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THE INFLUENCE OF GEOMAGNETIC ACTIVITY ON THE DAY-TO-DAY VARIABI--ETC(U)

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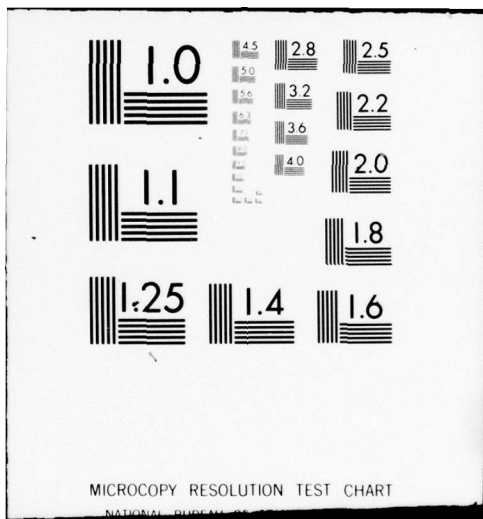
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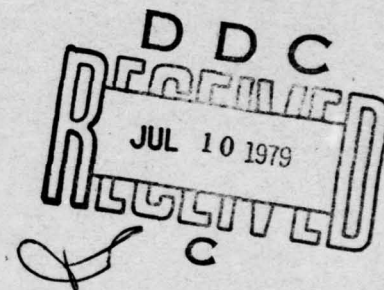
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THE INFLUENCE OF GEOMAGNETIC ACTIVITY ON THE
DAY-TO-DAY VARIABILITY OF THE IONOSPHERIC F-REGION

Michael Mendillo and Francis X. Lynch

Department of Astronomy
Boston University
725 Commonwealth Avenue
Boston, Massachusetts 02215



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→ The geomagnetic storm associated disturbed days within a month are themselves best handled by superimposed epoch derived average storm patterns for each day of a storm period. Thus, if storm days and QQ days are removed from a monthly distribution, the remaining 15-20 days may either fall within acceptable variability limits or lend themselves to "QQ-like" or "DD-like" classifications.

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CHAPTER I. INTRODUCTION

Every ionospheric parameter varies in space and time. Given the sparsity of ionospheric observing stations and the cost factors associated with creating new ones, one must often resort to prediction schemes in order to have an estimate for a particular parameter. Given the fact that an observed parameter ($P_o(t)$) is not the same every day, one can define a mean or median diurnal pattern $\overline{P_o(t)}$ for each month. The standard deviations for the observed $P_o(t)$ may be denoted $\sigma_o(t)$, and thus a month's worth of observations at a given site $\{P_o(t)\}$ may be described in the average as $\overline{P_o(t)} \pm \sigma_o(t)$.

The crux of the problem facing ionospheric forecasters centers on the need to know the diurnal values of P at a site where observations are not available. The main approach to this problem has centered on the use of large ionospheric data bases, $\Sigma \{P_o(t)\}$, which are analyzed in statistical ways to search for trends and correlations which may aid the long and short term needs of forecasters. The main goals a statistical analysis of ionospheric data can hope to achieve with respect to the formulation of prediction schemes are:

- (1) Specification of the magnitudes of the standard deviations for each parameter, and thus the determination of whether or not predictions of average monthly behavior $\overline{P(t)}$ can realistically address the needs of individual users.
- (2) A search for statistically significant patterns of ionospheric variability and thus reduce the uncertainty implied by the $\pm \sigma_o$ values attached to any predicted $\overline{P(t)}$ curve.

- (3) An examination of the correlations between ionospheric variability seen at different sites in order to extend individual measurements to cover a wider geographical area.

A great many studies have been carried out in each of these areas, and thus approaches toward realistic prediction schemes have been formulated for several ionospheric parameters. Rush (1973) has reviewed the situation for short-term predictions of radio propagation conditions at mid-latitudes by examining hourly critical frequencies for the E, F1 and F2 regions (i.e., f_oE , f_oF1 and f_oF2 , respectively). For the E-region during the 0900-1500 LT period, the observed standard deviations for f_oE (σ_o expressed in percent with respect to a monthly median) were generally less than 6% -- implying that 95% of all observations lie within $\pm 12\%$ of their median value. For f_oF1 , the $\sigma_o(\%)$ were found to be only slightly more variable with the difference being greatest during solar maximum years. The conclusion reached by Rush was that for most needs the day-to-day variability of f_oE and f_oF1 is such that monthly median (or mean) values can be used to represent the diurnal variations. This implies that forecasters' attention should be given to the methods of predicting average behavior, rather than to ways of taking into account the inherent variability of the E and F1 regions. This has, in fact, been a fruitful avenue in that the median values of f_oE and f_oF1 at mid-latitude can, for the most part, be predicted to within an accuracy of $\pm 5\%$ (Muggleton, 1972; DuCharme et al., 1971).

For the F2 region, the situation is quite the opposite. Rush (1976), for example, suggests that an average value of $\pm 15\%$ provides a good estimate for the standard deviations observed in f_oF2 behavior at mid-latitudes, regardless of local time, season or solar cycle conditions. It should be

emphasized that while the experimentally-measured and propagation system-dependent parameter is often a critical frequency, e.g., f_oF2 (in MHz), the physically important parameter from a modeling point of view is the electron density (N_e , in $\#el/cm^3$). Since a critical frequency or plasma frequency, f_p , is related to electron density by $f_p(MHz) \approx \{9 N_e (10^6 el/cm^3)\}^{1/2}$, the variabilities in the maximum electron density, $\sigma_o(Nm)$, of each ionospheric region (NmE , $NmF1$, $NmF2$) are proportionally larger than those quoted for their respective critical frequencies (f_oE , f_oF1 , f_oF2).

Some ionospherically-affected propagation systems depend on the electron densities themselves and thus their relatively large standard deviations about average monthly conditions become the variability factor of prime concern. For example, satellite navigation and detection radar systems can be limited in accuracy by the time delay imposed upon their RF signal's passage through the entire ionosphere. The total number of electrons contained along a vertical ray path through the ionosphere is called the Total Electron Content (TEC), a parameter capable of being measured routinely by satellite radio beacon techniques (Titheridge, 1972). Since 90% or more of the TEC occurs in the F2 region, the large TEC data base which has been assembled since the mid-1960's is a valuable source for F2 region studies. Recently, Johanson et al. (1977) described a study of TEC day-to-day variability effects by analyzing the observed standard deviations, σ_o (%), from monthly mean TEC behavior recorded at an 11-station network in the northern hemisphere. They concluded that TEC variability, as described by σ_o (%), was approximately $\pm 25\%$ with only small additional dependences upon local time, season, latitude and solar flux conditions. Hawkins and Klobuchar (1974) showed that for a single mid-latitude site (Sagamore Hill/Hamilton MA), the monthly mean diurnal curve for TEC may be predicted via a simple relationship between

TEC and solar flux which has a correlation coefficient higher than 0.9 for all months. This suggests that, at least for mid-latitudes, a forecaster's attention should not be directed toward improved prediction schemes for average behavior, but rather toward the search for ways to predict (or correct for) the inherent day-to-day variability of the F-region. This, as we have seen, is precisely the opposite view facing E and F1 region prognosticators.

CHAPTER II. POSSIBLE APPROACHES TO THE VARIABILITY QUESTION

As discussed in the previous section, we may assume that a prediction for the monthly mean diurnal behavior of an F2-region parameter (Nmax or TEC) is available. We denote this prediction $\bar{P}(t)$ and attach to it some error ($\pm e$) from the observed mean behavior $\bar{P}_O(t)$. Associated with $\bar{P}_O(t)$ is an observed standard deviation $\pm \sigma_O$; it is generally agreed that $|e| < |\sigma|$ by approximately a factor of 2. Thus, as a first approach to modifying a monthly prediction $\bar{P}(t)$ for day-to-day variability effects, it makes good sense to concentrate on reducing the impact of the magnitude of σ_O .

Rush (1976) considered the case for short-term predictions of f_oF2 via real-time updates from a network of stations. Correlation coefficients for Δf_oF2 were obtained as a function of station separation distances for a full range of local time, seasonal and north-south vs. east-west conditions. These results were used to test the concept of using real-time measurements at one site to update monthly median-based predictions at another site. Thus, consider the case that at site A data are available while at site B only $\bar{P}(t) \pm \sigma_O$ exists. Based on percentage departures from median conditions at A, $\bar{P}(t) \rightarrow P'(t)$ at B. Depending upon the separation between A and B, this update can reduce the uncertainty at B associated with its monthly median prediction, that is, $\sigma_O \rightarrow \sigma'$. Rush found that for σ_O to be reduced by 50%, the approximate separation distances for such an extrapolation/update had to be less than 500km for north-south sites and 1000 km for east-west sites. Thus, it was concluded that to achieve this degree of improvement under most conditions at mid-latitudes an observational network would be required capable of reporting real-time ionospheric measurements from a global grid 10° in latitude and 20° in longitude. In a broad sense, this represents "state of the art" conclusions

for the day to day variability problem.

II. 1. E-Region Considerations

One approach to F-region variability is to examine the related E-region effects. To do this, the daily values of $N_m E$ and $N_m F2$ from Wallops Island and TEC from Sagamore Hill were plotted together with their respective monthly means for the first half of 1968. The year 1968 was chosen since the E-region data is more nearly complete closer to the peak of the solar activity cycle. Figures 1 and 2 are representative examples of the type of computer plots constructed.

The initial scanning of many individual plots revealed only one type of correlation between the E and F region variabilities. The effect is illustrated in Figures 1 and 2 between the $N_m E$ and $N_m F2$ ionosonde data ($L \approx 2$). A distinct 180° phase difference between the E and F region fluctuations suggests that these fluctuations are of gravity wave origin.

The percent deviations from the monthly means, averaged over the 1100 to 1300 local time period, for each day of various months were also plotted. Such data for January 1968 are shown in Figure 3. The solid line represents the daily data and the X's represent 3-day smoothing. Comparisons of the smoothed curves for $N_m E$ and $N_m F2$ show a phase lead of approximately 3 days for long-term E-region fluctuations relative to the F-region fluctuations. This time delay is of the same order as the lifetime of atomic oxygen at F-region heights which produces the dominant ion. Hence, this variation suggests the cause is fluctuations in the neutral composition, particularly in the oxygen concentrations.

The further study of correlations between the E and F regions was limited by the unanticipated poor quality of the $f_o E$ measurements available to us. Our preliminary work did, however, suggest that important physical links are present.

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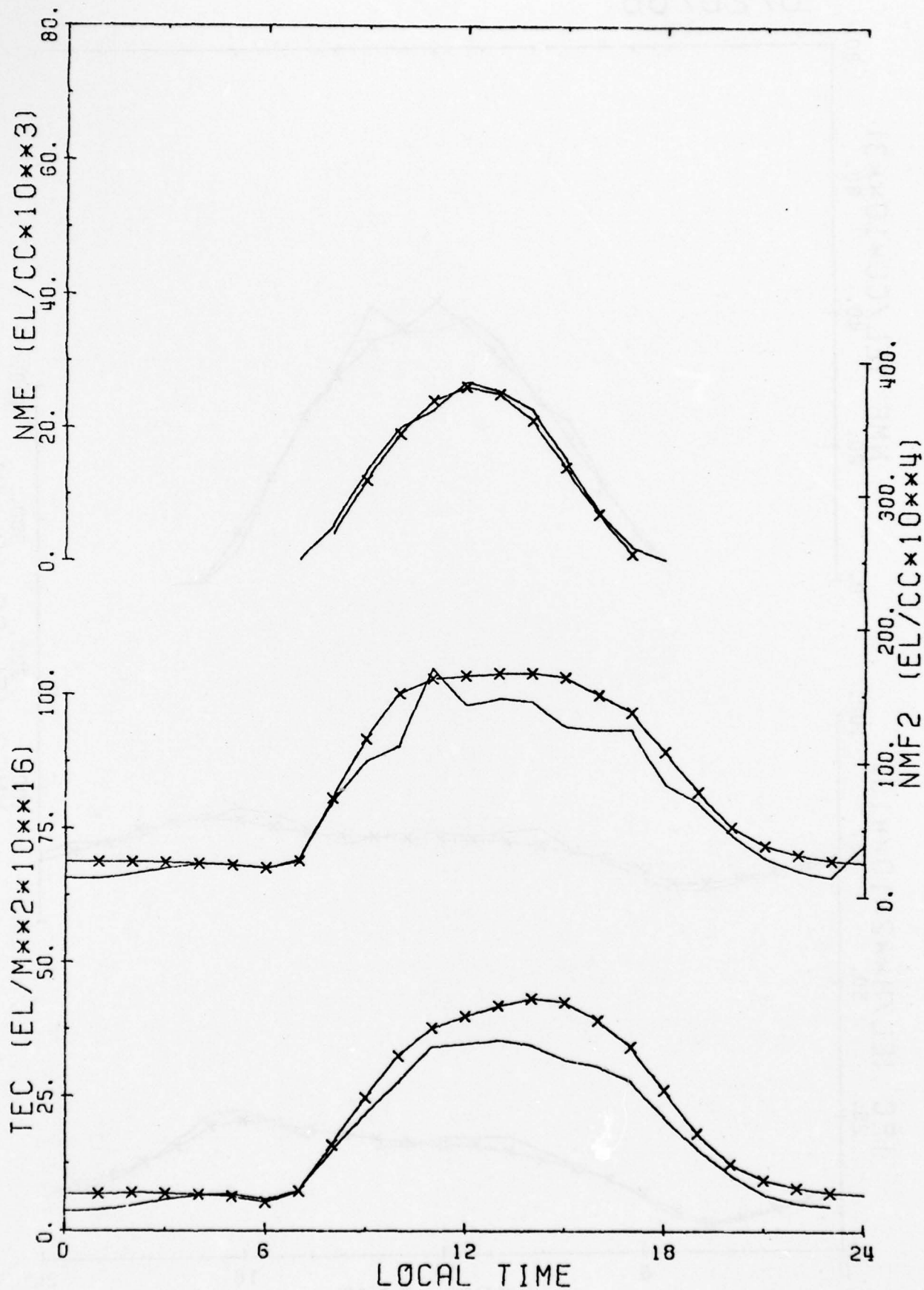


Figure 1

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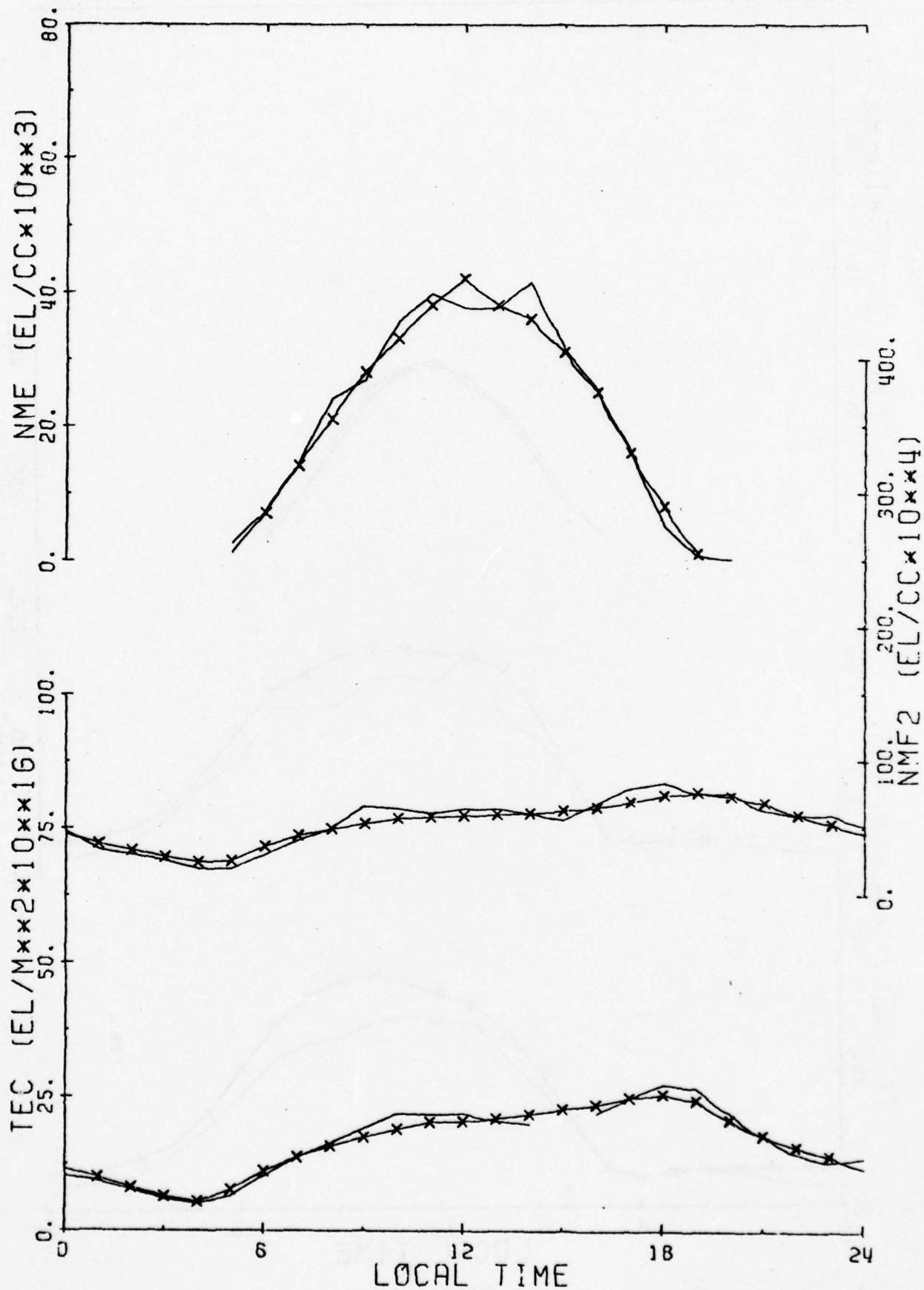


Figure 2

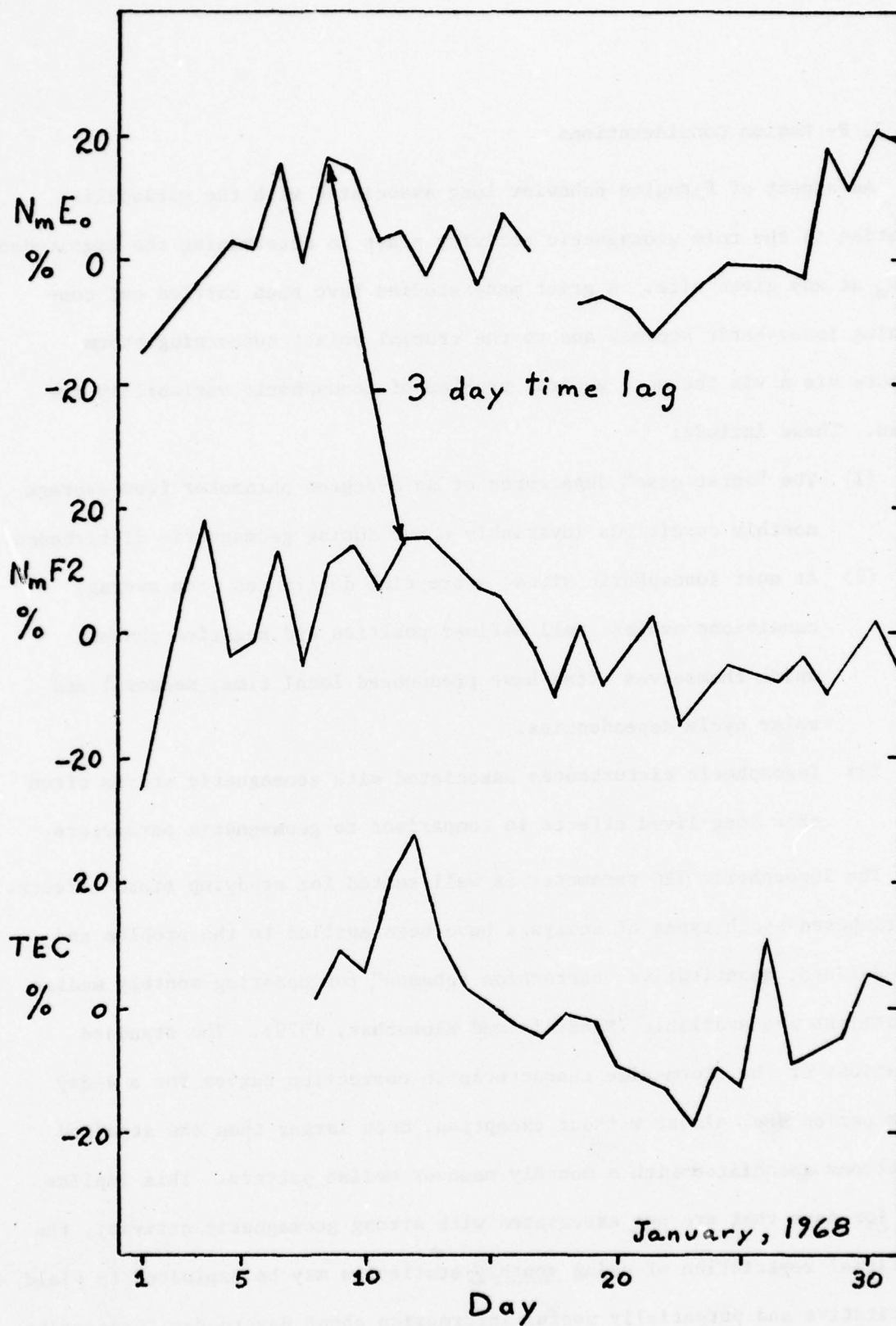


Figure 3

II, 2, F- Region Considerations

An aspect of F-region behavior long associated with the variability question is the role geomagnetic activity plays in determining the magnitudes of σ_0 at any given site. A great many studies have been carried out concerning ionospheric storms, and so the crucial points concerning storm effects vis à vis the more general problem of ionospheric variability are known. These include:

- (1) The "worst case" departures of an F-region parameter from average monthly conditions invariably occur during geomagnetic disturbance.
- (2) At most ionospheric sites, storm-time departures from average conditions exhibit well defined positive and negative phases, which themselves often have pronounced local time, seasonal and solar cycle dependencies.
- (3) Ionospheric disturbances associated with geomagnetic storms often show long-lived effects in comparison to geomagnetic parameters.

The ionospheric TEC parameter is well-suited for studying storm effects. Superimposed-epoch types of analyses have been applied to the problem and well-defined, quantitative "correction schemes" for updating monthly median predictions are available (Mendillo and Klobuchar, 1979). The standard deviations of the storm-time characteristic correction curves for a 4-day storm period are, almost without exception, much larger than the standard deviations associated with a monthly mean or median pattern. This implies that for days that are not associated with strong geomagnetic activity, the artificial restriction of using monthly statistics may be exploited to yield quantitative and potentially useful information about day-to-day forecasting. Consider, for example, a 30-day month for which we have ordered the days by

a suitable geomagnetic parameter into six 5-day categories ranging from very quiet to very disturbed conditions. We denote these 5-day periods as QQ, Q, q, d, D and DD days. Results of storm effects in the TEC data (essentially the DD and D days) implicitly tell us something about the remaining days.

For example:

- (1) The standard deviations for the QQ to d days must be smaller than the observed σ_0 for the entire month.
- (2) If the amplitudes and phases (+ or -) of storm-time corrections are reasonably well-defined, then at least the dominant phase of the variations for the non-disturbed days can be inferred.

We have tested these approaches in several ways using data obtained from the AFGL network of TEC observing sites. These include the latitudinal chain near 70°W comprised of sites characterized (geomagnetically) by L=5 (Narssarssuaq), L=4 (Goose Bay), L=3 (Sagamore Hill/Hamilton) and L=2 (Kennedy Space Flight Center), as well as the three additional sites near L=2 of Rosman (No. Carolina), Osan (Korea) and Athens (Greece). In all cases, the data base available covered the declining and minimum portions of the past solar cycle ($\approx$ 1971-1976).

In the following Chapter, the data obtained from the L=2-5 latitudinal network are examined in an attempt to show how geomagnetic activity may be used as a key to specifying the hierarchy of F-region variability contained in statistically-based ionospheric forecasts. Only sample results are shown in order to highlight the findings; a complete set of curves describing the station-by-station, season-by-season and yearly statistical results are presented in a set of Appendices.

CHAPTER III. A STATISTICAL TREATMENT OF THE GEOMAGNETIC CONTROL OF F-REGION VARIABILITY

The initial search for a geomagnetically-controlled hierarchy to F-region variability should concentrate on extreme cases, and thus our first analysis centered on defining the essential differences between very quiet days (QQ) and very disturbed days (DD). Hourly values of ionospheric TEC data for each site were used to form percentage variations from monthly mean conditions for the 5-QQ and DD-days of each month. The average diurnal behaviors ($\overline{QQ}$ and $\overline{DD}$), averaged over all months, are given in Figure 4 (a) Narssarssuaq, (b) Goose Bay, (c) Hamilton and (d) KSFC. When examined in this way, a remarkable degree of consistency emerges in that the QQ and DD curves are virtually "mirror images" for all local times at all four stations. The dichotomy does not always extend to precise magnitudes and phases, nor to the zero percentage line as the "mirror point" -- but nevertheless it does suggest a strong ordering influence related to geomagnetic activity. Previous studies have shown that ionospheric storm morphologies are best ordered by a superimposed-epoch scheme carried out for several days, and thus a single curve labeled "Disturbed Day Variation" cannot capture the true and often multi-phase development of an ionospheric storm (Mendillo, 1978). The DD curves presented here thus point to the most long-lived effects associated with storms -- and therefore the QQ curves describe the absence of these perturbations. Consider, for example, daytime effects over the $L = 2-5$ range. At high latitudes, the DD curves show essentially negative effects while enhancement appear at $L = 2$. Consequently, the QQ variations also exhibit a latitudinally dependent phase change. Thus if one considers

"QQ-like behavior" versus "DD-like behavior" then the spatial extent over which correlations occur may be greatly enhanced. The implication to forecasters is obvious, as will be discussed more fully below.

