World Data Center C_2 for Geomagnetism

DATA BOOK No. 1

Equivalent current systems of
the daily geomagnetic variations

MARCH 1978

Data Analysis Center for
Geomagnetism and Spacemagnetism
FACULTY OF SCIENCE
KYOTO UNIVERSITY

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No. 1

Equivalent Current Systems of the Daily Geomagnetic Variations in December 1964

by A. Suzuki and H. Maeda

APPENDIX: Successive Mapping of Sq Current Systems

by A. Suzuki

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PREFACE

One of the roles of WDC-C's is to perform attentive services in each discipline such as corrections, standardizations, digitizations, illustrations, and/or basic analysis of original data. For this reason we are planning to publish the results of analysis as DATA BOOK, which includes contributions from not only inside but also outside of the center. We hope your comments on and contributions to this DATA BOOK.

March 1, 1978

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WDC-C2 for Geomagnetism*

* WDC-C2 for Geomagnetism is operated by the Data Analysis Center for Geomagnetism and Spacemagnetism of the Faculty of Science, Kyoto University, Kyoto 606, Japan

CONTENTS

Equivalent Current Systems of the Daily Geomagnetic Variations in December 1964

1. Introduction

Currents in the ionosphere and the magnetosphere and their induced parts in the earth make magnetic fields on the earth's surface. As the direct observation of the currents is not yet available nowadays, the equivalent current systems calculated from the magnetic data observed on the ground are usually used to study the physics of the earth and its environment. However, the equivalent current systems for a fixed instant are, in general, difficult to obtain because of the insufficient distribution of magnetic observatories, and the Sq current systems are usually calculated as an average for some quiet days. Suzuki (1978) revised the gaussian method for Sq analysis by introducing some ghost stations to cover the shortage of the observatories and made the instantaneous analysis possible. The method was applied to the daily geomagnetic variations on 6 quiet days in September 1964 and all the current systems obtained are included in this Data Book as a supplement.

In order to make clear the characteristics of daily geomagnetic variations, the method has been further applied to geomagnetic data over one month (December 1964) when geomagnetically quiet days continue relatively long. Equivalent current systems are calculated for every two hours through the month, and their pictures are drawn by XY-plotters. In this report all current figures and main terms of the field and potential coefficients are summarized.

2. Data and Results

The observatories used for the analysis are given in Table 1 together with their station codes*. They are chosen between ±60° in geomagnetic latitudes, so that they distribute as evenly as possible. Total number is 60, and 8 ghost stations are used for supplying data in ocean regions.

When the magnetic field distribution at universal time T(=t - λ, t: local time, λ: east longitude) is expressed in the form

$$\begin{aligned} H &= \sum_m \sum_n (a_n^m \cos mt + b_n^m \sin mt) X_n^m(\theta) , \\ D &= \sum_m \sum_n (-b_n^m \cos mt + a_n^m \sin mt) Y_n^m(\theta) , \\ Z &= \sum_m \sum_n (a_n^m \cos mt + b_n^m \sin mt) P_n^m(\theta) . \end{aligned} \tag{1}$$

The current functions of external (Je) and internal (Ji) origins are given by

$$\begin{aligned} Je &= -\sum_n \frac{10}{4\pi} \frac{2n+1}{n+1} \left(\frac{a}{r}\right)^n V_n , \\ Ji &= \sum_n \frac{10}{4\pi} \frac{2n+1}{n} \left(\frac{r}{a}\right)^{n+1} V_n , \end{aligned} \tag{2}$$

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* The station code gives the colatitude of the station by the first three figures and the east longitude by the last three.

where a and r are the geocentric distances of the current sheet and the magnetic potential V_n which is expressed as

$$V_n = C + \sum_m \sum_n \left\{ \left(e_{na}^m \frac{r^n}{R^{n-1}} + i_{na}^m \frac{R^{n+2}}{r^{n+1}} \right) \cos mt + \left(e_{nb}^m \frac{r^n}{R^{n-1}} + i_{nb}^m \frac{R^{n+2}}{r^{n+1}} \right) \sin mt \right\} P_n^m(\cos\theta) \tag{3}$$

The relation between the coefficients (e_{na}^m, e_{nb}^m, i_{na}^m and i_{nb}^m) of potentials and those (a_n^m, b_n^m, a_n^m and b_n^m) of fields is given as follows:

$$e_{na}^m = \frac{(n+1)a_n^m + n a_n^m}{n(2n+1)}, \qquad e_{nb}^m = \frac{(n+1)b_n^m + n b_n^m}{n(2n+1)},$$
$$i_{na}^m = \frac{a_n^m - a_n^m}{2n+1}, \qquad i_{nb}^m = \frac{b_n^m - b_n^m}{2n+1} \tag{4}$$

2-1. *Current systems*

Hourly mean values of the three components read from daily means are used for the present analysis. In the usual Sq analyses, however, night values are often used as a datum line, because only a little current flows in the nighttime ionosphere. This method cannot be used in the present analysis since local night is different for different observatories. However, in order to apply obtained figures of the current systems to ionospheric studies, the figures in which the nighttime currents almost vanish may be more useful. For this reason we drew the following two current systems: (1) current systems based on daily means, and (2) current systems based on midnight values. The latter (2) is simply estimated from the former (1) by calculating $J(\theta, t) - J(\theta, 24^h)$.

Current systems of these two types are illustrated in Fig. 1 (p. 7) and Fig. 2 (p. 71). The figures 1 and 2 show the external (left) and internal (right) current systems at every two UT hours, so that one day is covered by 24 figures. The ordinate shows the geomagnetic latitudes and the abscissa shows the local times. Current contours are drawn every 20×10^3 amperes. Plus an minus peaks of the current function are marked by double cross (※) and cross (X), respectively. As they are marked automatically by a plotting machine, they do not always show the centre of daytime current vortices. Peak values are shown just above (for plus peaks) and below (for minus) the marks in units of 10^3 amperes. Electric currents flow counter-clockwise round the plus peak and clockwise round the minus peak, as viewed from above the current sheets. An example is shown by arrows in the figures at 0200Z on Dec. 1. As current contours are drawn between $\pm 300 \times 10^3$ amperes the figures at 1400Z on Dec. 16 which is geomagnetically disturbed day is not completed.

For reference, the music tone diagram for 1964 and a table of three hour indices Kp in December are given in p. 5.

2-2. *Harmonic coefficients*

Universal time changes of typical field coefficients (in γ, $1\gamma = 1\,nT$) for the horizontal components (a_2^1,

a_3^2, a_4^3, b_2^1, b_3^2 and b_4^3) and the vertical components ($\mathbf{a}_2^1$, $\mathbf{a}_3^2$, $\mathbf{a}_4^3$, $\mathbf{b}_2^1$, $\mathbf{b}_3^2$ and $\mathbf{b}_4^3$) obtained by Eq. (1) are given in Fig. 3 (p. 134). In each figure, values are plotted at every two hours from left to right. Some coefficients are plotted by reversed sign as shown at the bottom of figures for the convenience of relative comparison. Furthermore, ordinate scales are not the same for the horizontal and vertical coefficients. Universal time changes of typical potential coefficients for the external (e_{2a}^1, e_{3a}^2, e_{4a}^3, e_{2b}^1, e_{3b}^2 and e_{4b}^3) and the internal parts (i_{2a}^1, i_{3a}^2, i_{4a}^3, i_{2b}^1, i_{3b}^2 and i_{4b}^3) calculated by Eq. (4) are summarized in Fig. 4 (p. 139). Again, some coefficients are plotted by reversed sign, and ordinate scales are not the same for the external and internal parts.

3. Acknowledgements

The data used in the present analyses are supplied from the WDC-C2 for Geomagnetism. Analyses were made by using facilities at the Data Analysis Center for Geomagnetism and Spacemagnetism of the Faculty of Science, and the Data Processing Center of Kyoto University.

4. Reference

Suzuki, A., Geomagnetic Sq fields at successive universal times, J. atmos. terr. Phys., 1978 (in press).

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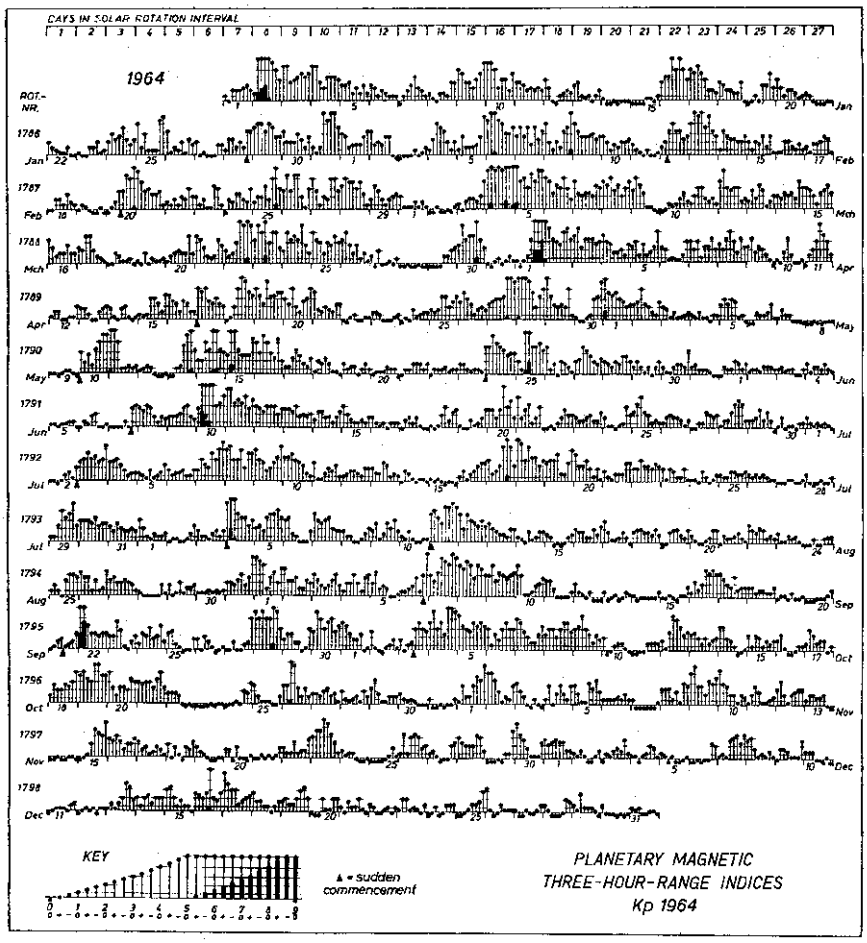
Table 1. The observatories used in the analysis.

No.	Name	Station Code	Factor w2	No.	Name	Station Code	Factor w2
1.	Yakutsk	028130	0.95	36.	Muntinlupa	076121	1.16
2.	Lovö	031018	0.75	37.	M'Bour	076343	0.86
3.	Sverdlovsk	033061	0.80	38.	Guam	077145	1.23
4.	Moscow	035037	0.75	39.	Paramaribo	084305	0.99
5.	Eskdalemuir	035357	0.75	40.	Fuquene	085286	1.06
6.	Wingst	036010	0.75	41.	Bangui	086019	0.85
7.	Irkutsk	038104	0.93	42.	Moca	087009	0.86
8.	Kieb	039030	0.74	43.	Nairobi	091037	0.90
9.	Hartland	039356	0.76	44.	Tatuoka	091311	1.01
10.	Victoria	041237	1.03	45.	Luanda	099013	0.92
11.	Wien-Kobenzl	042016	0.74	46.	Port Moresby	099147	1.34
12.	Odessa	043031	0.74	47.	Apia	104188	1.44
13.	Y. Sakhalinsk	043143	1.04	48.	Tsumeb	109018	0.98
14.	Memambetsu	046144	1.05	49.	Tananarive	109048	1.03
15.	Tbilisi	048045	0.77	50.	La Quiaca	112294	1.16
16.	Logrono	048358	0.76	51.	Vassouras	112316	1.10
17.	Capri	049014	0.74	52.	Gnangara	122116	1.33
18.	Tashkent	049070	0.84	53.	Pilar	122296	1.21
19.	Boulder	050255	1.02	54.	Hermanus	124019	1.07
20.	Askhabad	052058	0.81	55.	Toolangi	128145	1.42
21.	Fredericksburg	052283	0.95	56.	Amberley	133173	1.49
22.	San Miguel	052334	0.82	57.	Trelew	133295	1.26
23.	Almeria	053358	0.76	58.	Aux Francais	139070	1.25
24.	Kakioka	054140	1.09	59.	Macquarie Is.	145159	1.46
26.	Dallas	057263	1.02	60.	Argrentine Is.	155296	1.34
27.	Tucson	058249	1.07	61.	M1	100090	
28.	Kanoya	059131	1.09	62.	M2	105240	
29.	Misallat	060031	0.77	63.	M3	130215	
30.	Santa Cruz	062344	0.81	64.	M4	120260	
31.	Centro Geofisico	067278	1.01	65.	M5	135340	
32.	Honolulu	069202	1.27	66.	M6	145260	
33.	Teoloyucan	070261	1.06	67.	M7	150020	
34.	Alibag	071073	0.94	68.	M8	150210	
35.	San Juan	072294	0.98				



	Kp	Sum
1	3-2o2+3- 2+2+1+1+	17o
2	1o1-1+1- 0o0o1-1+	6-
3	0o1o1-1+ 2-1+3-1o	10-
4	1-1-0o1- 1o2o2-1-	7+
5	1o1-0o1- 0o0o0+1-	3+
6	0o0o0+0o 0+0+2+2o	5+
7	1-1o1-3- 3o3+2+3+	17o
8	3-3o2-1- 1o1-1+1-	12-
9	0+2-2-1+ 1-1-1-3-	10-
10	1+1+1+0+ 0+0o1-0o	5+
11	0o0+1-1- 1-0+1o1+	5o
12	0o0+1-0+ 1-0o1-1-	3+
13	1-1+1-1+ 2o4-3+2-	15-
14	2o1o2o2+ 1+2o2o2o	15-
15	3o3+2o1o 2-1o1o0+	13+
16	3-2+2o3- 5+2o2-3-	21+
17	5-4-3o3o 1+2-2o2+	22-
18	3-2-2-1o 1o0+1o2-	11o
19	2-2o1+1+ 2o3o3+2o	17-
20	0+0o0o2o 1-1-2o2o	8-
21	1o0+2-1o 1o2o1-0+	8o
22	1+1o0+0+ 1-1o0+1o	6o
23	1-2o2o1- 1o1-0+1+	9-
24	0o0+1o0o 0+1+1+1+	6-
25	0o0o0+1- 1+1+2-3o	8+
26	3+1-0o0+ 1+1-1-1-	8-
27	1-0o0o1- 0+0+1-1+	4o
28	1+1-0o0o 0o0+2o2-	6o
29	1+1-3-1o 1o1o0+0o	8o
30	1+0+0+0+ 0o0+0o0+	3o
31	1o1-1o0+ 0+1-1-0+	5o

Five quiet days : 5, 12, 27, 30, 31.
Ten quiet days : 2, 5, 10, 11, 12, 22, 24, 27, 30, 31.
Five disturbed days : 7, 13, 16, 17, 19.

