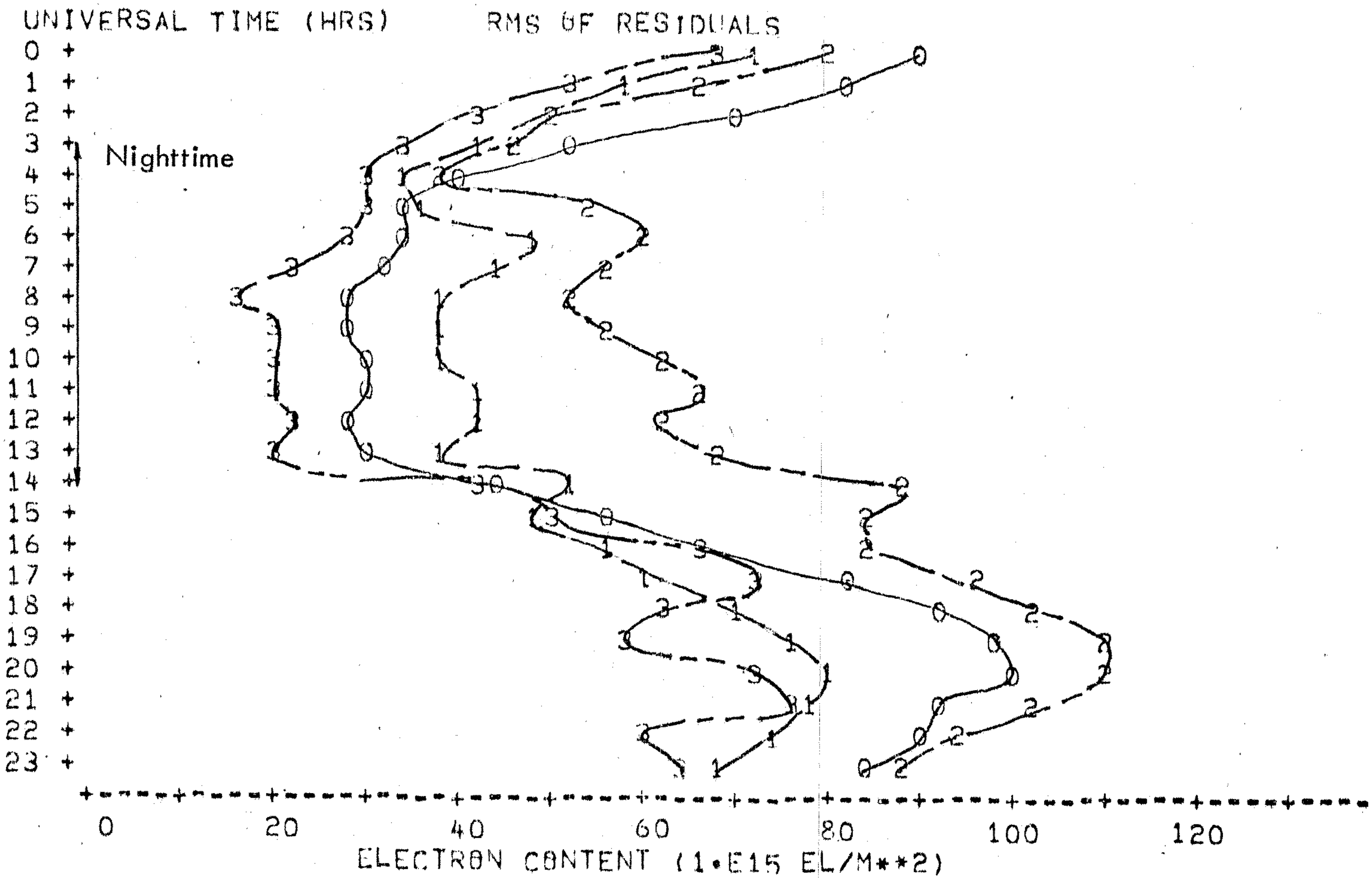


FIGURE 13t. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= COLD ATS1

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	EDMO ATS1

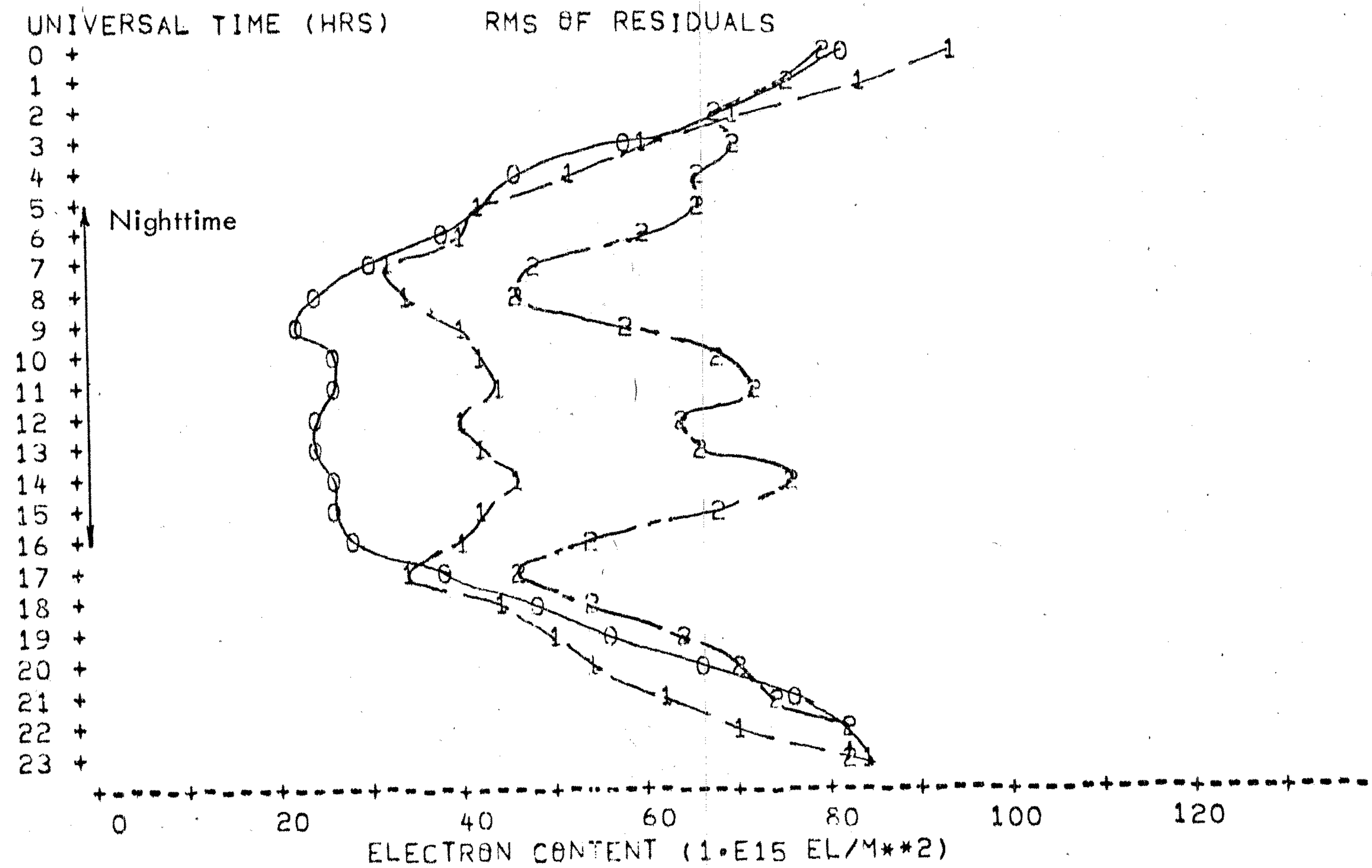


FIGURE 13u. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= URBA ATS3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATIONS
0	0		NONE
1	1	NT	EDMO ATS1 SAGA ATS3 HONO ATS1
2	1	NT	SAGA ATS3
3	1	FOF2	WALL OPS