Since ionospheric storm effects have well-known seasonal variations, it is not surprising that the QQ behavior also follows a seasonal control. For example, in Figure 4(c), the Hamilton QQ/DD curves for all months averaged together show very little variation from monthly mean conditions during the 10:00 - 16:00 LT period. Figure 5 contains a Summer versus Winter breakdown of the same data base; the amplitudes of the curves are much larger and of different sign and thus an accurate description of QQ behavior at $L = 3$ requires a seasonal analysis simply because the storm effects at $L = 3$ have a strong seasonal dependence. This is not necessarily the case, however, for all latitude regions (Mendillo, 1978), as may also be seen in the Appendices.

The results presented in Figure 4 and 5 suggest that a knowledge of ambient geomagnetic conditions may be sufficient to achieve a meaningful real-time update to monthly mean predictions of F-region behavior. It would appear that several implementation schemes for this information should be considered and tested. For illustration purposes, we concentrate here on the case where geomagnetic information is available to predict that a day is probably one of the 5 QQ-days of the month. For the site in question, where $\bar{P}(t) \pm \sigma_o(t)$ is the predicted monthly mean pattern and associated variability, one could update this value in several possible ways:

- (1) Using curves similar to those shown in Figures 4 and 5, one could update $\bar{P}(t)$ by the appropriate $\Delta P_{QQ}(\%)$ and assign a new uncertainty $\pm \sigma_{QQ}$. This type of scheme would require interpolation according to geomagnetic latitudes, with a full breakdown of seasonal effects in the $QQ(t)$ patterns and their associated standard deviations σ_{QQ} .

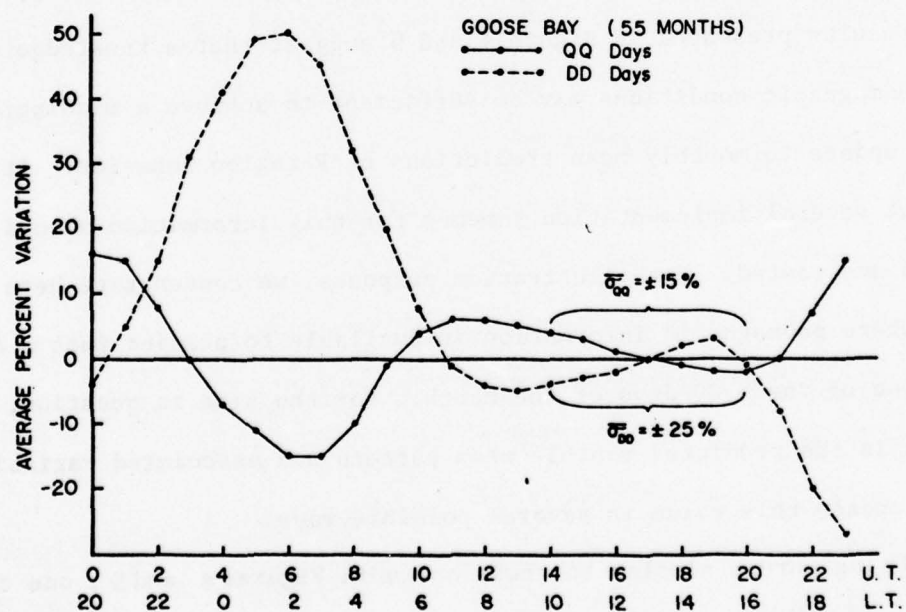
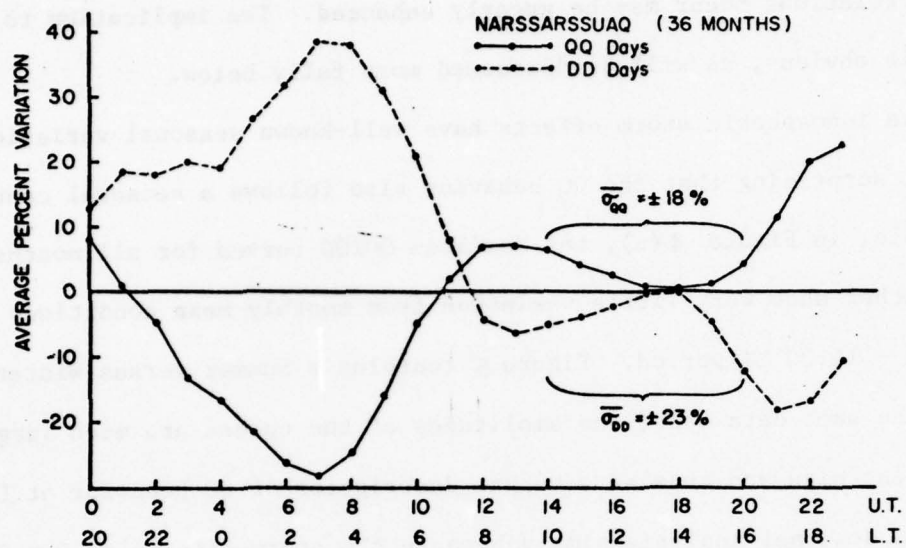


Figure 4.
Average diurnal behavior of $\Delta\text{TEC}(\%)$ for the 5 QQ-days
and the 5 DD-days of a month for
(a) Narssarssuaq and (b) Goose Bay.

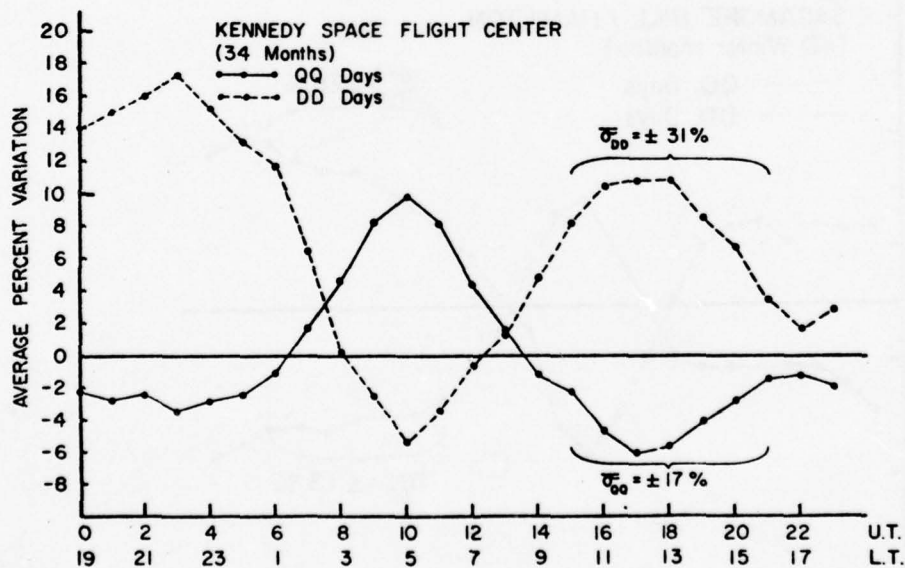
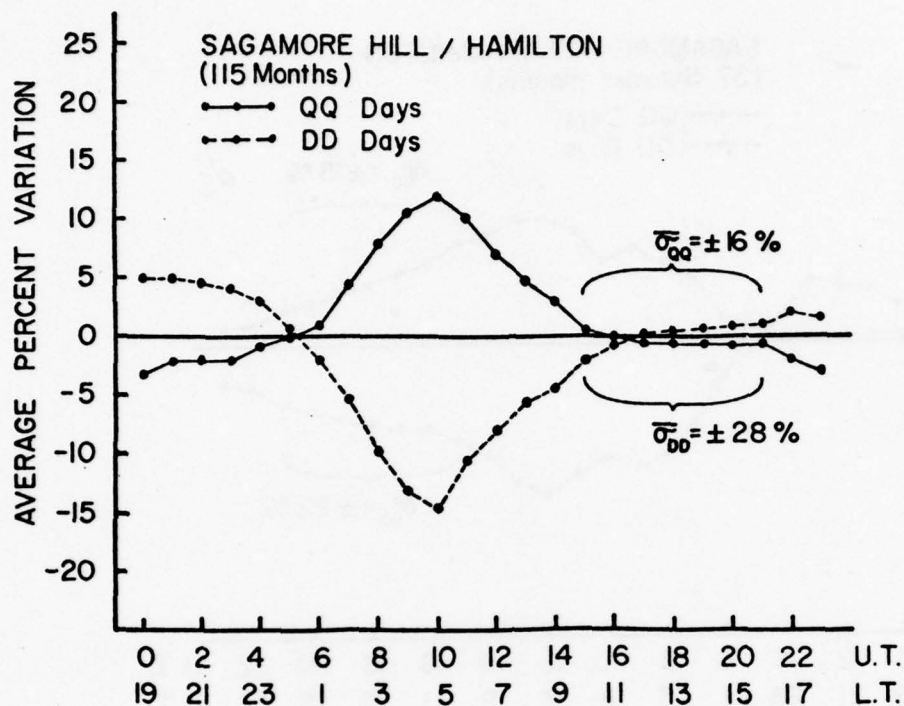


Figure 4.
 Average diurnal behavior of $\Delta\text{TEC}(\%)$ for the 5 QQ-days
 and the 5 DD-days of a month for
 (c) Hamilton and (d) Cape Kennedy.

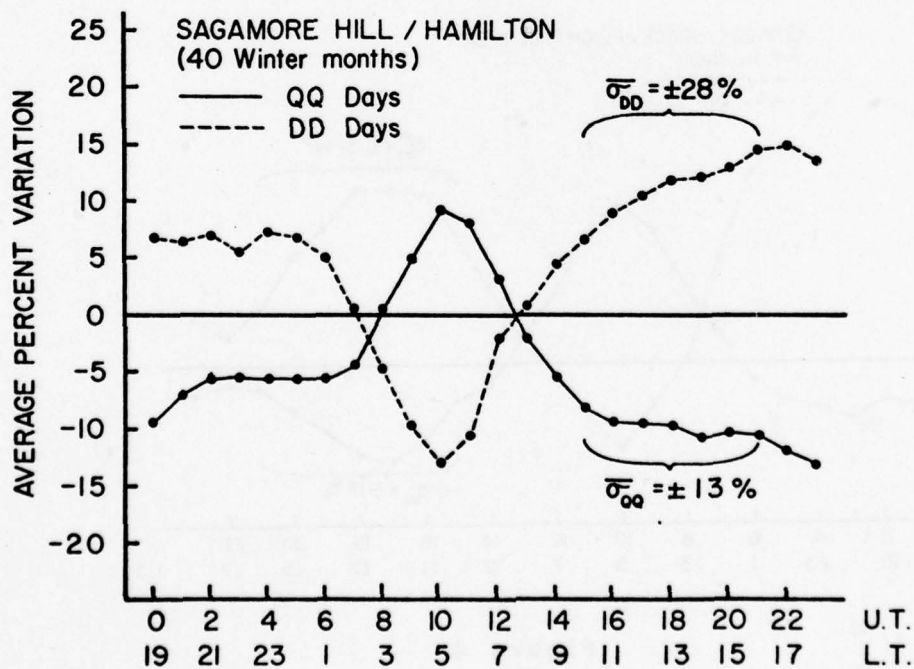
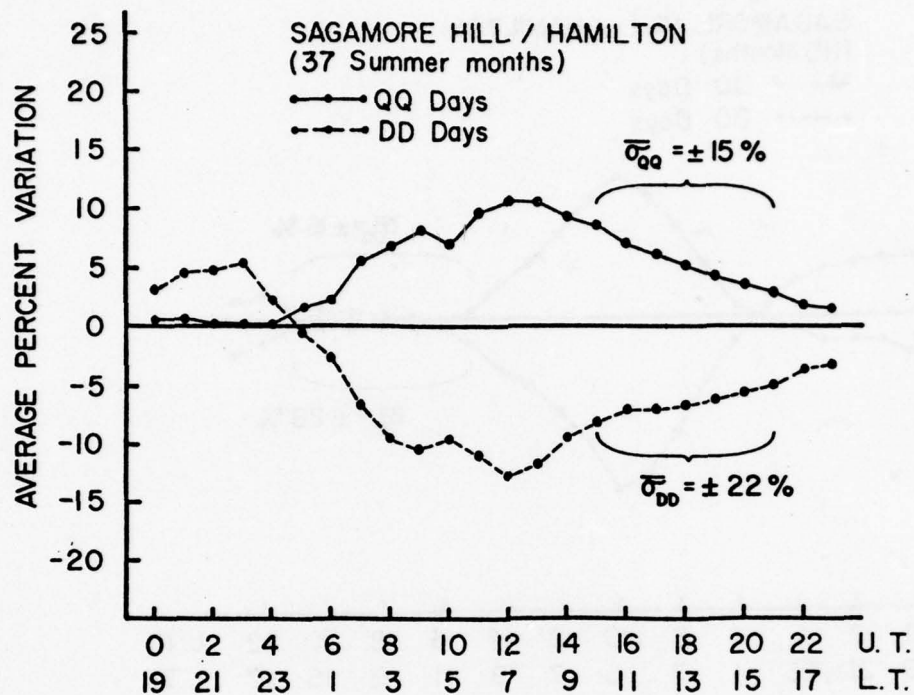


Figure 5.
 Average diurnal behavior of $\Delta\text{TEC}(\%)$ for the QQ-days and DD-days
 for Summer and Winter months at Hamilton ($L \approx 3$).

Thus, each of the QQ days would have a predicted diurnal pattern changed from $\bar{P}(t) \pm \sigma_o(t)$ to $\bar{P}(t) + \Delta P_{QQ}(t) \pm \sigma_{QQ}(t)$. Since $\sigma_{QQ}(t)$ is demonstrably smaller in magnitude than σ_o (usually quoted to be $\pm 25\%$), an updated value with reduced uncertainty (say to $\pm 15\%$, i.e., a 40% improvement) has been achieved.

- (2) An alternate scheme could take advantage of the fact that Figures 4 and 5 show that during certain local time periods and seasons, the QQ patterns fall well to the positive or negative side of the mean behavior. Thus knowledge that a certain day is a QQ day implies that only the positive or negative half of the excursion associated with $\pm \sigma_o$ is likely to occur and updates should be made accordingly. Under such conditions, the monthly mean based prediction

$\bar{P}(t) \pm \sigma_o(t)$ would be changed to :

$$\bar{P}(t) \left\{ 1 + \frac{\sigma_o}{2} \right\} \pm \frac{\sigma_o}{2} \text{ for positive effects} \quad (1)$$

or

$$\bar{P}(t) \left\{ 1 - \frac{\sigma_o}{2} \right\} \pm \frac{\sigma_o}{2} \text{ for negative effects.} \quad (2)$$

The end result is again a value updated in magnitude, but now with an uncertainty reduced by 50%. The possibility thus exists for using simple positive or negative QQ-pattern sectors to achieve a 50% improvement in forecasting without recourse to a large network of real-time observing sites. If real-time measurements can be made, the additional possibility exists of using a single observation in conjunction with QQ patterns (which may be either positively or negatively correlated over wide latitude spans) to forecast F-region updates over regions far in excess of simple in-phase correlation distances.

CHAPTER IV. CASE STUDIES AT LOW LATITUDES

As an example of the concepts discussed in the previous sections, Figures 4 and 5 describe geomagnetic hierarchy effects in the day-to-day variability patterns observed at the lower mid-latitude site Cape Kennedy (KSFC, $L = 2$) for the winter season. The average local time disturbance pattern $\{SD(TEC, \%) \}$ for winter storms at KSFC is given in Figure 6a (Mendillo, 1978). This is a relatively simple pattern of daytime enhancements with only small nighttime depletions for each day of the storm pattern. The absence of both positive and negative daytime phases causes the DD-day pattern for Winter months (Fig. 6b) to describe this simple pattern with a 5-day average of approximately $\pm 20\%$ during the daytime hours. While this type of correction would suffice for days 2 and 3 of a storm period, it is factors of 2 to 3 too small a correction for the first day of a storm. This re-emphasizes the fact that $SD_i(TEC, LT)$, $i = 1, 4$ patterns should be used to update storm periods and not DD-curves.

The character of the QQ curve represents a more realistic description for day-to-day effects because (1) the standard deviations are lower and (2) the 5 QQ-days of a month are not usually sequential. To test for the consistency of the QQ vs DD descriptions implied by Figure 6b, we examined several Winter month's worth of KSFC total content data. Figure 7 (a,b,c,d) summarize the analysis for the Winter months of 1974 and 1975. The days of the month were ordered by ΣKp and percentage deviations from the monthly mean were computed for each UT-hour. The vertical scale in Figure 7 shows 5-day groupings according to ΣKp and the horizontal axis gives UT/LT steps. To separate the positive excursions from the negative excursions for easy visual inspection, cross-hatchings were used for any hour where the deviation

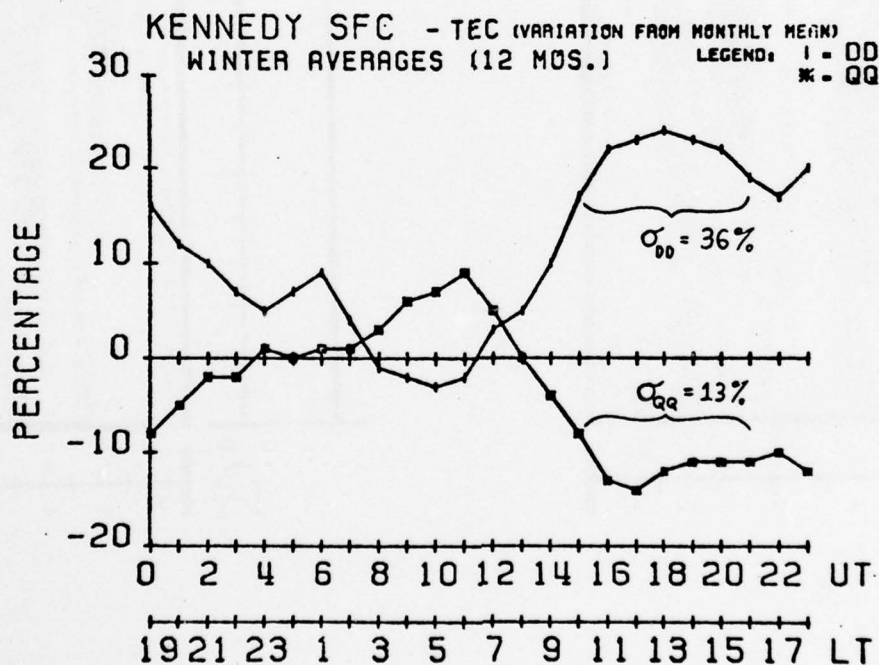
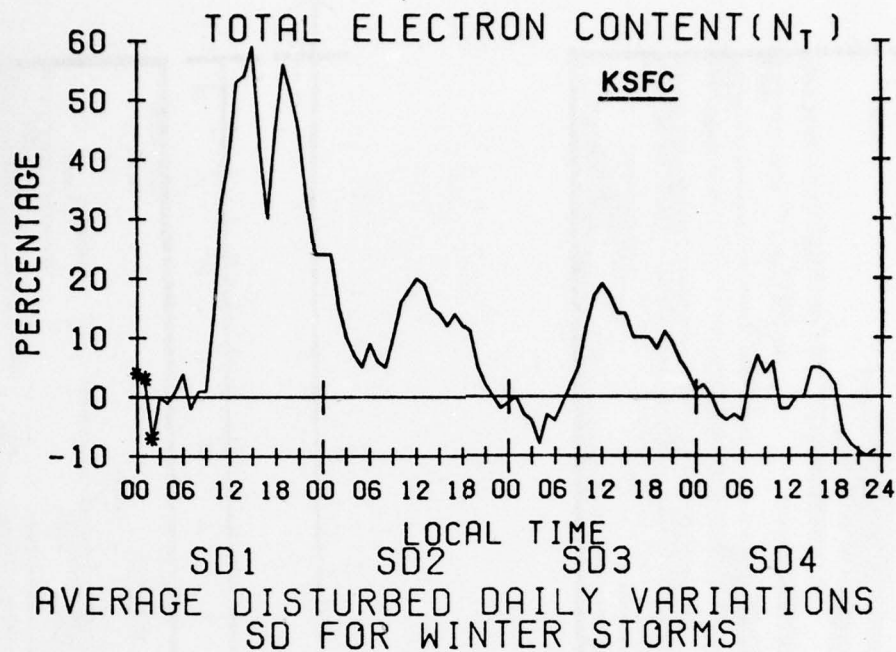


Figure 6.

(a) Average Disturbed Daily Variations of $\Delta\text{TEC}(\%)$ for Winter Storms at Cape Kennedy ($L \approx 2$).

(b) Average diurnal behavior of $\Delta\text{TEC}(\%)$ for the QQ-days and DD-days for Winter months at Cape Kennedy ($L \approx 2$).

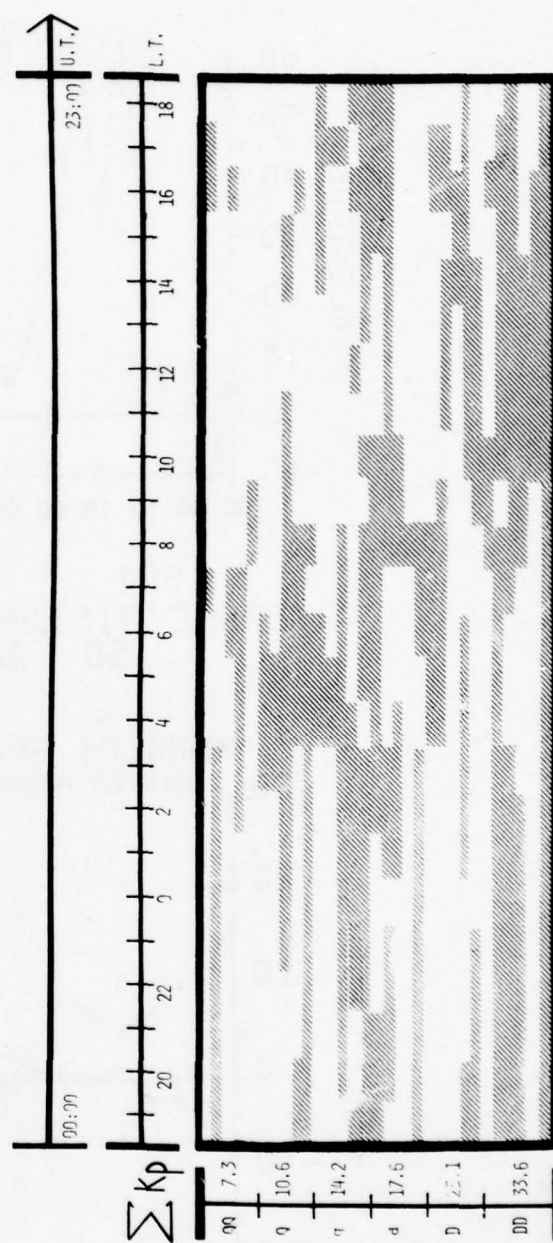
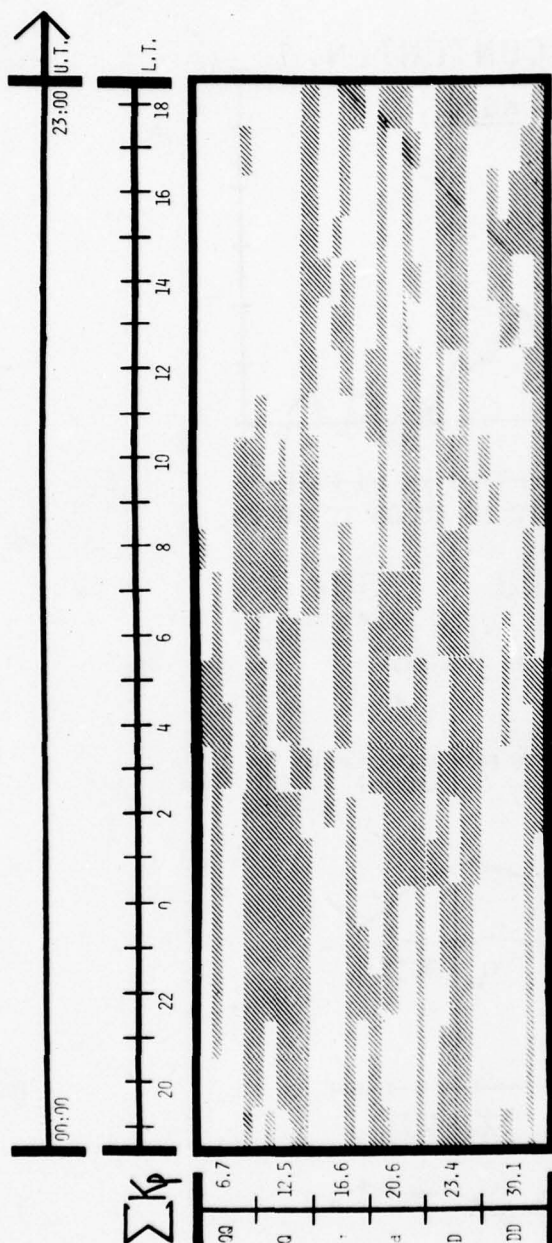


Figure 7a.
Examples of geomagnetic ordering of TEC variability for
Winter months at Cape Kennedy for January, 1974 (top)
and January, 1975 (bottom). Shaded areas give
periods where $\Delta\text{TEC}(\%) \geq 0$.

was zero or positive (i.e., $\Delta \text{TEC} \geq 0$). The clear areas of Figure 7 therefore describe hourly/daily periods where $\Delta \text{TEC} < 0$. Note that the phases of the ΔTEC (%) variations in the top portion of Figure 7 are very similar to those predicted by the QQ-curve in Figure 6b. For example, during the daytime period (10:00-16:00 LT) when the F-region generally attains its largest density values (and therefore uncertainties are most important), the negative values persist on nearly all of the QQ-days shown. As pointed out in the previous section, knowledge of the plus or minus side of $\pm \sigma_0$ may lead to an updated F-region prediction. This may be accomplished by real-time data, to decide whether a station will respond in either a QQ-like or DD-like fashion. This would help predict a small portion of the F-region TEC variability.