FIGURE 1

The external (left) and internal (right) parts of equivalent current systems at every two UT hours in December 1964, where daily mean values are used as datum lines of the daily geomagnetic variations.

DEC. 1.1964

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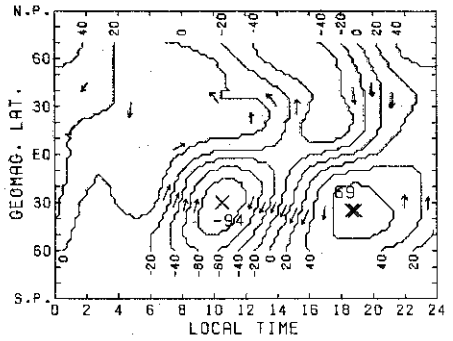

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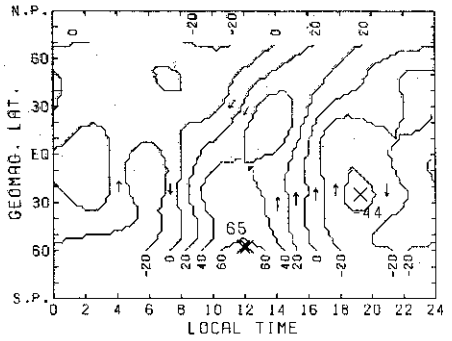

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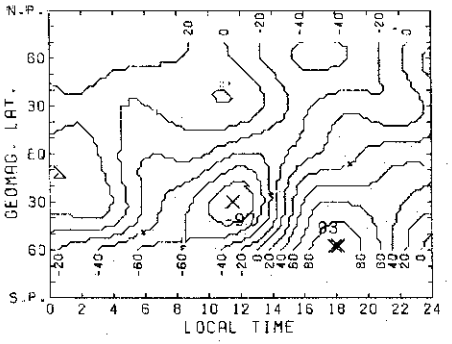

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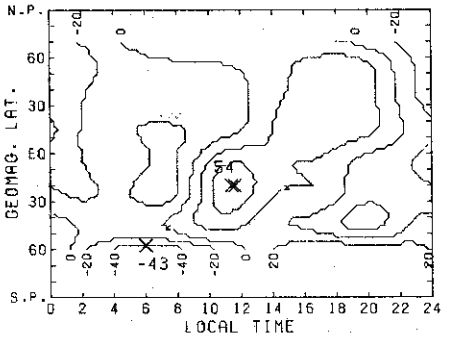

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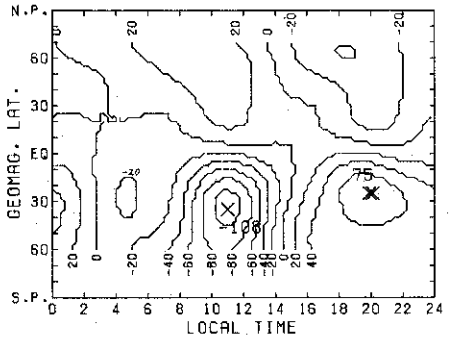

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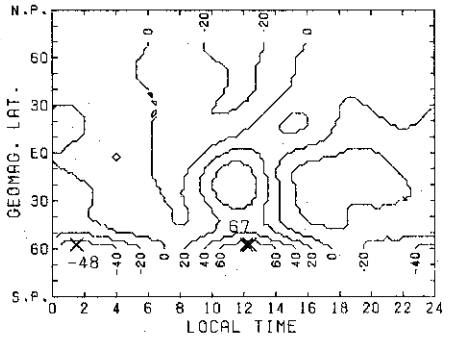

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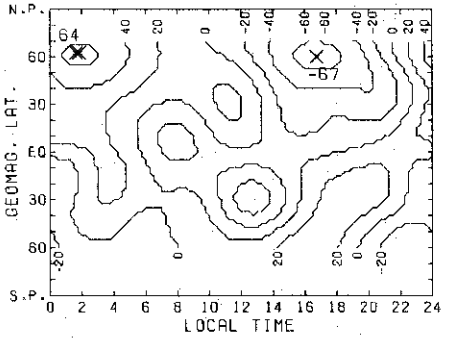

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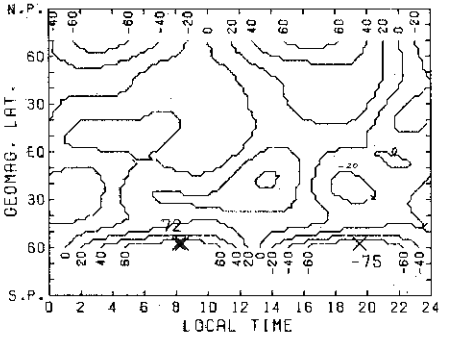

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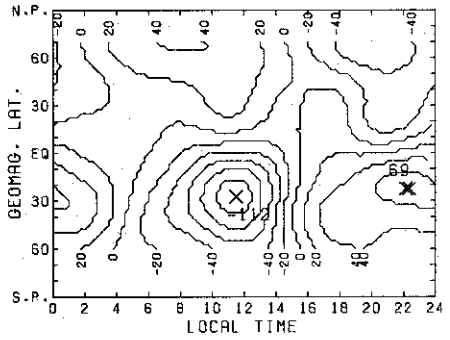

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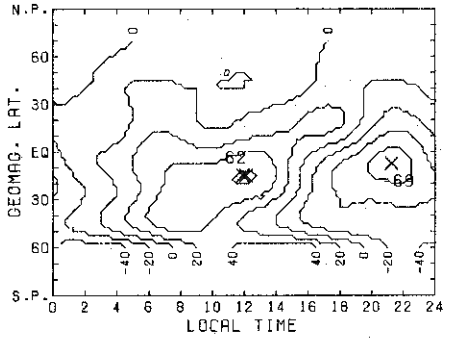

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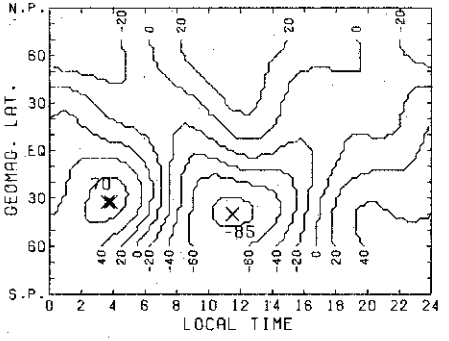

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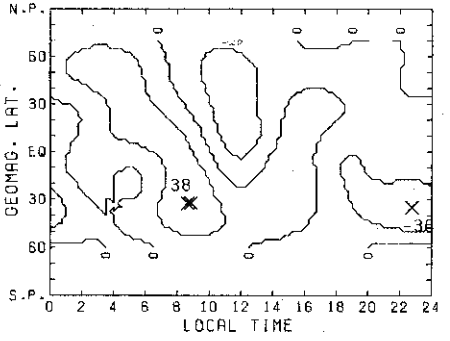

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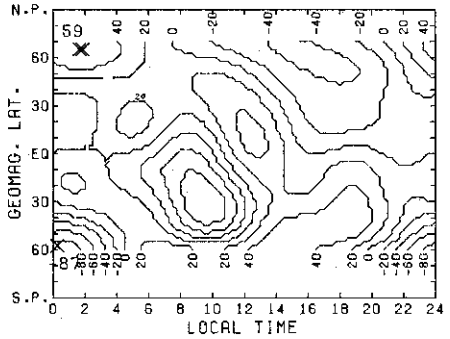

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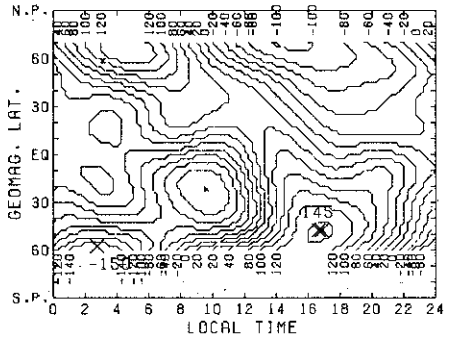

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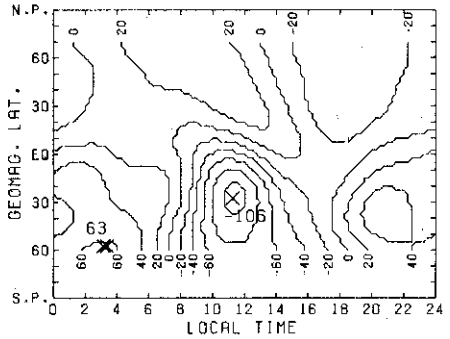

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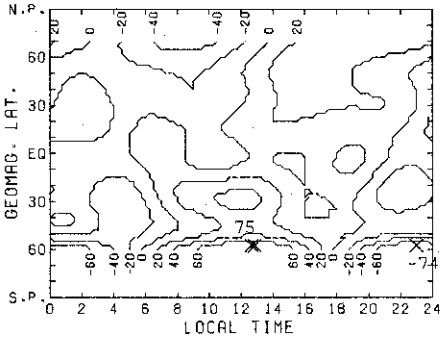

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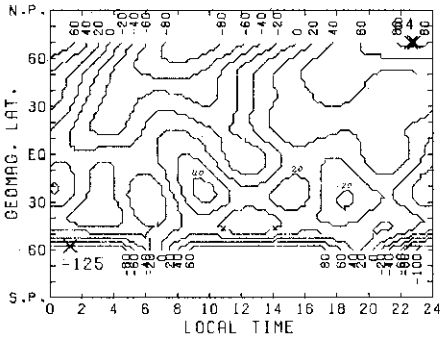

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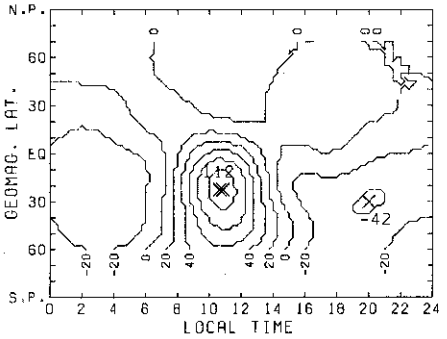

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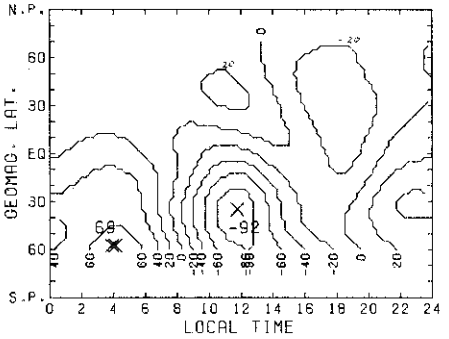

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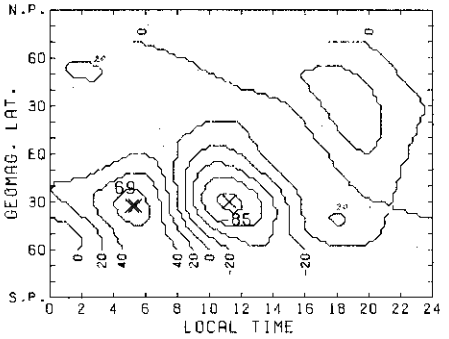

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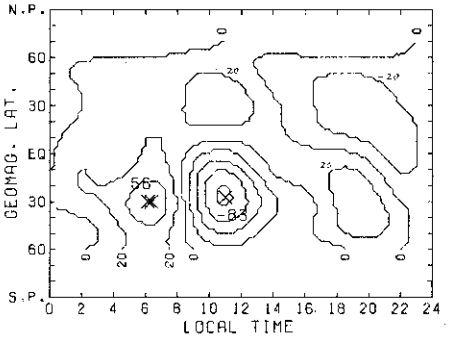