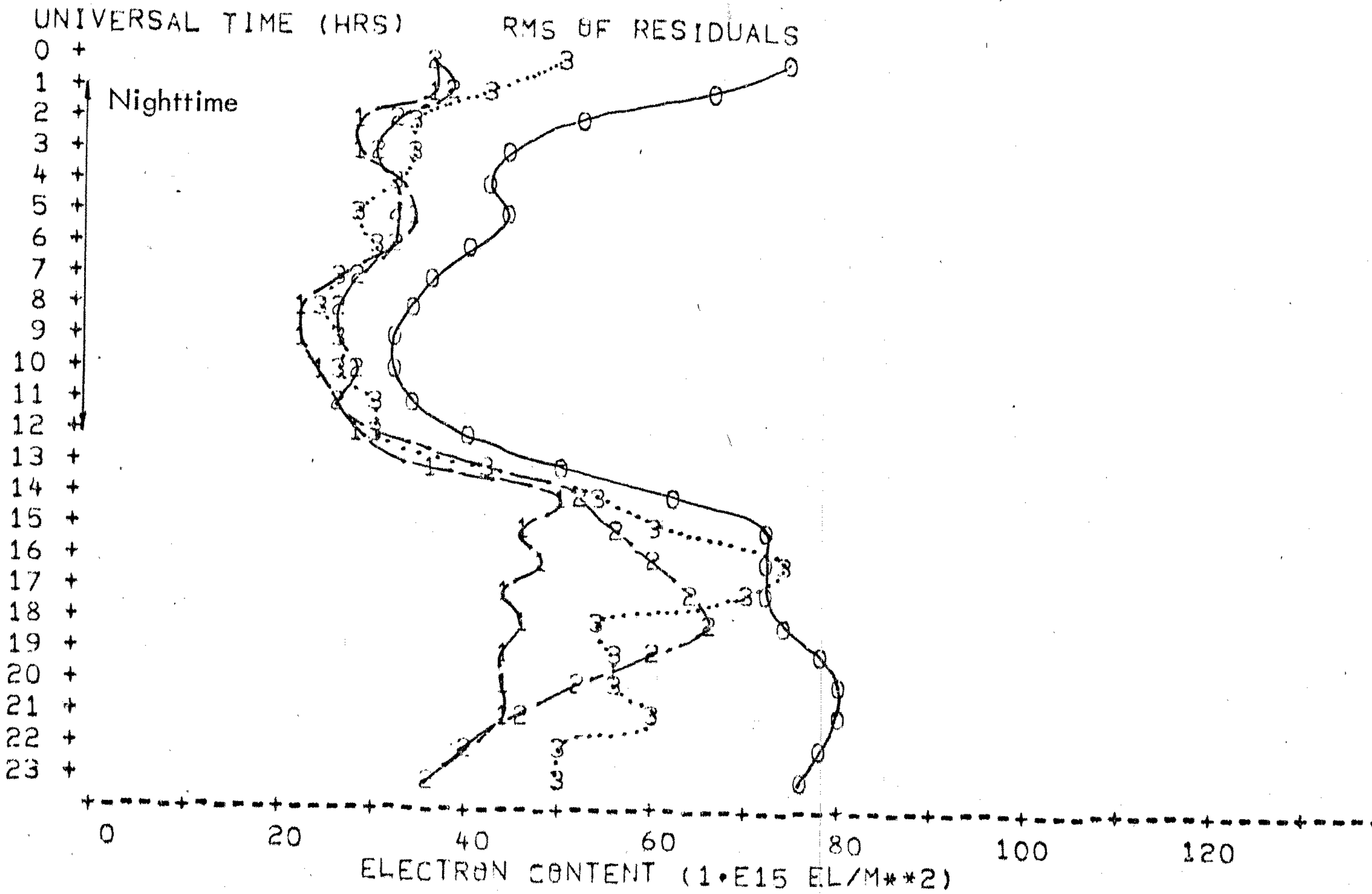


FIGURE 13v. HOURLY RMS OR STD OF RESIDUALS

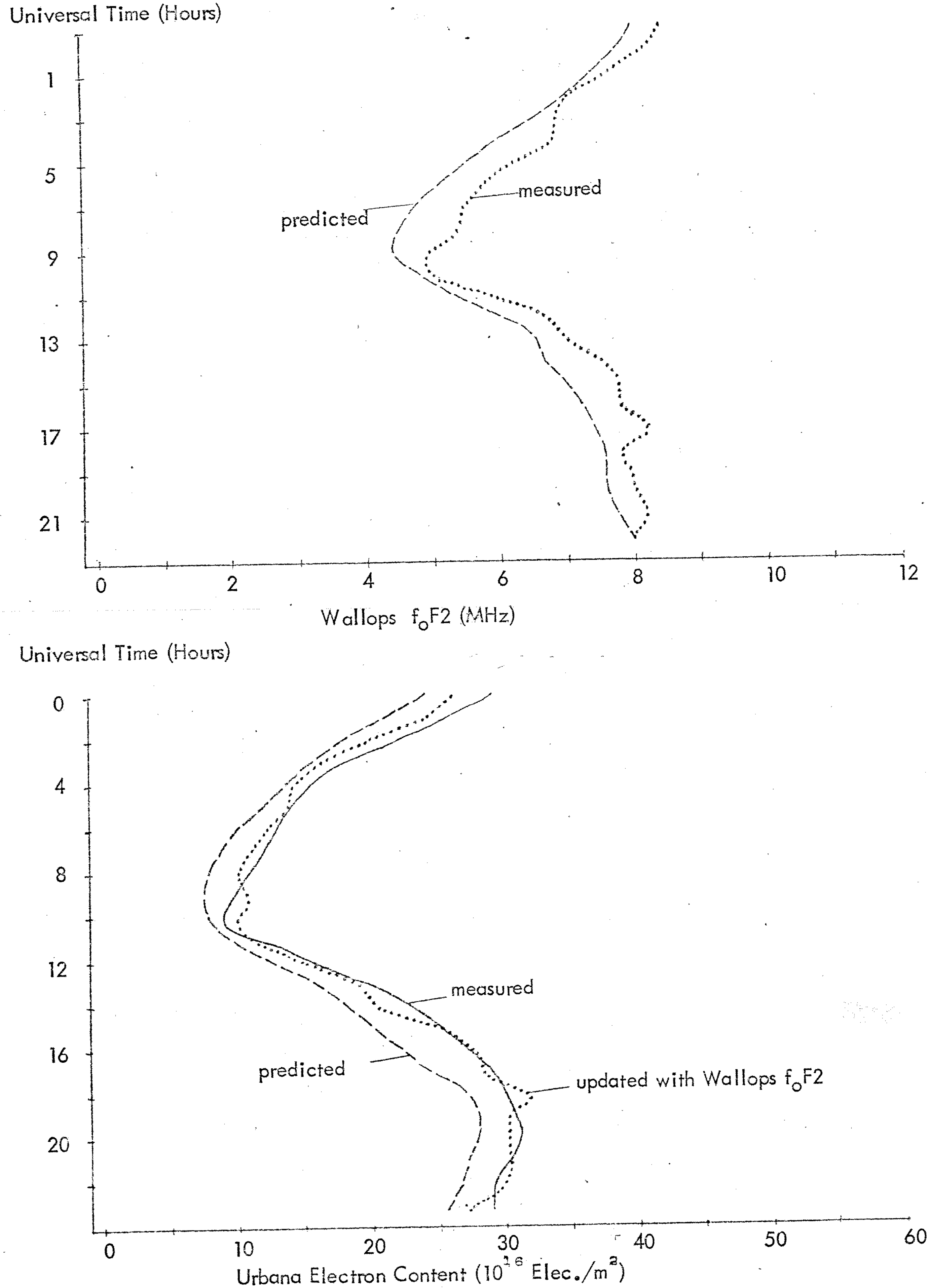
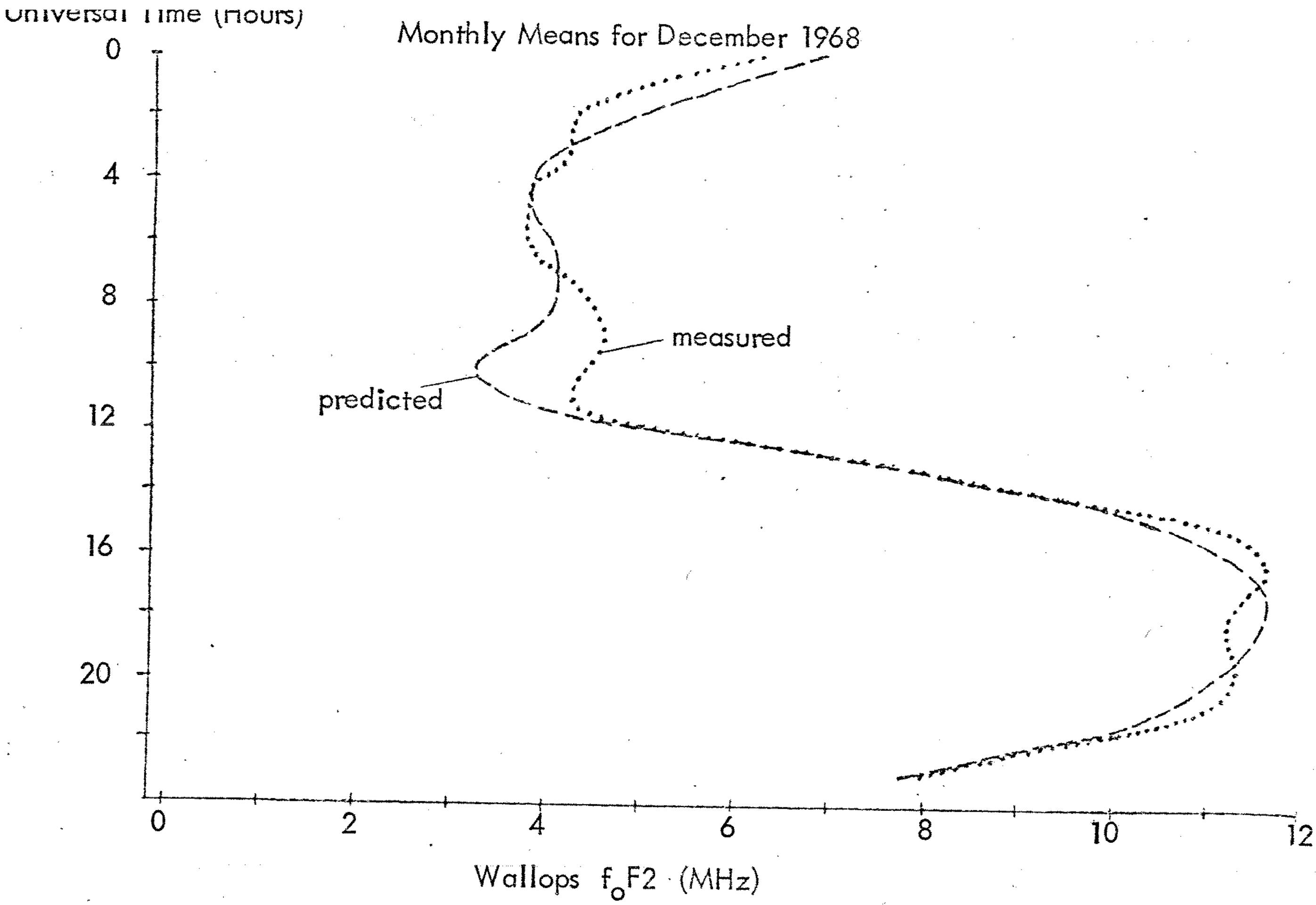


Figure 14a. Diurnal Variation of Electron Content and f_oF2 Used in Update



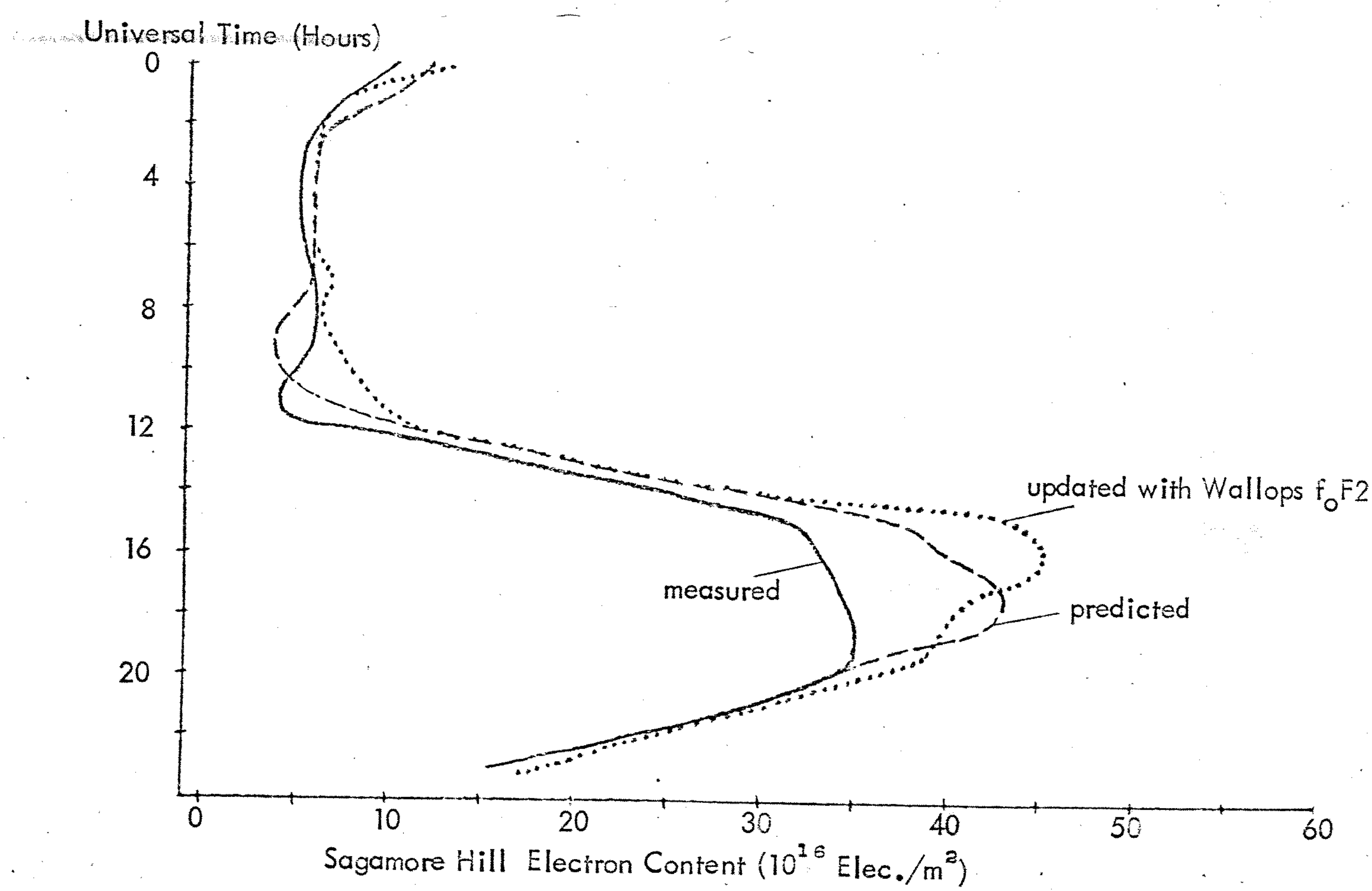


Figure 14b. Diurnal Variation of Electron Content and f_oF2 Used in Update

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION# Saga.ATS 3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATION#S
0	0	N_T	none
2	0	f_oF2	Wallops

MONTH = 12

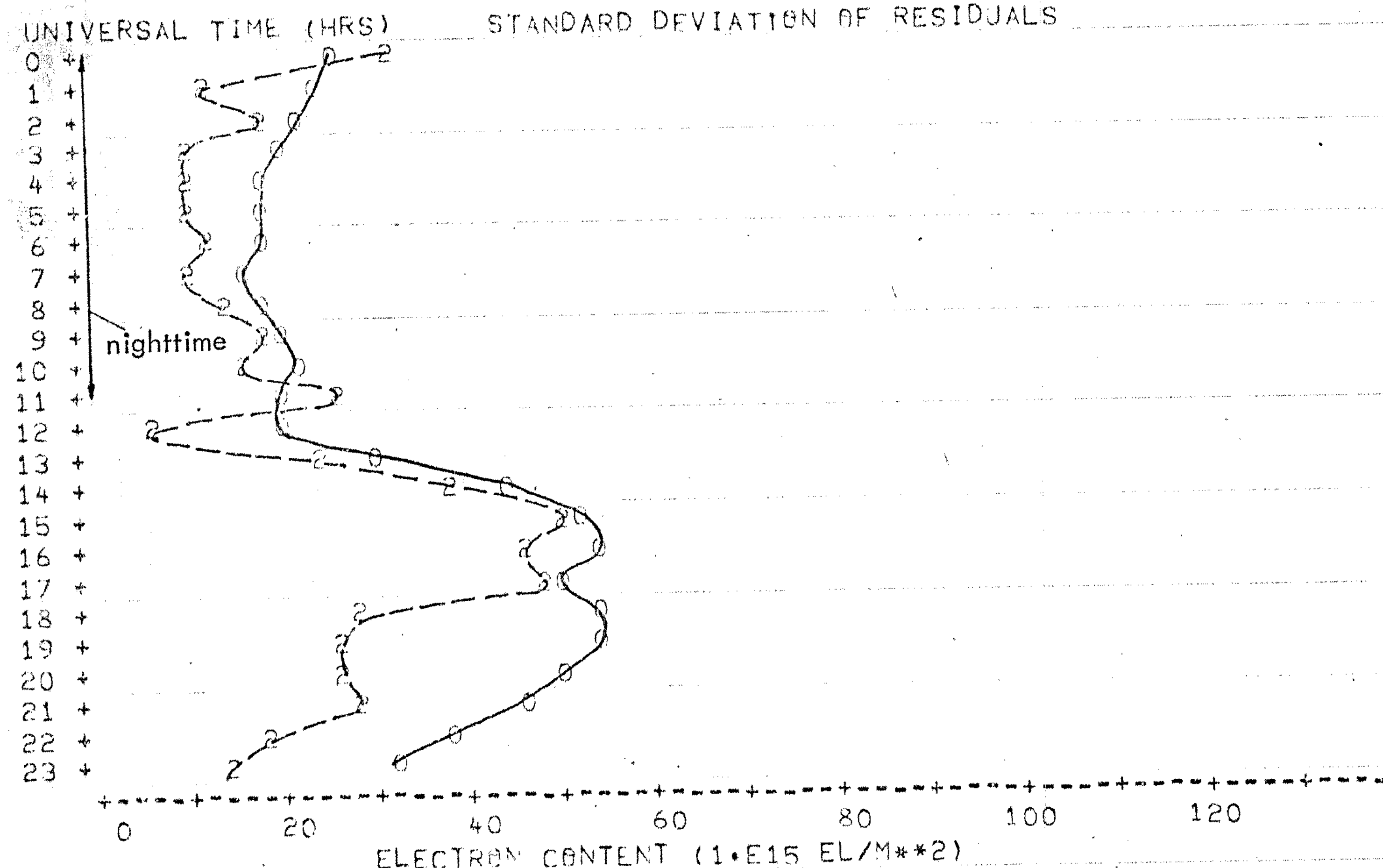


Figure 15a.