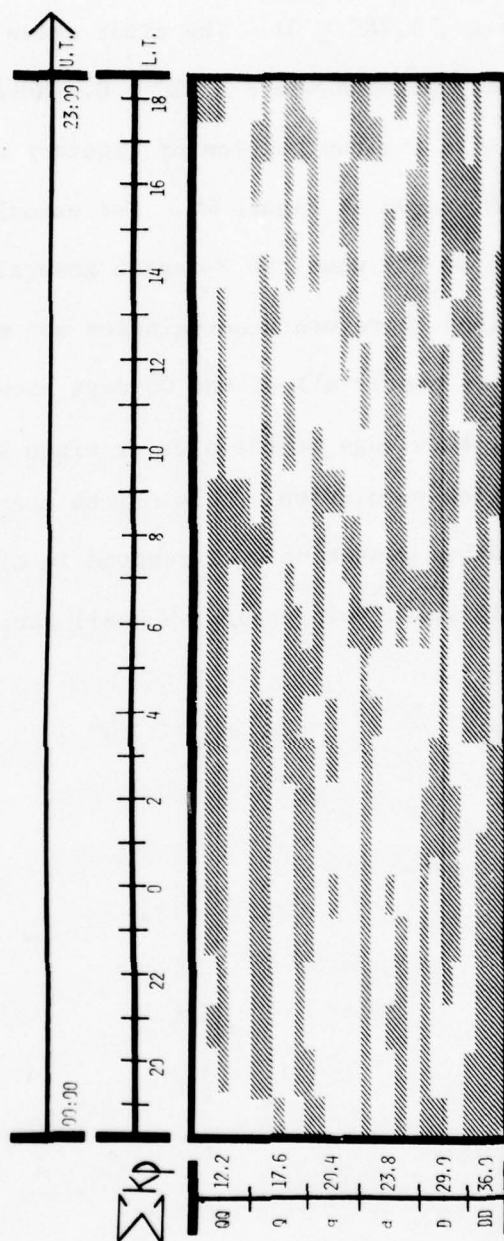


Figure 7b.
 Example of geomagnetic ordering of TEC variability for
 Winter months at Cape Kennedy for February, 1975.
 Shaded areas give periods where $\Delta\text{TEC}(\%) \geq 0$.

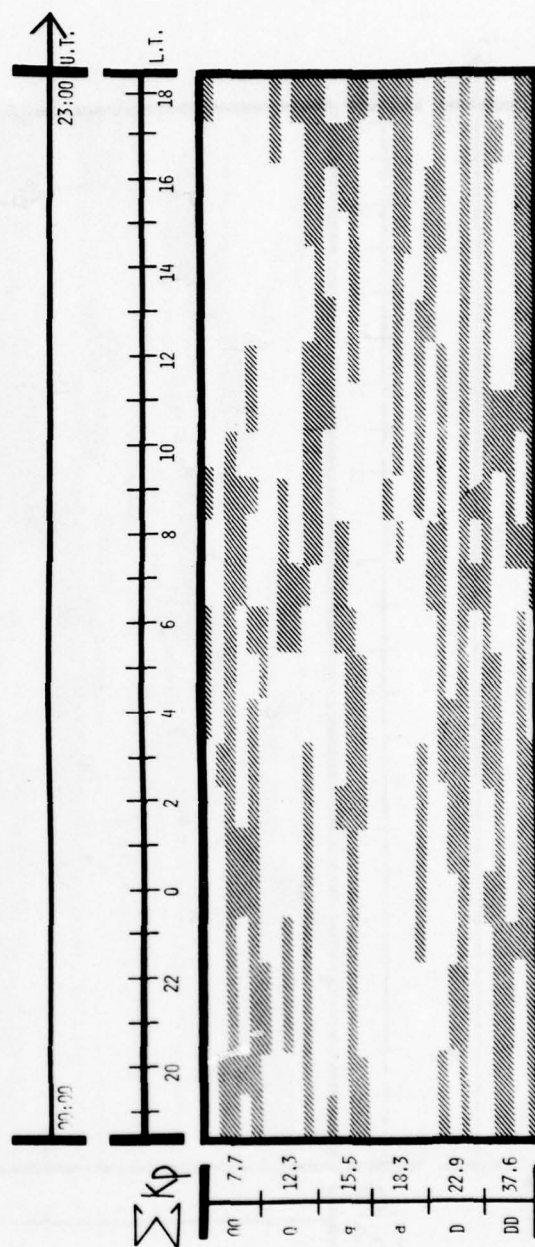
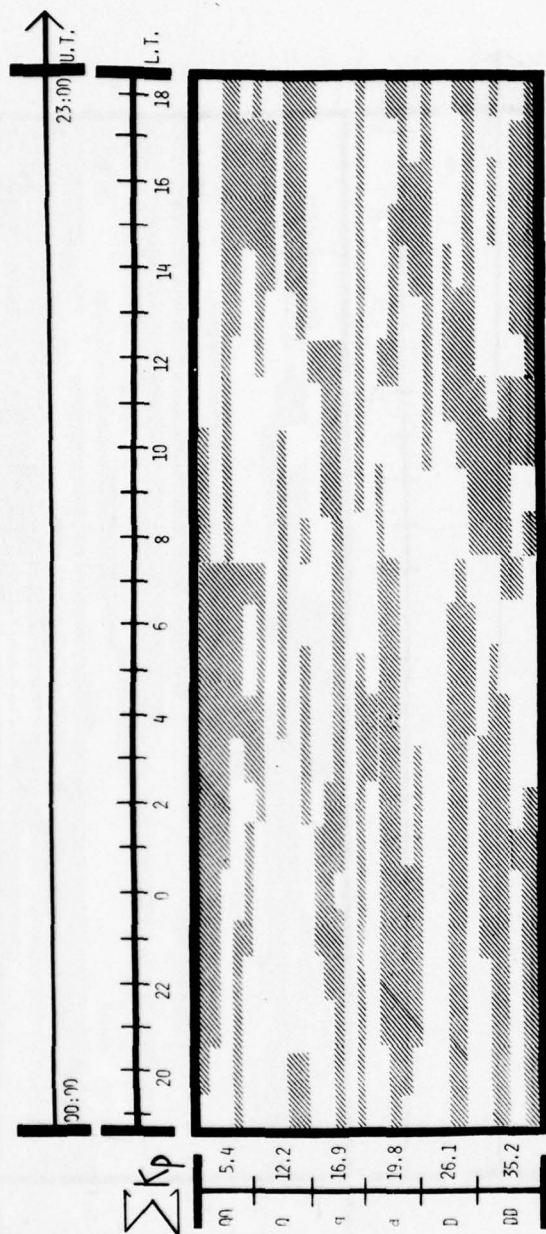


Figure 7c.
Examples of geomagnetic ordering of TEC variability for
Winter months at Cape Kennedy for November, 1974 (top)
and November, 1975 (bottom). Shaded areas give
periods where $\Delta\text{TEC}(\%) \geq 0$.

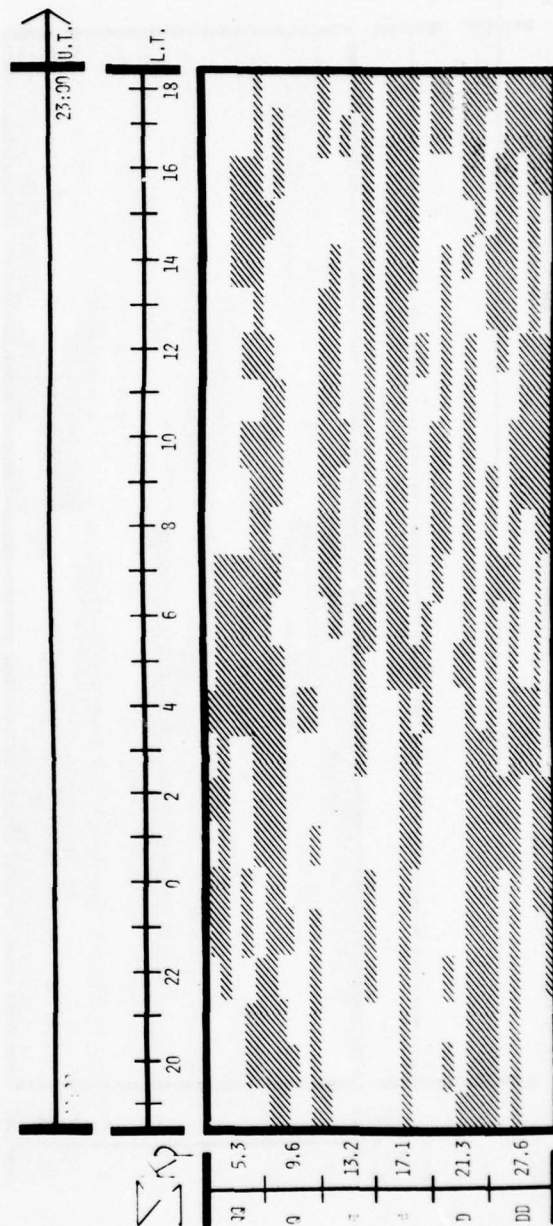
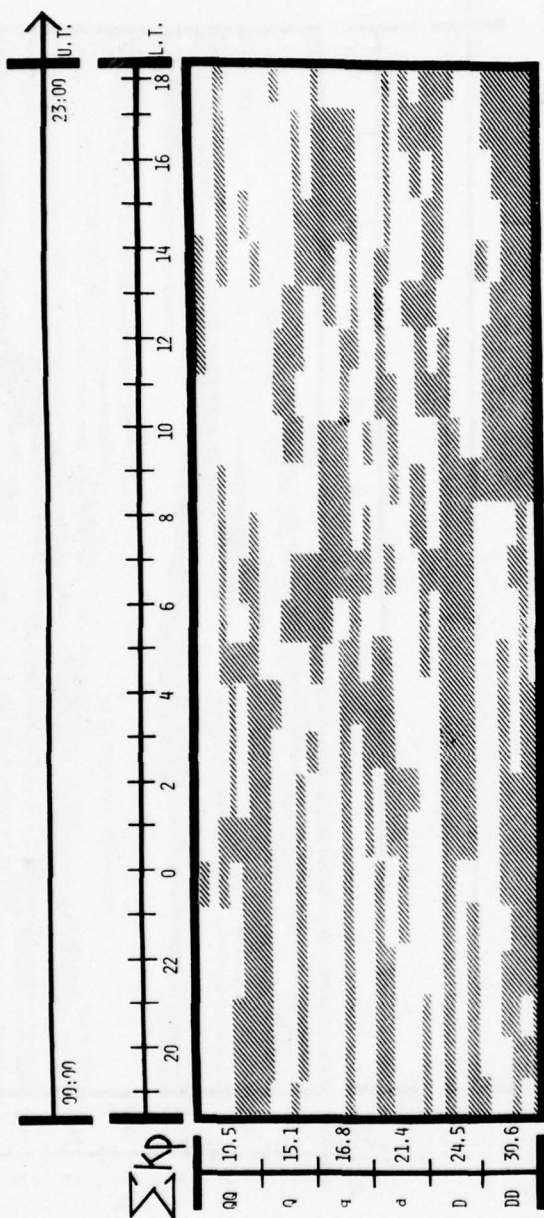


Figure 7d.
Examples of geomagnetic ordering of TEC variability for
Winter months at Cape Kennedy for December, 1974 (top)
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periods where $\Delta\text{TEC}(\%) \geq 0$.

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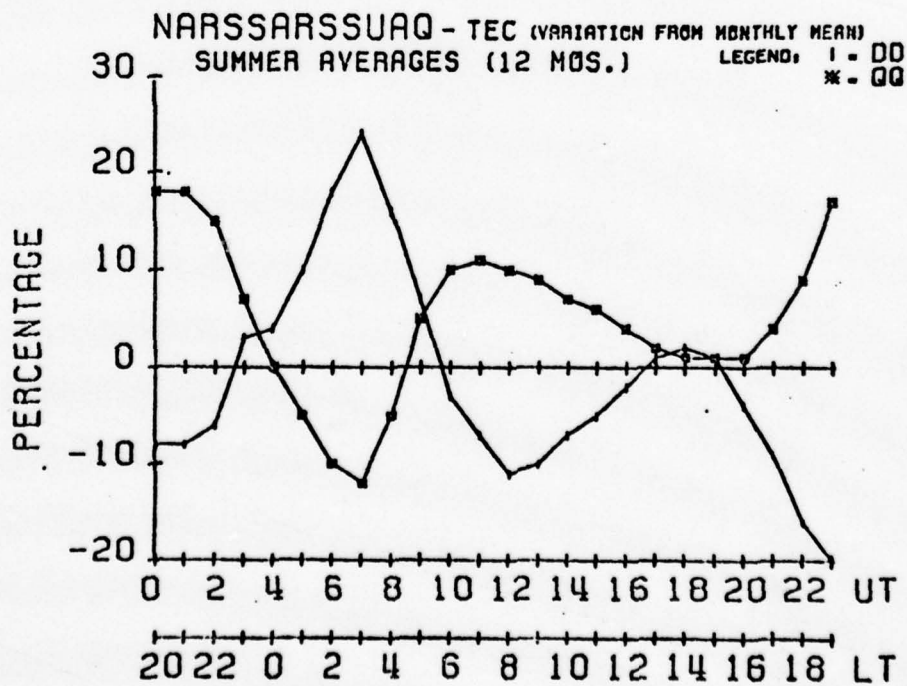
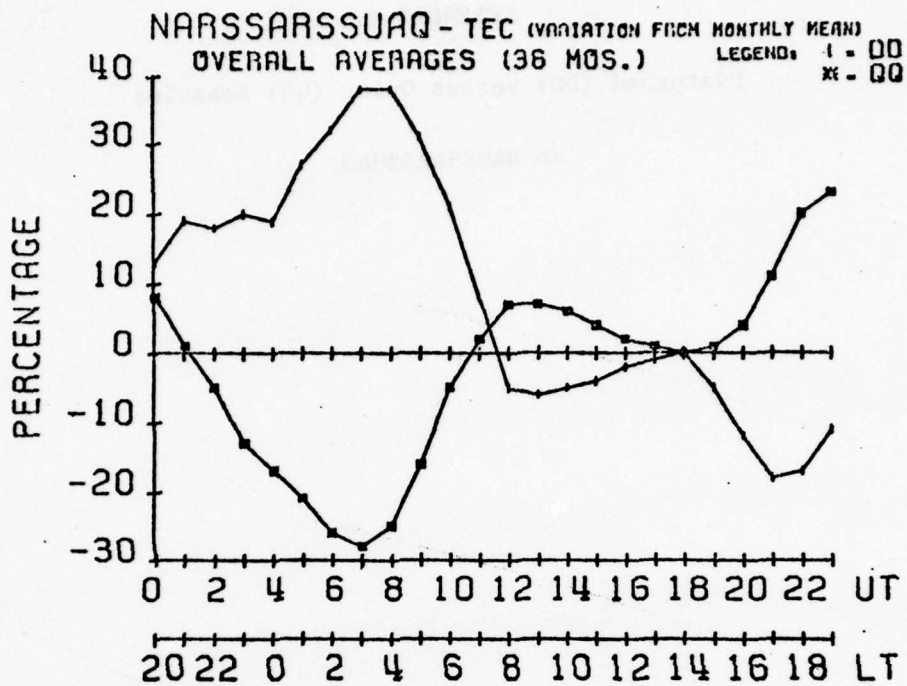
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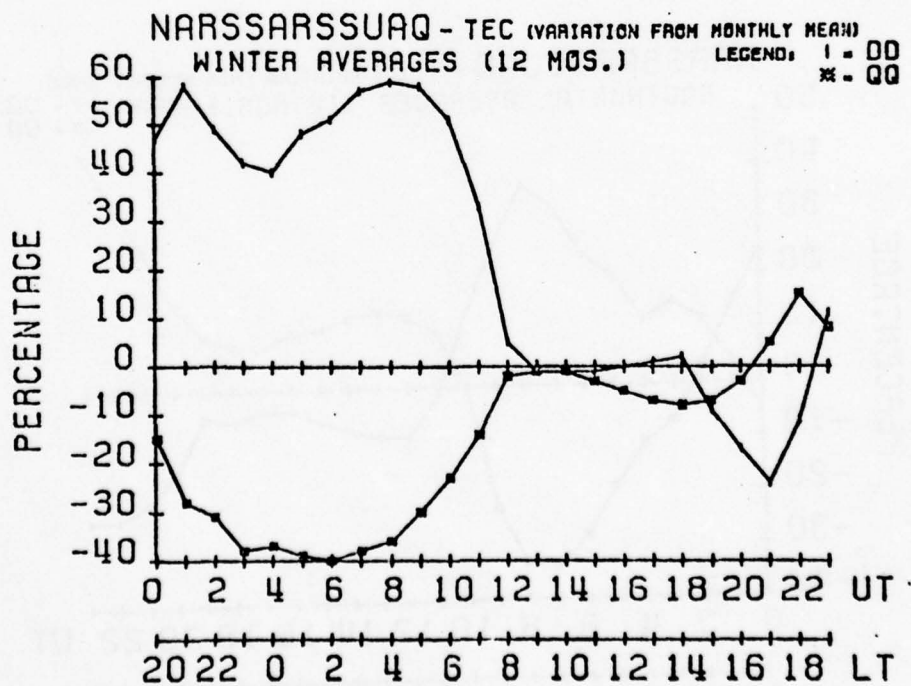
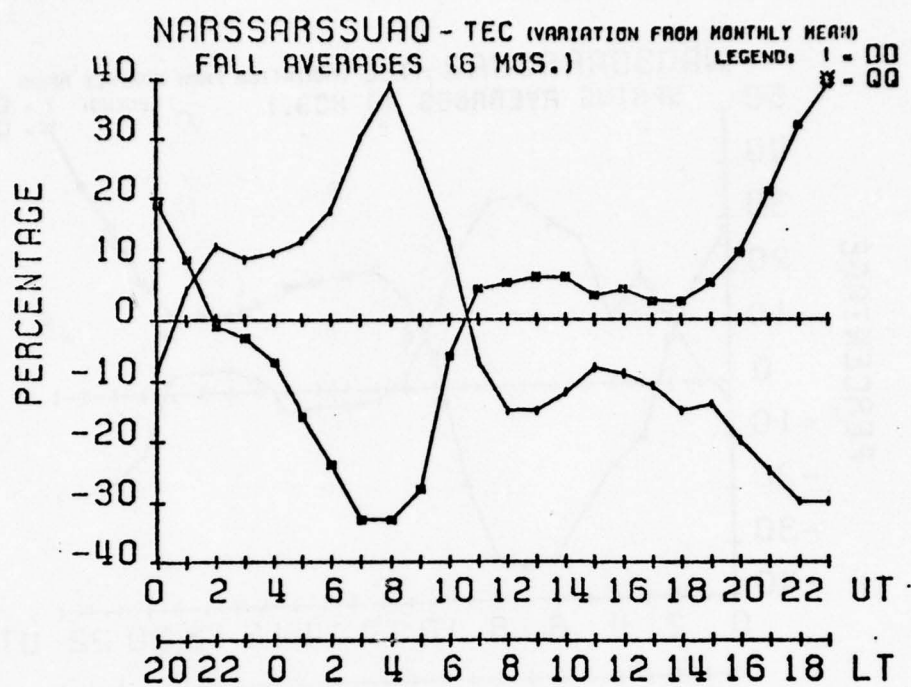
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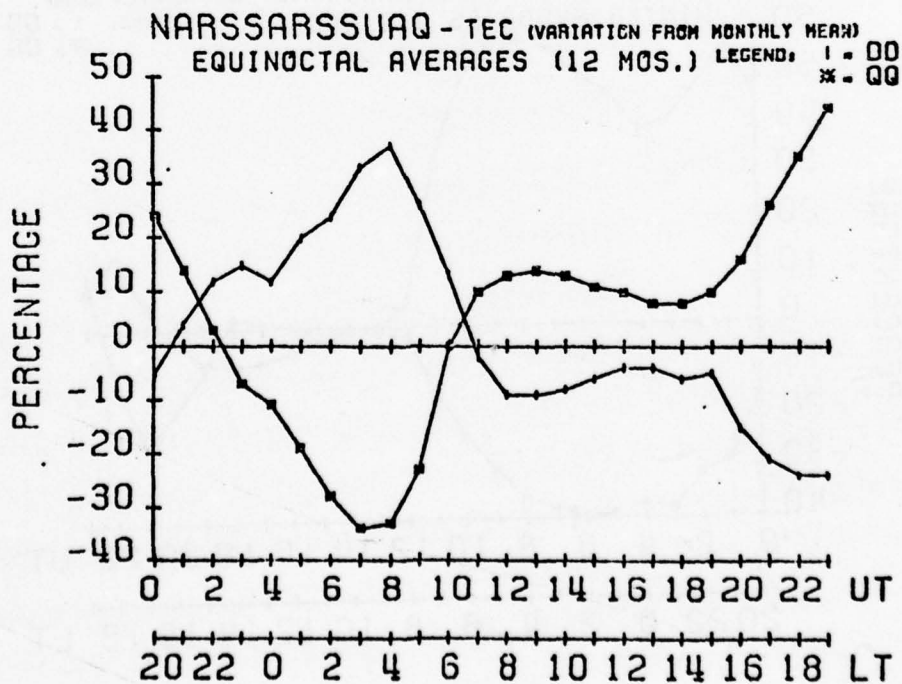
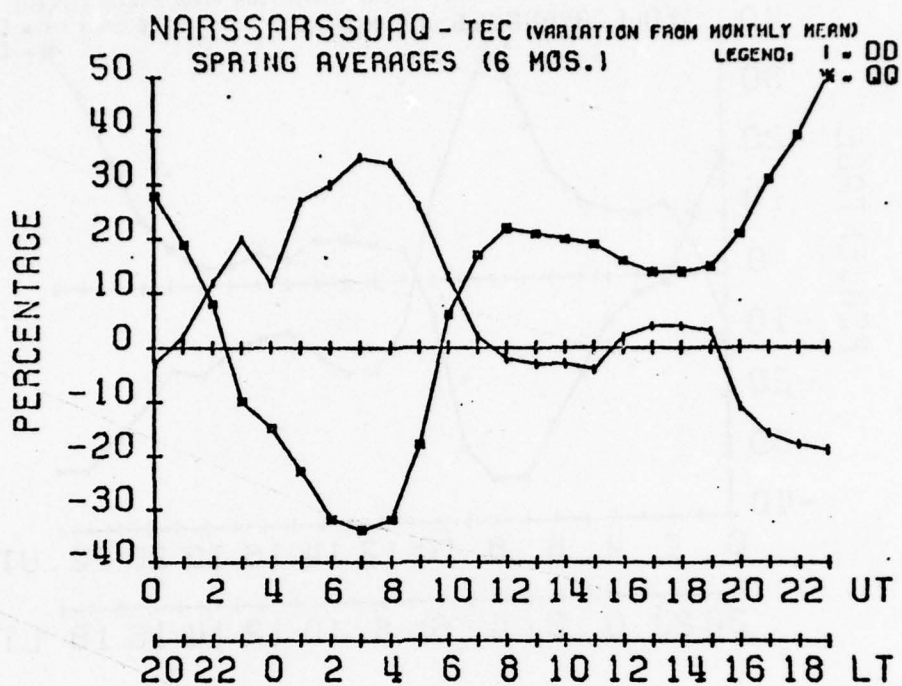
APPENDIX A.