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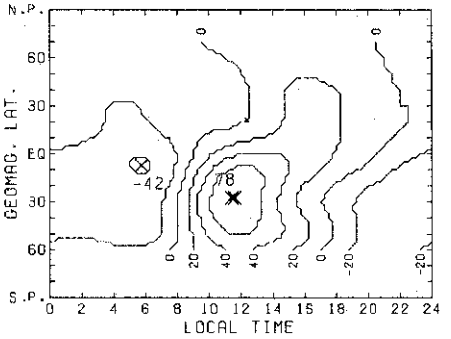

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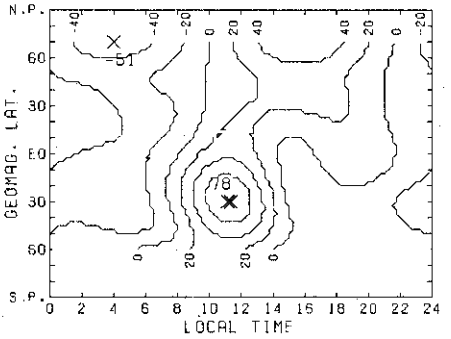

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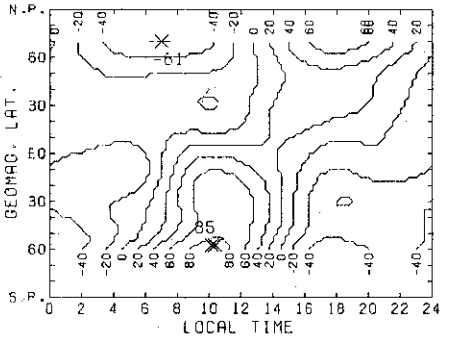

DEC. 2,1964

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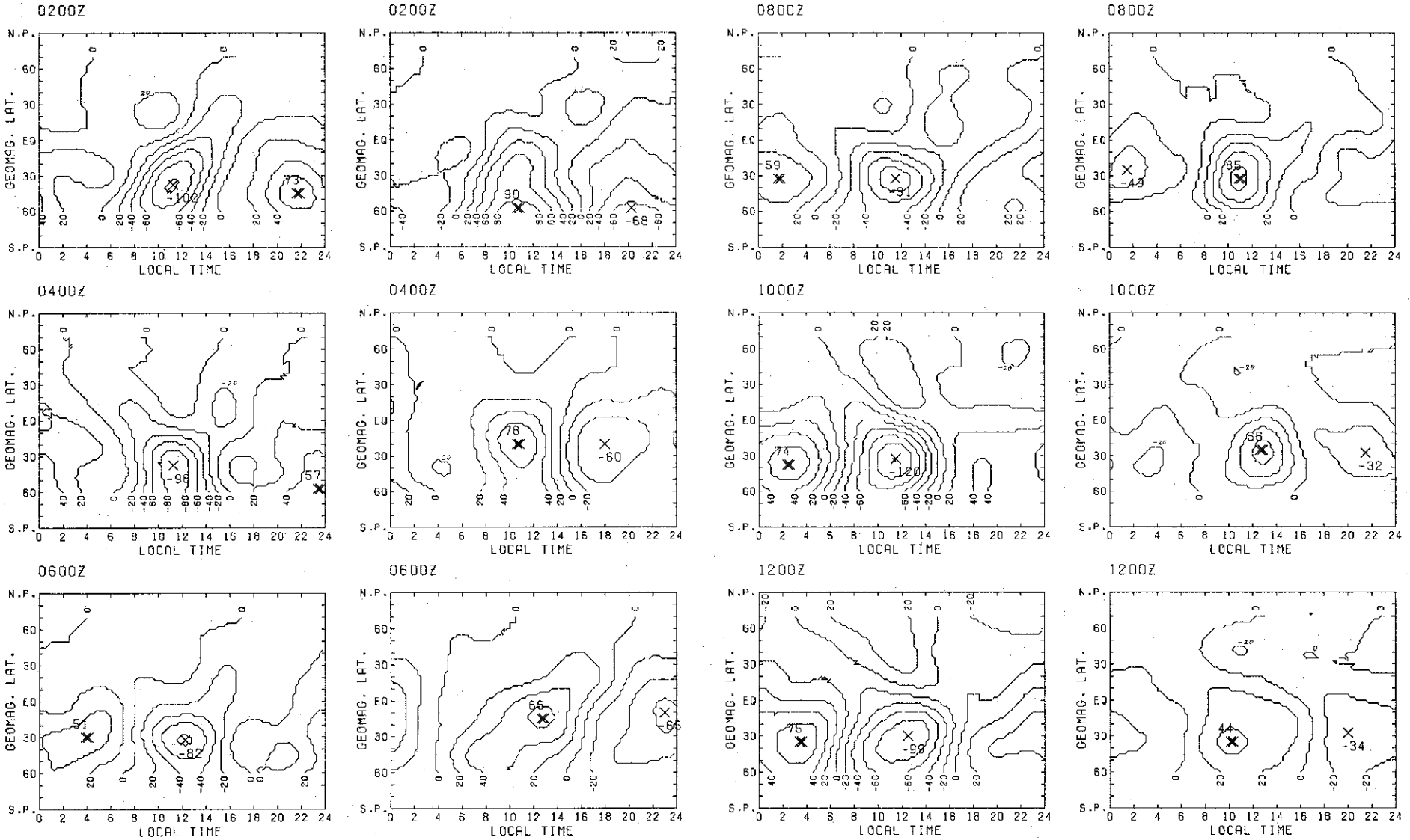

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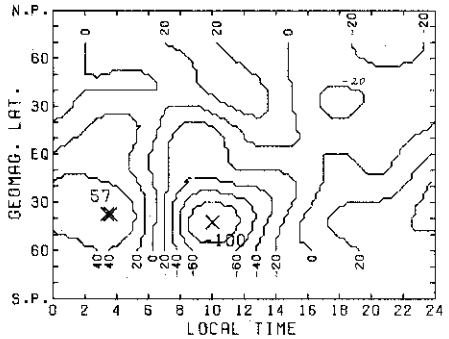

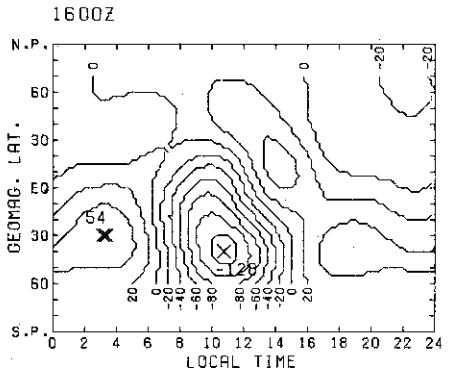

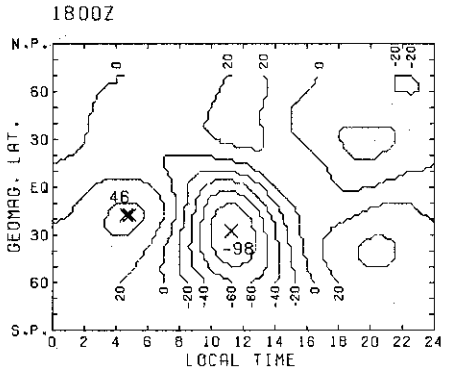

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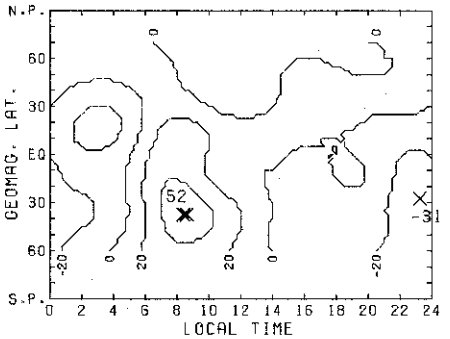

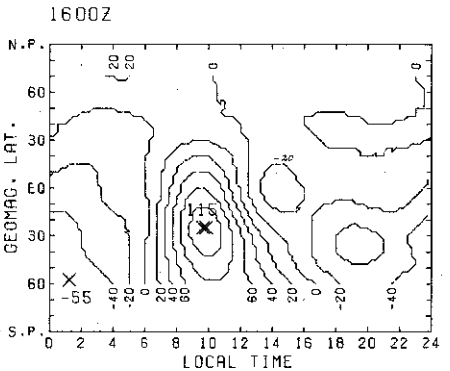

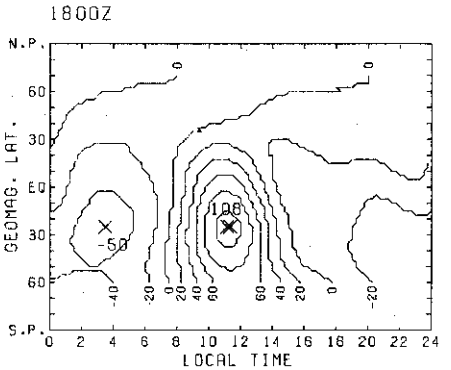

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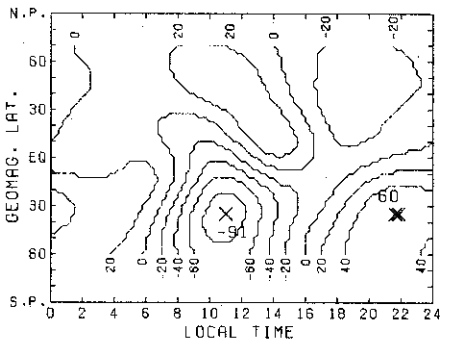

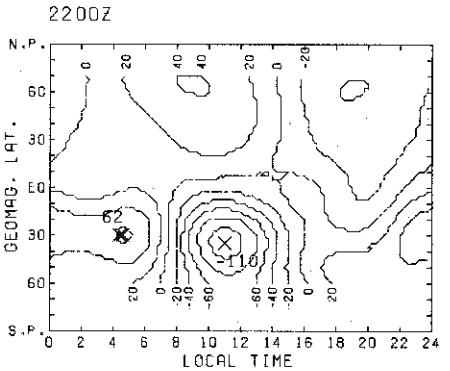

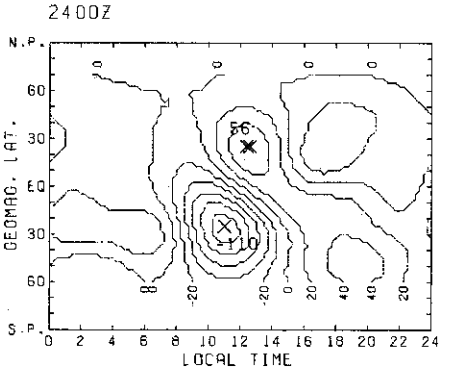

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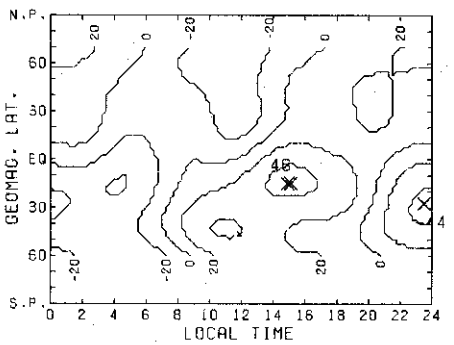

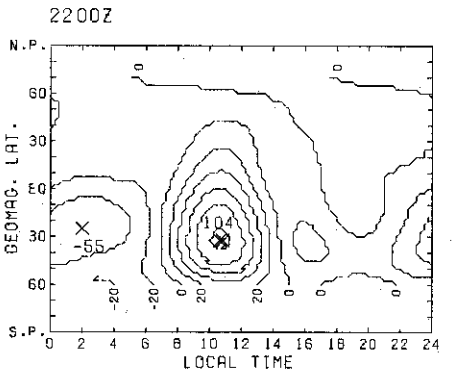

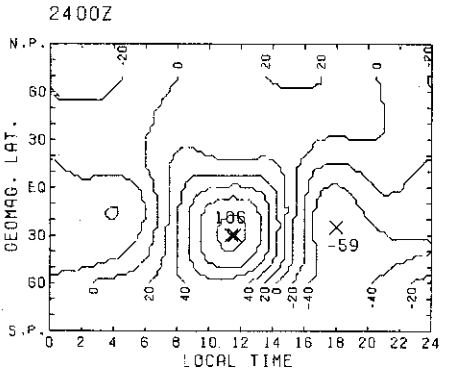

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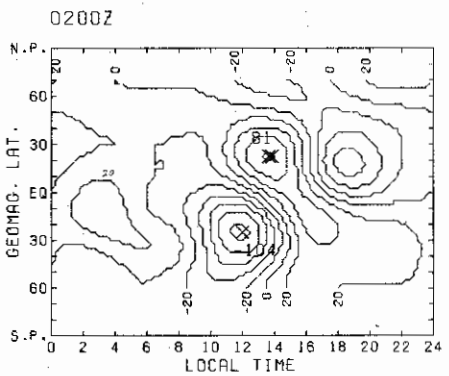