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION# Saga.ATS 3

SYMBOL	#HOURS PRIOR	STATION TYPE	UPDATE STATION#S
0	0	N_T	none
2	0	f_oF2	Wallops

MONTH = 12

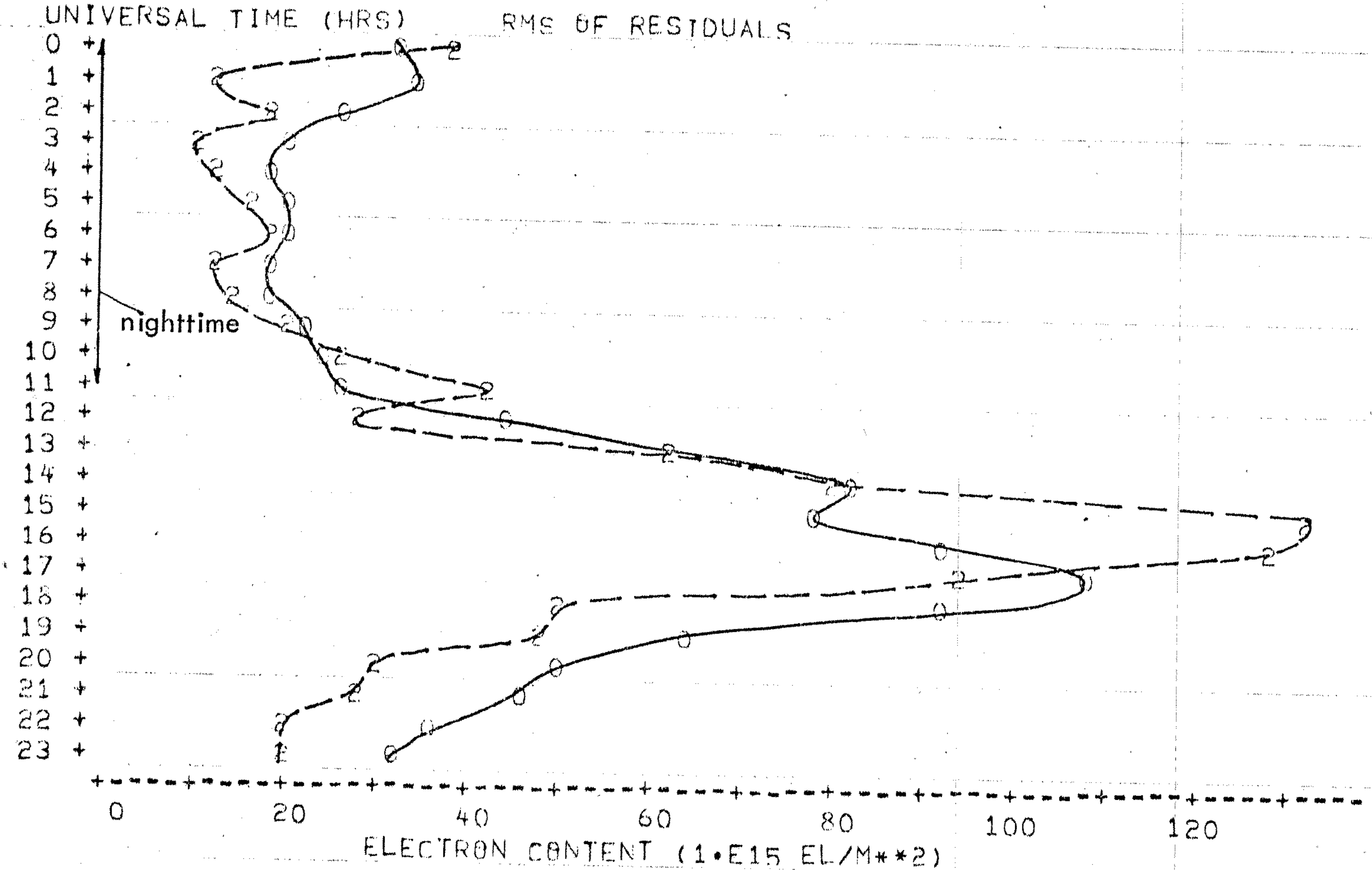


Figure 15b.

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION= HONO ATS1
UPDATE WITH MAUI FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

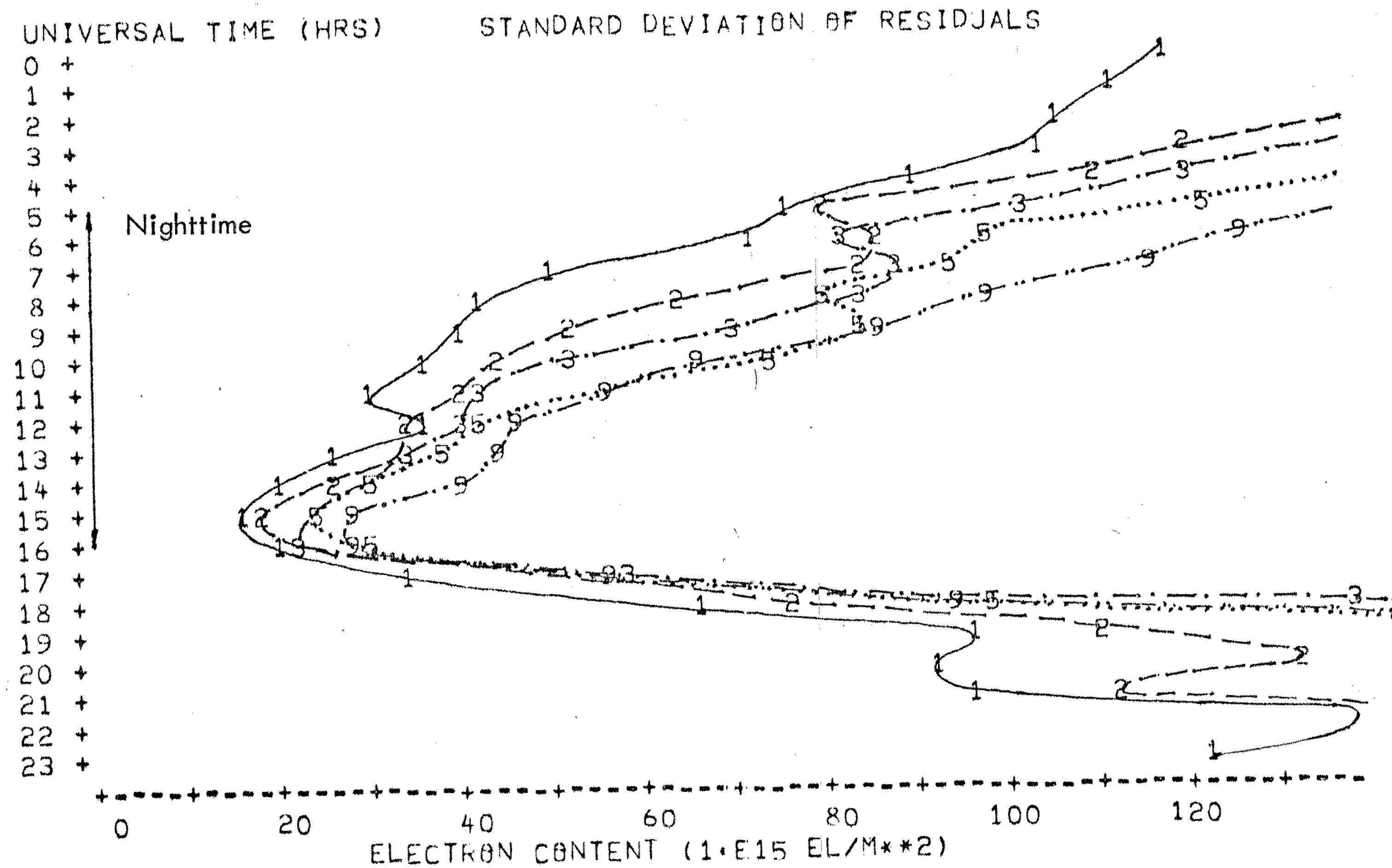


FIGURE 16a. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4   PERIOD 68 1 1 TO 681231   EVALUATION STATION= SAGA ATS3
UPDATE WITH WALLOPS FOF2 0,1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

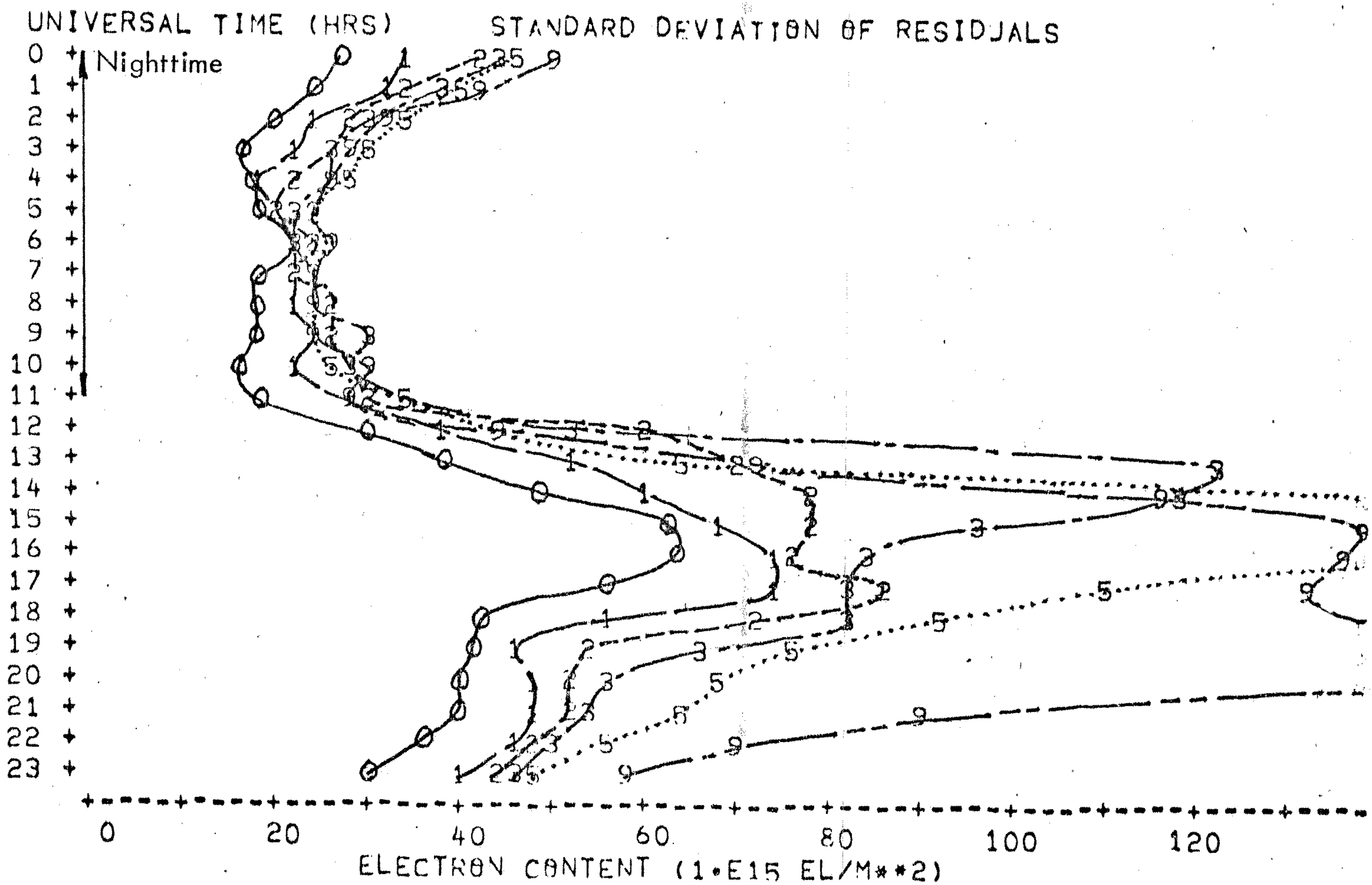


FIGURE 16b. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5   PERIOD 6812 1 TO 691113   EVALUATION STATION= STAN ATS1
UPDATE WITH ARGUELLO FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

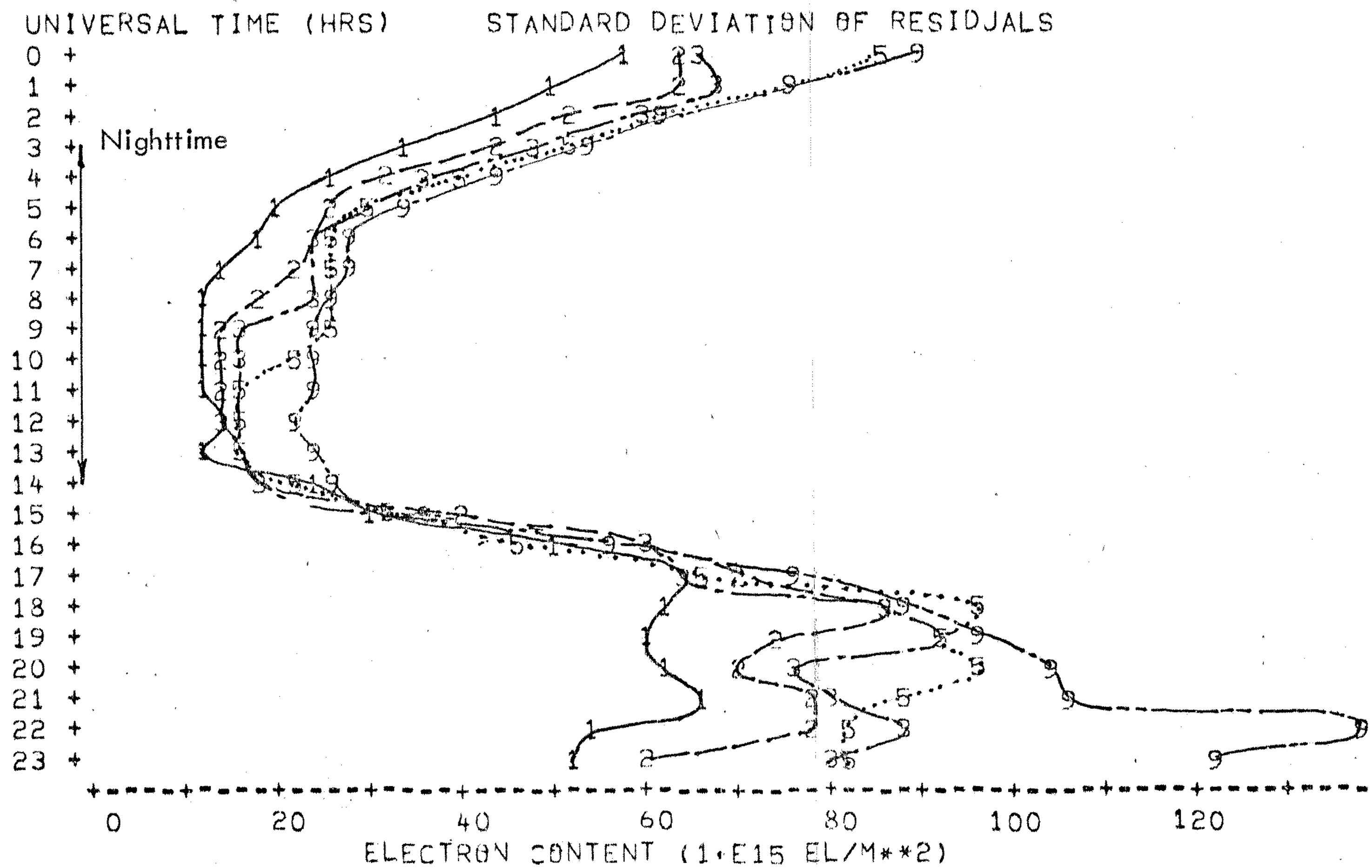


FIGURE 16 c. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5   PERIOD 6812 1 TO 691113   EVALUATION STATION= URBA ATS3
UPDATE WITH WALLOPS FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