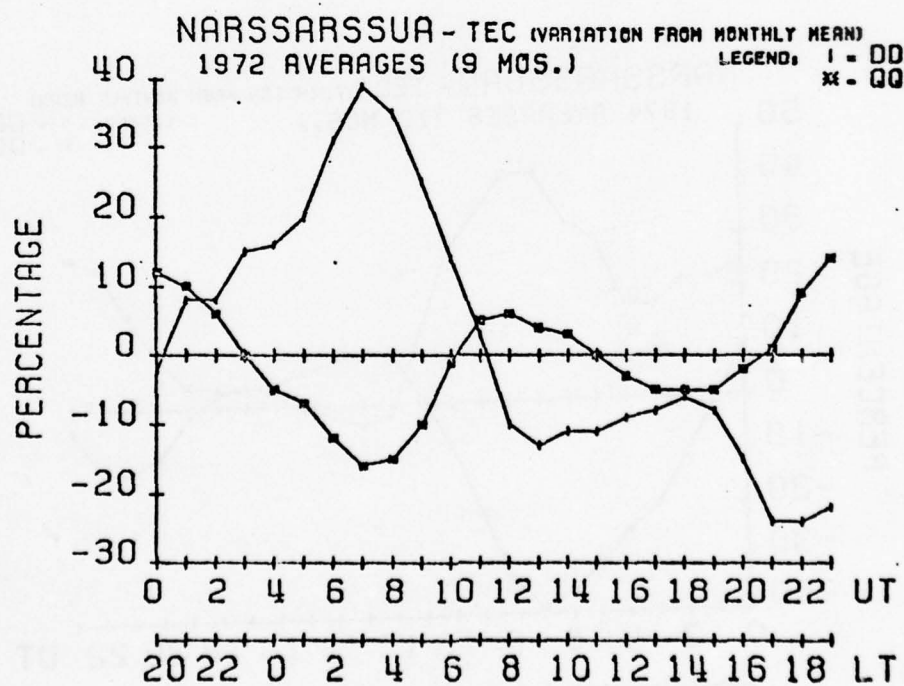
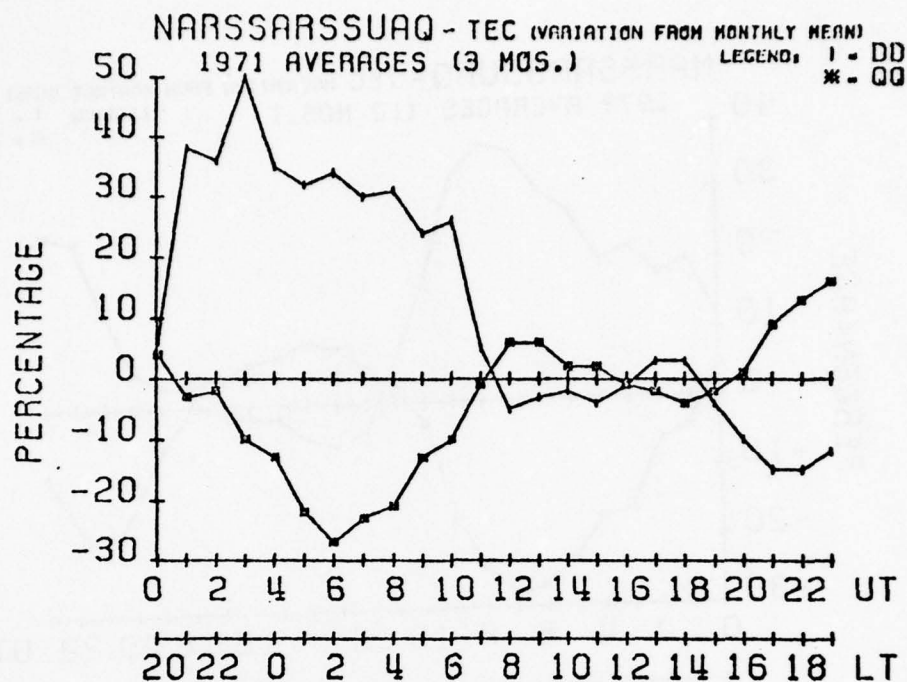
Disturbed (DD) versus Quiet (QQ) Behavior

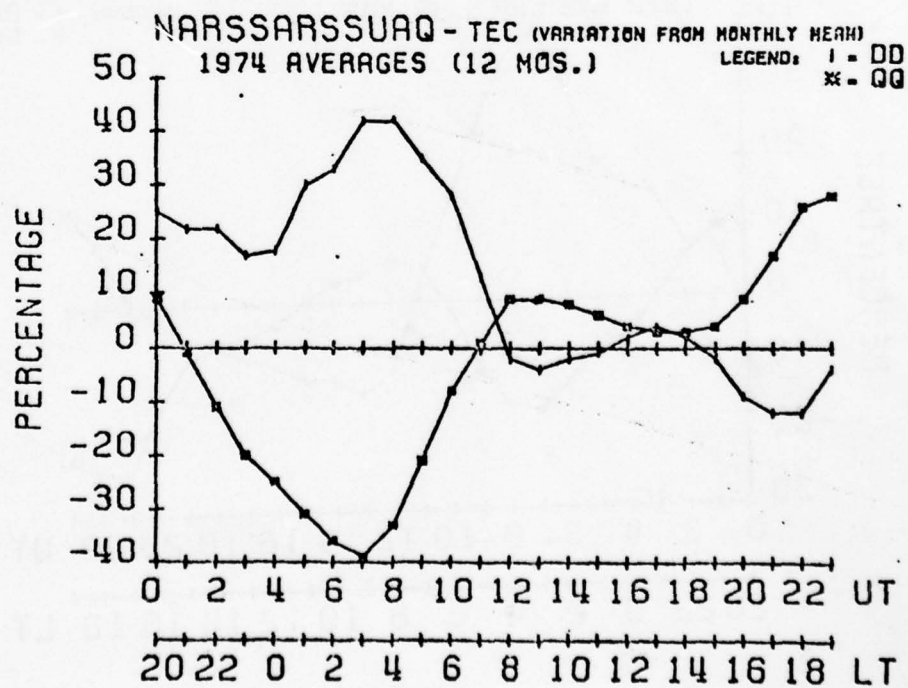
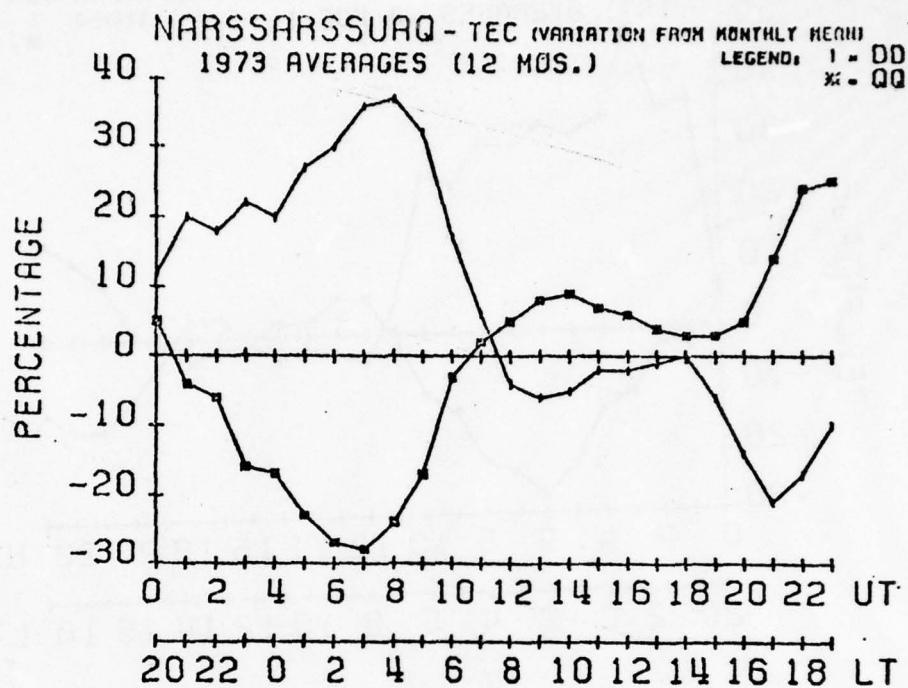
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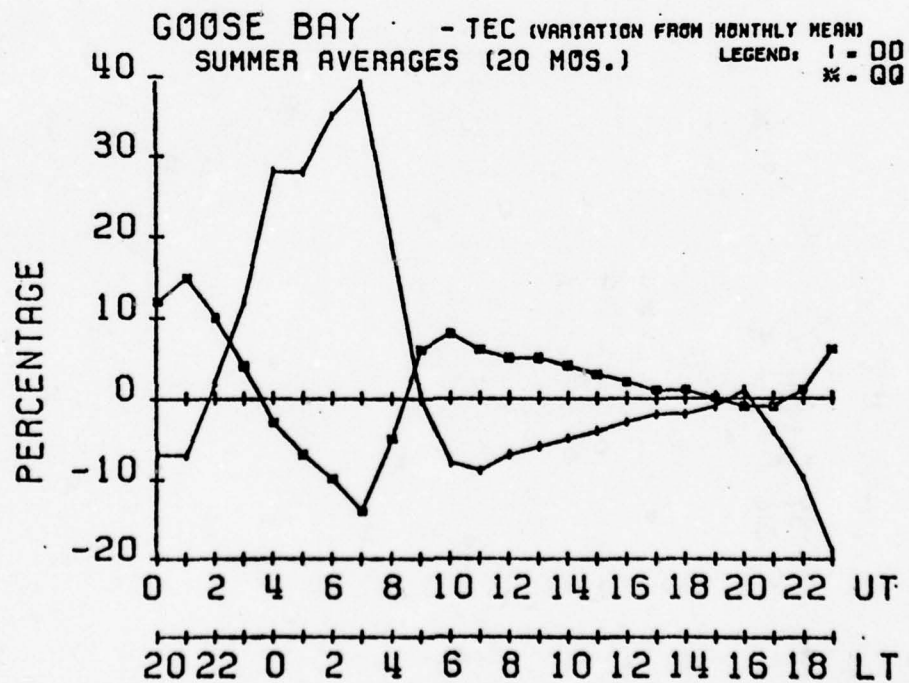
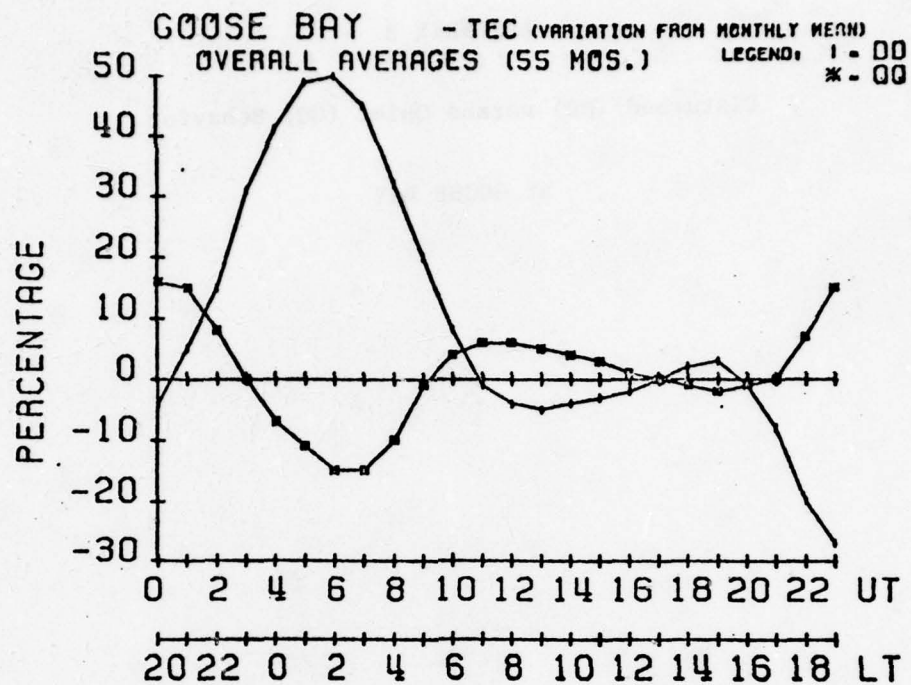


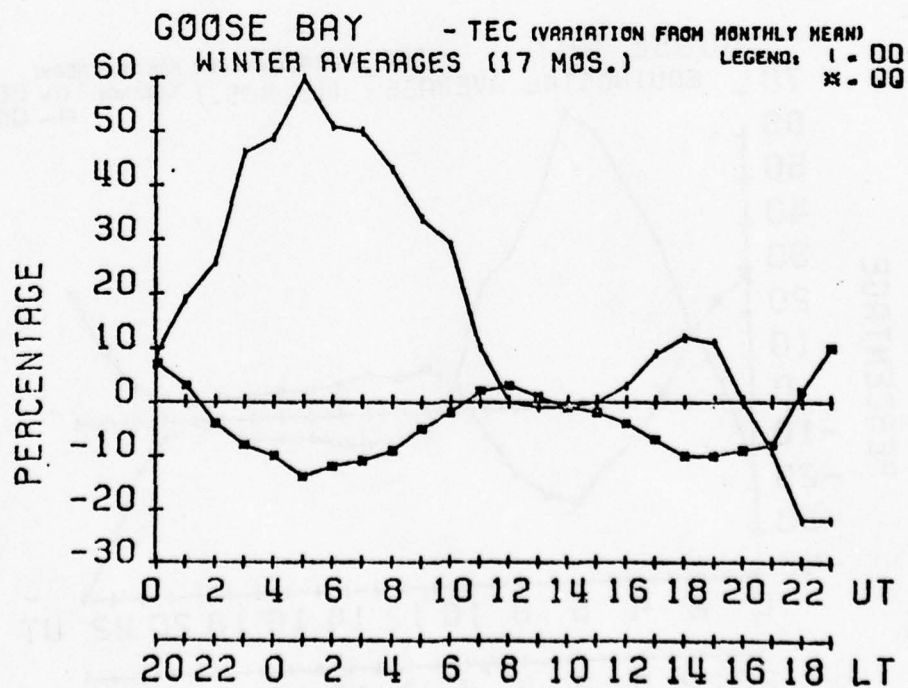
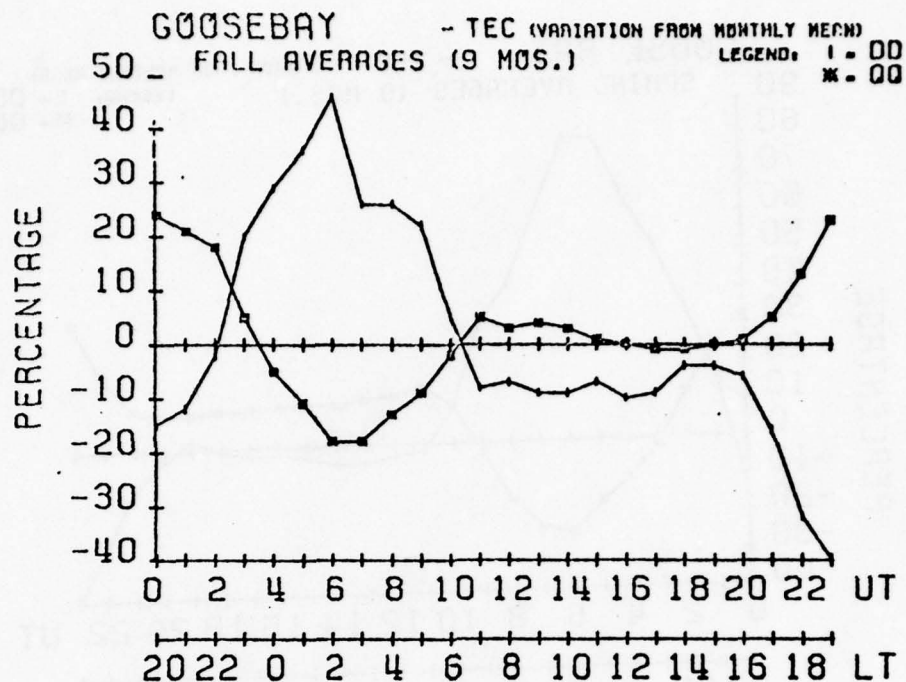


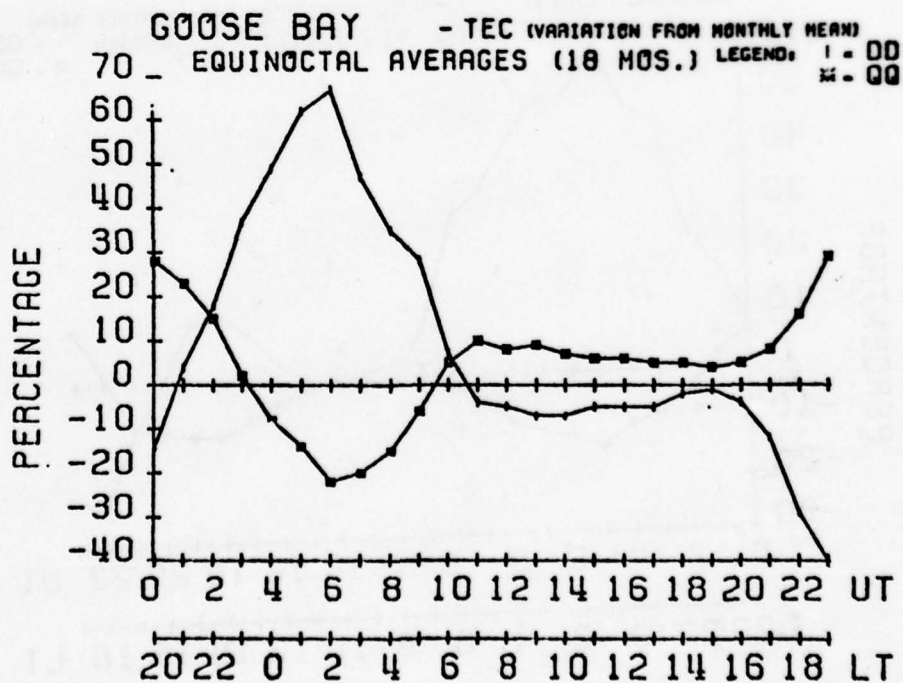
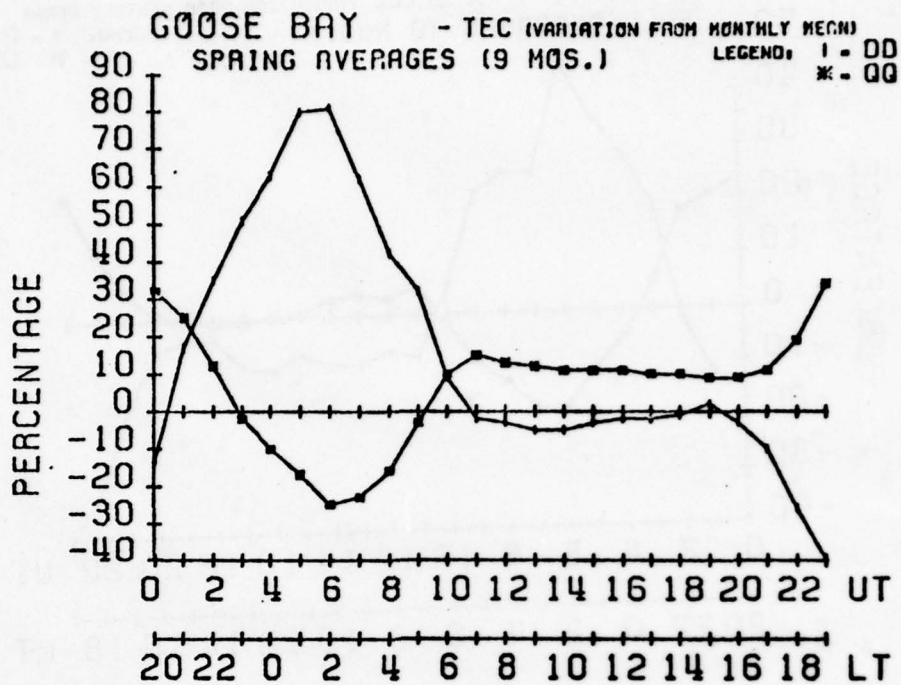
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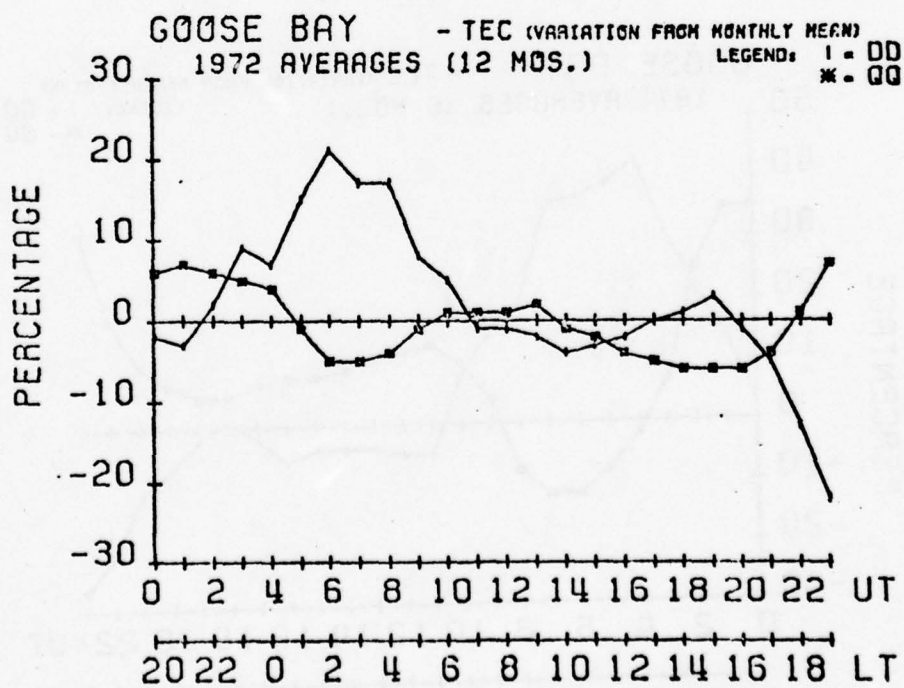
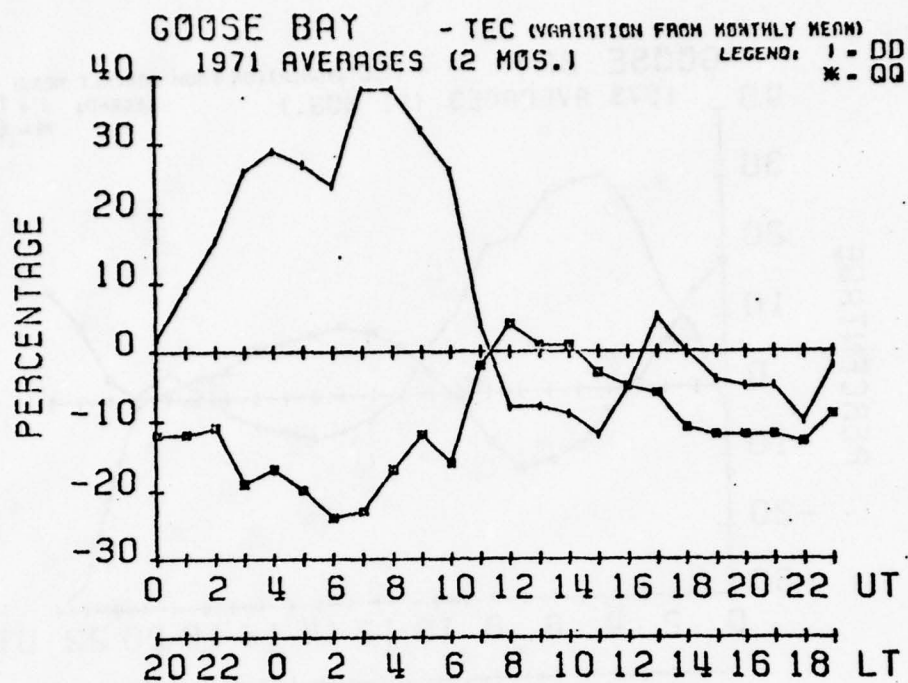
Disturbed (DD) versus Quiet (QQ) Behavior