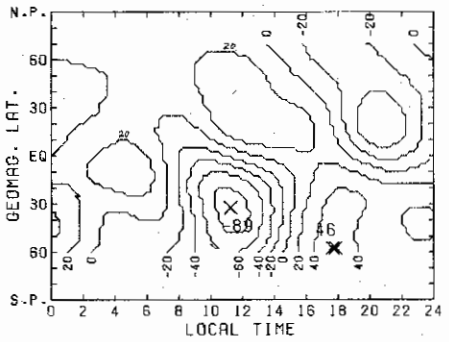

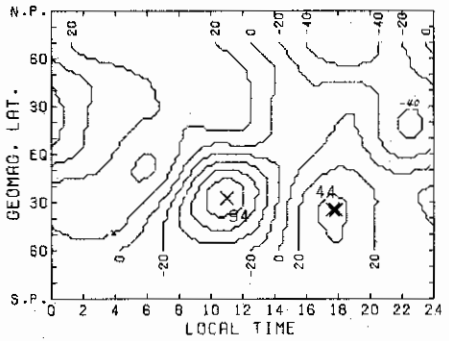

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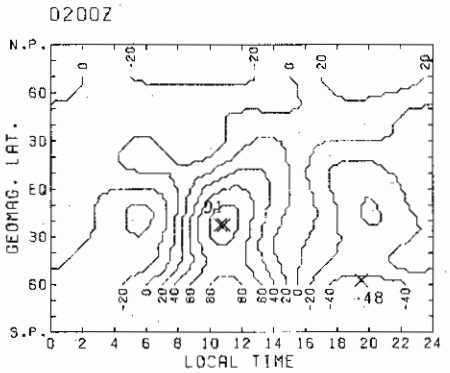

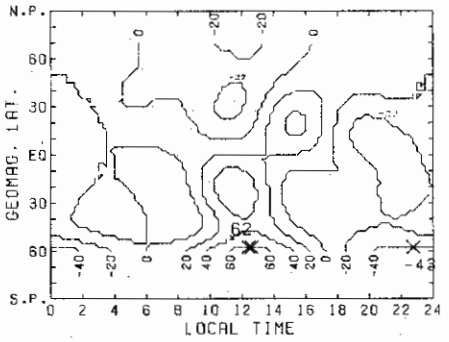

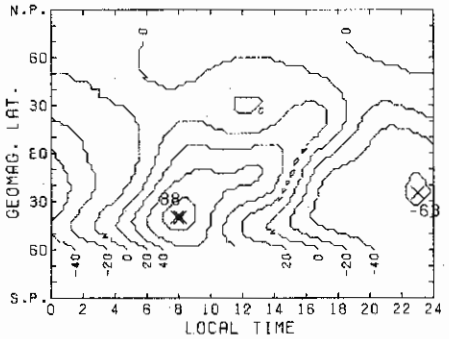

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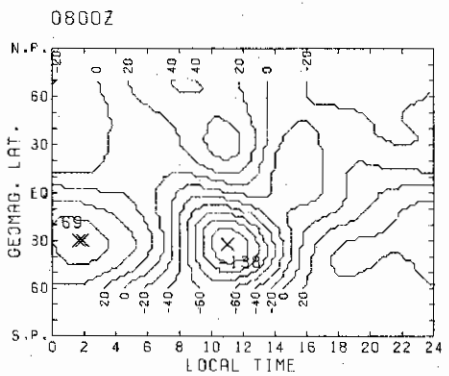

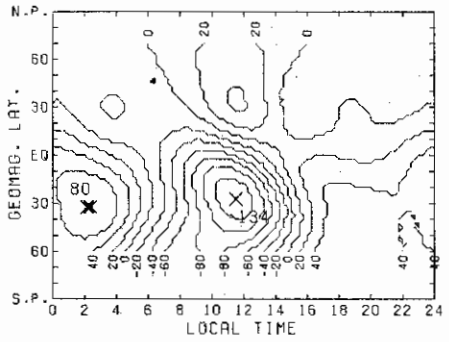

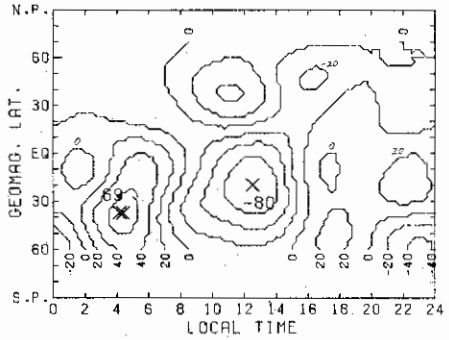

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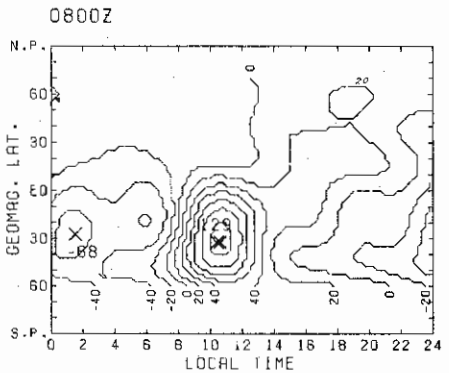

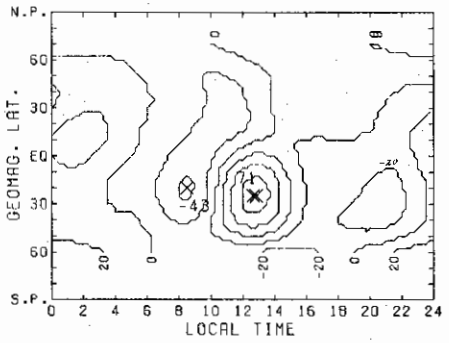

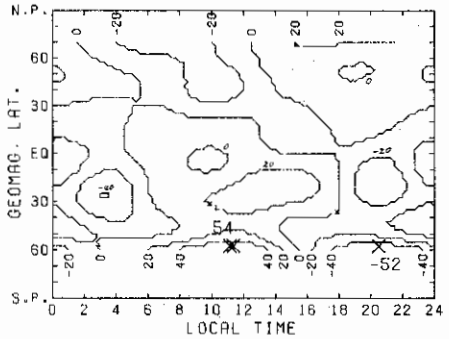

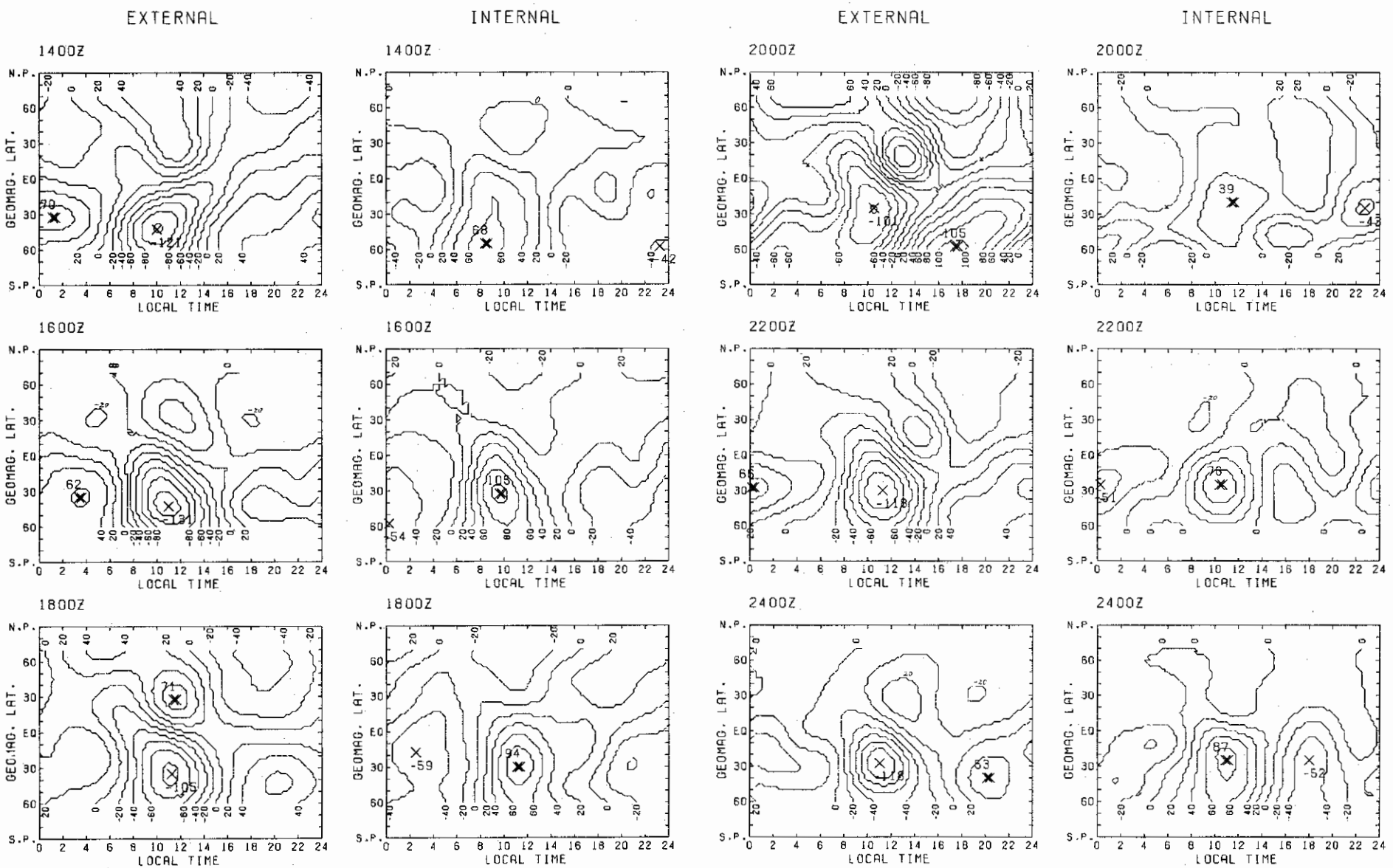
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EXTERNAL

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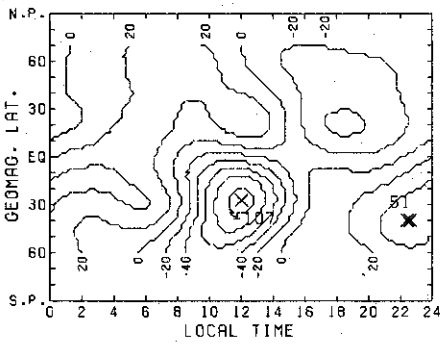

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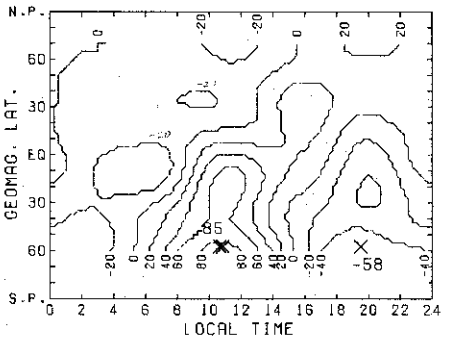

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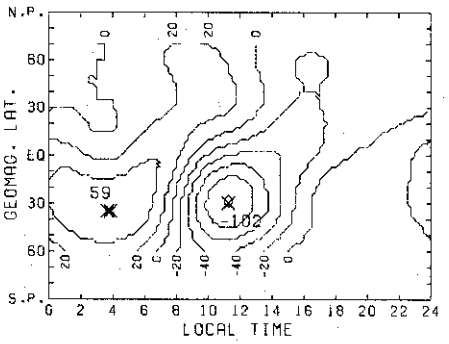

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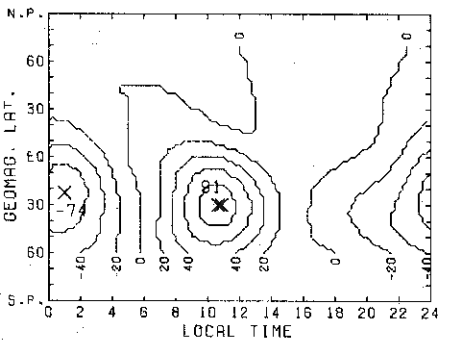

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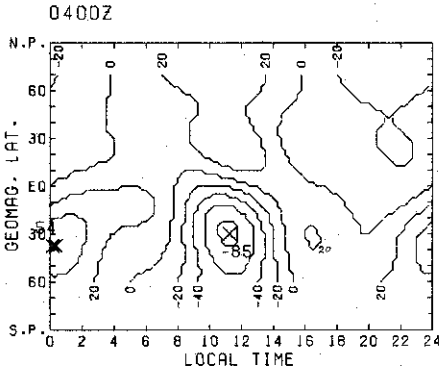

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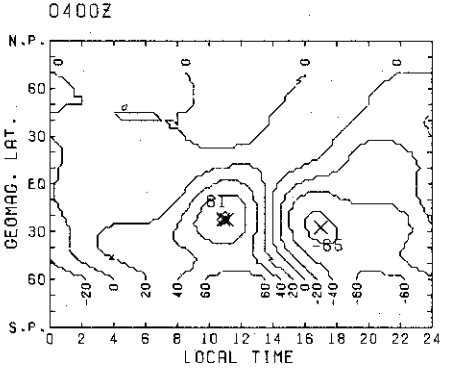

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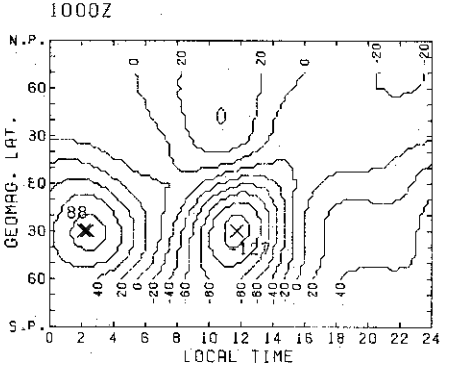

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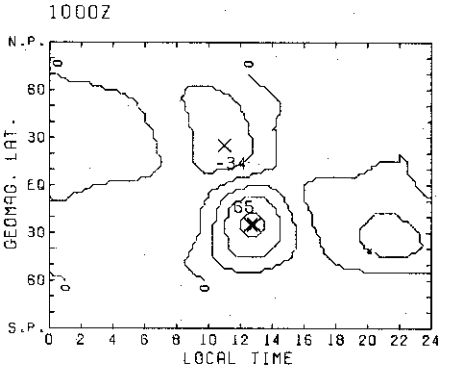