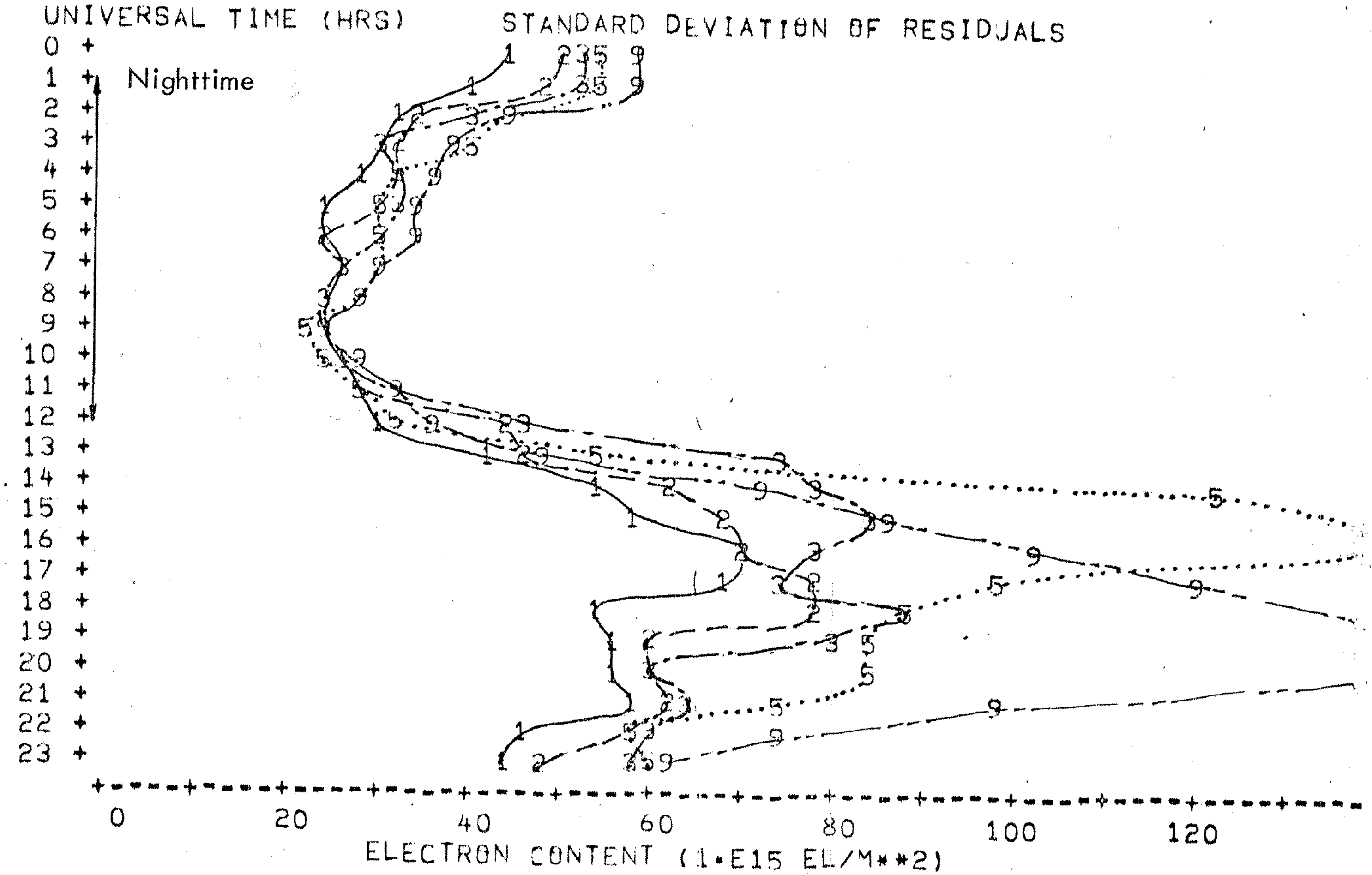


FIGURE 16d. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4   PERIOD 68 1 1 TO 681231   EVALUATION STATION= HONO ATS1
UPDATE WITH   MAUI FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

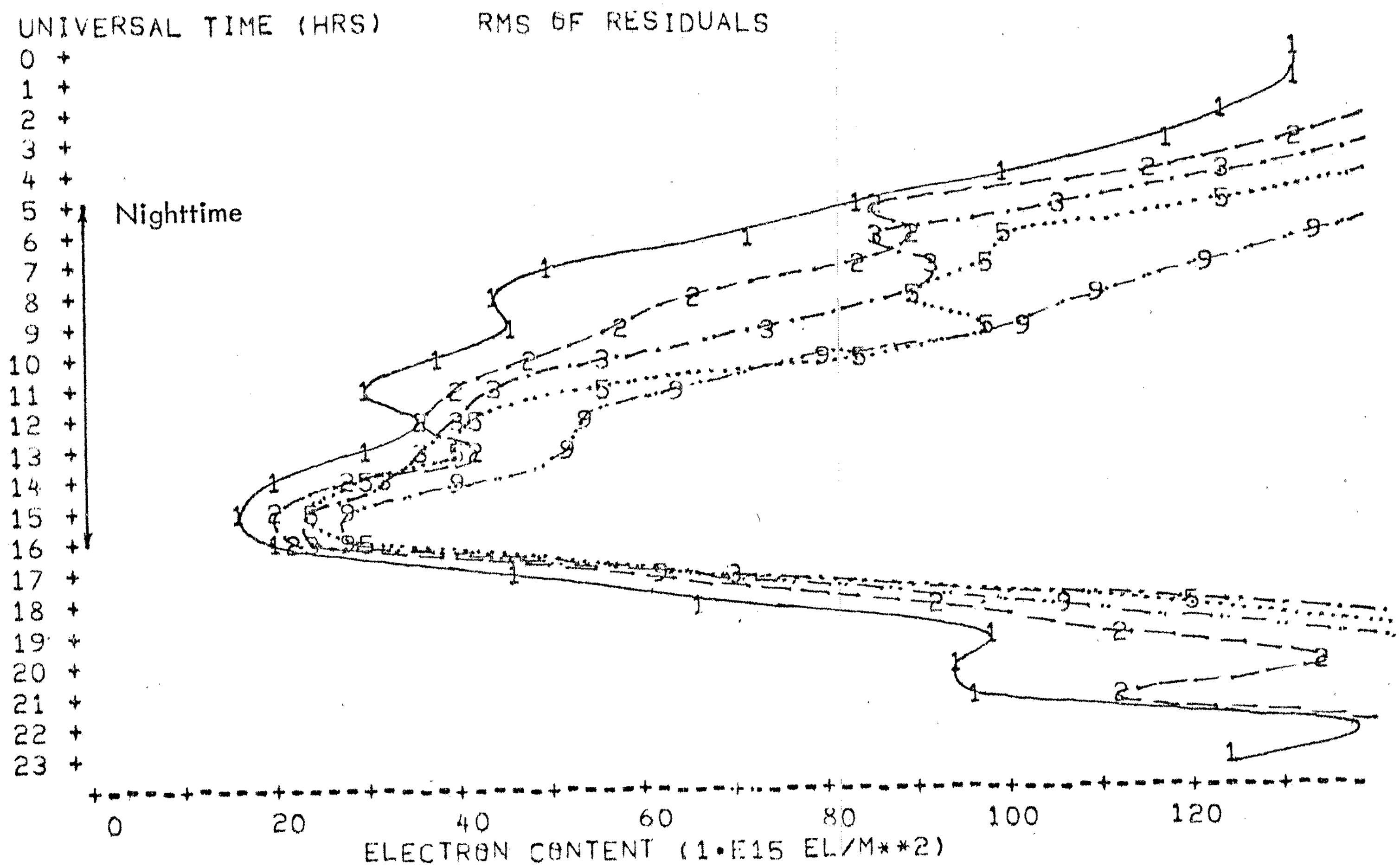


FIGURE 16e. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 4 PERIOD 68 1 1 TO 681231 EVALUATION STATION= SAGA ATS3
UPDATE WITH WALLOPS FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

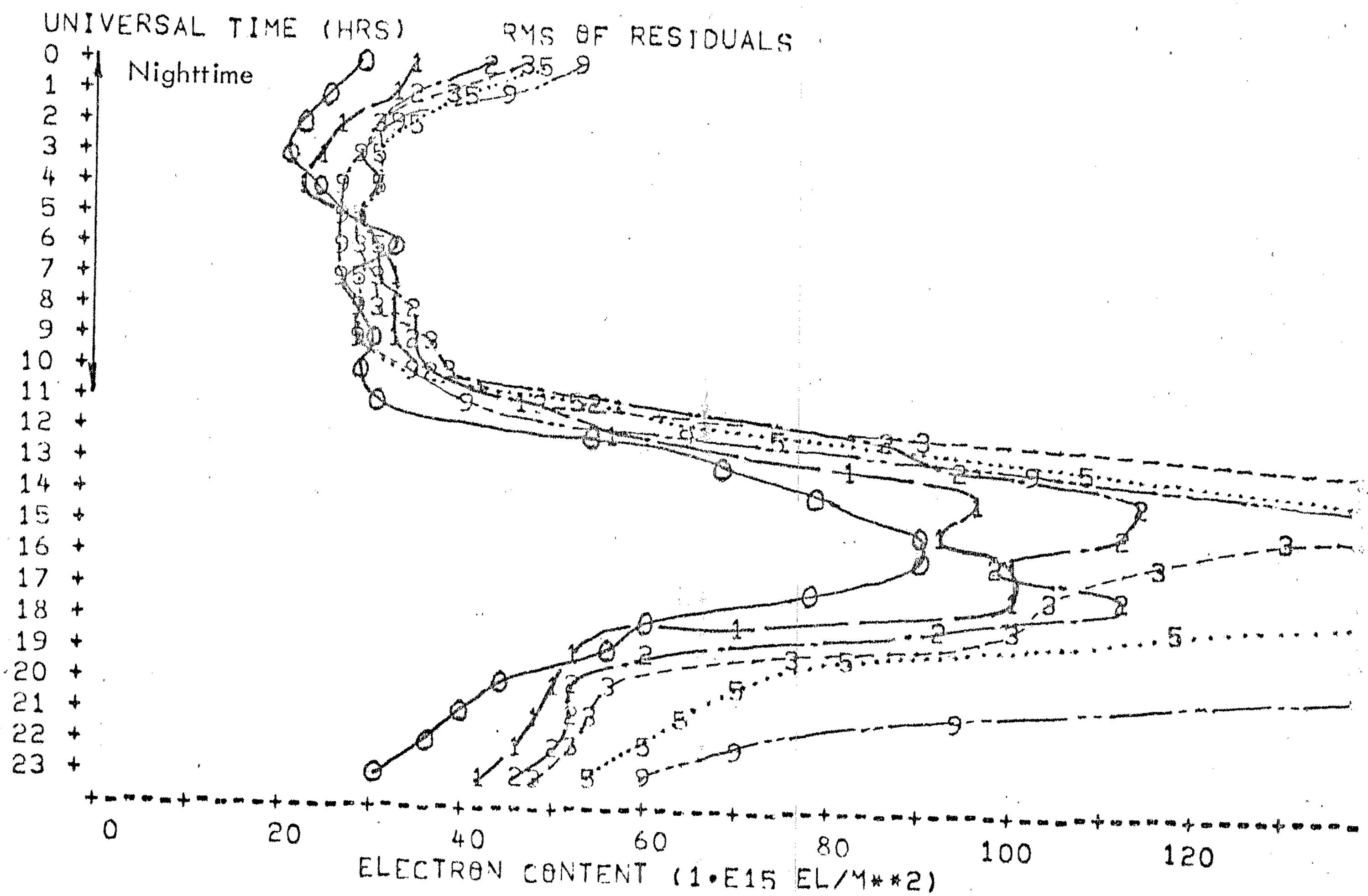


FIGURE 16f. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= STAN ATS1
UPDATE WITH ARGUELLO FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