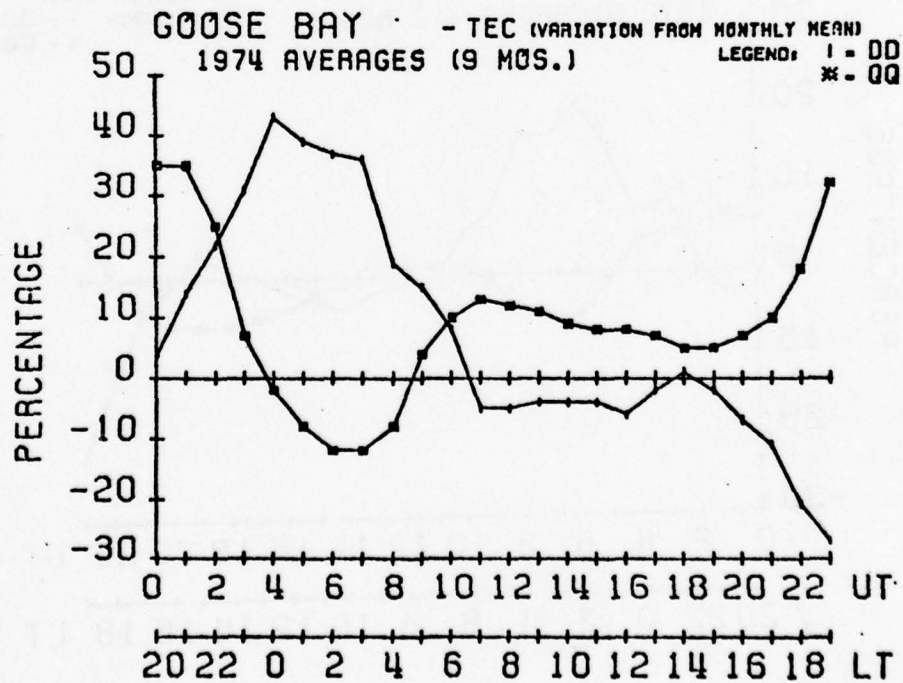
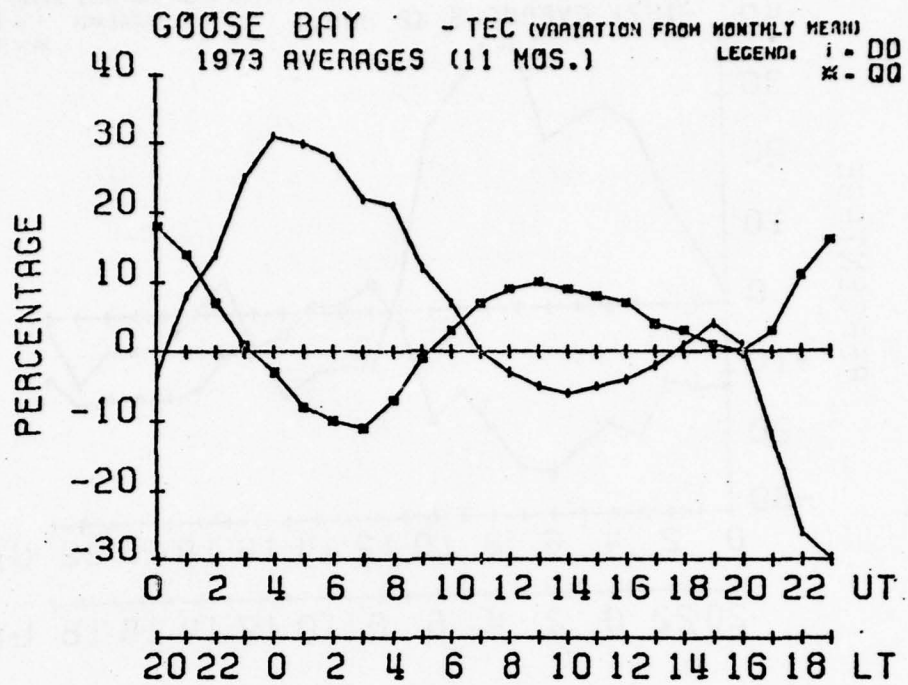
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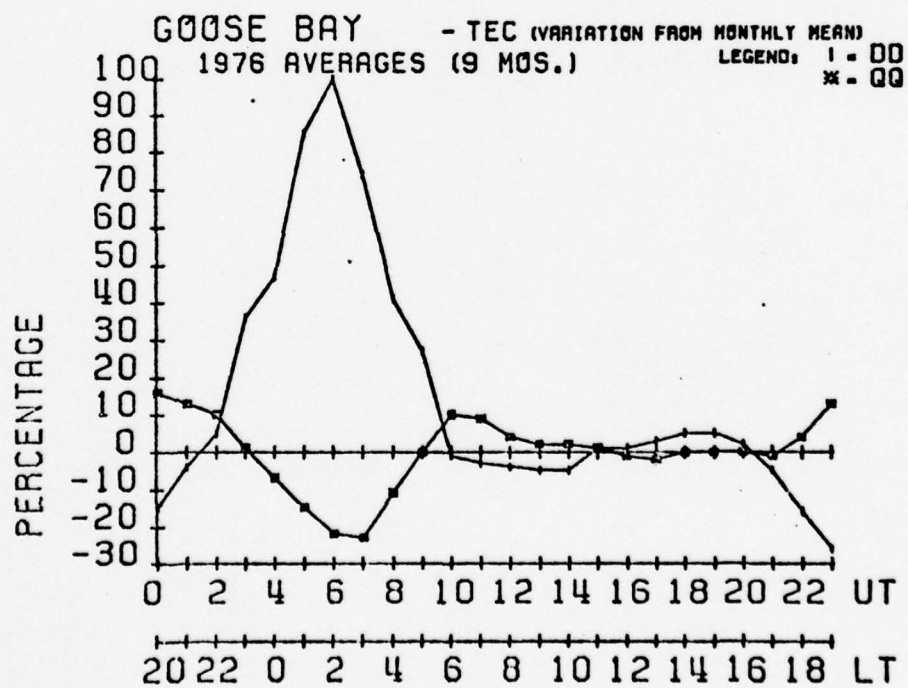
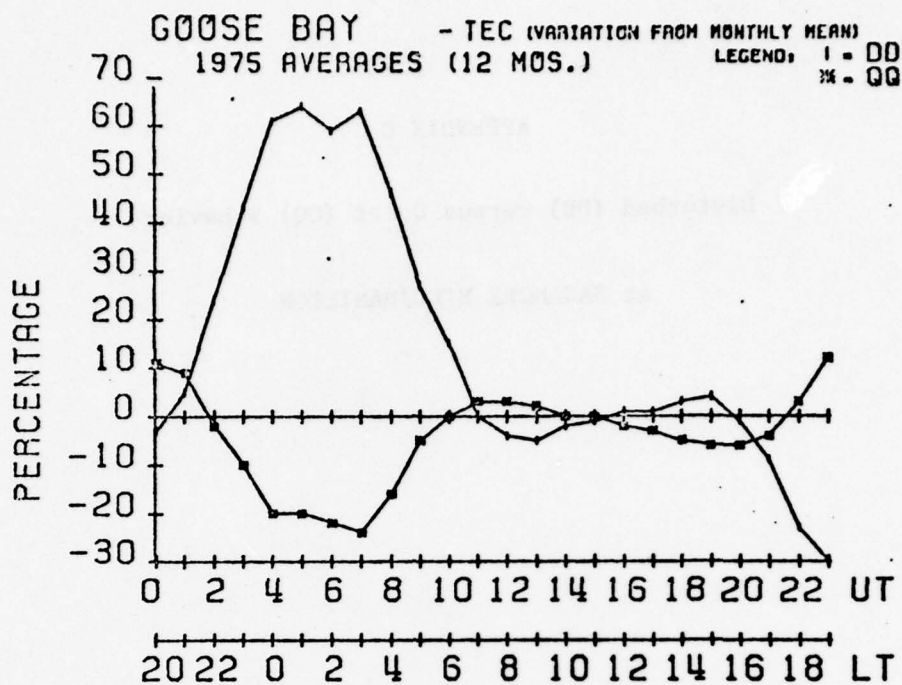








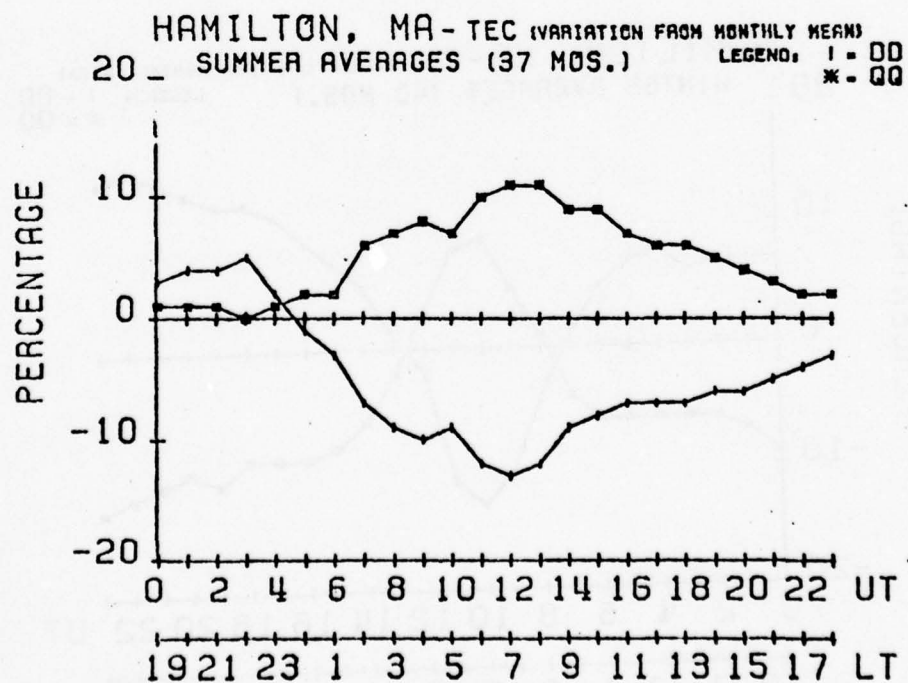
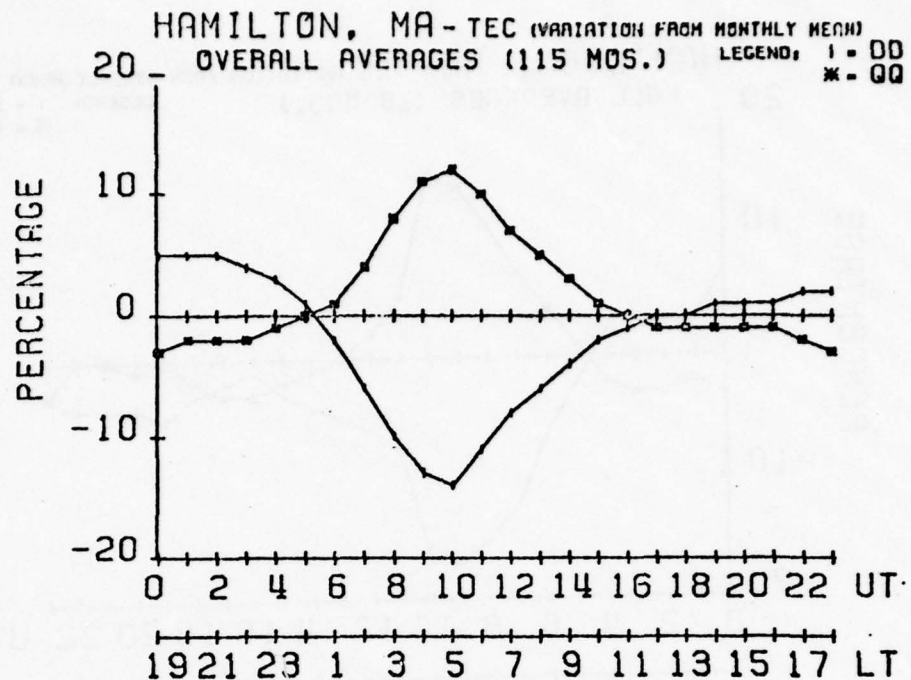


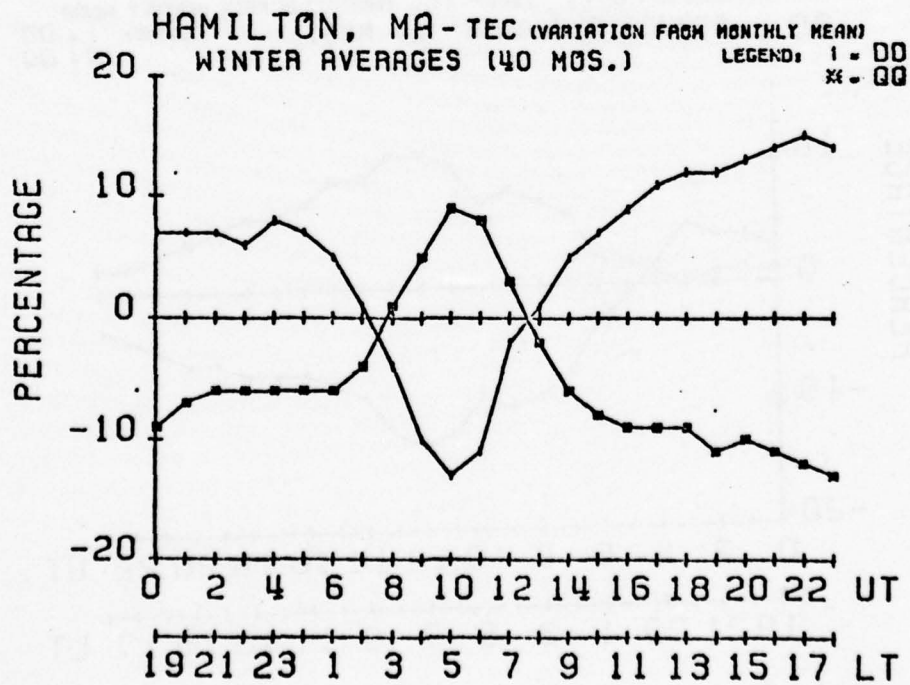
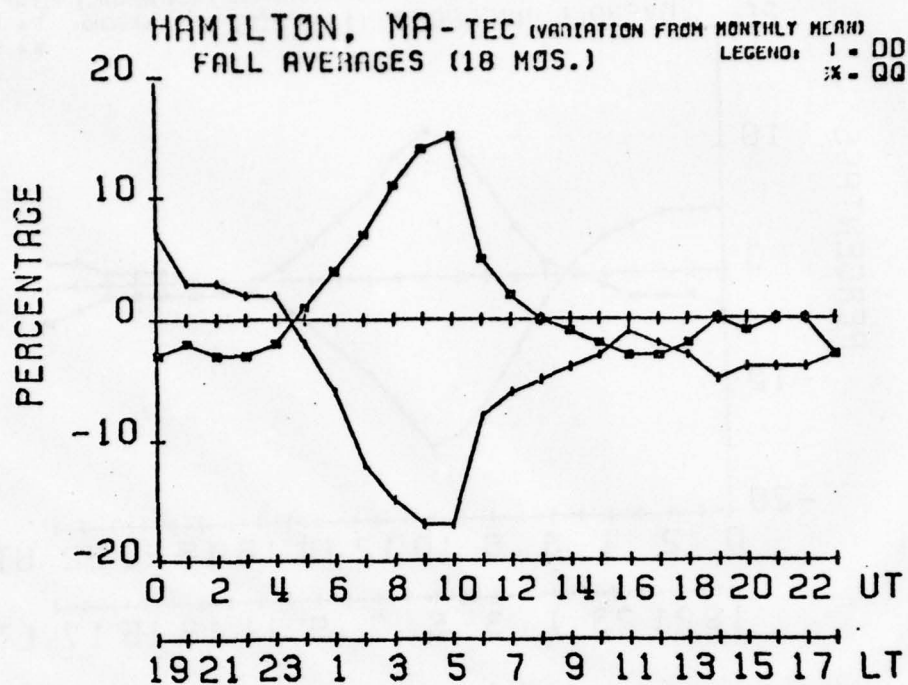


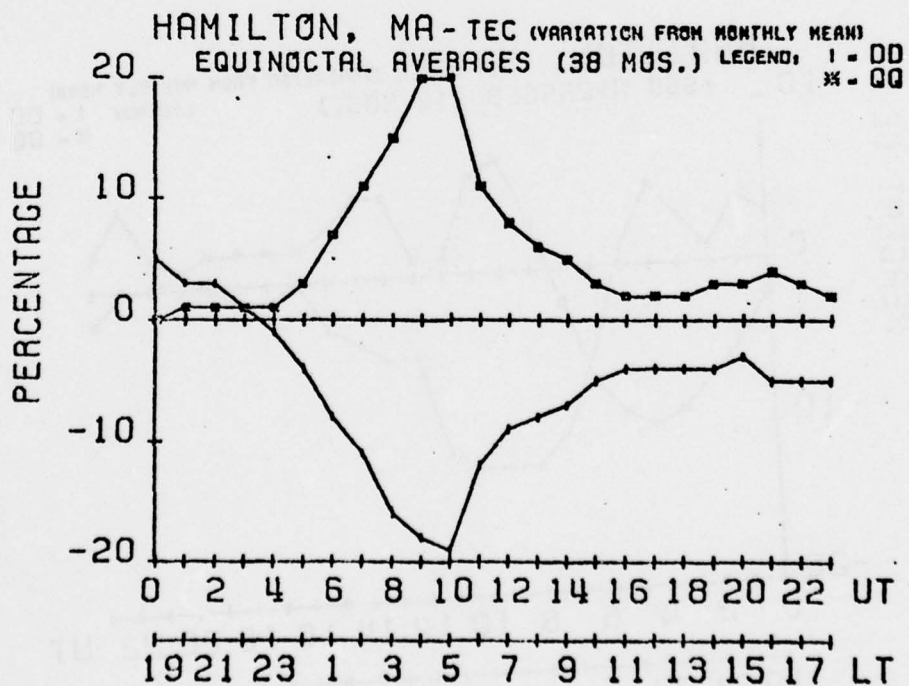
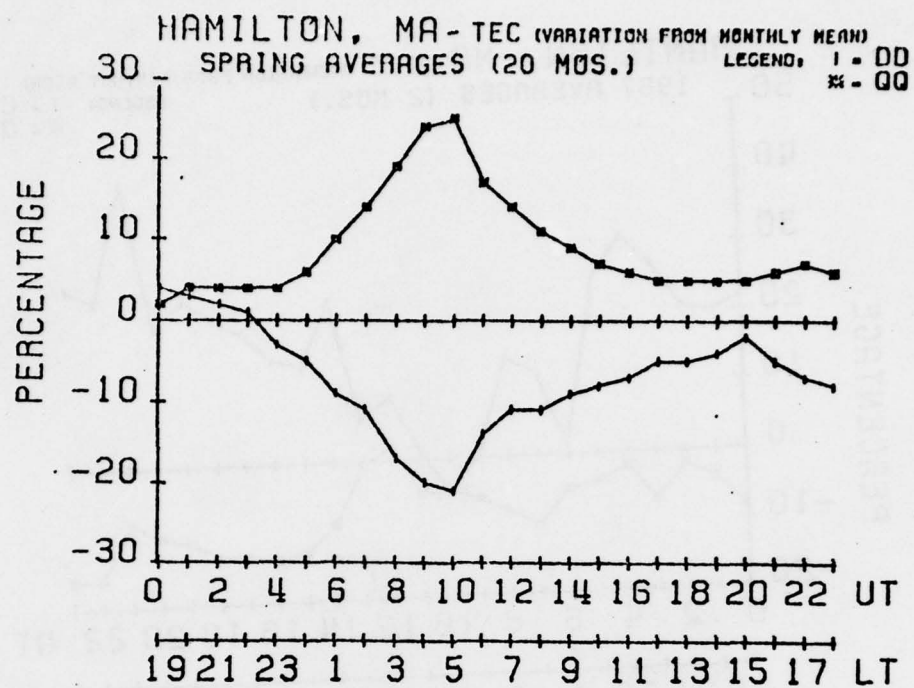
APPENDIX C

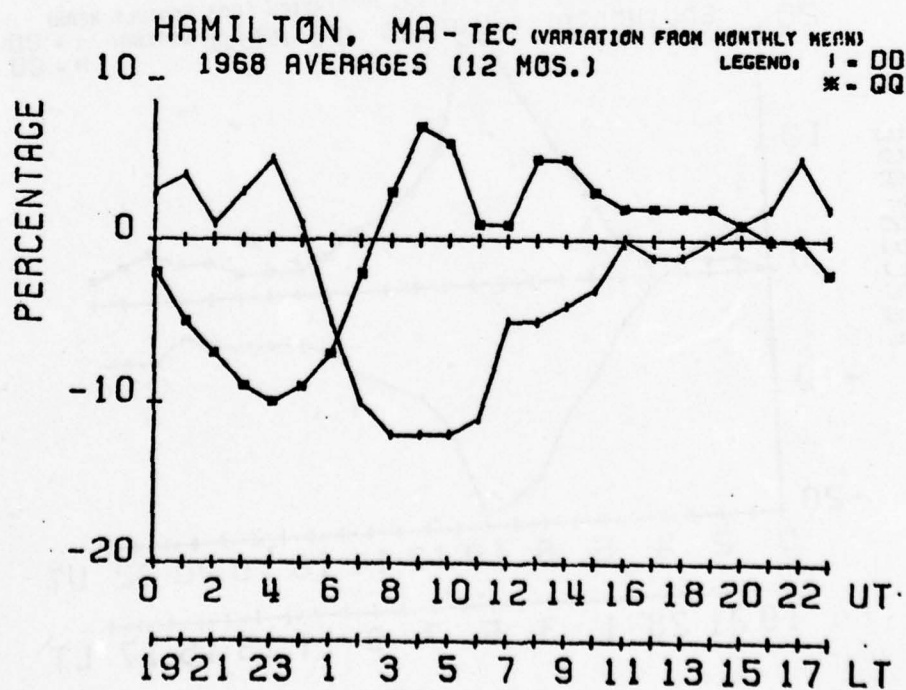
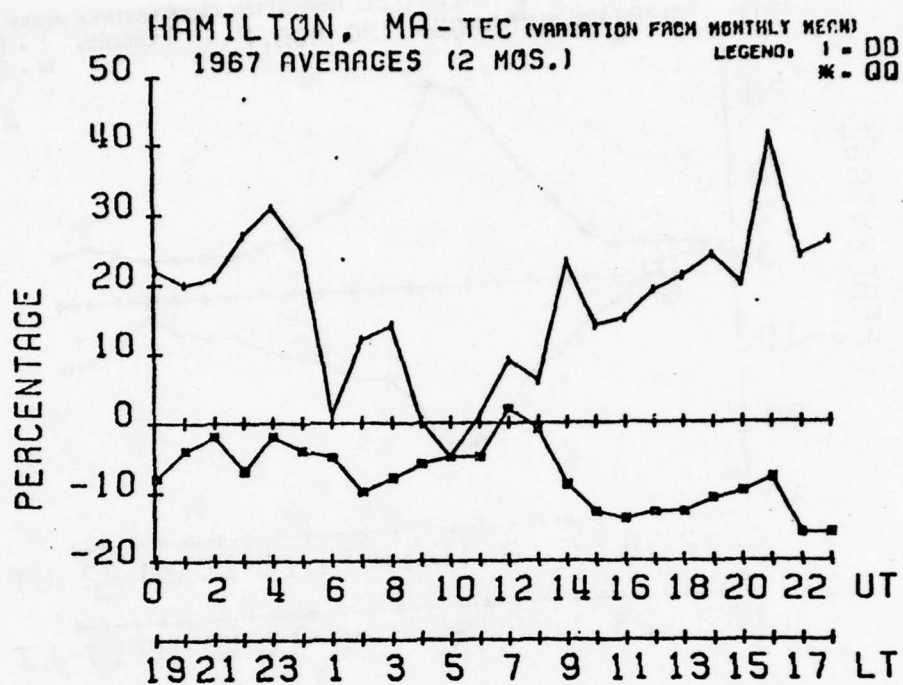
Disturbed (DD) versus Quiet (QQ) Behavior

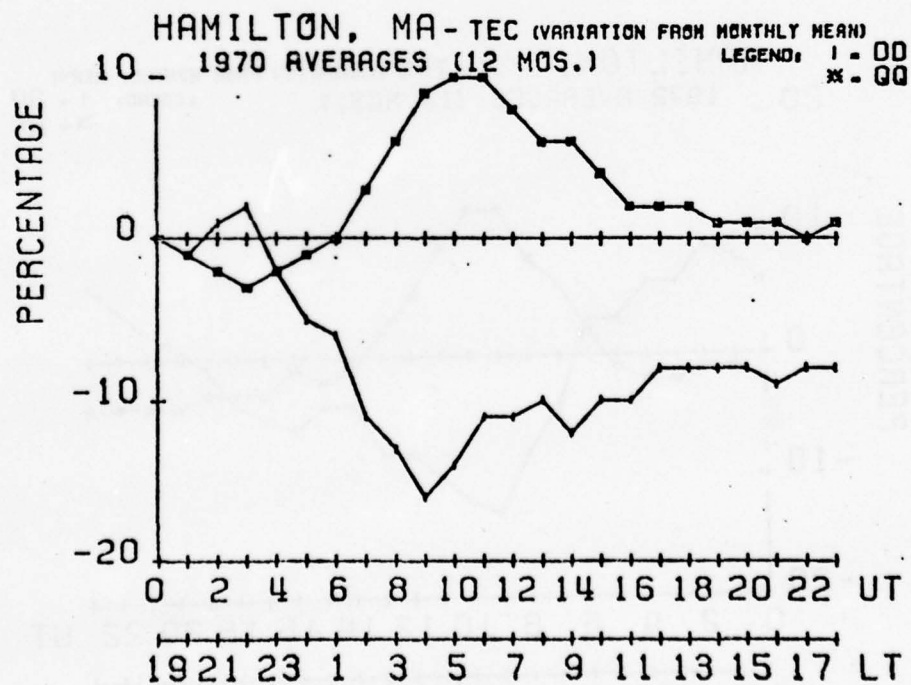
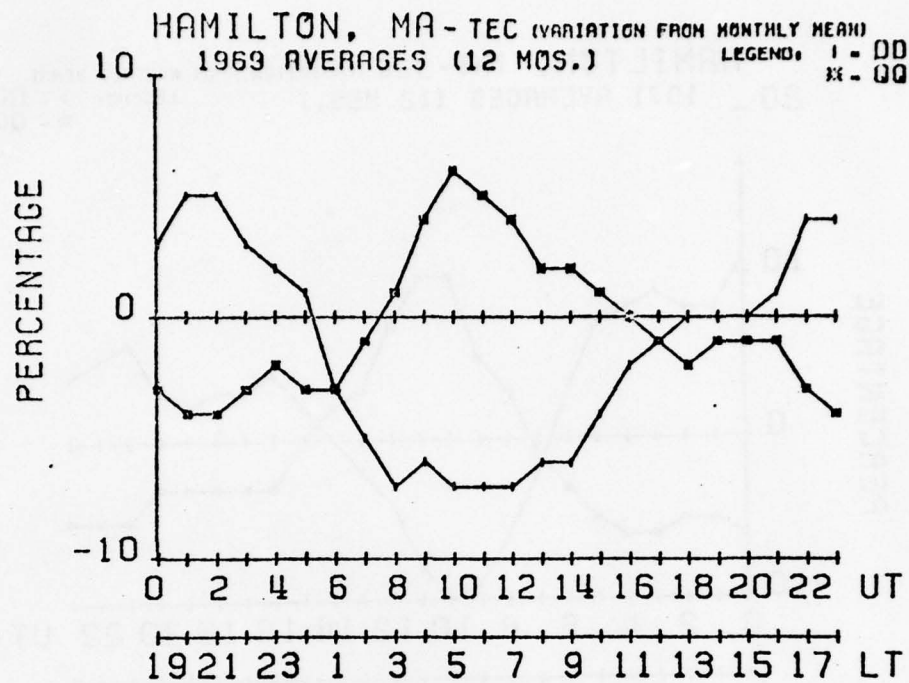
at SACAMORE HILL/HAMILTON





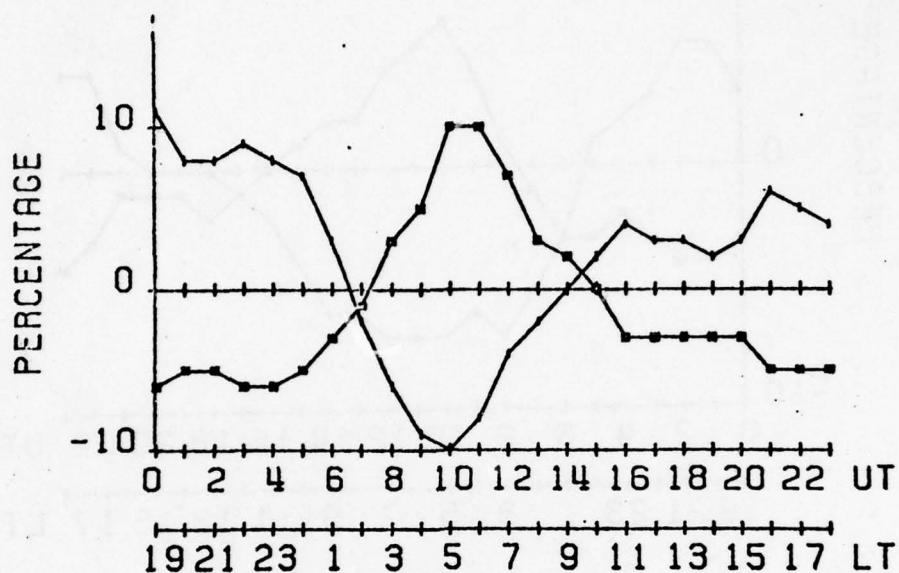






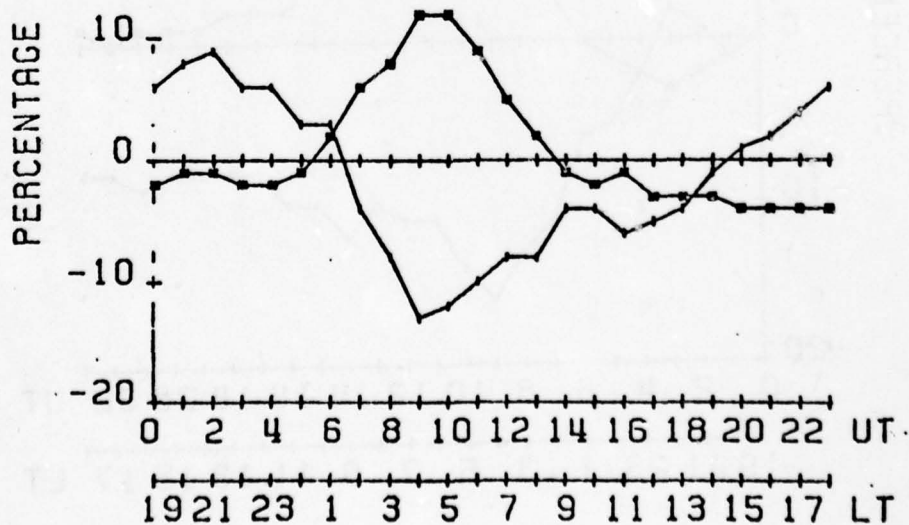
HAMILTON, MA - TEC (VARIATION FROM MONTHLY MEAN)
 20 - 1971 AVERAGES (12 MOS.)