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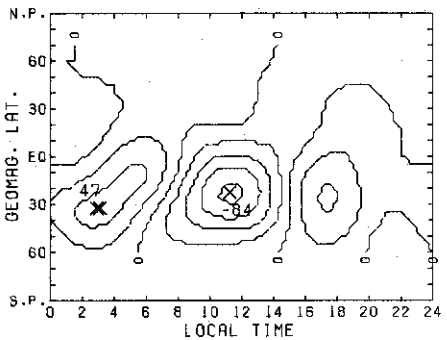

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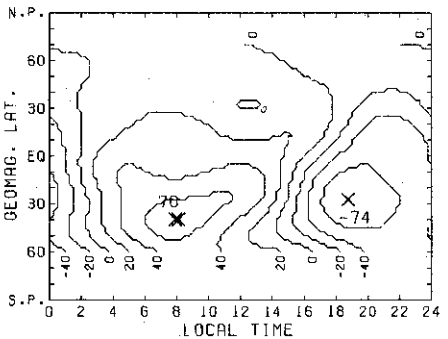

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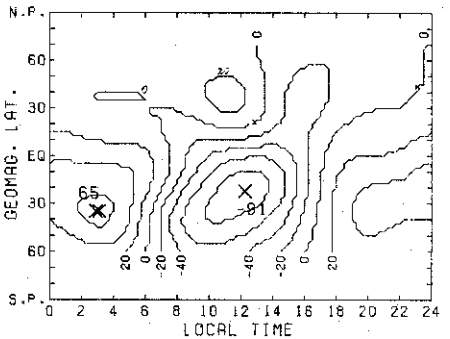

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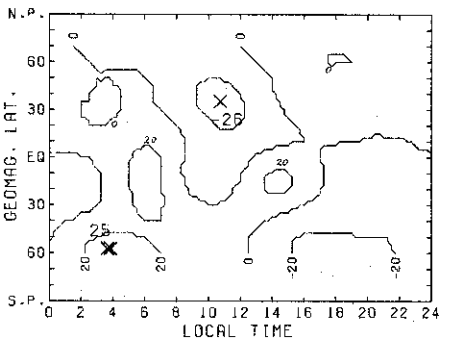

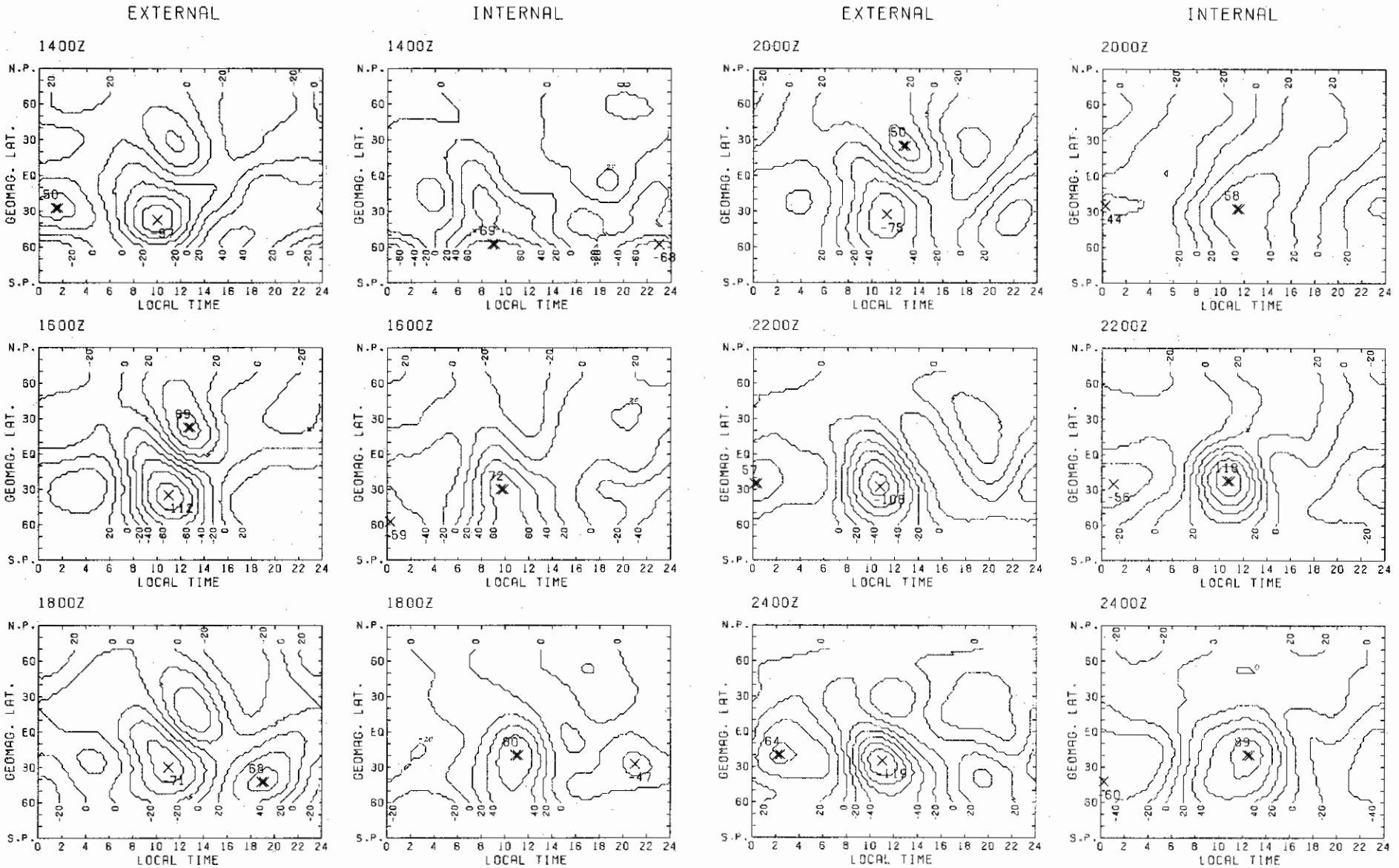
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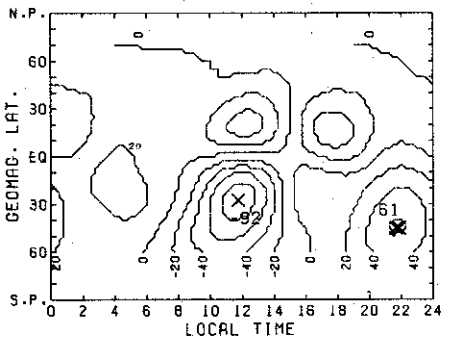

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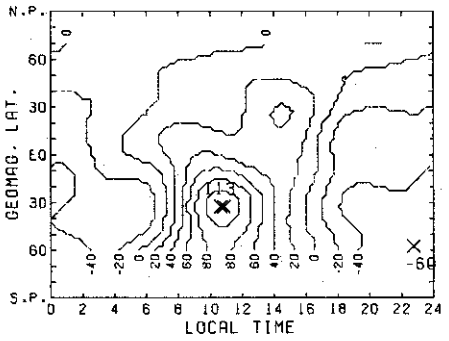

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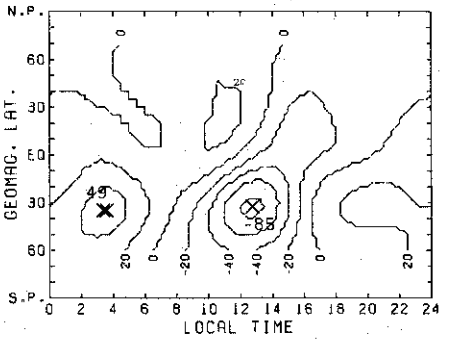

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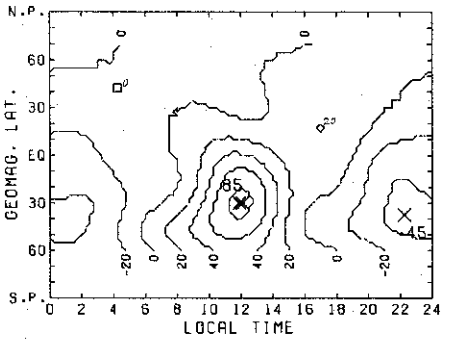

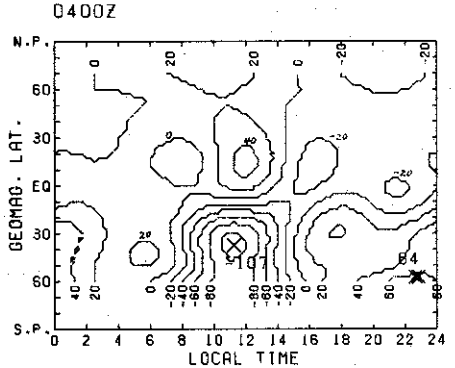

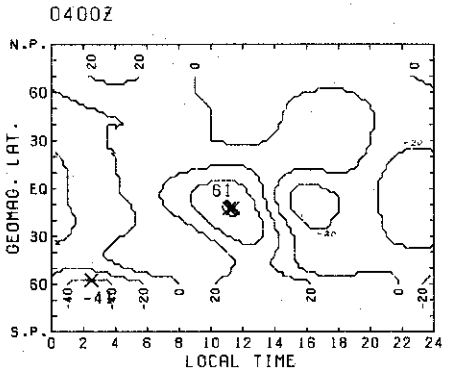

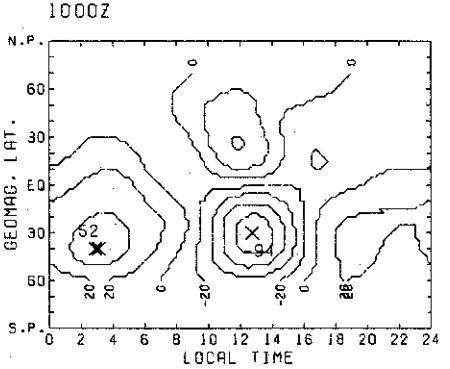

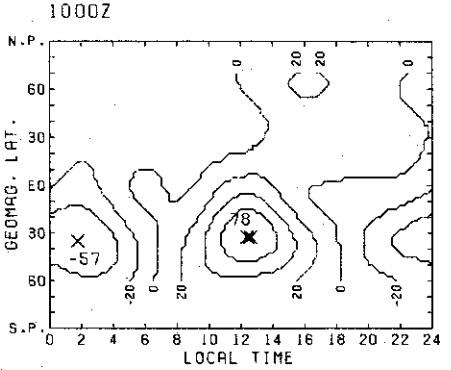

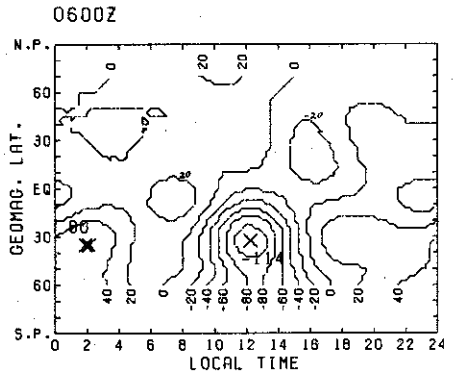

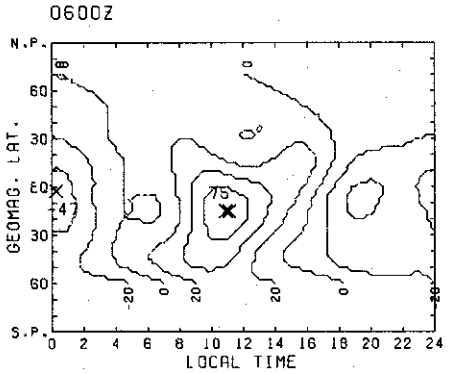

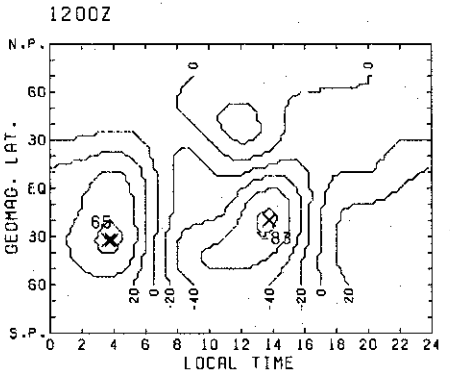

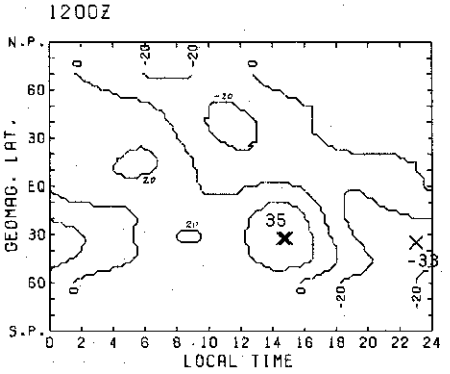

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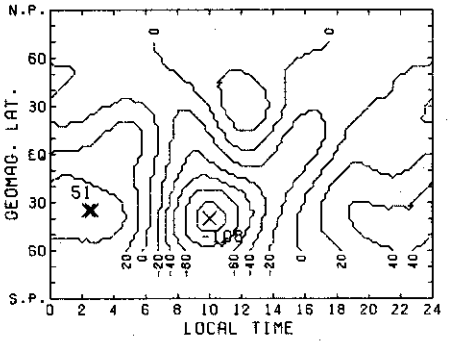