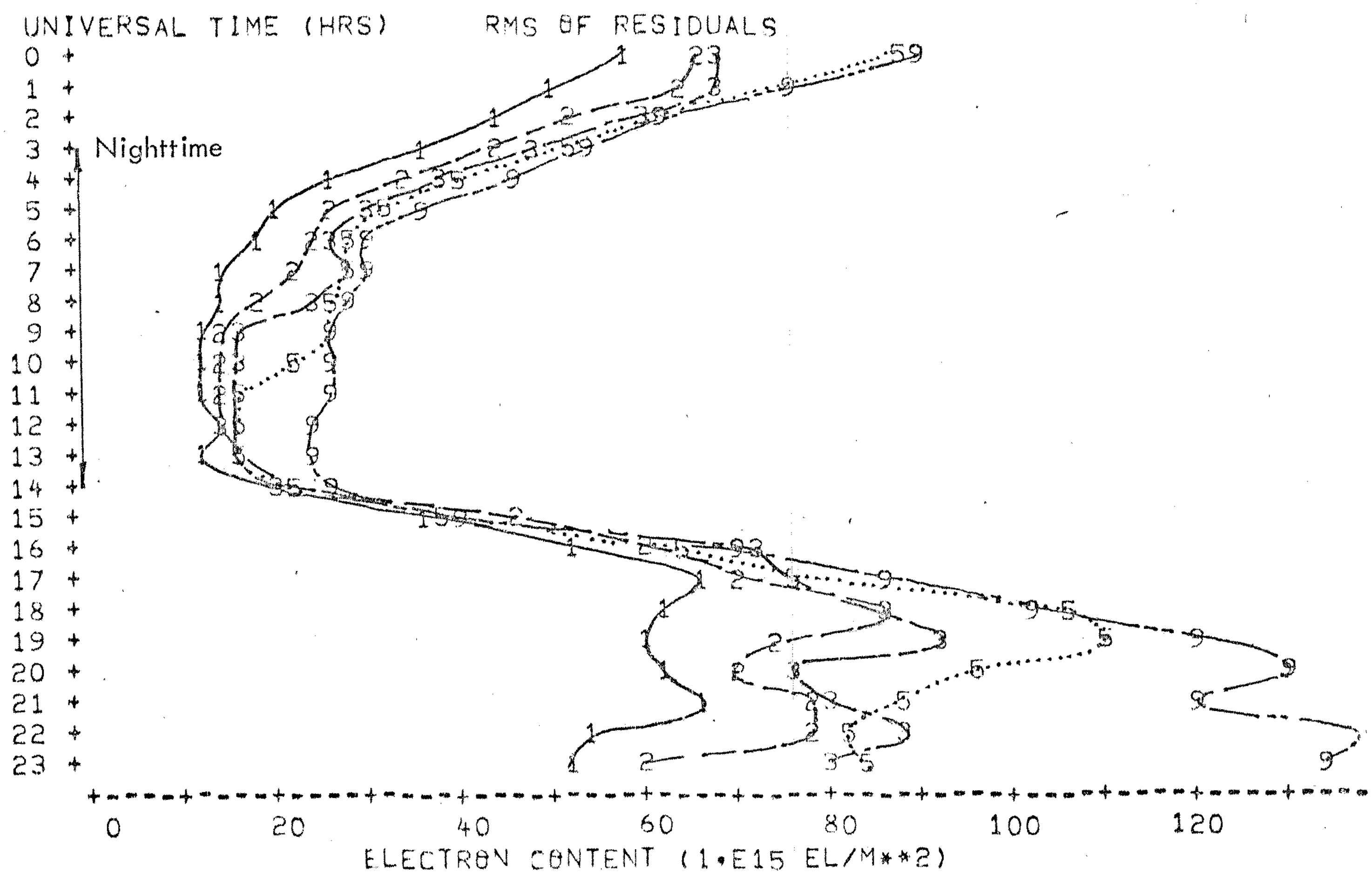


FIGURE 16g. HOURLY RMS OR STD OF RESIDUALS

CONDITION# 5 PERIOD 6812 1 TO 691113 EVALUATION STATION= URBA ATS3
UPDATE WITH WALLOPS FOF2 1,2,3,5,9 HOURS PRIOR TO EVAL.TIME

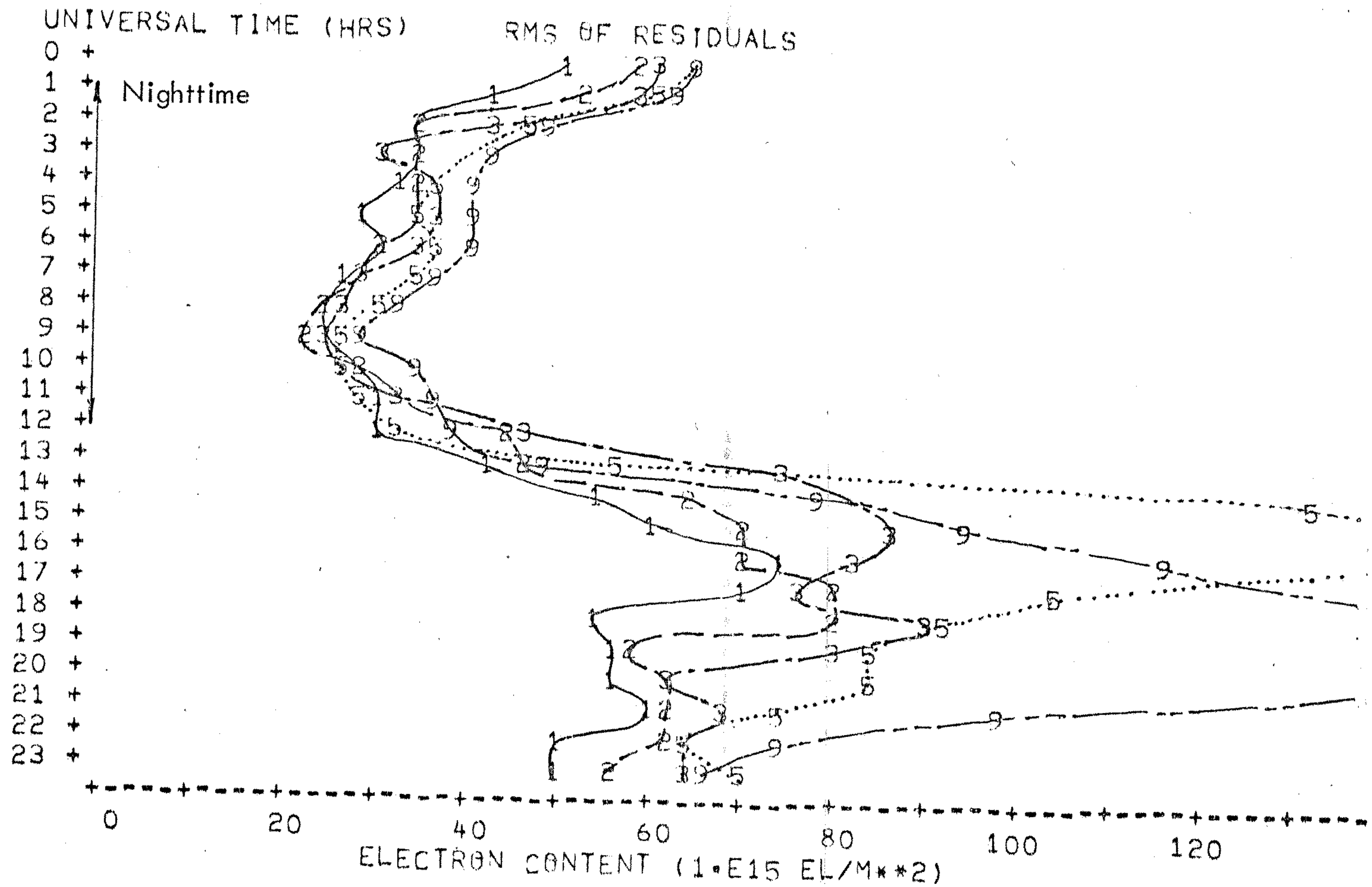


FIGURE 16h. HOURLY RMS OR STD OF RESIDUALS

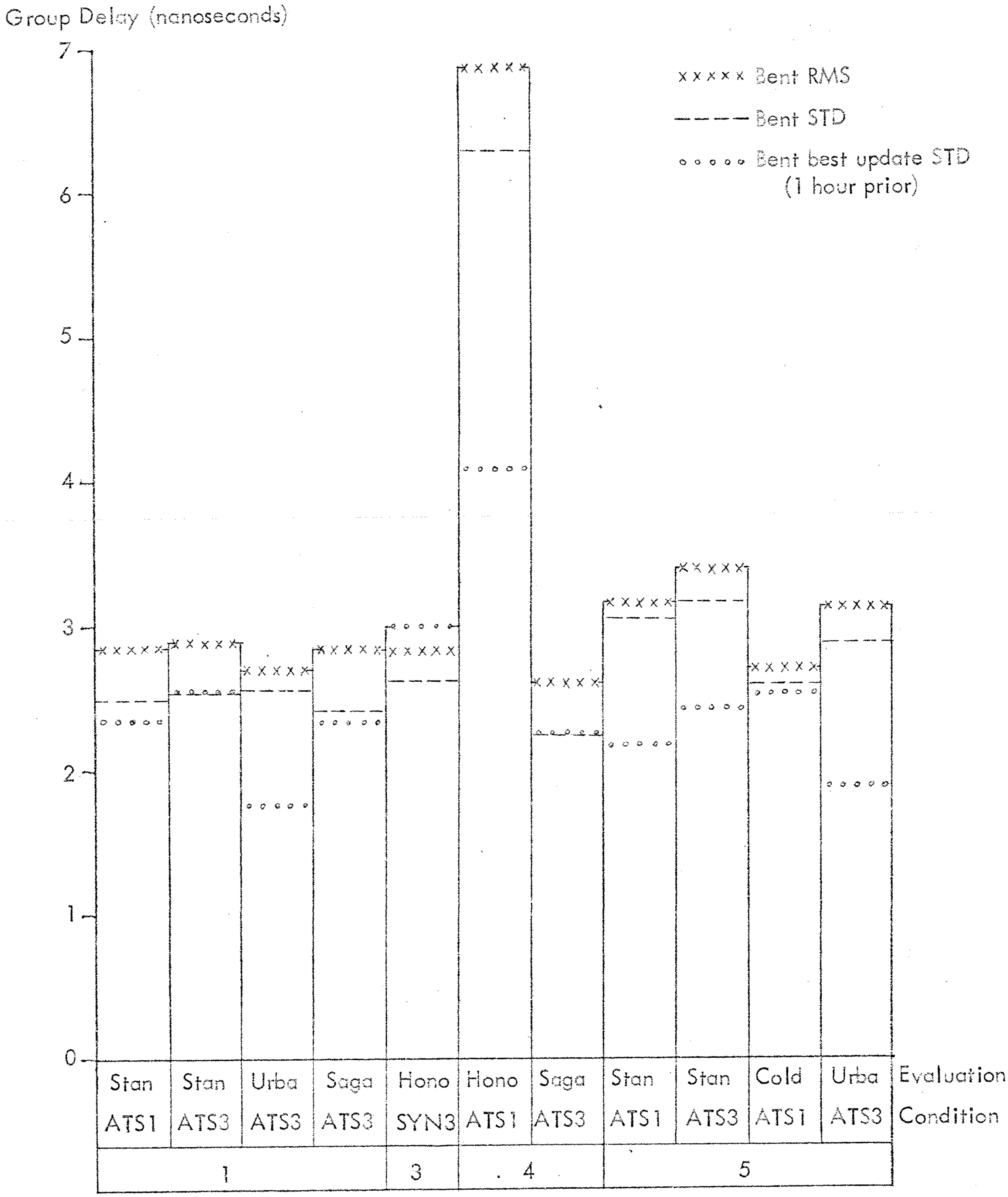


Figure 17. Overall RMS and STD of Residual Group Delay for Each Evaluation Condition

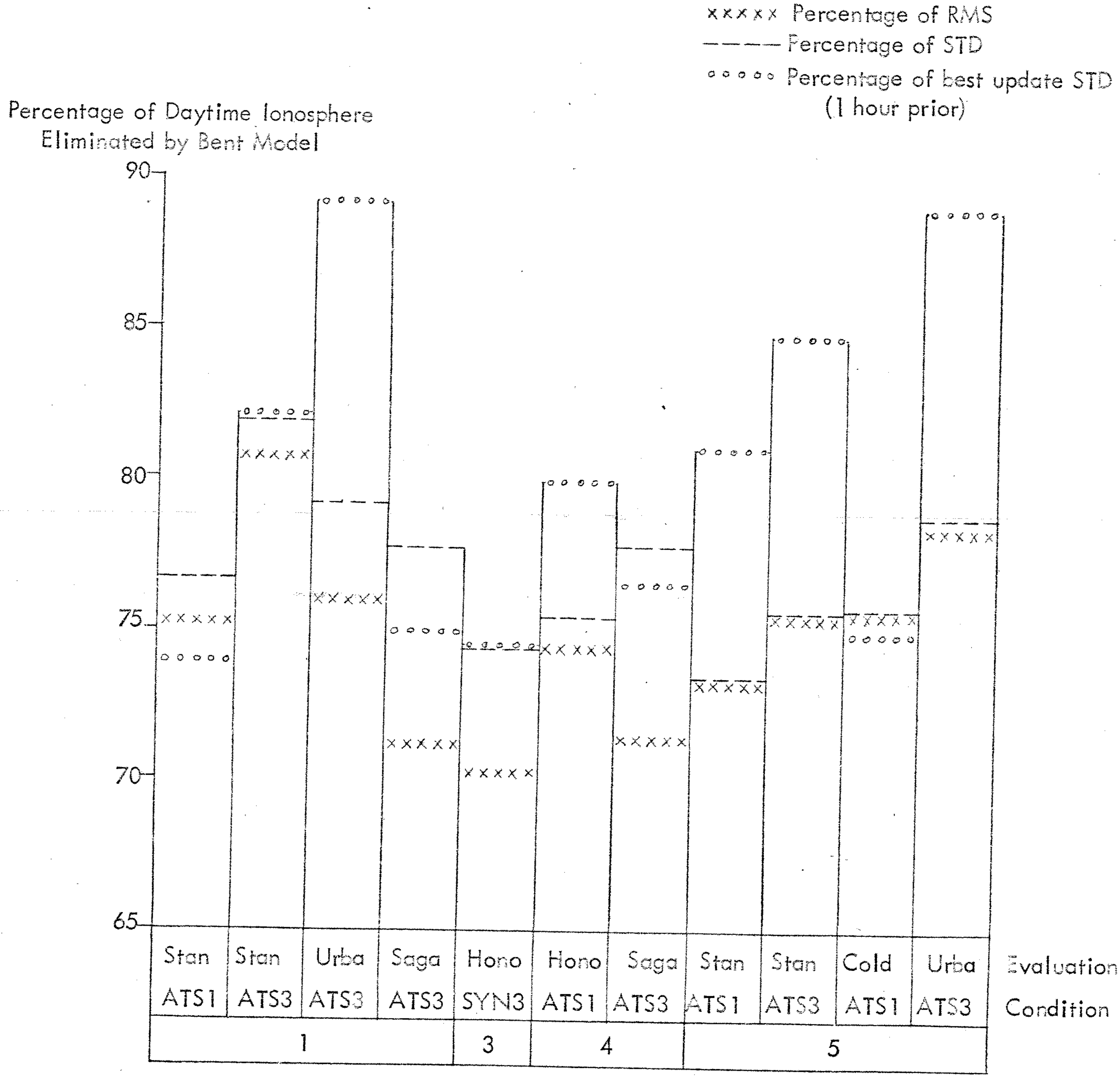


Figure 18. Percentage of Daytime Ionosphere Eliminated for Each Evaluation Condition