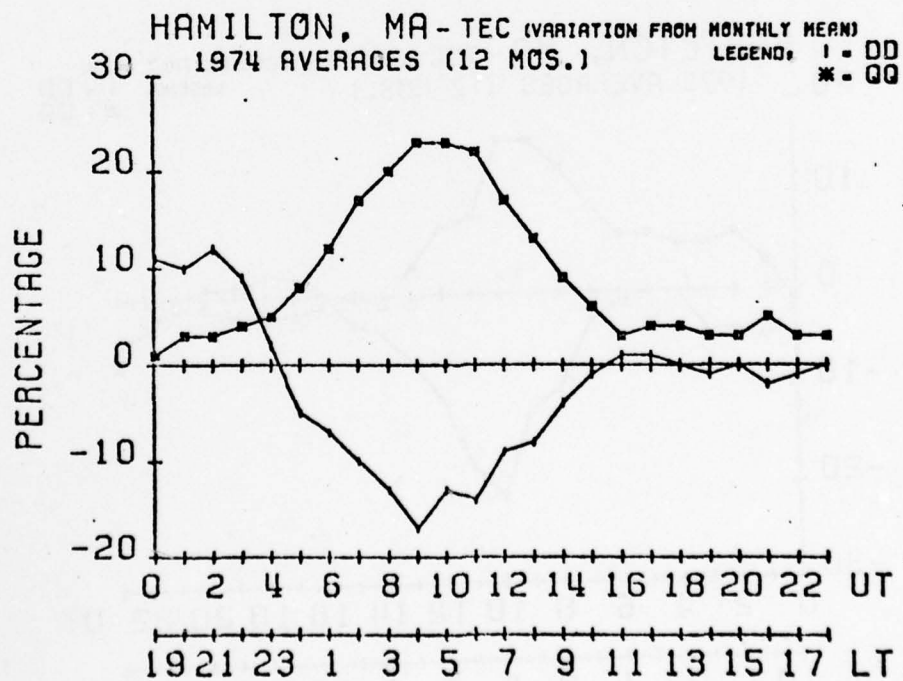
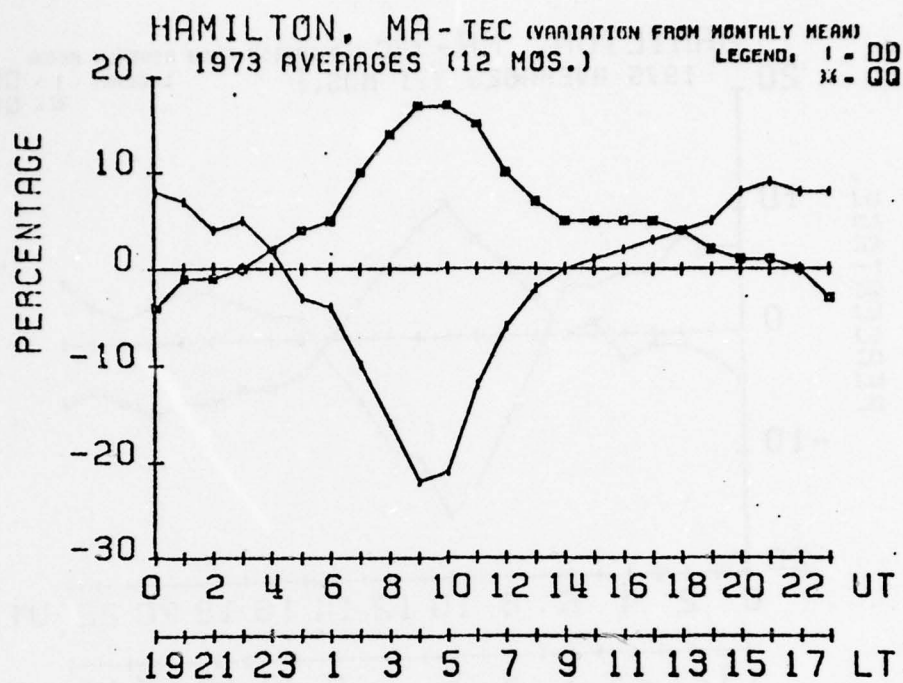
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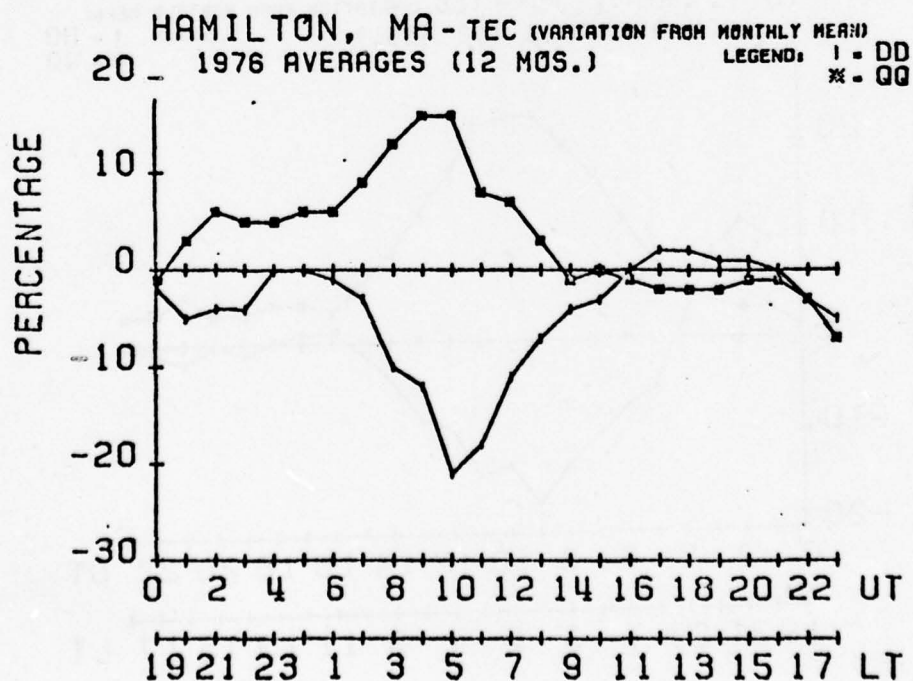
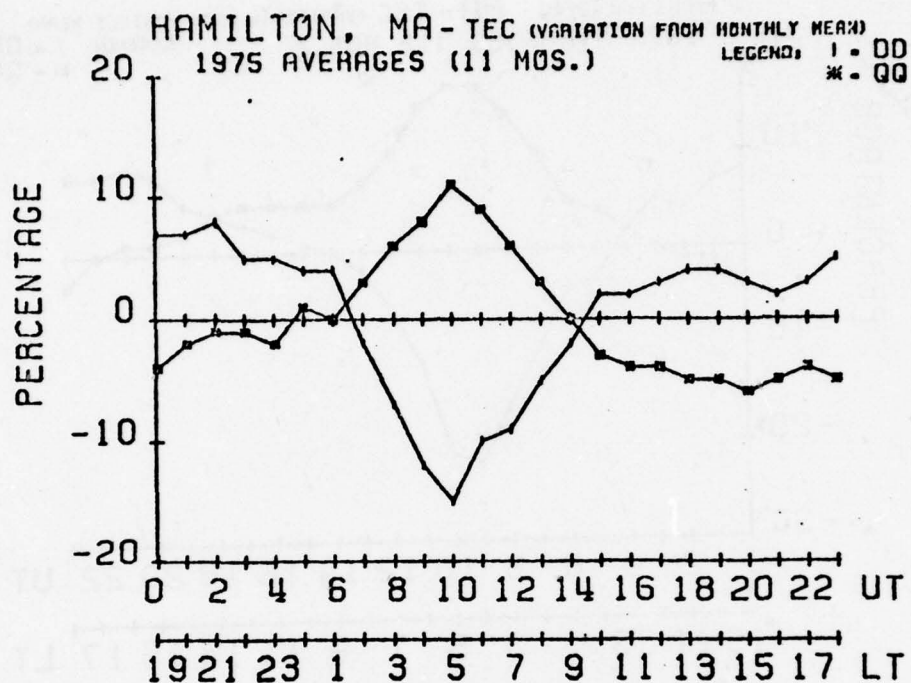


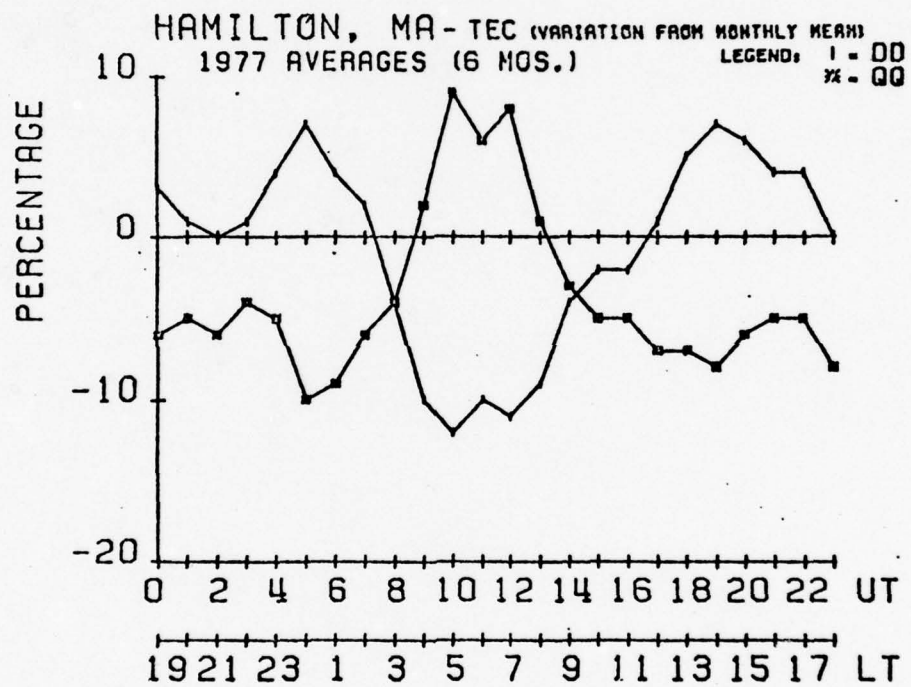
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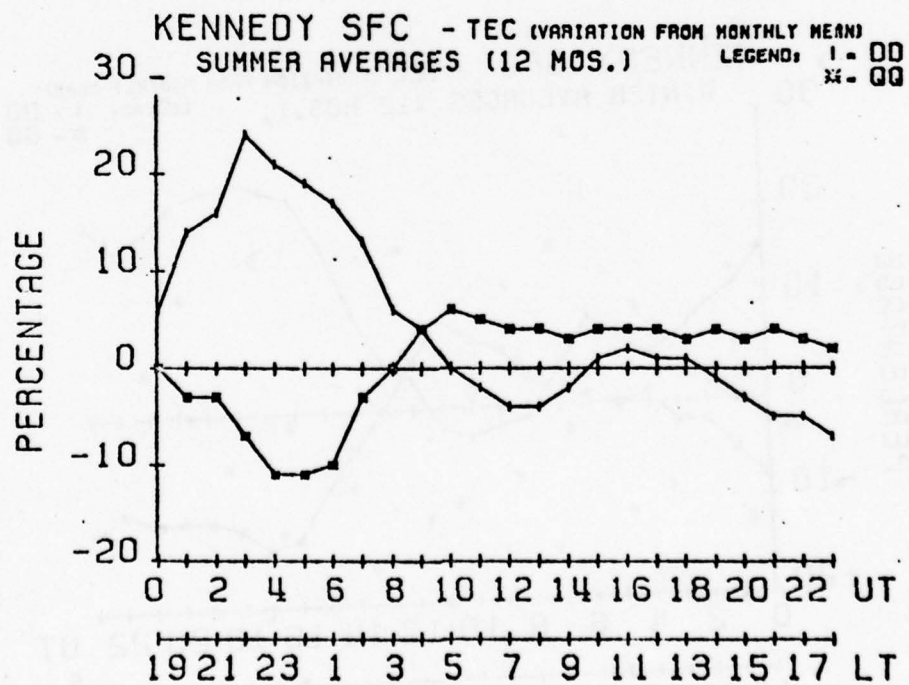
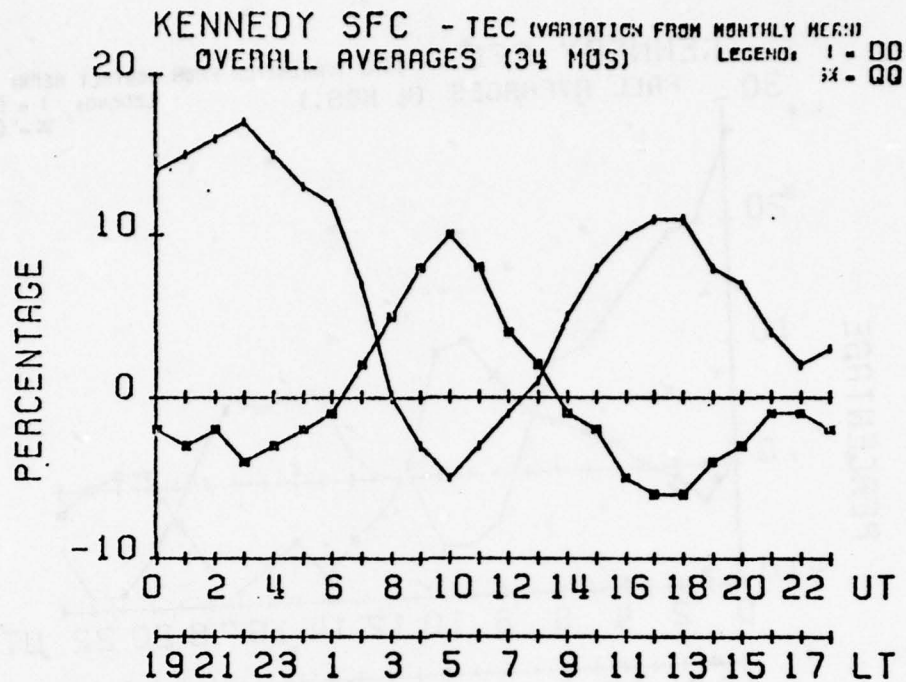


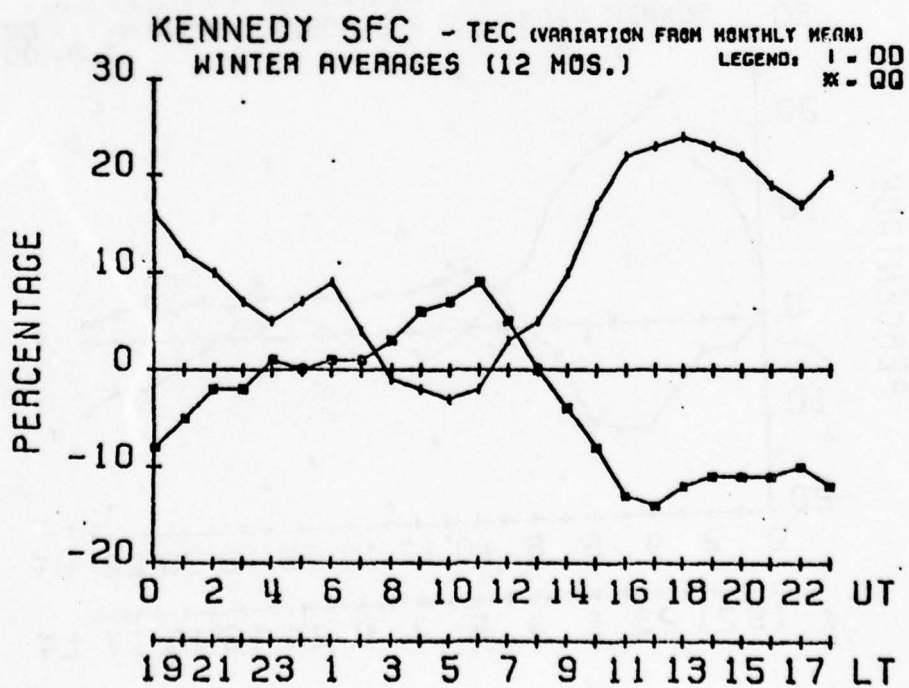
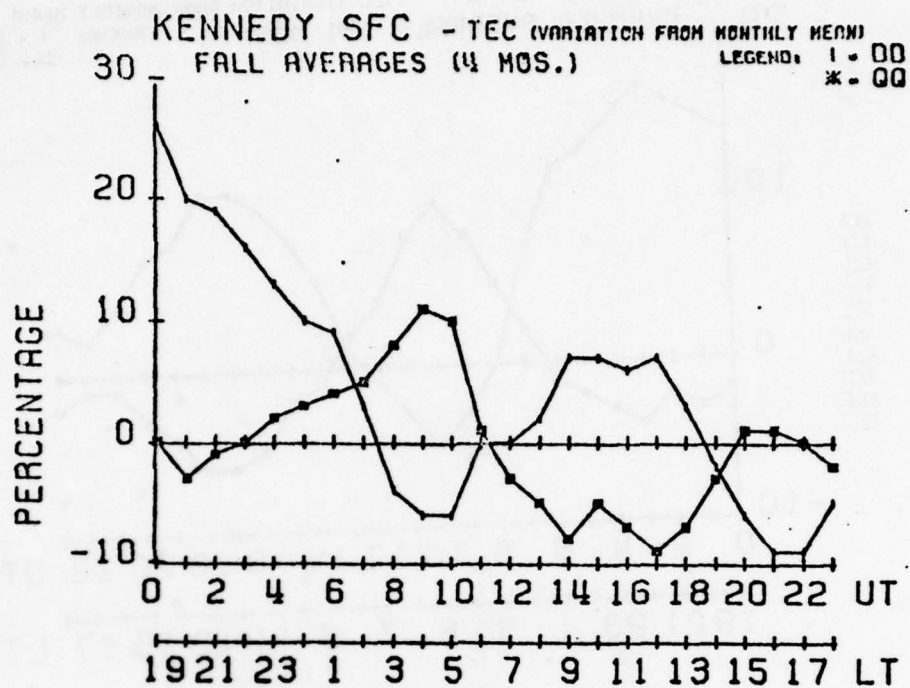
APPENDIX D

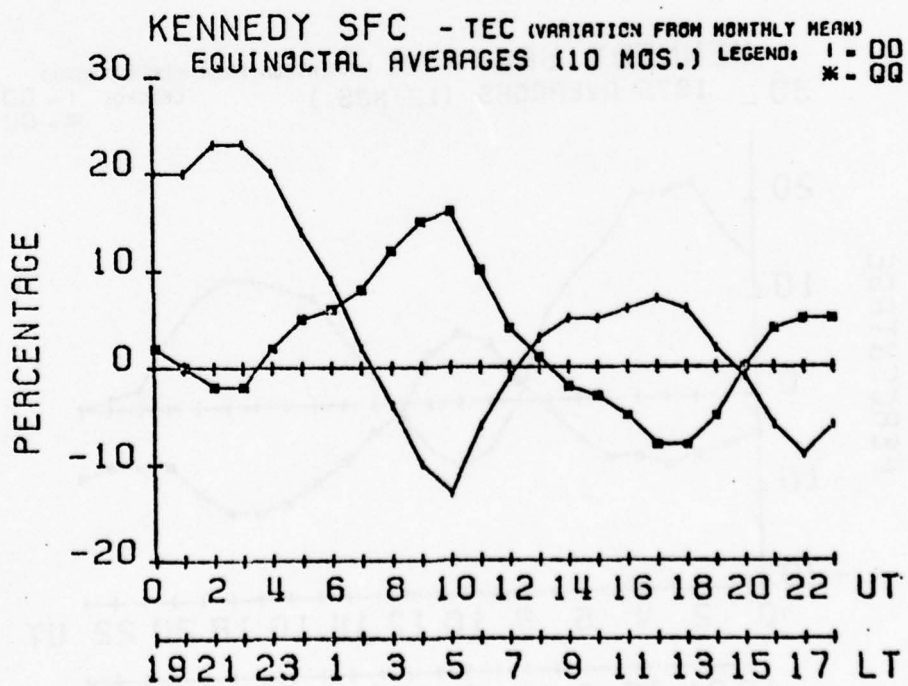
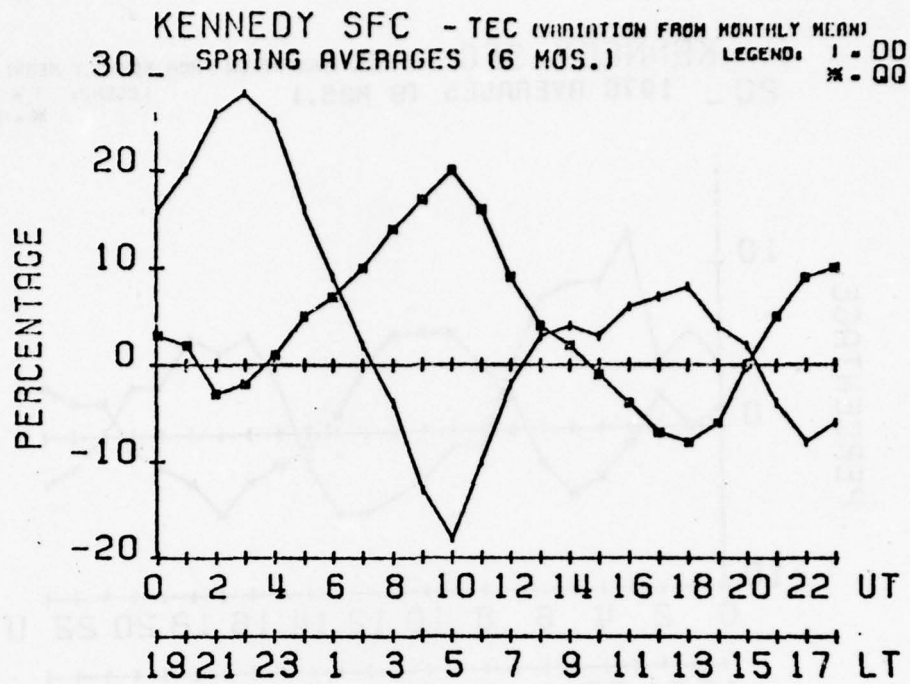
Disturbed (DD) versus Quiet (QQ) Behavior