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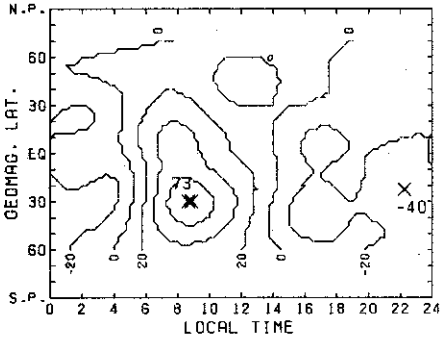

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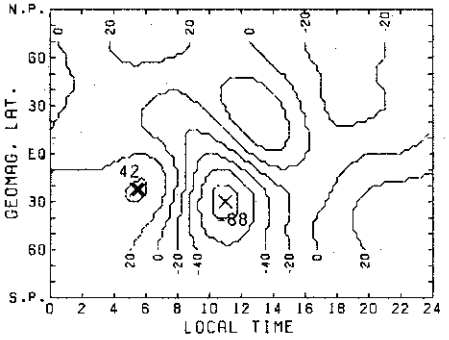

INTERNAL

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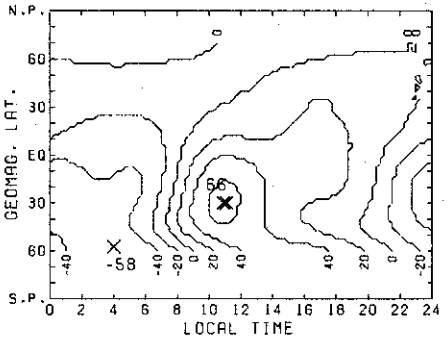

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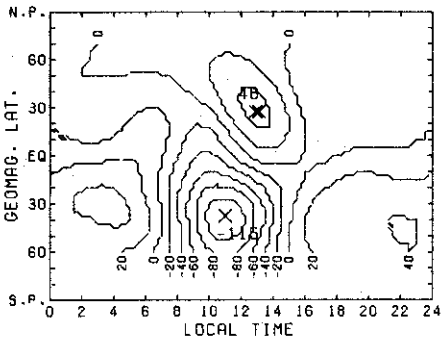

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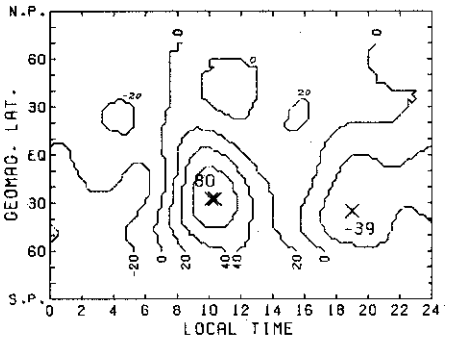

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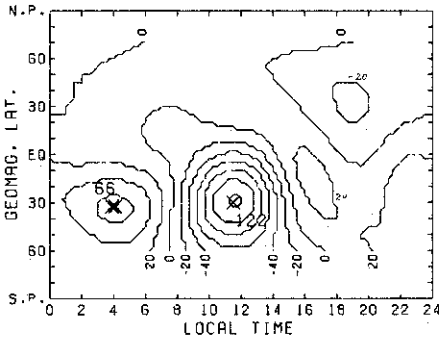

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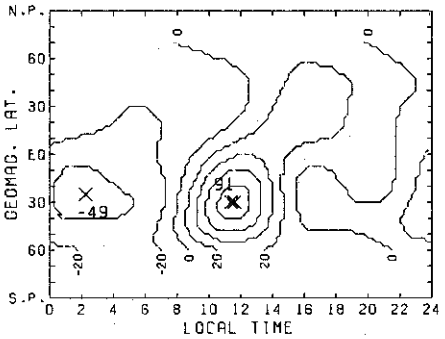

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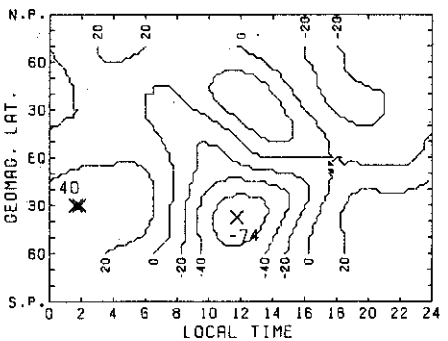

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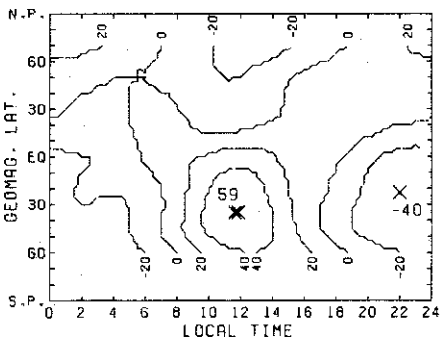

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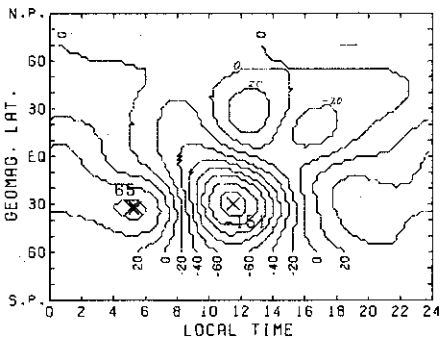

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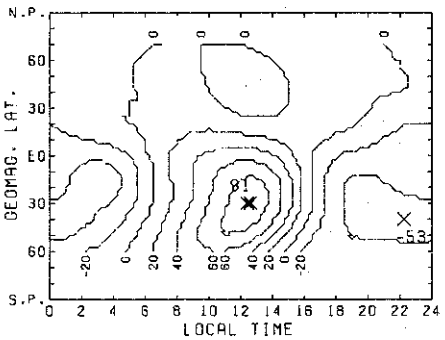

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EXTERNAL

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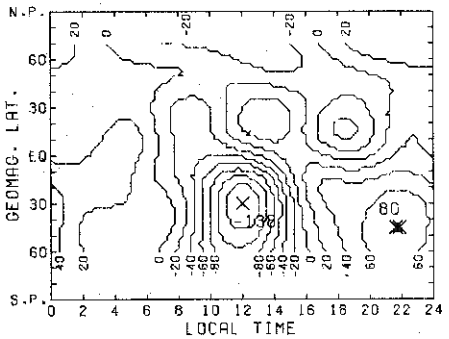

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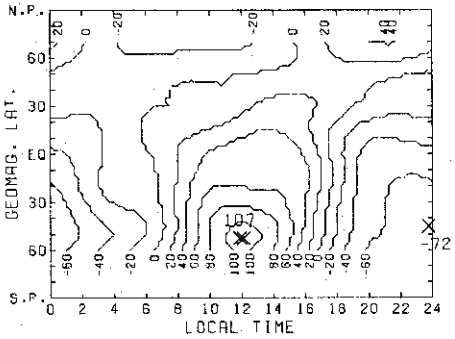

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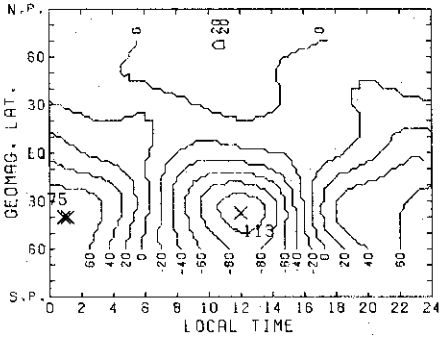

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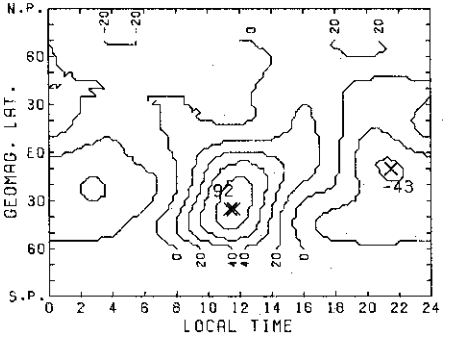

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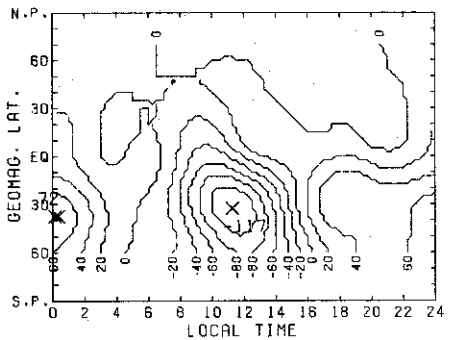

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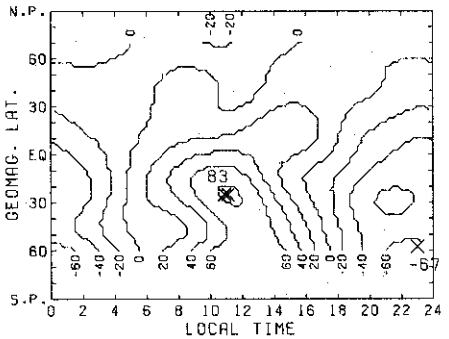

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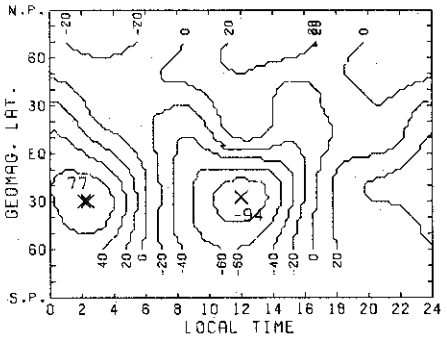

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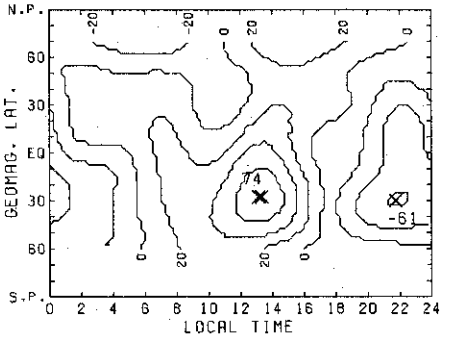

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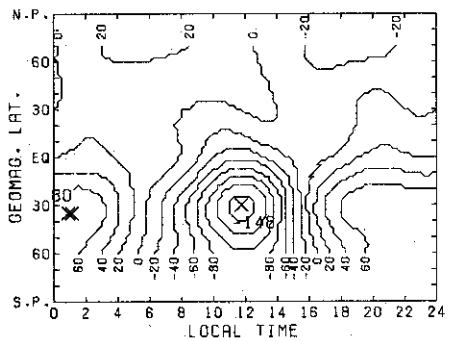

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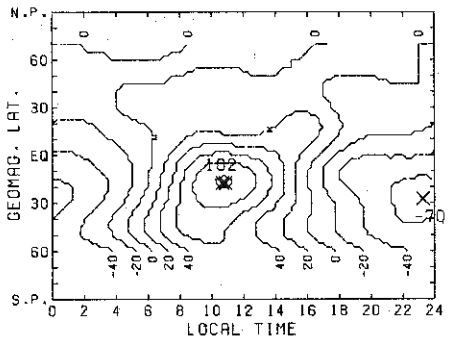

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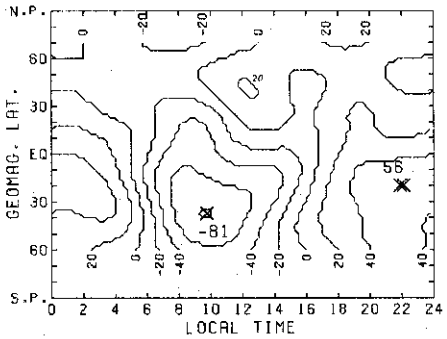

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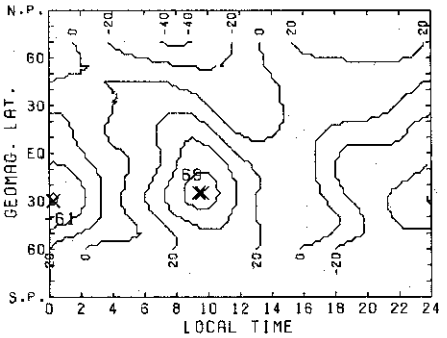

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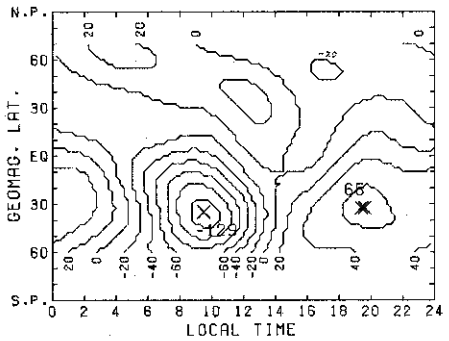

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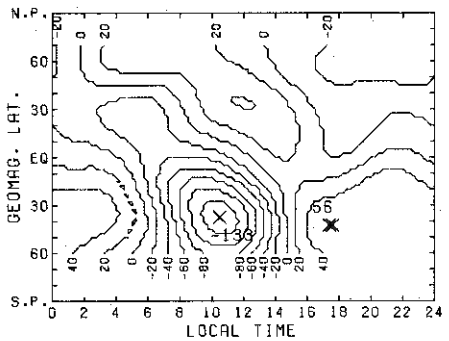