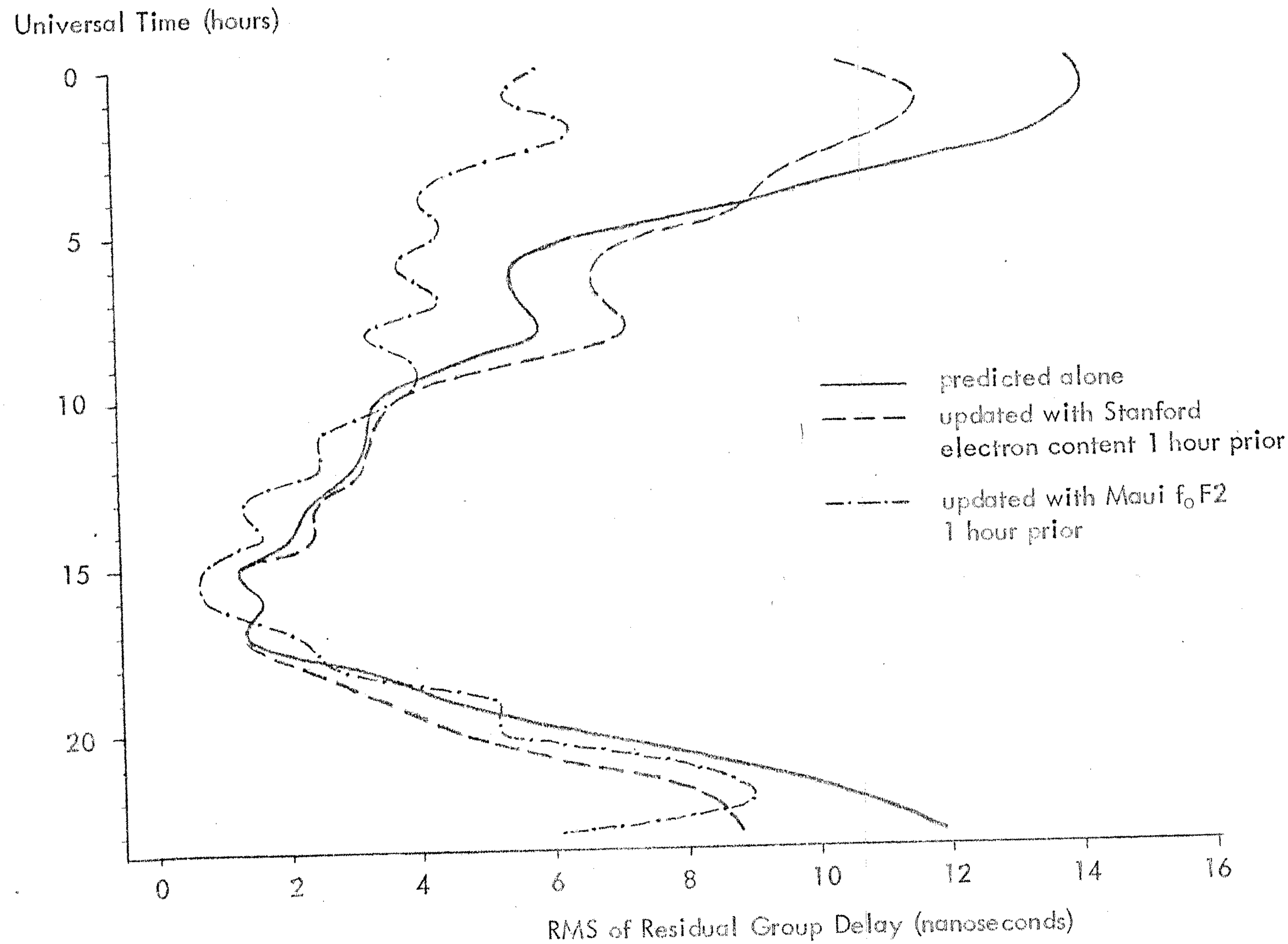


Figure 19. Monthly Average of Hourly RMS Residuals for Honolulu in February 1968

TABLE 9. CUMULATIVE PROBABILITY DISTRIBUTION OF RESIDUALS OVER ENTIRE EVALUATION PERIOD
1 JANUARY 1965 TO 31 DECEMBER 1965

EVALUATION CONDITION NUMBER 3
EVALUATION STATION: HONOLULU SYN-3
UPDATE CONDITION: NONE

RMS OF RESIDUALS: 2.83 NANOSECONDS
NUMBER OF RESIDUALS: 8241
NUMBER OF RESIDUALS EXCEEDING 25 NANOSECONDS IS 0

GROUP DELAY NANOSECONDS	PERCENT PROBABILITY	GROUP DELAY NANOSECONDS	PERCENT PROBABILITY
0	52.21	0	52.21
1	77.78	-1	24.79
2	87.17	-2	17.05
3	92.02	-3	12.34
4	95.02	-4	8.72
5	96.68	-5	5.67
6	97.72	-6	3.53
7	98.28	-7	2.14
8	98.75	-8	1.20
9	99.04	-9	.66
10	99.31	-10	.34
11	99.51	-11	.19
12	99.71	-12	.12
13	99.78	-13	.07
14	99.83	-14	.01
15	99.94	-15	.00
16	99.96	-16	.00
17	99.98	-17	.00
18	100.00	-18	.00
19	100.00	-19	.00
20	100.00	-20	.00
21	100.00	-21	.00
22	100.00	-22	.00
23	100.00	-23	.00
24	100.00	-24	.00
25	100.00	-25	.00

TABLE 10. Correlation Coefficient For Evaluation Station Pairs

Condition	Period	Station Pair	Correlation Prediction Alone	Coefficients 1 Station f_oF2 Update	*1000: 1 Station N_T Update	2 Station N_T Update	3 Station N_T Update
1 & 2	8 Dec 67 — 18 Apr 68	Stan.ATS1/Stan.ATS3	866 (2547)	869 (2103)	---	941 (1469)	902 (1222)
			*884 (894)	890 (862)	---	944 (508)	896 (419)
		Stan.ATS3/Urba.ATS3	482 (2162)	---	358 (1727)	710 (1332)	569 (1106)
			*515 (564)	---	332 (431)	688 (327)	564 (262)
		Urba.ATS3/Saga.ATS3	729 (1928)	698 (1491)	---	881 (1247)	---
			*749 (541)	754 (442)	---	932 (319)	---
5	1 Dec 68 — 13 Nov 69	Stan.ATS1/Stan.ATS3	876 (2760)	778 (2520)	878 (2555)	---	812 (2409)
			*883 (921)	796 (880)	894 (870)	---	818 (816)
		Stan.ATS3/Urba.ATS3	493 (2838)	---	---	---	400 (2477)
			*516 (684)	---	---	---	458 (595)

In parenthesis: Number of residuals used in each computation.
Second line (*): Results from daytime correlation only (9-16 hours local time).

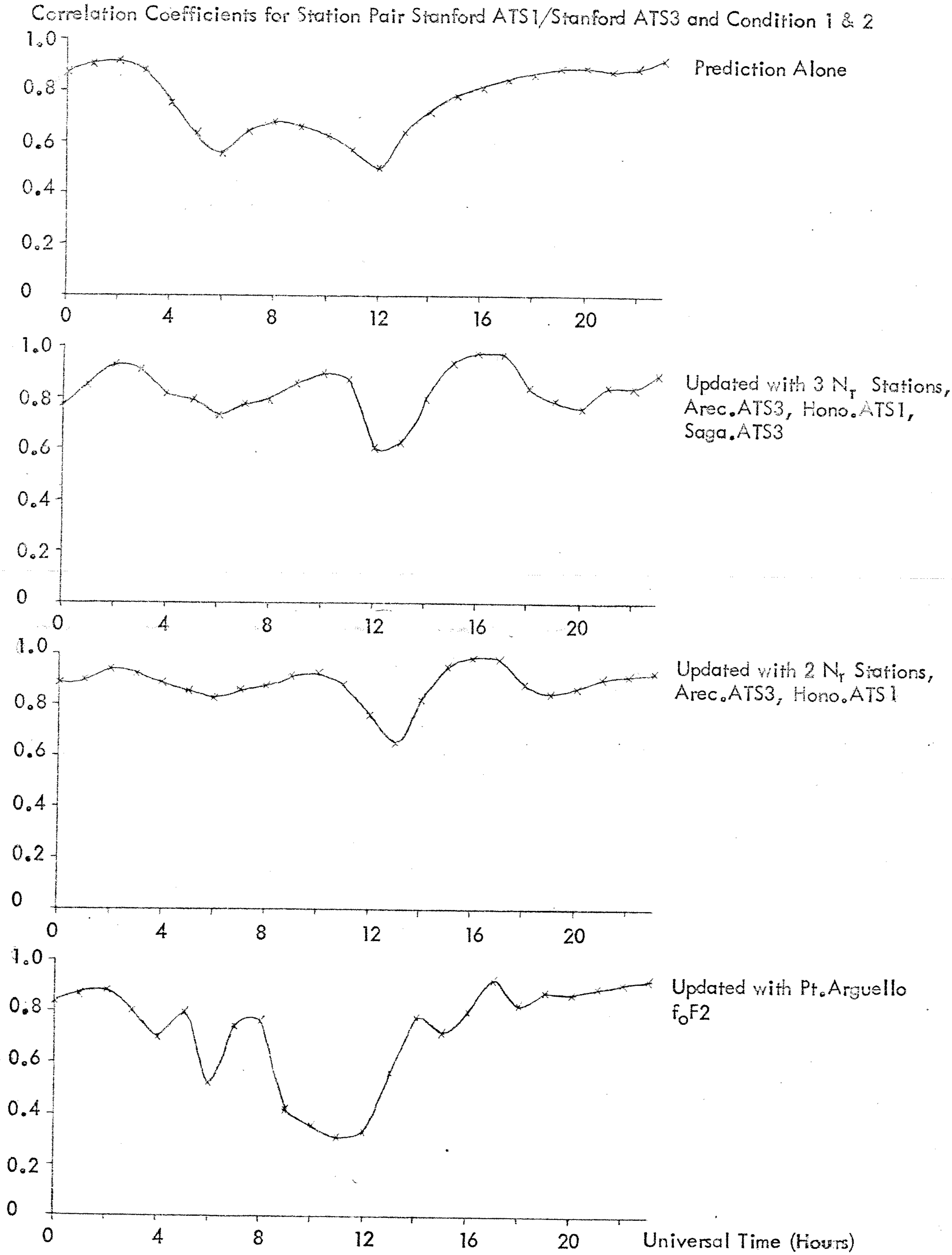


Figure 20a. Diurnal Variation of Correlation Coefficients

Correlation Coefficients for Station Pair Stanford ATS3/Urbana ATS3 and Condition 1 & 2

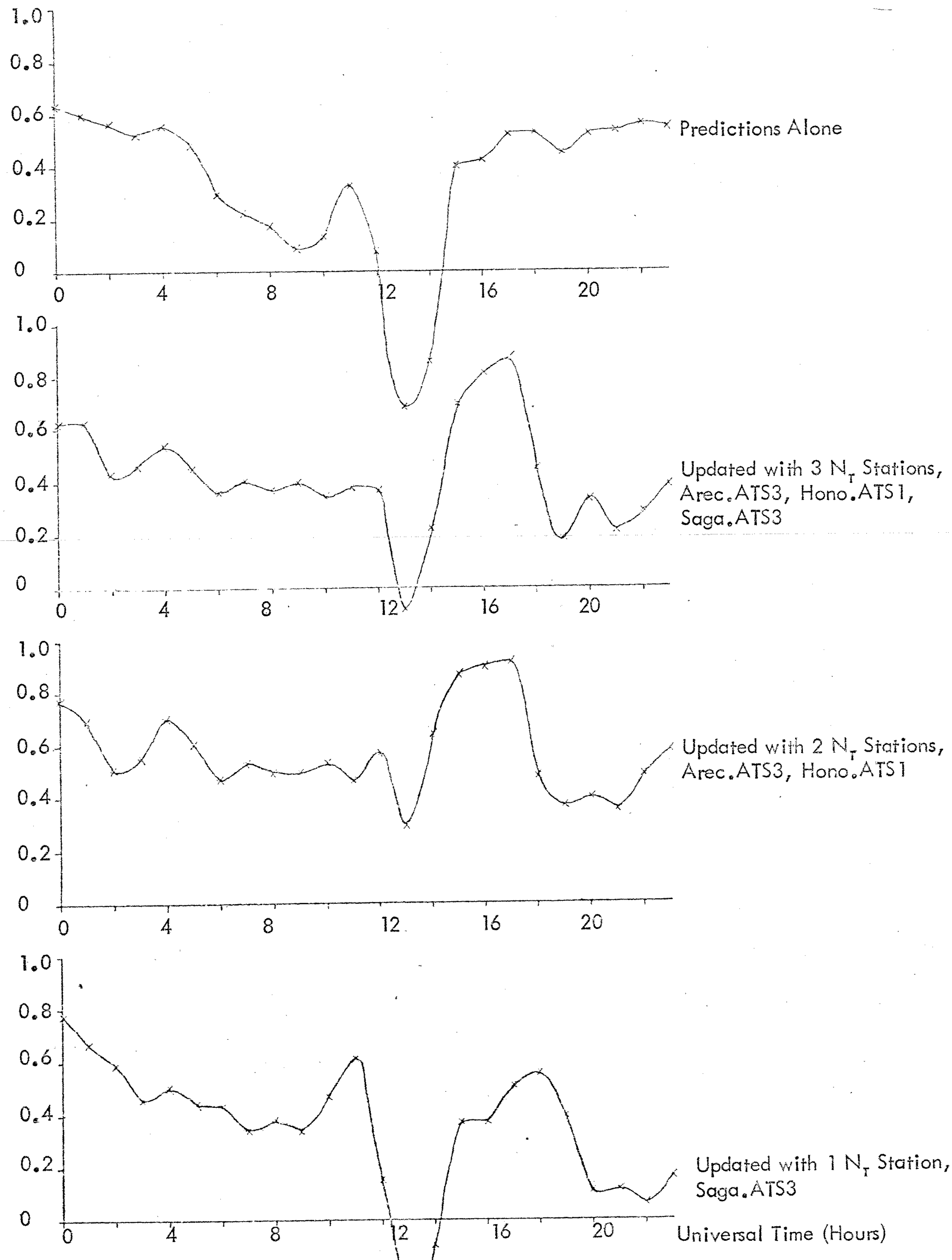


Figure 20b. Diurnal Variation of Correlation Coefficients

Correlation Coefficients for Station Pair Urbana ATS3/Sagamore ATS3 and Condition 1 & 2