at CAPE KENNEDY



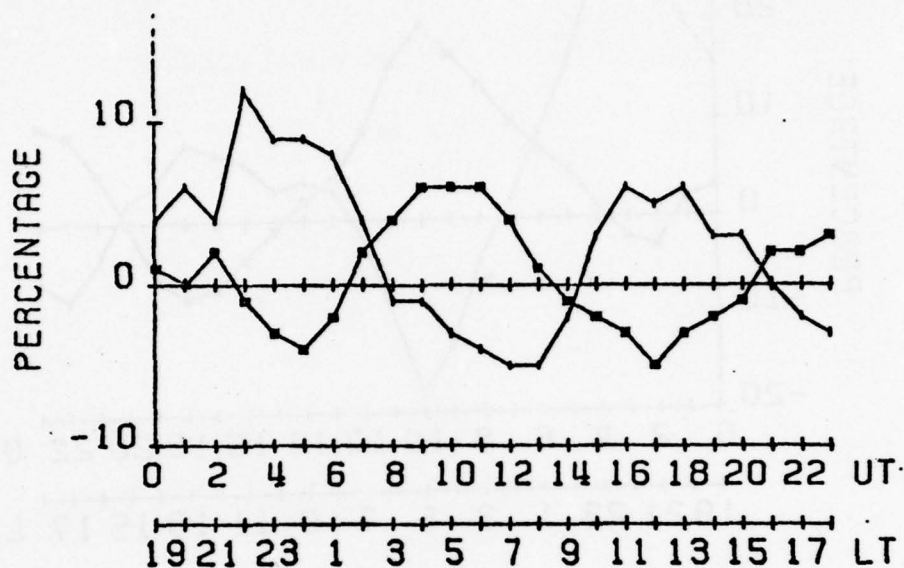






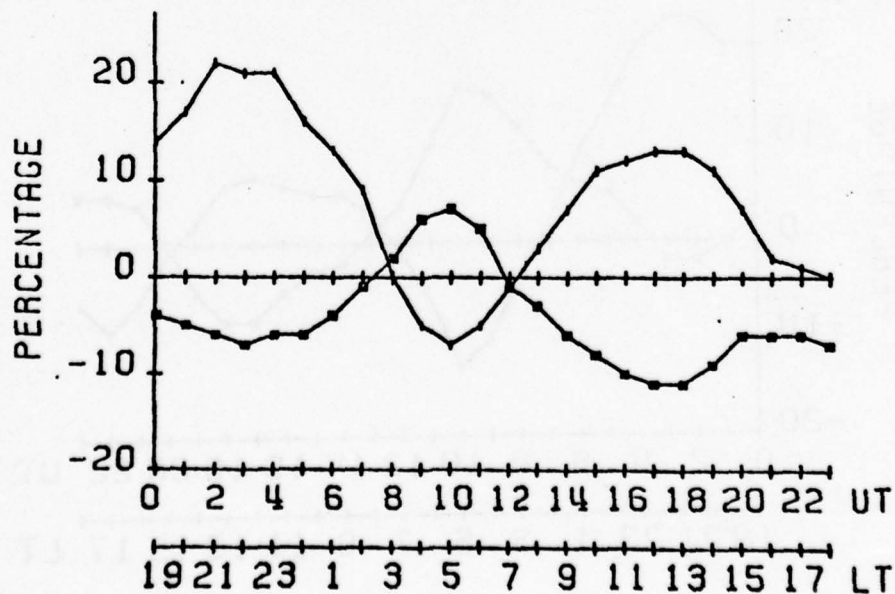
KENNEDY SFC - TEC (VARIATION FROM MONTHLY MEAN)
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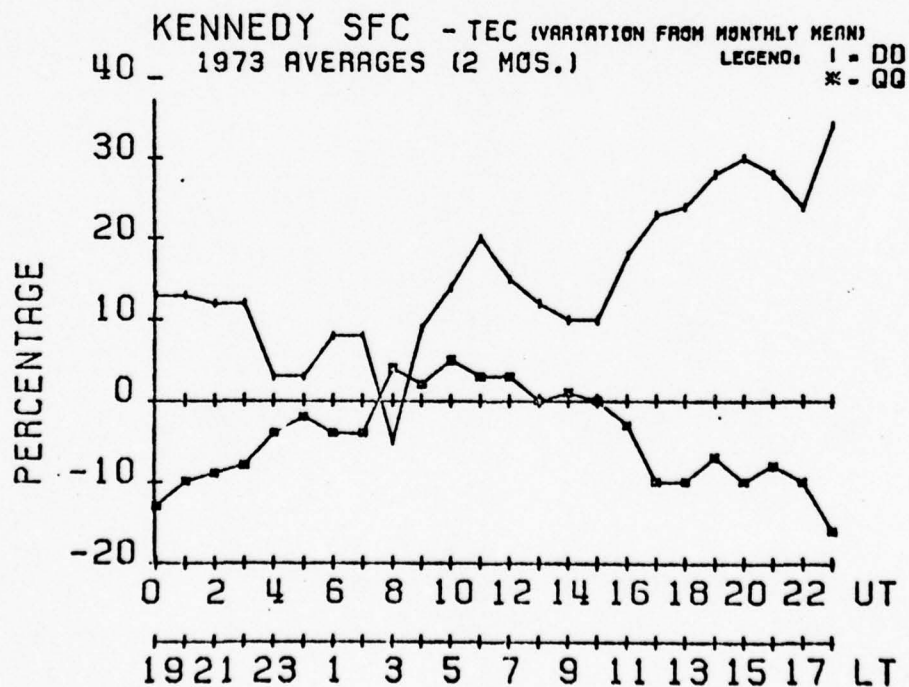
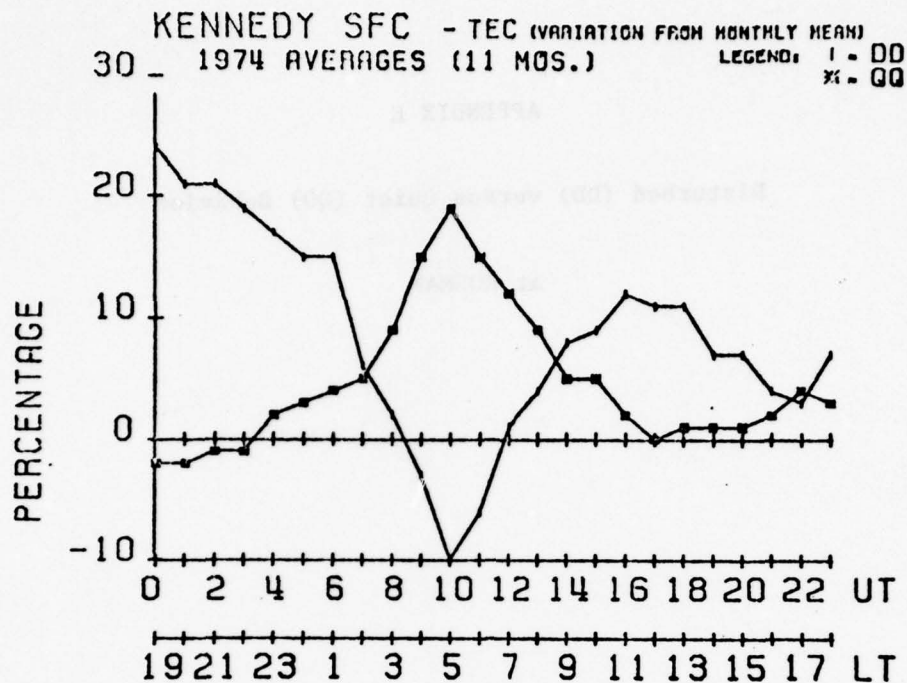
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 30 - 1975 AVERAGES (12 MOS.)

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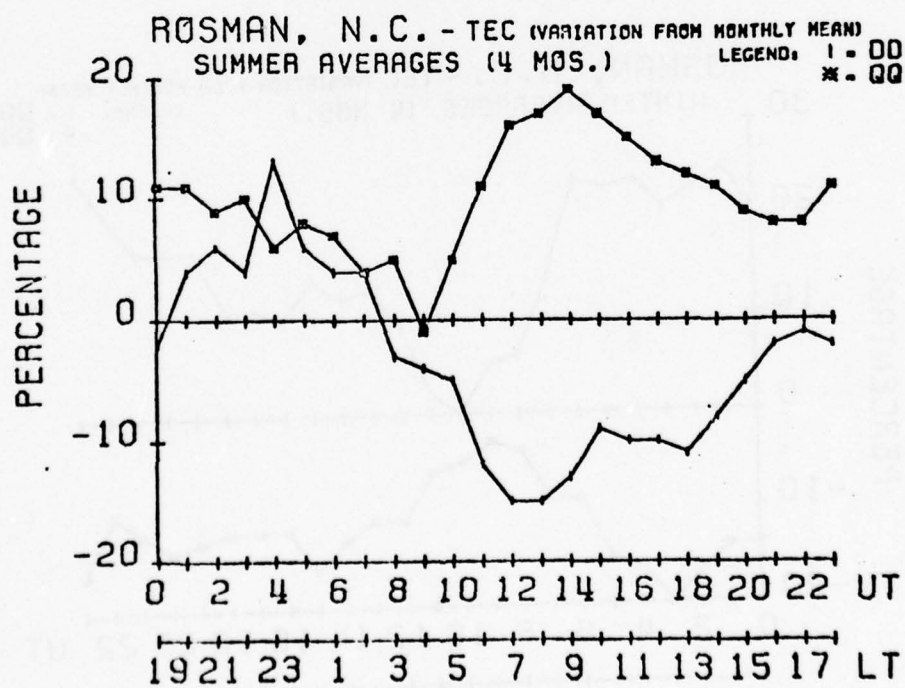
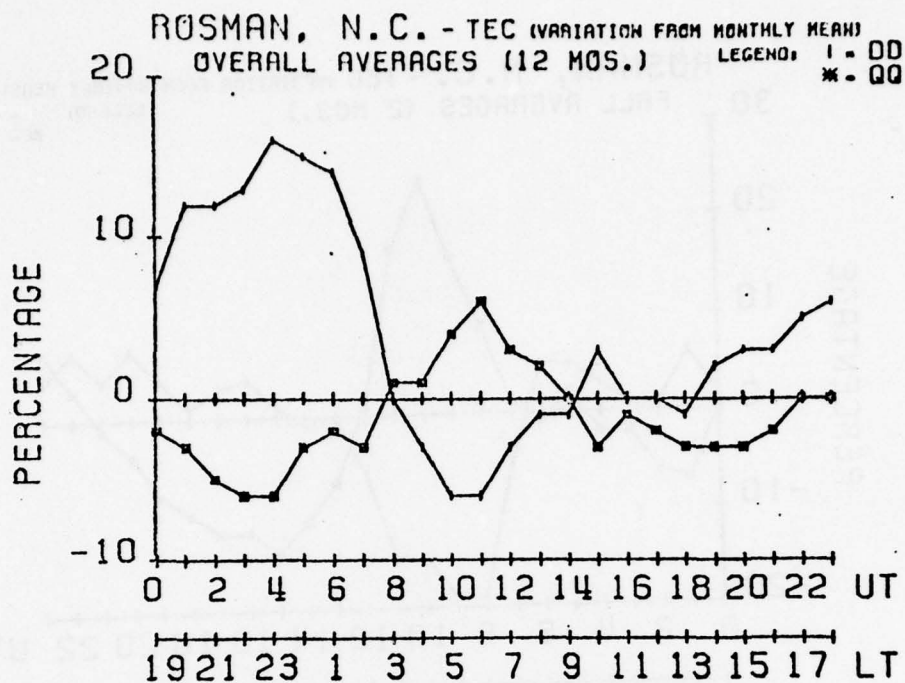


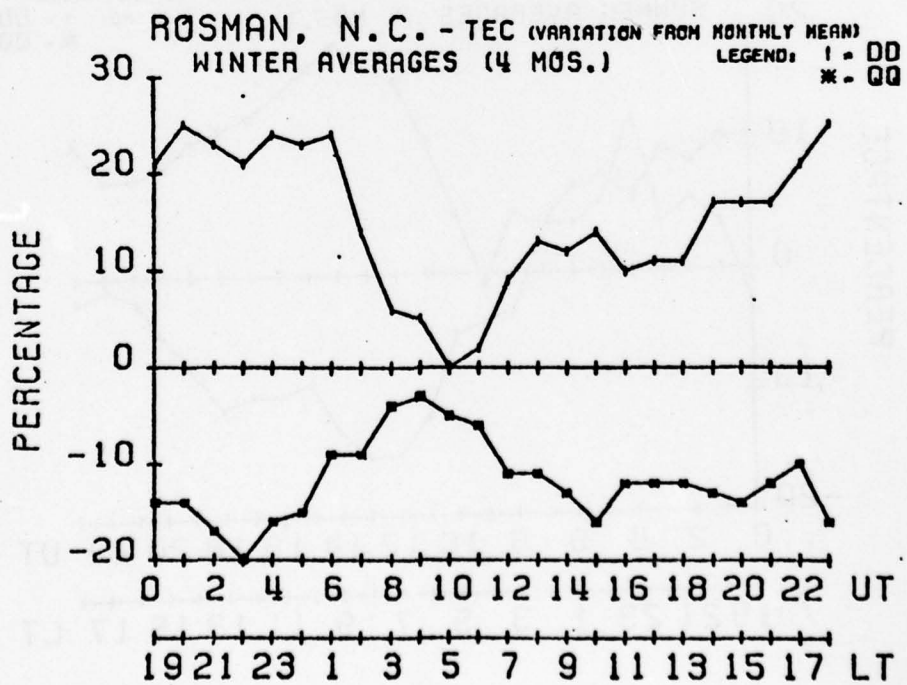
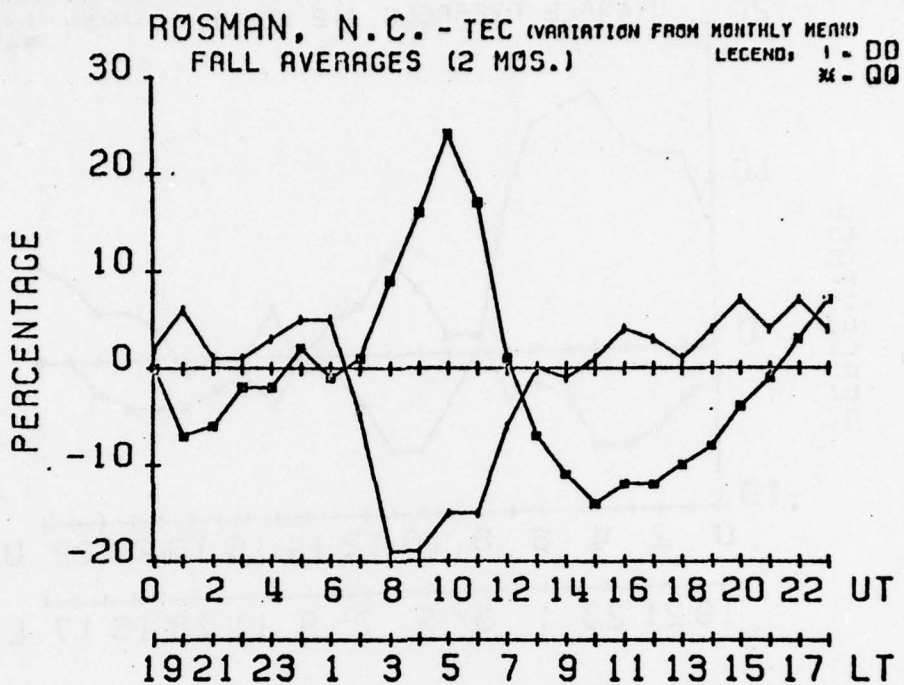


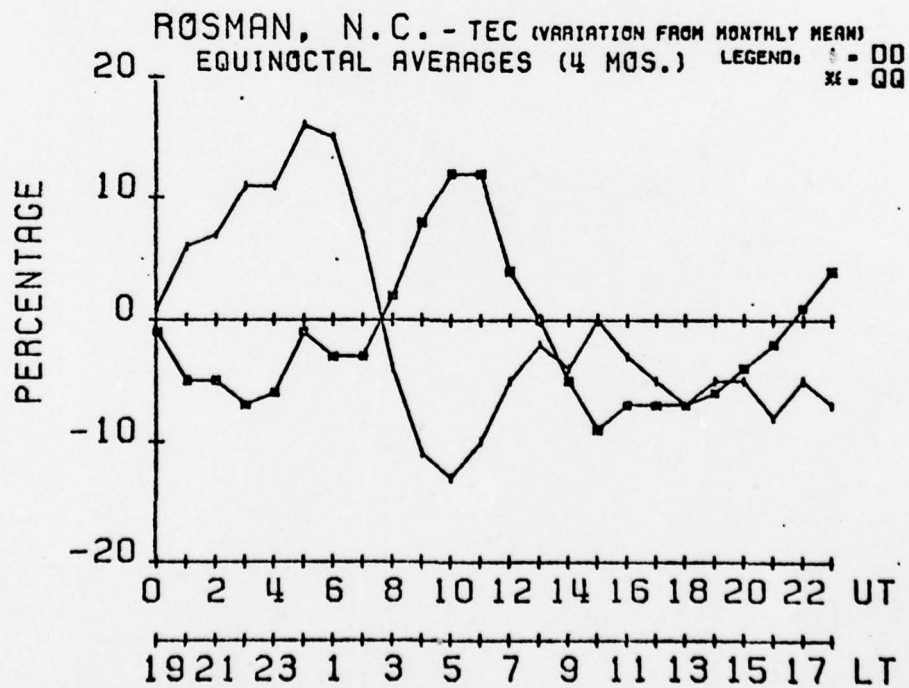
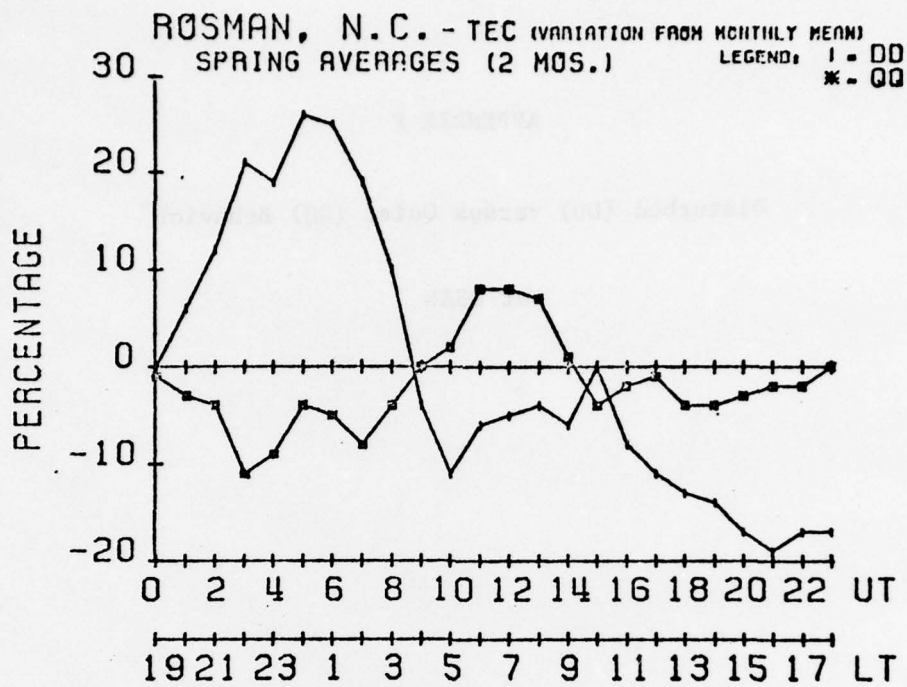
APPENDIX E

Disturbed (DD) versus Quiet (QQ) Behavior

at ROSMAN







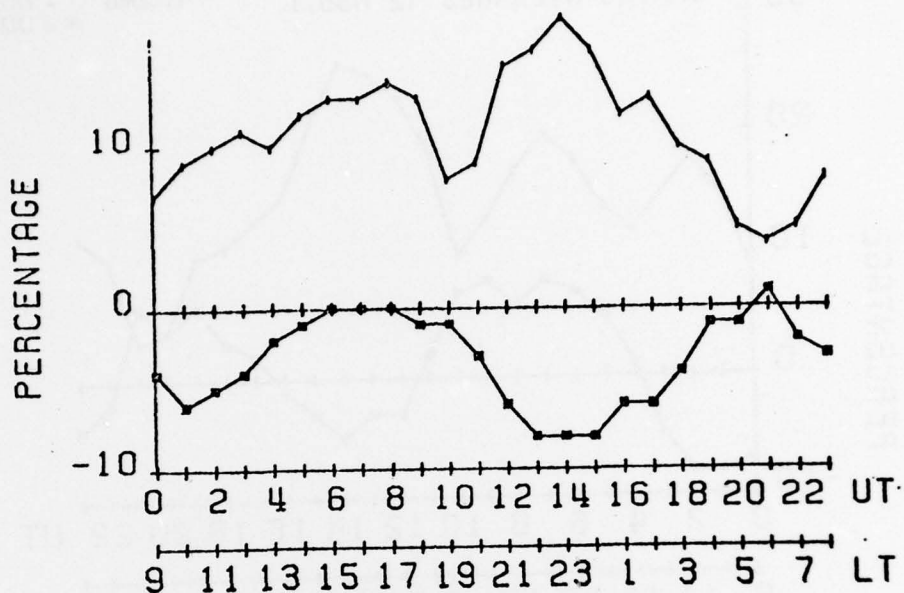
APPENDIX F

Disturbed (DD) versus Quiet (QQ) Behavior

at OSAN

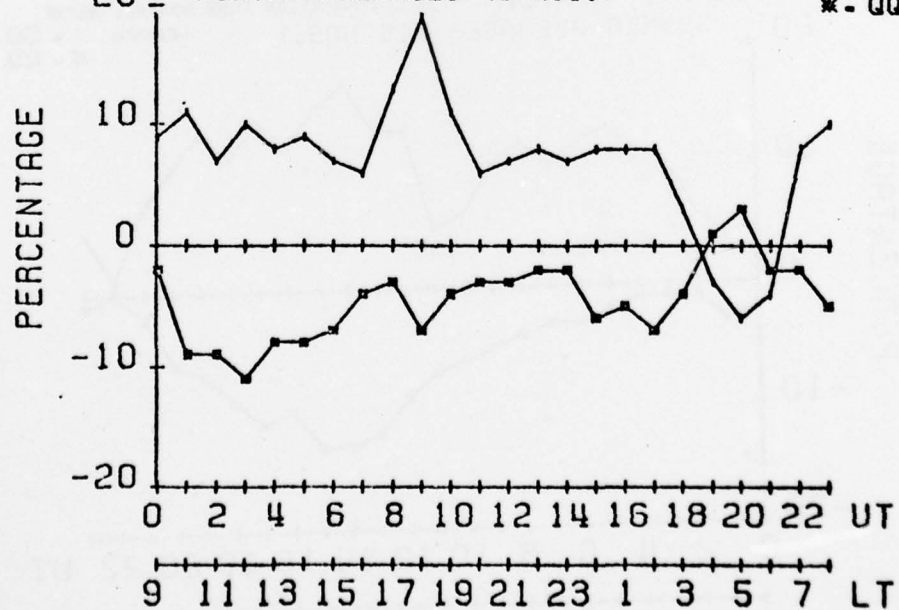
OSAN, KOREA - TEC (VARIATION FROM MONTHLY MEAN)
 20 - OVERALL AVERAGES (20 MOS.)

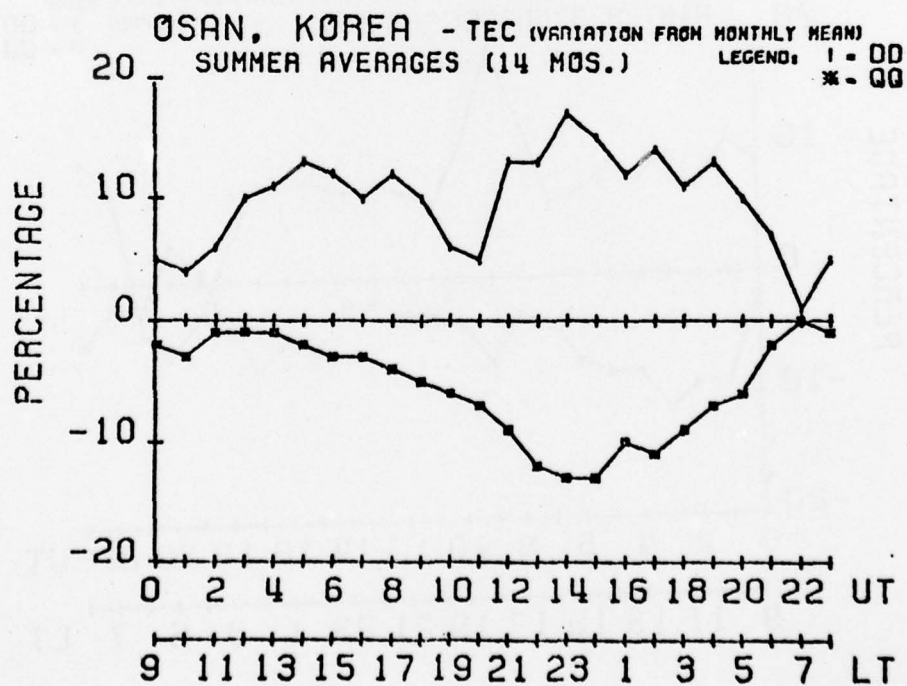
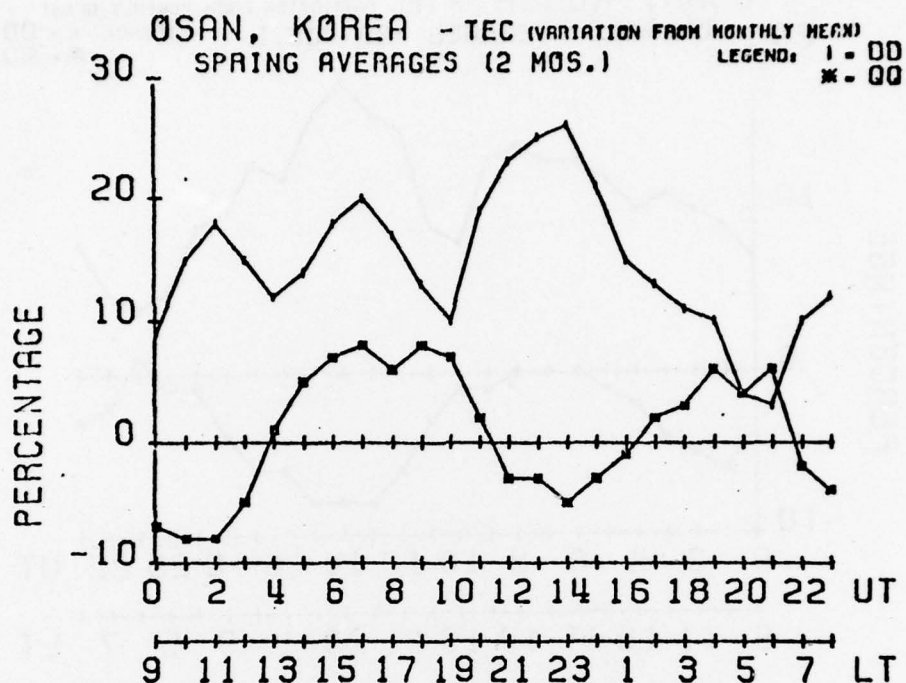
LEGEND: I - DD
 * - QQ