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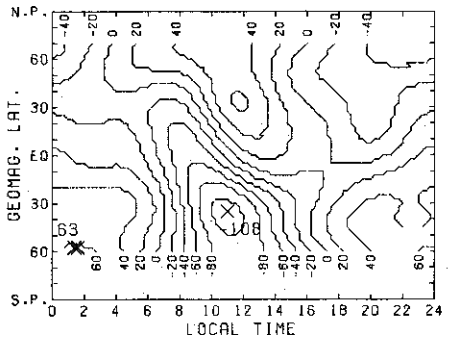

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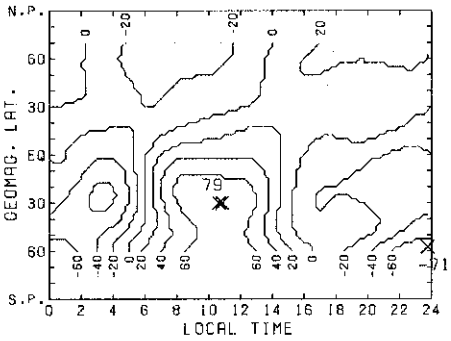

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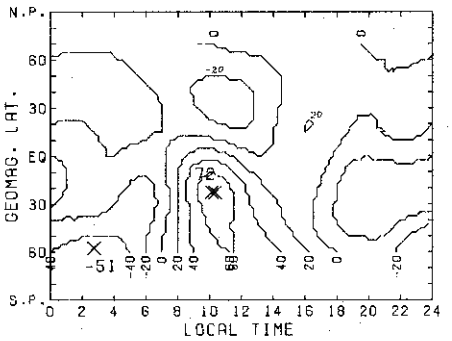

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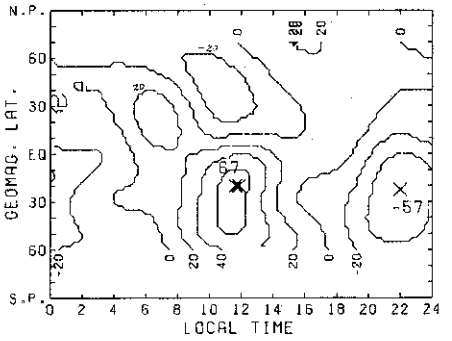

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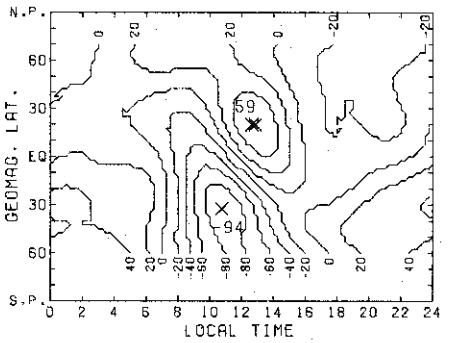

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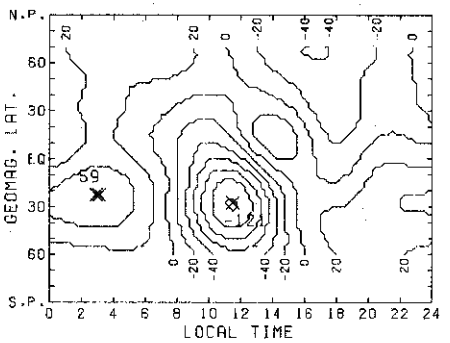

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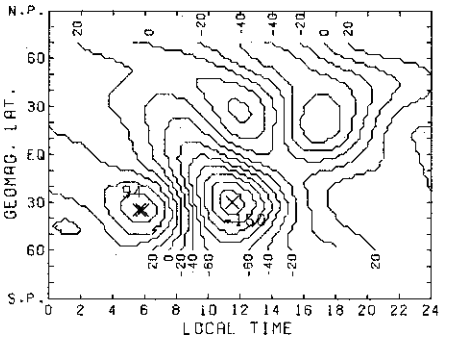

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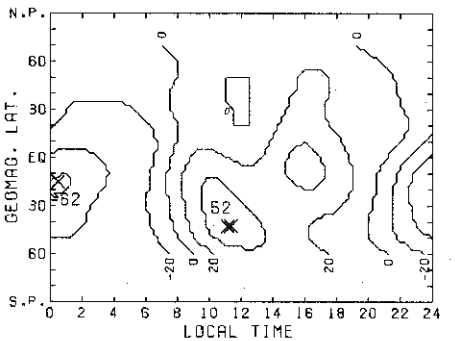

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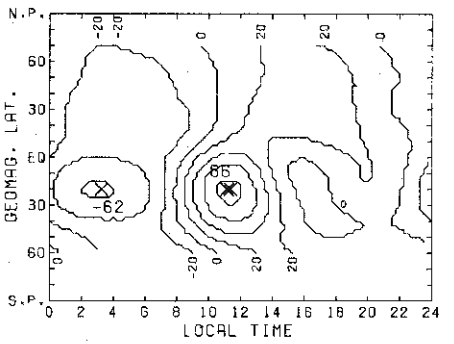

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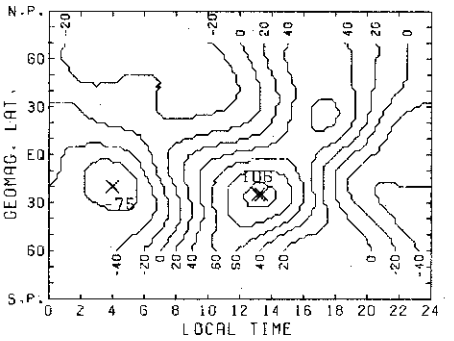

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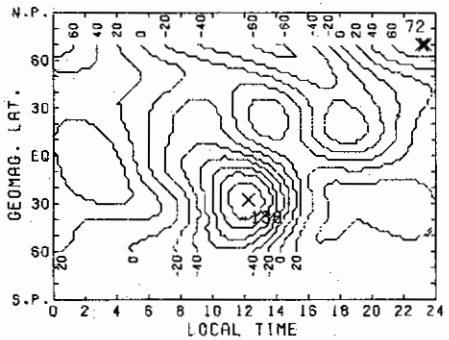

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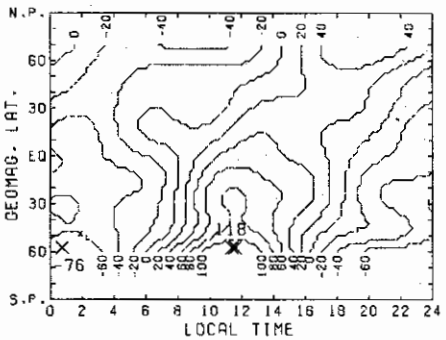

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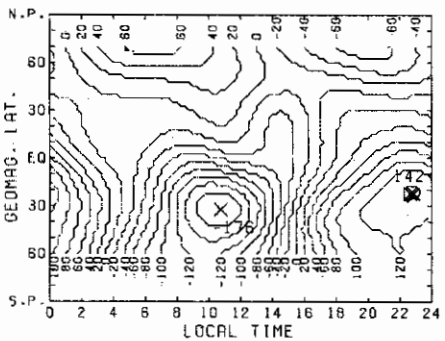

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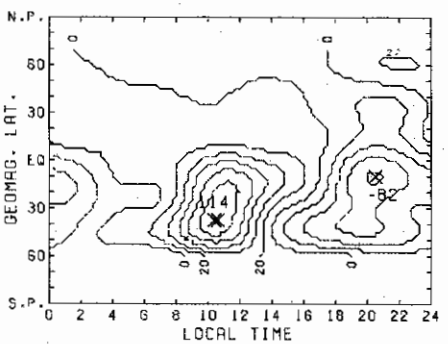

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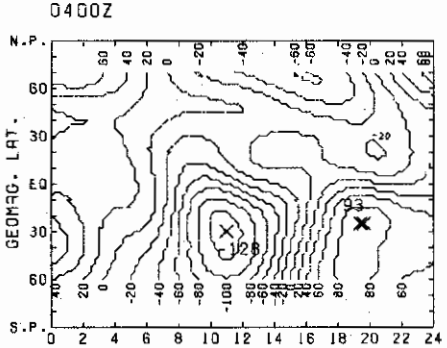

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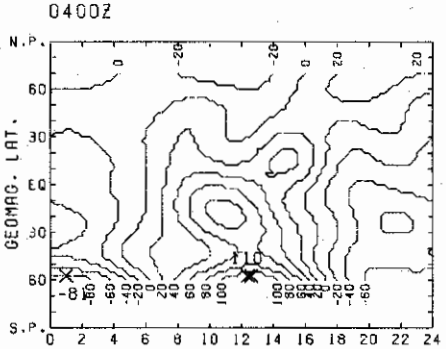

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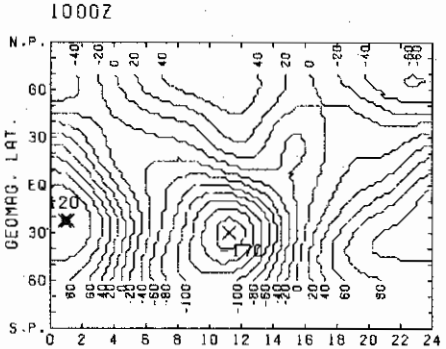

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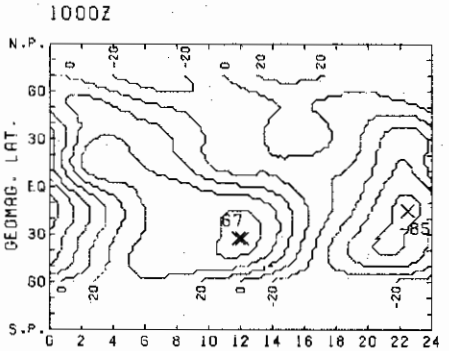

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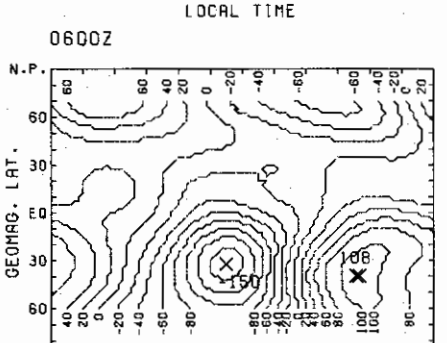

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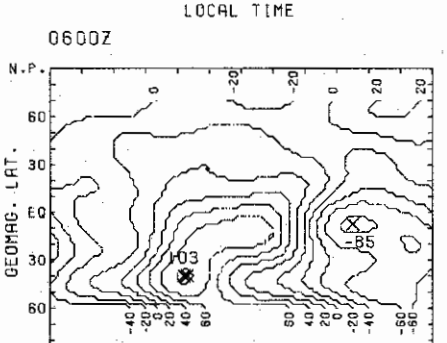

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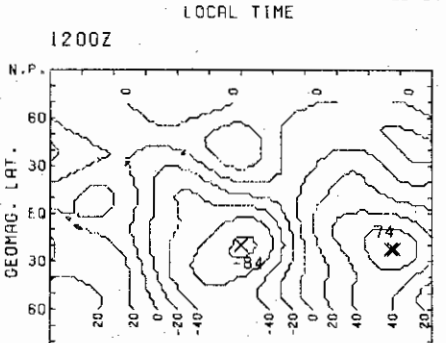

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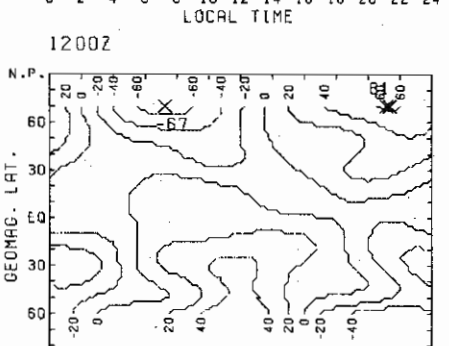

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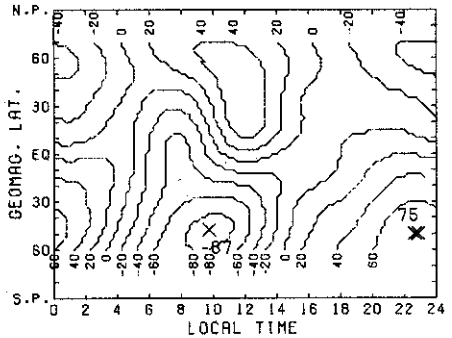

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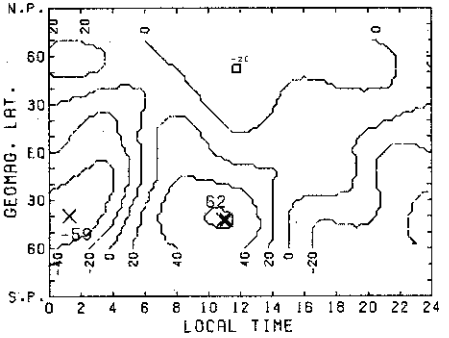

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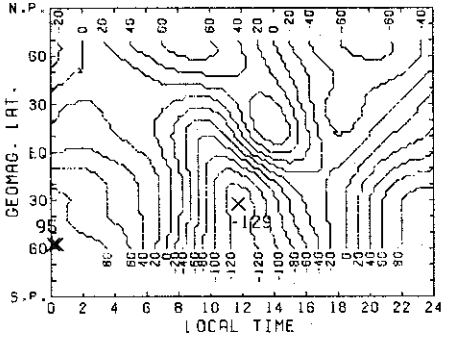