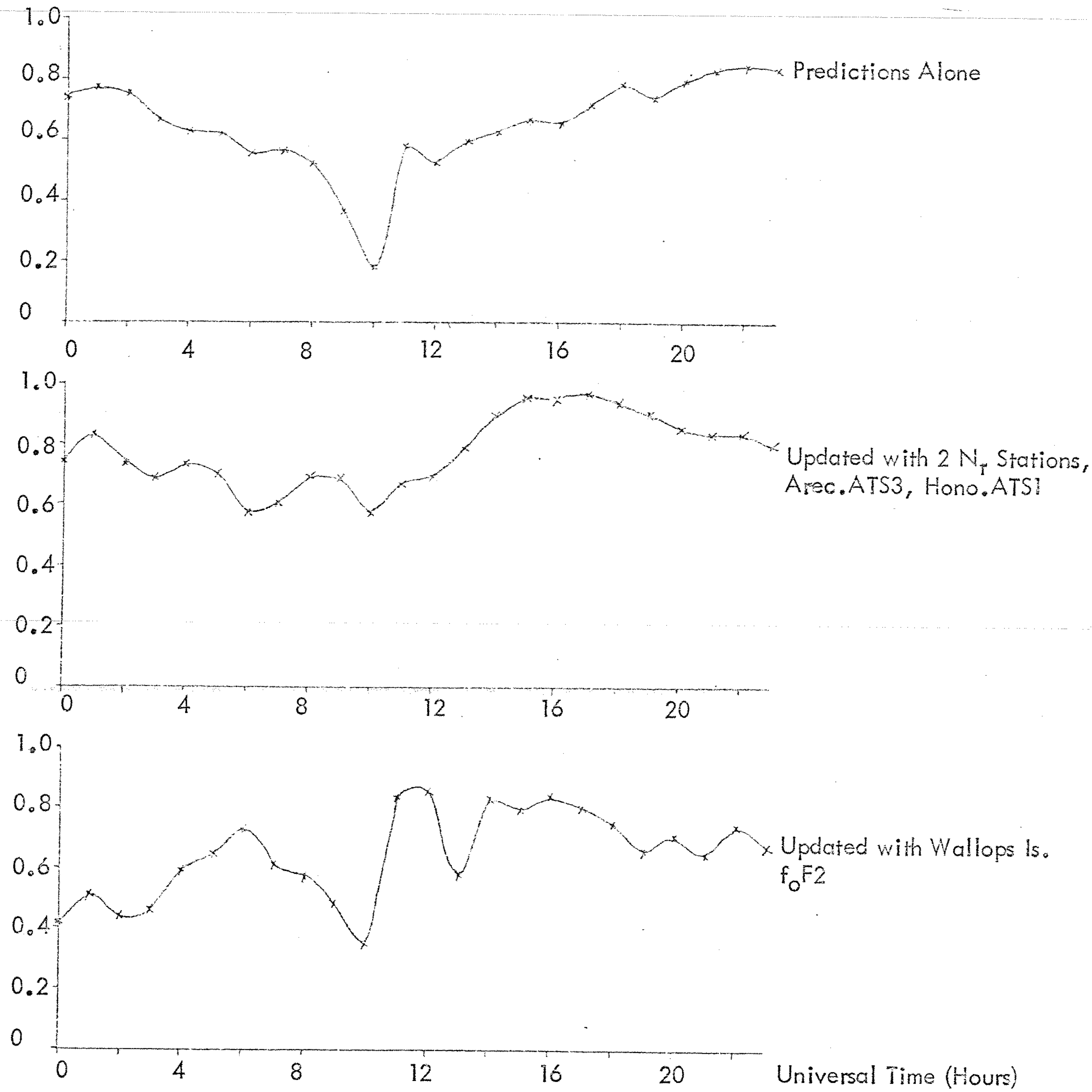


Figure 20c. Diurnal Variation of Correlation Coefficients

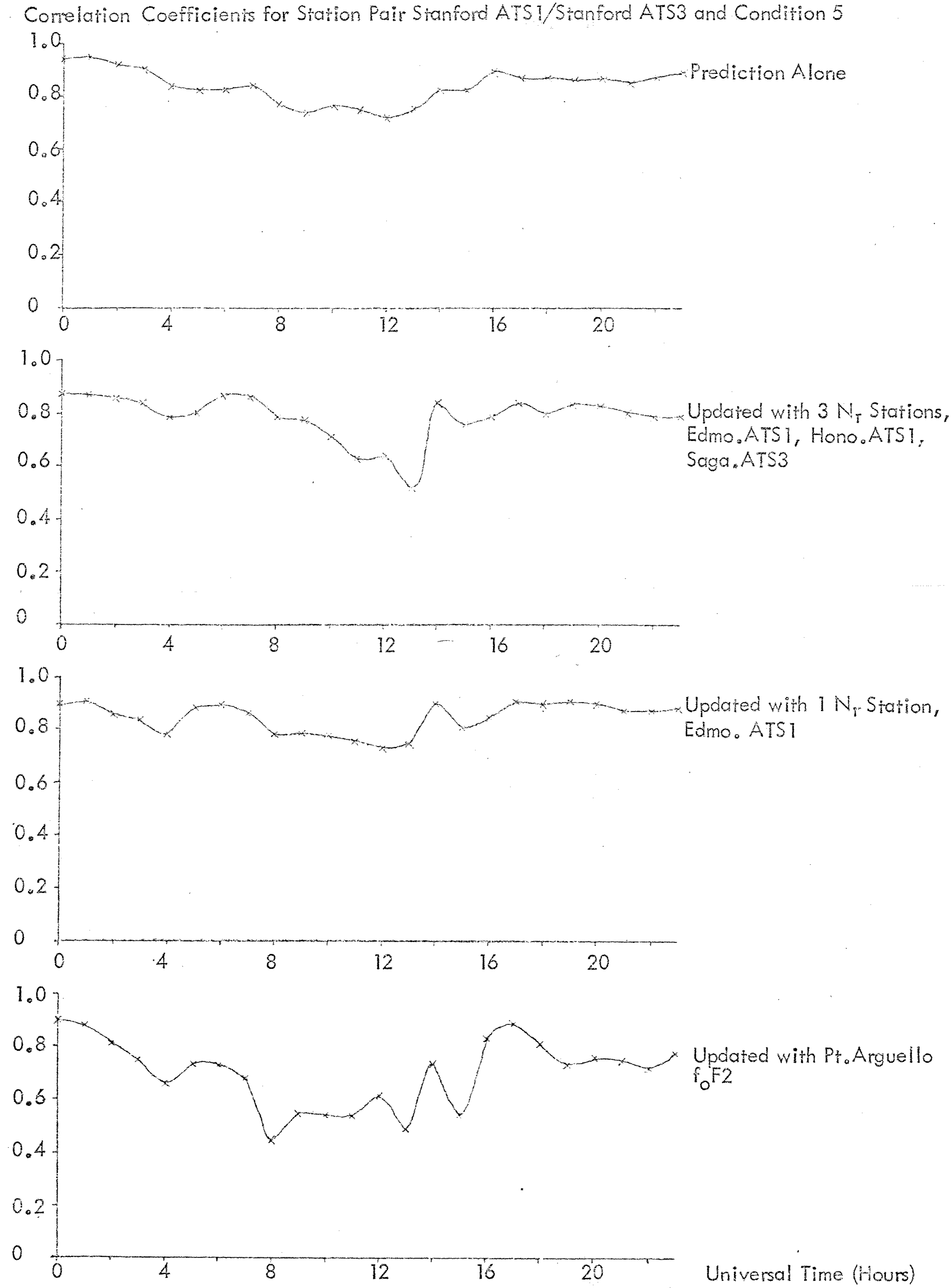


Figure 20d. Diurnal Variation of Correlation Coefficients

Correlation Coefficients for Station Pair Stanford ATS3/Urbana ATS3 and Condition 5

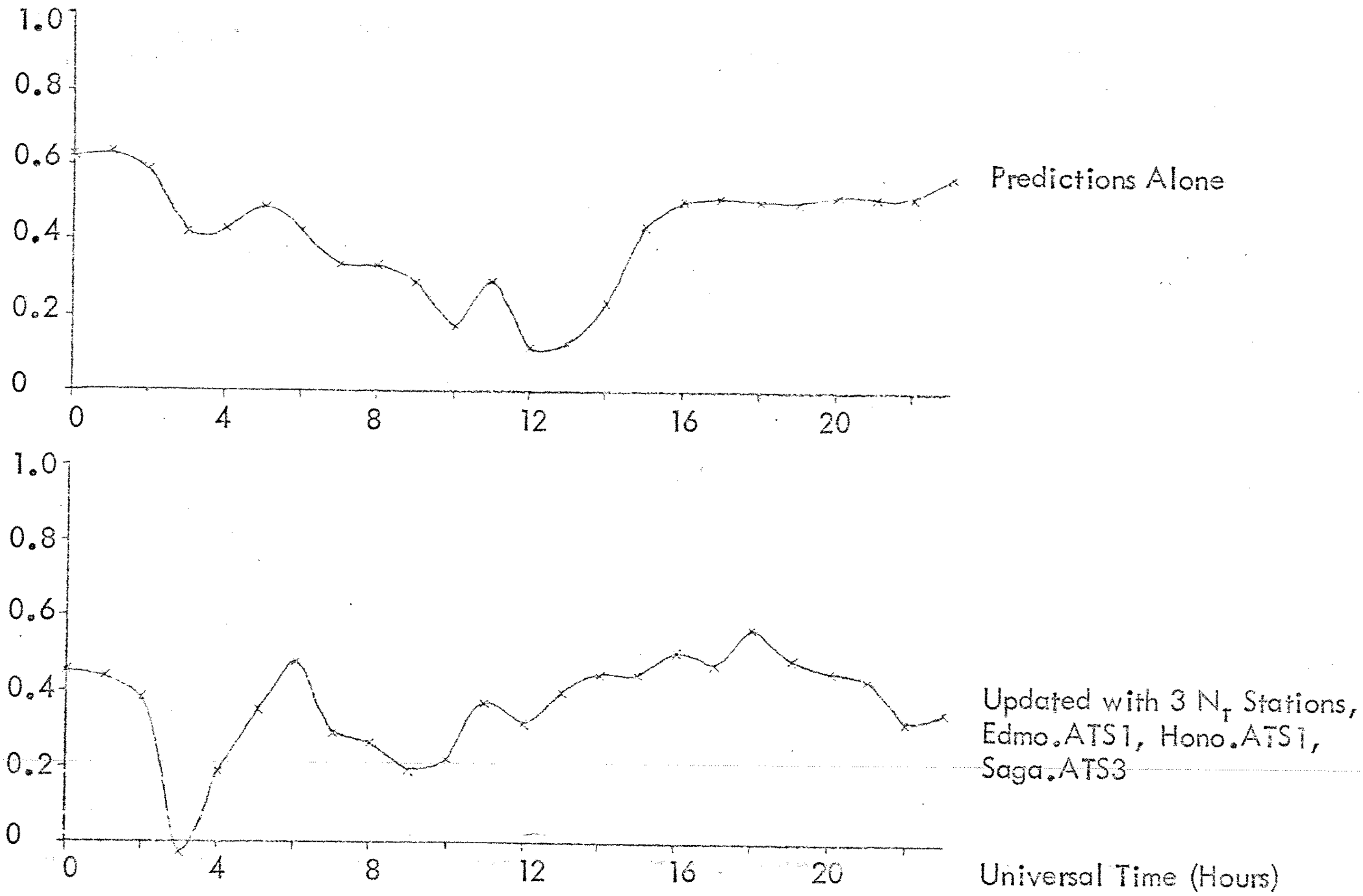


Figure 20e. Diurnal Variation of Correlation Coefficents

7.0 SUGGESTIONS FOR FURTHER STUDY

Undoubtedly one of the major factors in this ionospheric profile is the value of f_oF2. Preliminary tests have shown a large bias in the ITSA predicted value of f_oF2 as a function of latitude. In our opinion an improvement of this value is going to be the only factor that will change the model to give significantly better residuals in standard deviation. Much work needs to be performed on this topic so that correlations of predicted $f_o F2$ and the daily updated value of solar flux give much improved values as a function of local time, latitude and season. Hopefully such work would bring about a noticeable improvement in the standard deviation of the residuals.

It has already been suggested that the mean bias in the model can be improved to a point where the standard deviation and RMS values are similar. Preliminary improvements in the model have already been investigated and the RMS value for the entire period of evaluation condition 4 (Honolulu, 1968) was reduced to 6.35 nanoseconds. A short study should therefore be performed to improve this feature.

We have shown that update of the model works well at the times when the ionosphere is thick and a weakness in the model during morning hours has also been discussed. This problem should be alleviated without much difficulty. Again, however, the error is probably in the mean bias and very little improvement in the standard deviation will result.

Undoubtedly further study of the model over worldwide equatorial region stations should be performed along with f_oF2 or Faraday update. After these worldwide studies have been performed a thorough investigation of all the data analyzed should point out the errors the 621B system will have to contend with. A plan could then be devised to indicate when and where it is necessary to update the ionosphere, how this should be achieved and by how many hours prior the update data is required. A plan along these lines could be drawn up with the data analyzed to the present but it would need considerable study of the existing results which, as we know, exists in abundance.

A major problem for the 621B system may be the height of the ionosphere. We know that normal worldwide changes in the height of maximum electron density differ by a factor of 2. Let us consider an earth based observer monitoring a satellite 5° above the horizon. If he is situated at some point in the world where the height of maximum electron density is, say, 450km the earth central angle between him and the sub-ionospheric point may differ by over 3° to a similar observer in a region where the height is a normal 325km. This 3° in earth central angle can mean a change in total content of 20% due to the horizontal gradients at sunrise and near the equatorial anomaly. These are the places where dense ionospheres occur and so even if we could predict the ionospheric delay exactly for known positions, this 3° uncertainty would add errors of perhaps 20 nanoseconds. During this investigation for computing the sub-ionospheric point, the ionospheric height was kept constant at 325km in order to simplify the computation and enable correlations with the other contractors results to be more meaningful. The ionospheric height, however, must be an important consideration for the 621B system.