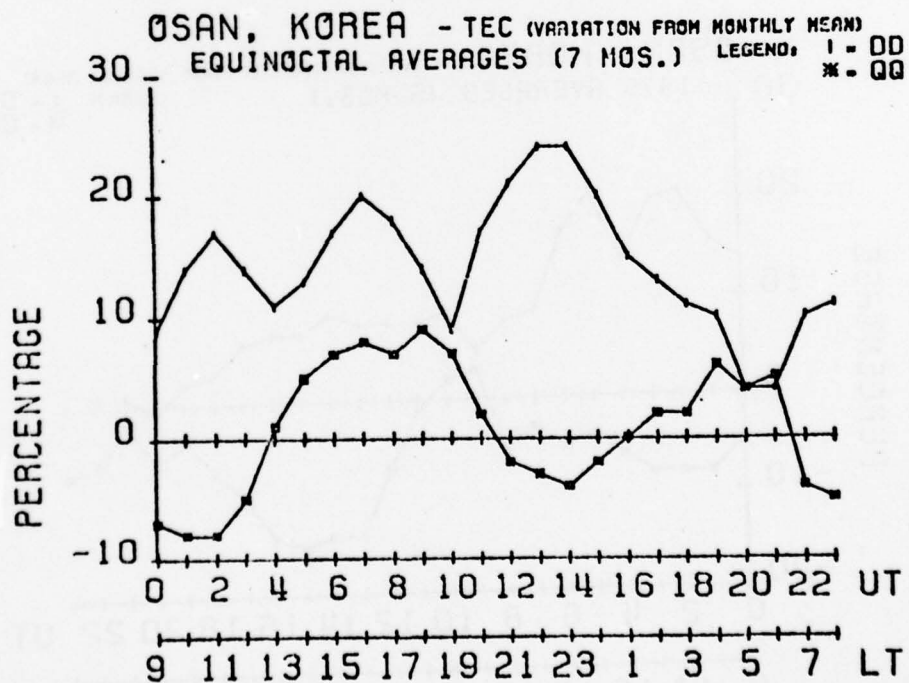
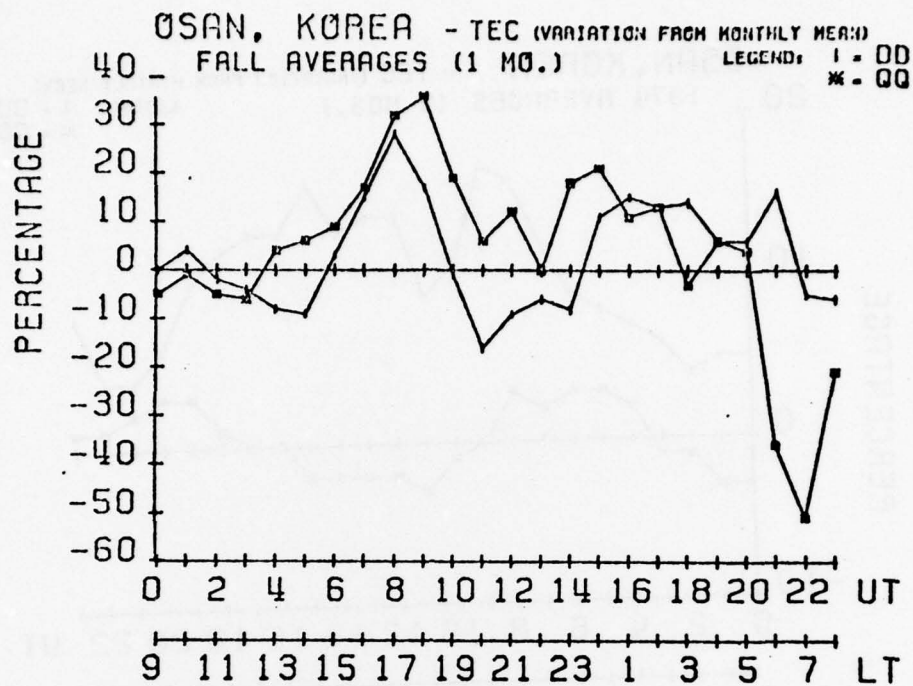


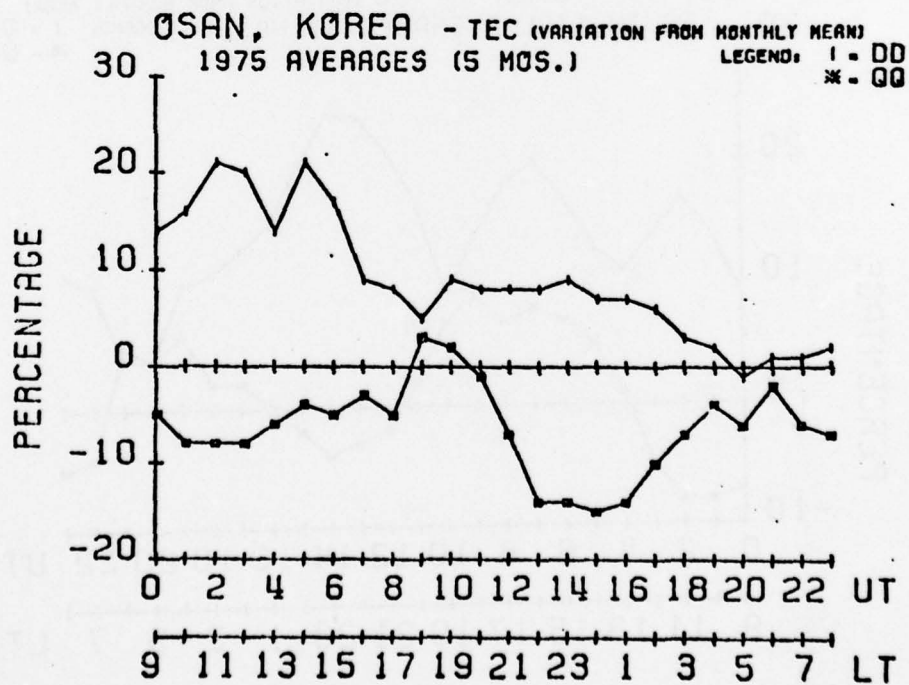
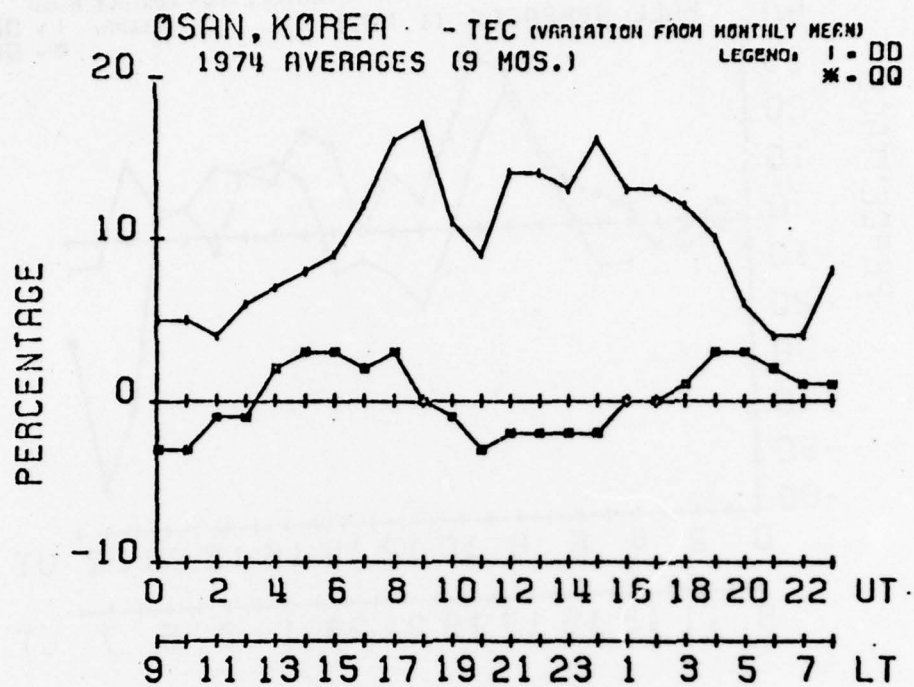
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 20 - WINTER AVERAGES (3 MOS.)

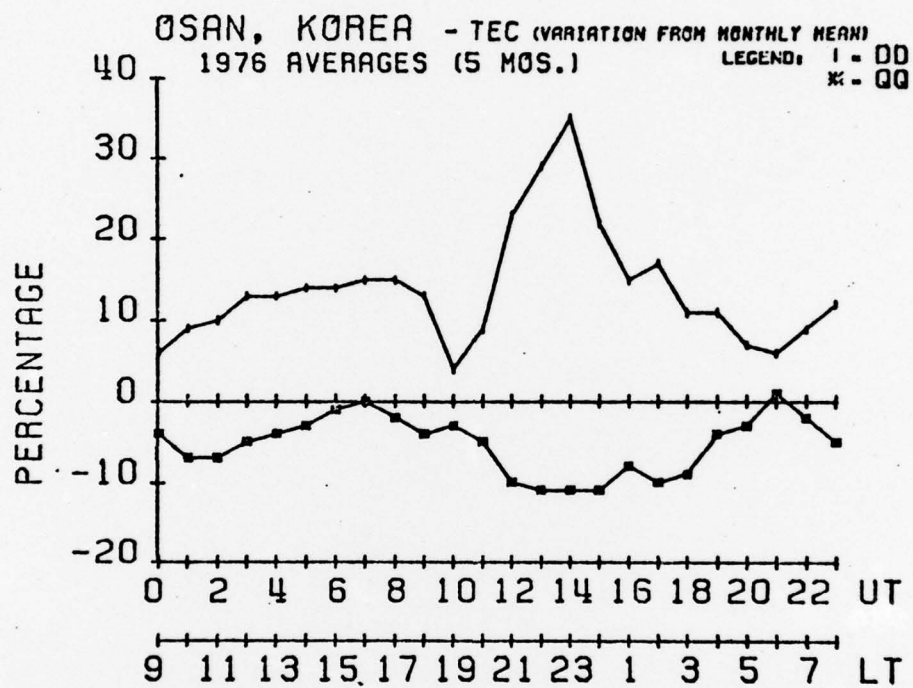
LEGEND: I - DD
 * - QQ







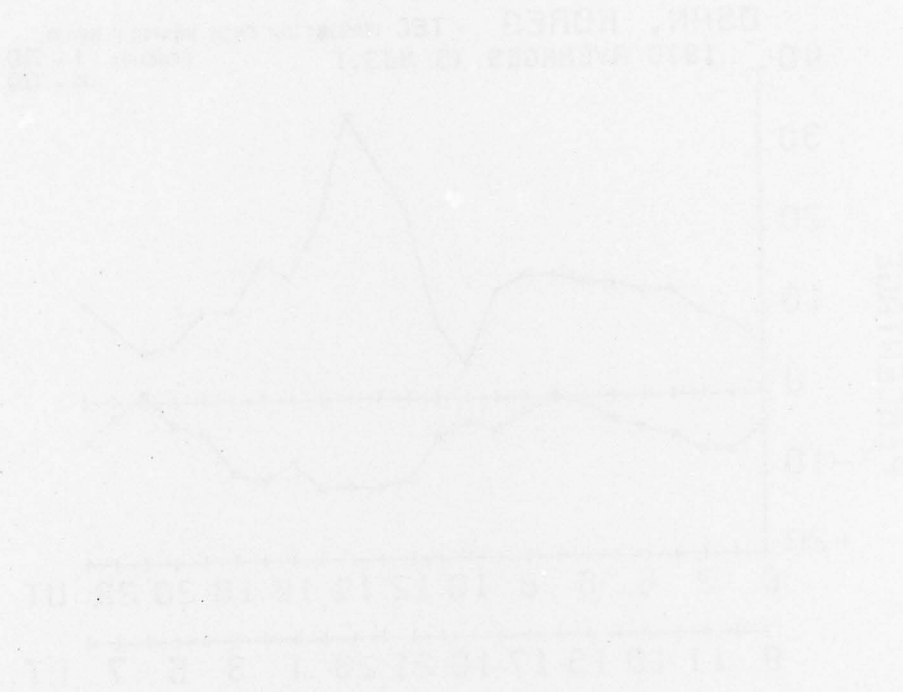


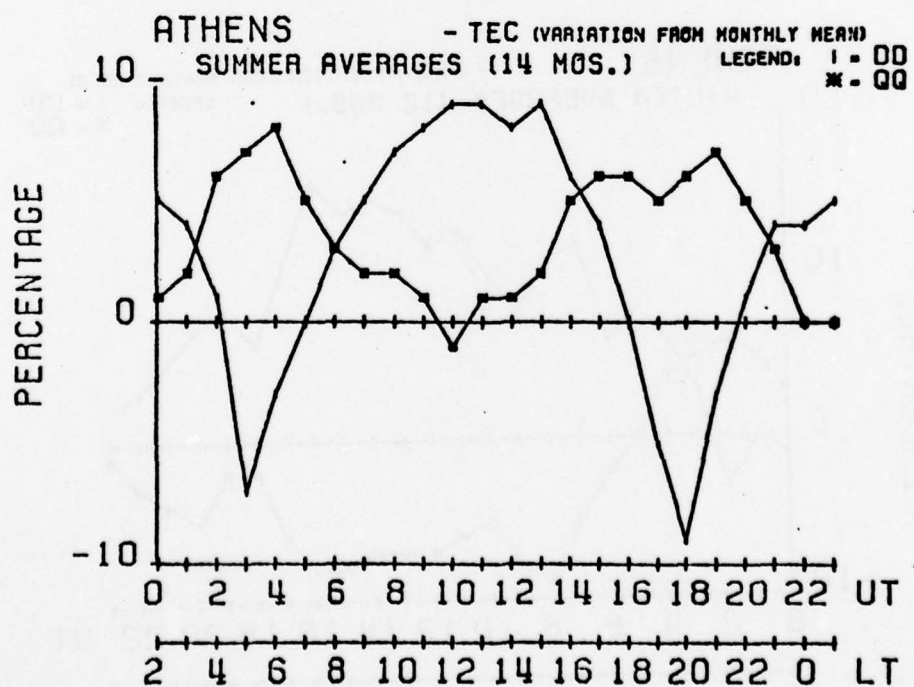
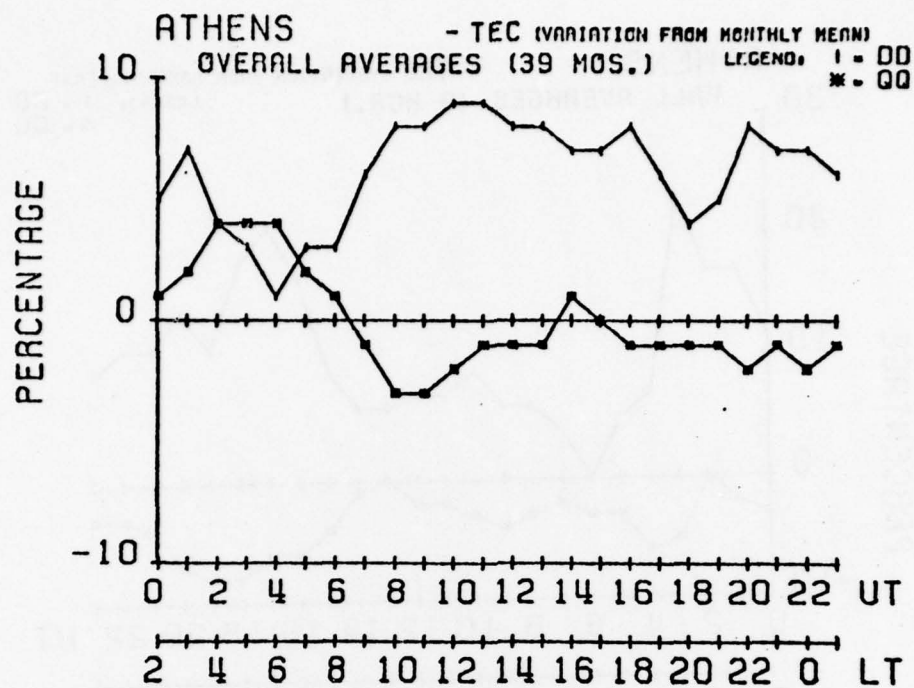


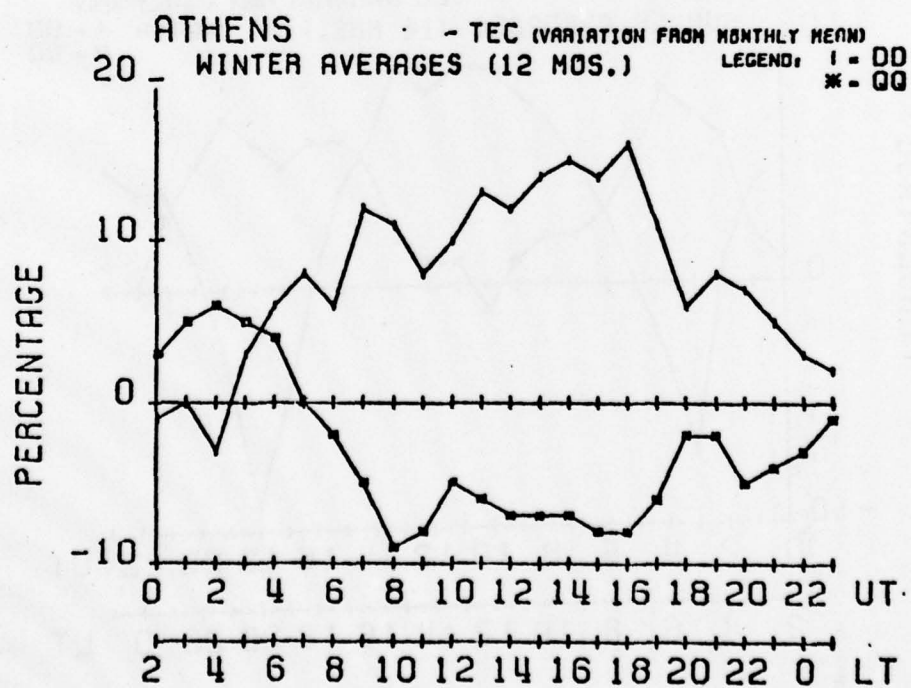
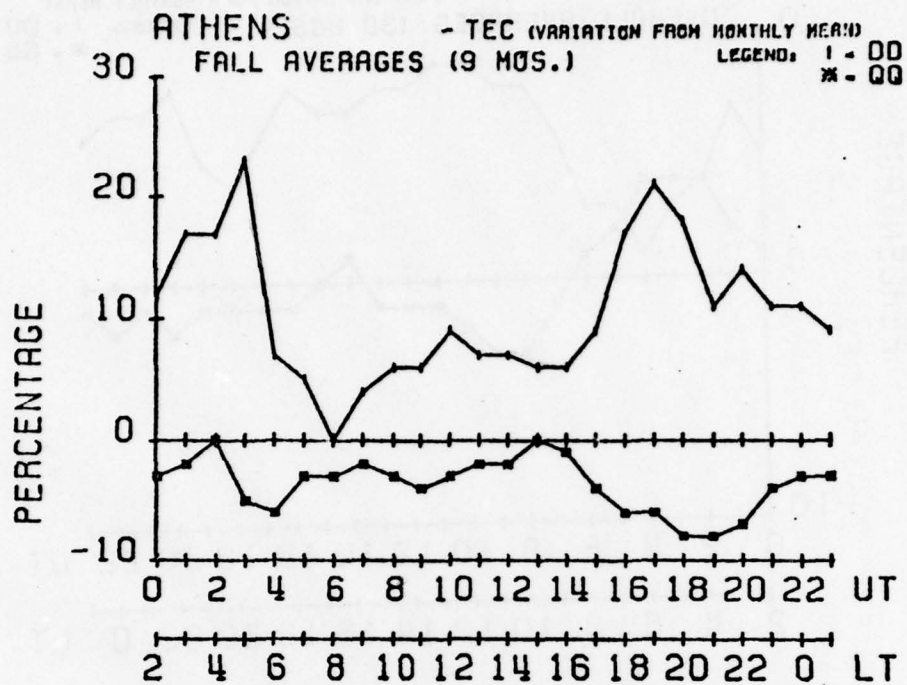
APPENDIX G

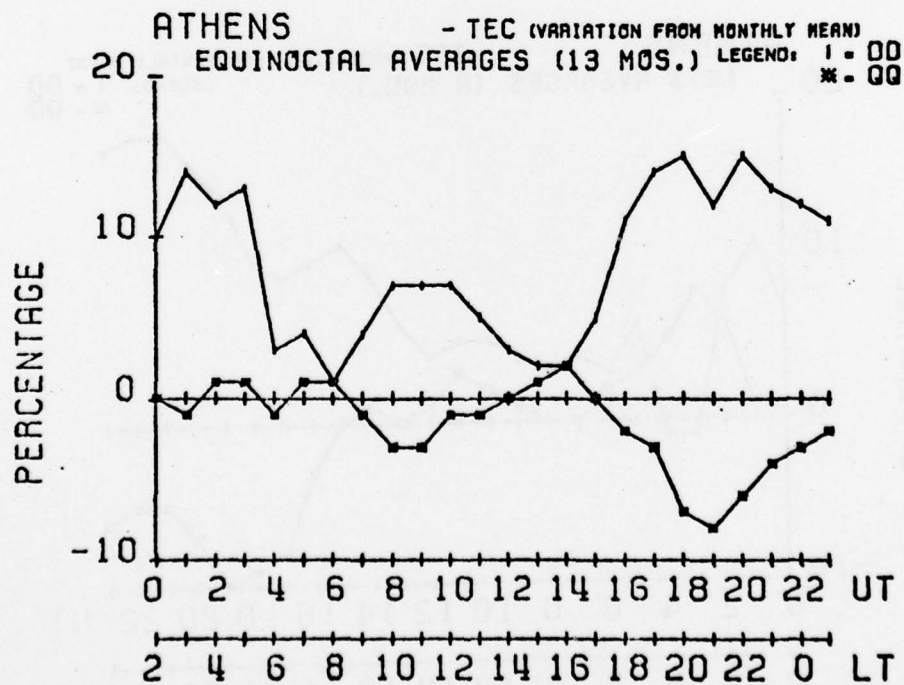
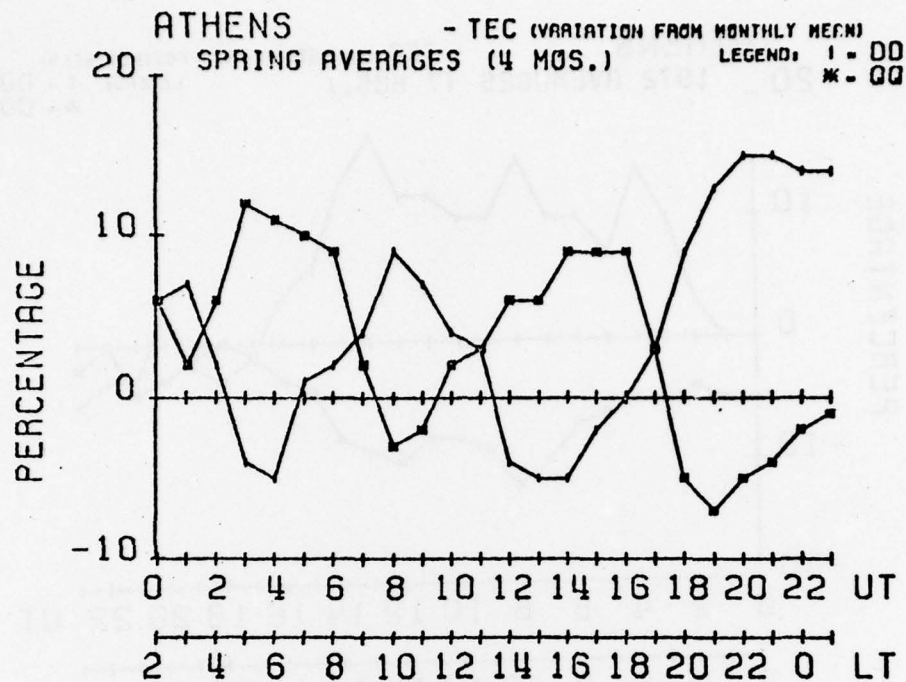
Disturbed (DD) versus Quiet (QQ) Behavior

at ATHENS



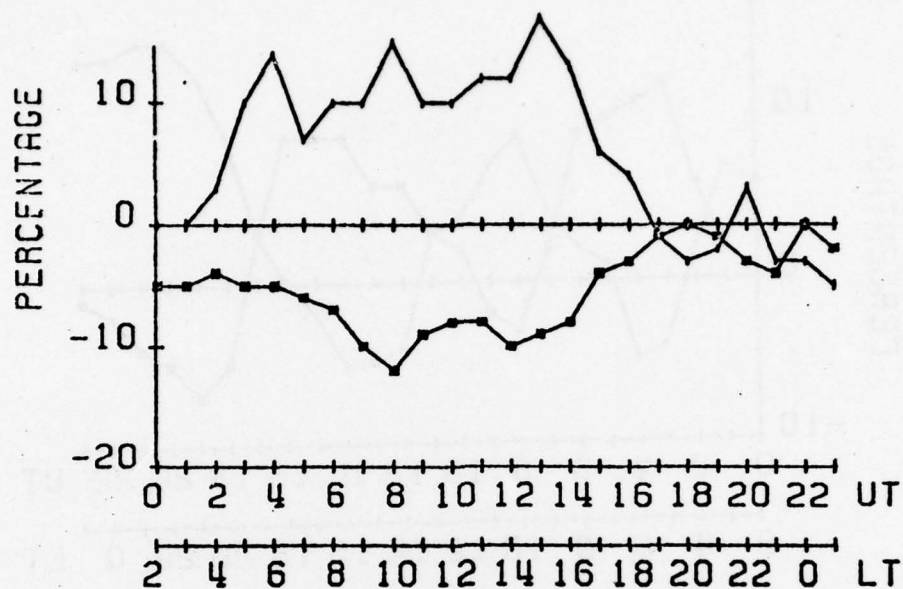






ATHENS - TEC (VARIATION FROM MONTHLY MEAN)
 20 - 1972 AVERAGES (7 MOS.)

LEGEND: I - 00
 X - 00



ATHENS - TEC (VARIATION FROM MONTHLY MEAN)
 20 - 1973 AVERAGES (9 MOS.)

LEGEND: I - 00
 X - 00