An example of the monthly median diurnal variation of ionospheric height for a specific equatorial point is shown in Figure 21.

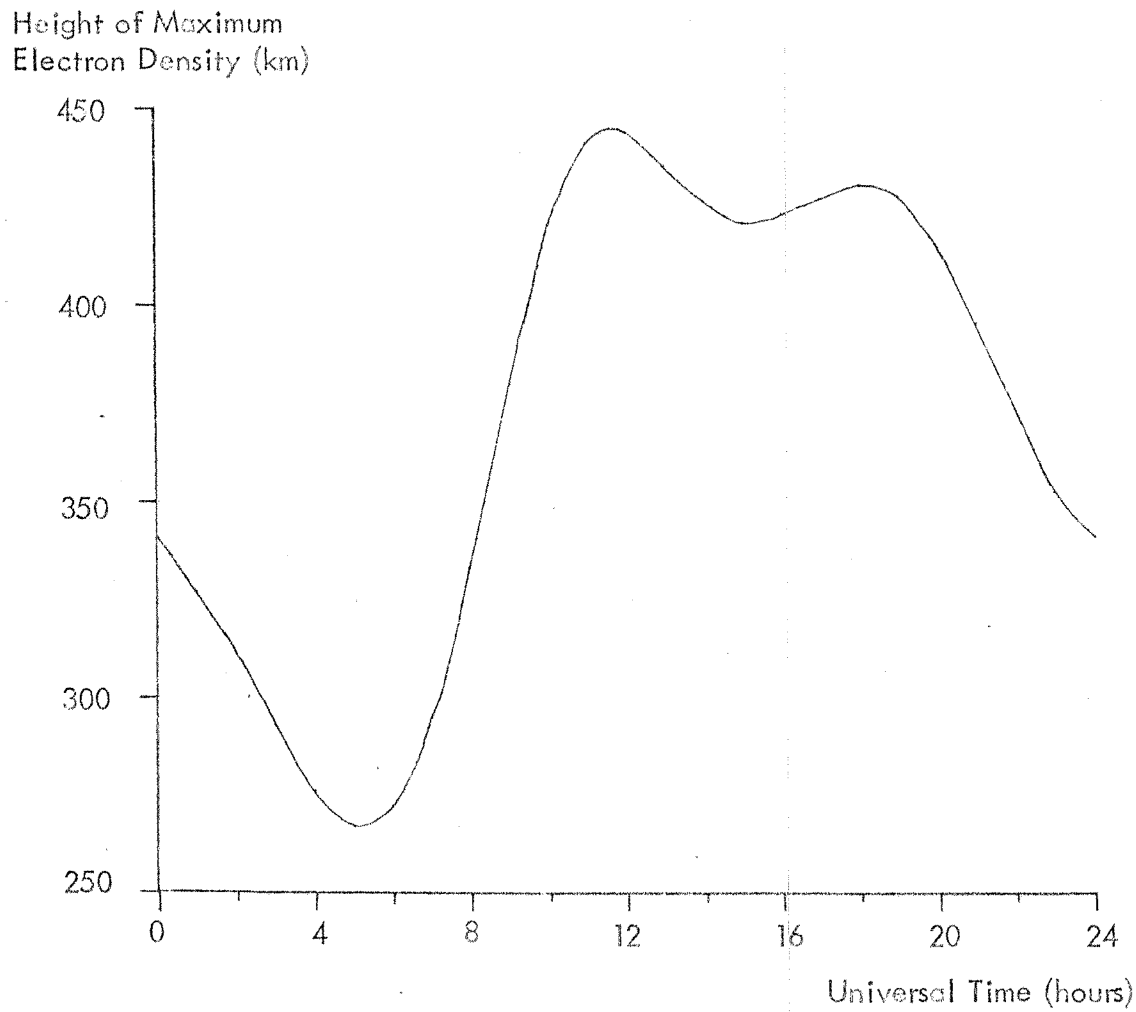


Figure 21. Diurnal Variation of h_m in October 1967 at Latitude = 0°, Longitude = 0°

8.0 DBA'S SUGGESTIONS FOR INCORPORATING THE BENT MODEL IN THE 621B SYSTEM

One of the major problems of this system is arranging for a user to obtain all the ionospheric data he needs in order to eliminate a large proportion of the ionospheric delay. The user may have with him a sophisticated computer, as in the case of a large ship, or he may be a soldier in the field carrying only the simplest electronic units. He must, however, be able to map the ionospheric delay to a reasonable accuracy and in particular be aware of the severe ionospheric gradients that will exist above him at some time of the day. We have already demonstrated that the total electron content along different line of sight paths from an observer to several satellites, will often differ by a factor greater than 5 at the same instant of time. These numbers therefore indicate the care that must be taken in deciding on the method used to transmit ionospheric data to the 621B system users.

If the user has a small computer, the ionospheric coefficients for several days could be put in the memory by land line prior to departure, or, if his computer is very small he can input time related grids of total electron content in his zone of interest for a complete day. Update information for this grid could then rapidly be transmitted by satellite and the user will need only to interpolate in time and direction. However, at certain times of day interpolating in time may not be linear and significant errors may result.

The ideal situation for all users would be to obtain the necessary ionospheric data from a high elevation satellite in his region. Let us assume that each satellite will periodically transmit ionospheric data for a region directly beneath it. If we refer to the diagram shown in Figure 22 the situation can be explained in detail. Consider a satellite S at some 36,000km above the earths surface and consider an observer at point A on the earths surface. At some specified time the satellite S transmits ionospheric data for point B followed by the data for the points on circle C that are separated by 5 degrees earth central angle. Data is then transmitted for circle D and so on until the pre-computed fixed areas are complete. The angles between B and C as well as C and D etc. also differ by 5 degrees earth central angle at the closest points.

These 'pre-computed fixed areas' are arranged so that at any one time the areas covered by all the satellites cover the earths surface. In effect each satellite will be providing ionospheric delay times for every 5 degrees earth central angle in its area. An observer would therefore be able to obtain a grid of ionospheric delay points in his visible sky from which he could easily interpolate in position to obtain the required delay from any satellite.

In the drawing of Figure 22 we will consider the user at position A. He selects the 621B satellite at the highest elevation; let us say this is satellite S. If the lowest elevation angle of the satellites he uses is β and this is in the direction shown, he must wait until satellite S transmits ionospheric data in increasing circles up to the point X. In the worst case β will be at 5 degrees elevation but in all probability this elevation angle will not be 180 degrees in azimuth different from satellite S.

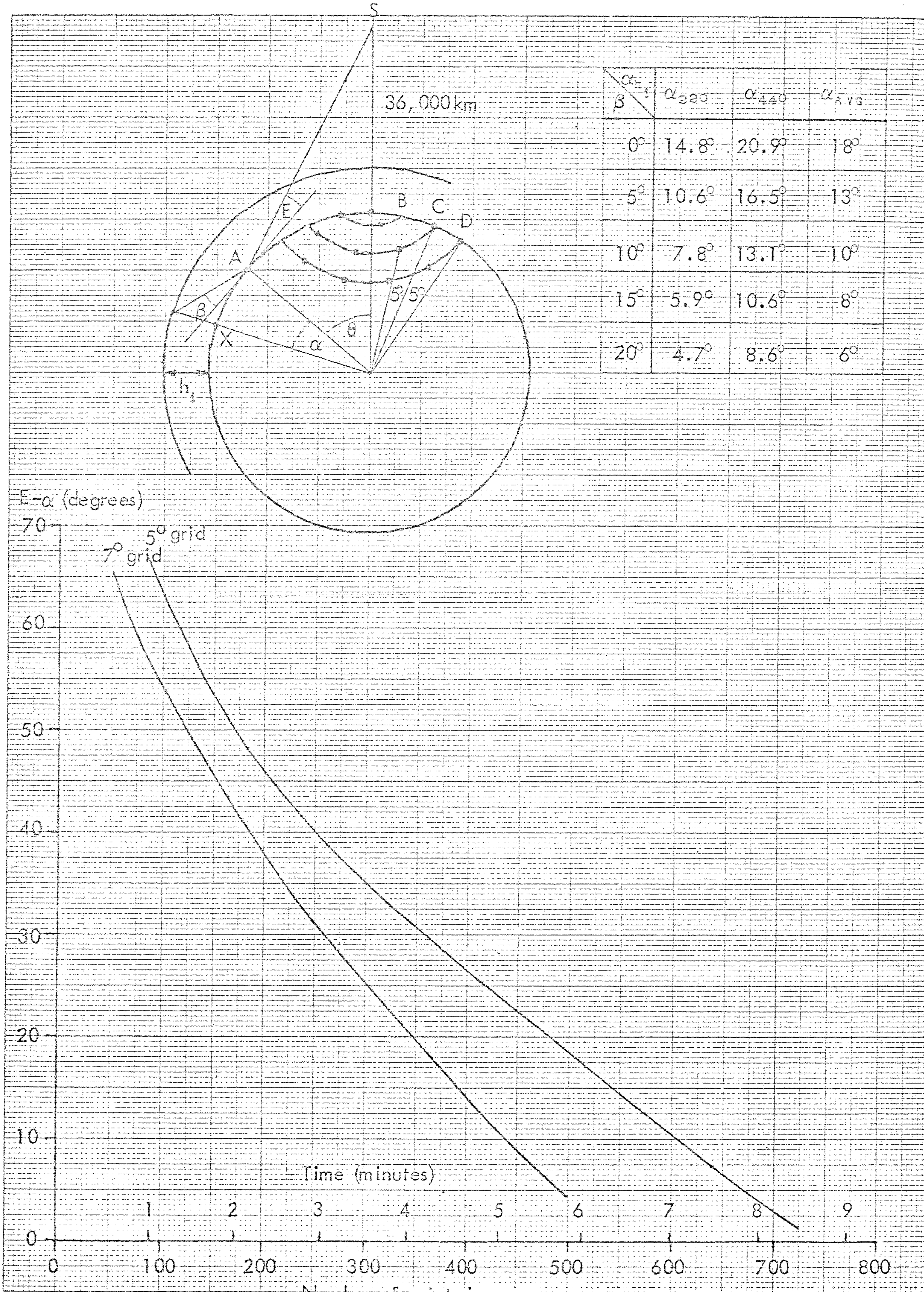
It is understood that 10 bits per second are allowed for ionospheric data to be transmitted from each satellite. A seven bit number (127) would be needed to transmit ionospheric data, which means that at 10 bits per second, 85.7 numbers can be transmitted each minute.

To explain how we compute the time of transmission to cover a particular zone with ionospheric delay time data let us assume that the maximum elevation angle of the satellites used is at 50 degrees. In order to compute the time needed for this satellite to transmit all ionospheric data to the point X we first find the earth angle α for a β of 5 degrees. This is shown in the table of Figure 18 to be, on average, 13 degrees. To a first, but close approximation, the value of α is subtracted from E and compared with the graph of Figure 22. In this case therefore, $50^\circ - 13^\circ = 37^\circ$ which relates, on a 5 degrees grid basis, to a value of 280 numbers, or 3.25 minutes. In other words the satellite could re-cycle its ionospheric data every $3\frac{1}{4}$ minutes and this would also be the maximum time an observer would need to obtain all the delay times he requires. The following table gives an indication of this re-cycling time under the worst conditions with a satellite at 5 degrees elevation and displaced 180 degrees in azimuth from the high elevation satellite. Values for a 5 degrees and a 7 degrees grid on the earths surface are given.

Elevation of high satellite	40°	50°	60°	70°	80°
	Minutes				
5° grid	4.55	3.25	2.22	1.52	.99
7° grid	3.27	2.45	1.69	.99	.53

The accuracy of interpolating from these grids needs to be determined for various positions and times. Obviously the greatest errors will occur where the ionospheric gradients are large and it is difficult to estimate the approximate errors without a detailed computer investigation. However, because the re-cycling time is less than 5 minutes, no time interpolation is necessary and we can concentrate purely on distance interpolation. The errors with a 5 degrees grid may approach 6 to 8% in delay time and 8 to 10% with a 7 degrees grid, but errors of this size may occur only over small areas where a gradient reversal occurs.

We have already indicated that the height of the ionosphere can be a major source of error in areas where severe horizontal gradients exist. It may be possible to input simple coefficients into a small computer to enable height to be computed to an adequate accuracy of, say, 15 km, but further research would be necessary to investigate these possibilities. If we assume the ionospheric height is to be transmitted from each satellite along with the ionospheric delay data and that the height accuracy is to be 15 km then 4 bits (15) of data will be required for each height. A minimum height of 225 km could be used as a base and each number up to 15 would add 15 km to this height giving a maximum of 450 km. The extra time needed for this transmission would be 4/7 of that needed for the ionospheric delay alone.



β \ α_1	α_{220}	α_{440}	α_{AVG}
0°	14.8°	20.9°	18°
5°	10.6°	16.5°	13°
10°	7.8°	13.1°	10°
15°	5.9°	10.6°	8°
20°	4.7°	8.6°	6°

Figure 22. Satellite Transmission Time for Ionospheric Data

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13. ABSTRACT

This study is directed towards evaluating a world-wide empirical ionospheric model by comparing it with total electron content data obtained from Faraday rotation measurements. The results are intended to assist in the design and implementation of a satellite navigational system which depends on signal ranging and hence the delay effects due to the ionosphere. The world-wide ionospheric model is evaluated in detail and the mean, standard deviation and root mean square of the residuals are computed along with correlation coefficients and cumulative probability distributions. Model update procedures and results are discussed where the update data is obtained from 1 to 9 hours prior to evaluation. The results show the capability of the model to remove a high proportion of the ionospheric effects but the conclusions indicate that caution is needed in reading too much optimism into these overall values and imply that diurnal trends should be reviewed in detail. Certain update procedures considerably improve the ionospheric residual during periods of high ionospheric density. Recommendations for future study and implementation of a model into the system are discussed.

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