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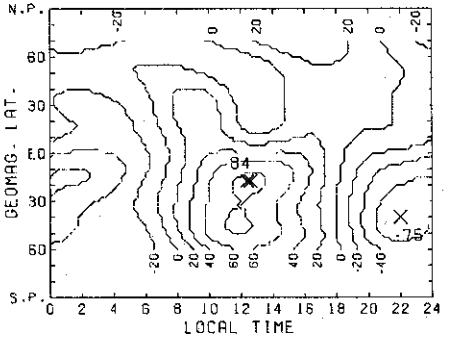

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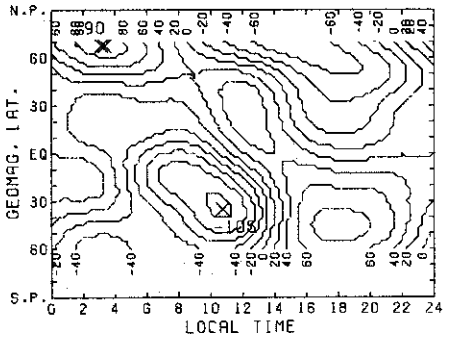

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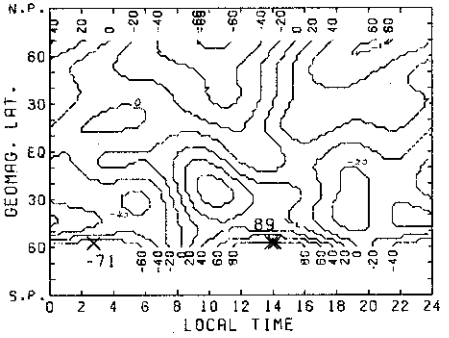

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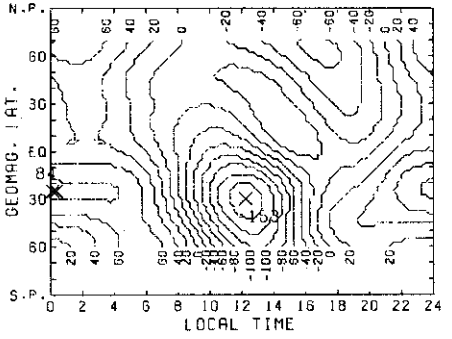

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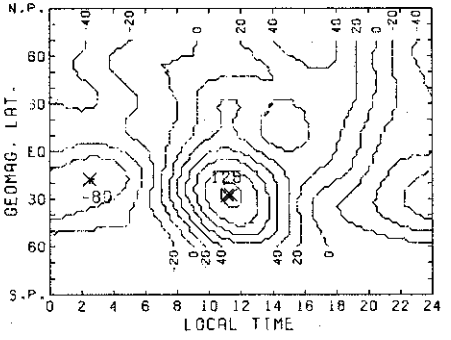

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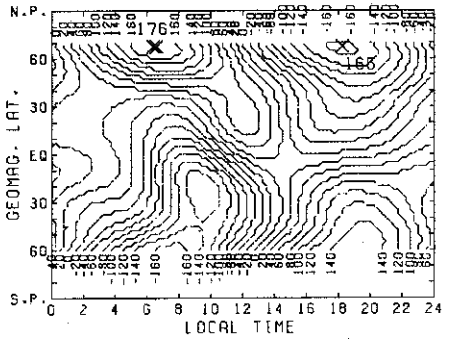

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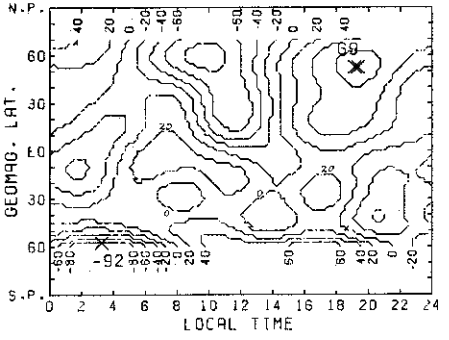

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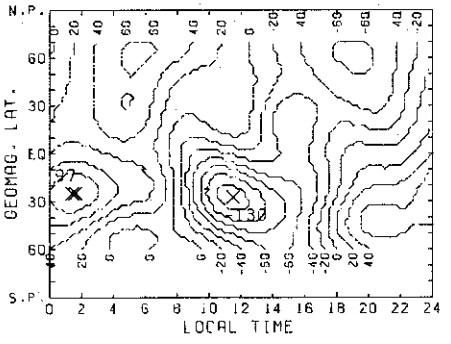

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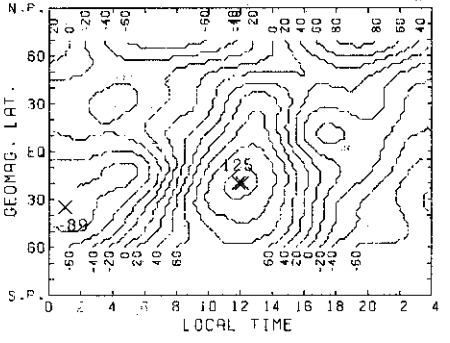

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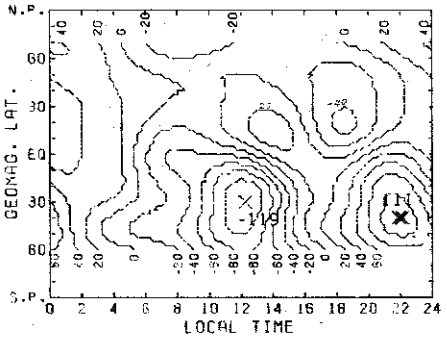

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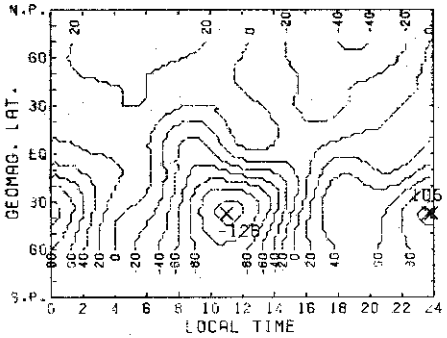

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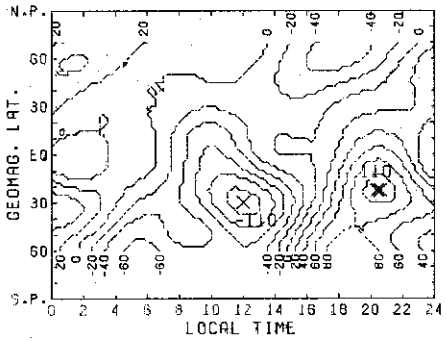

INTERNAL

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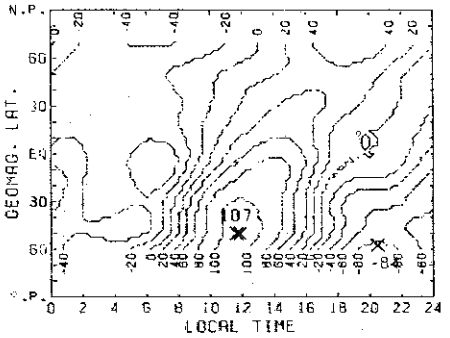

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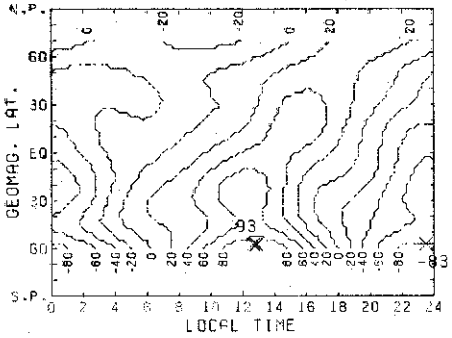

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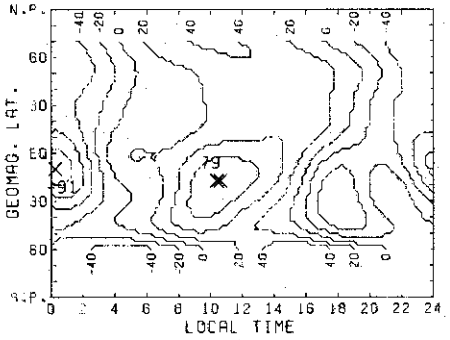

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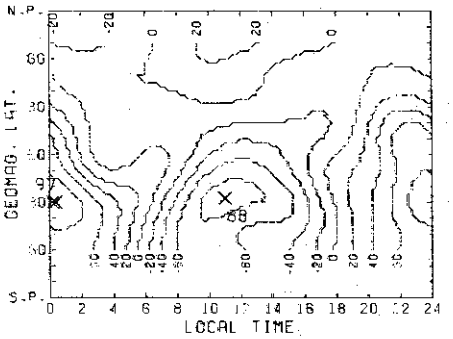

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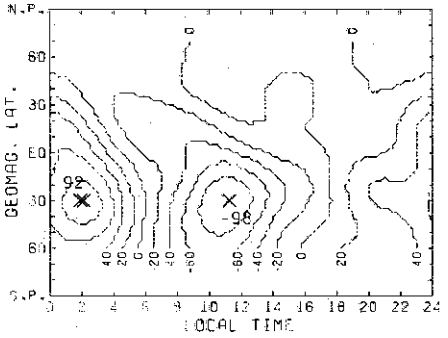

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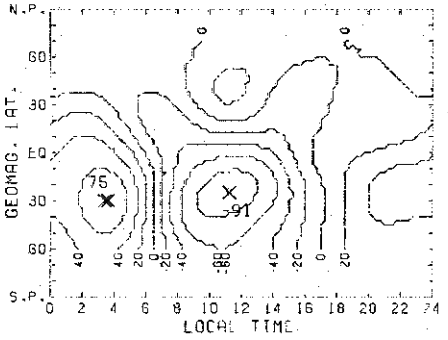

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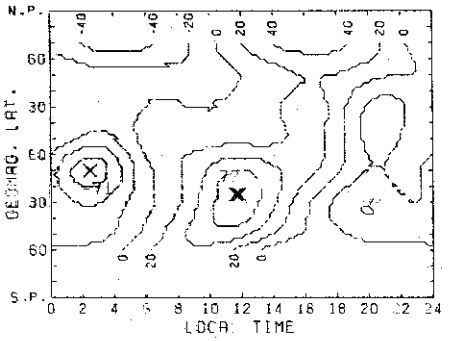

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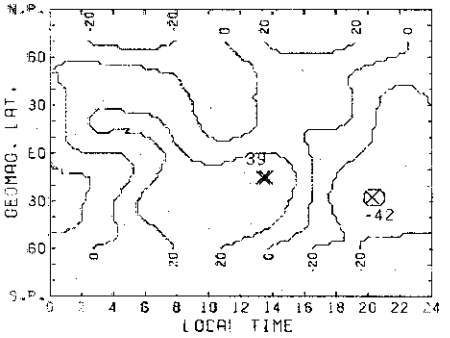

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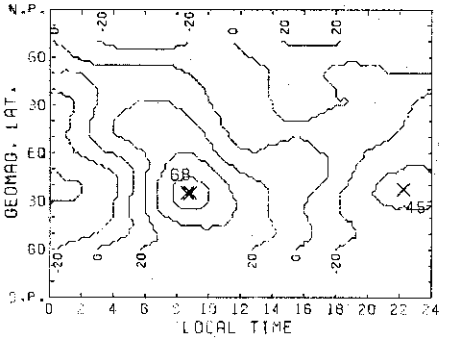

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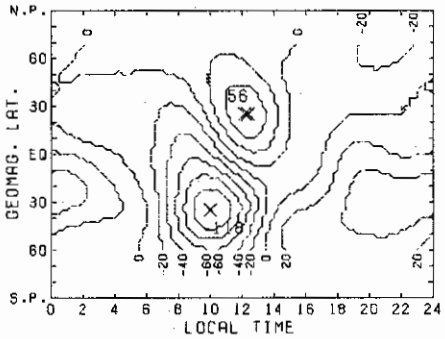

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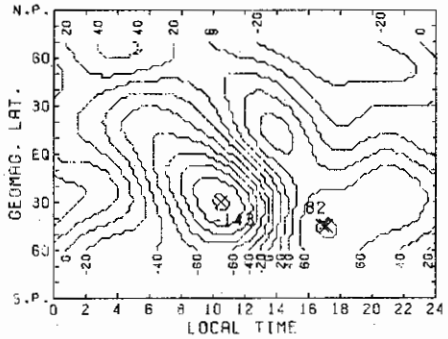

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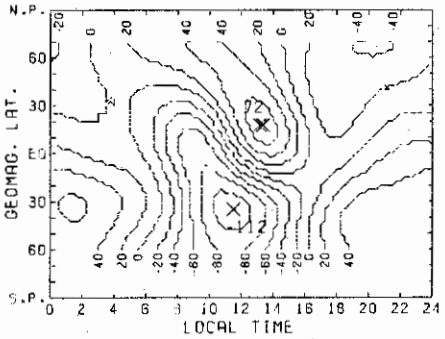

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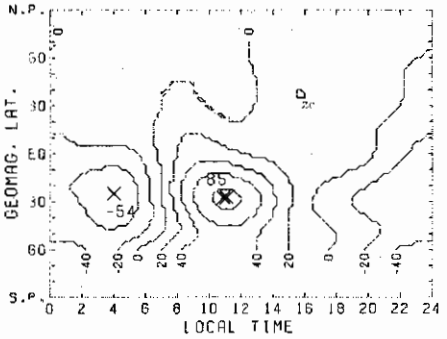

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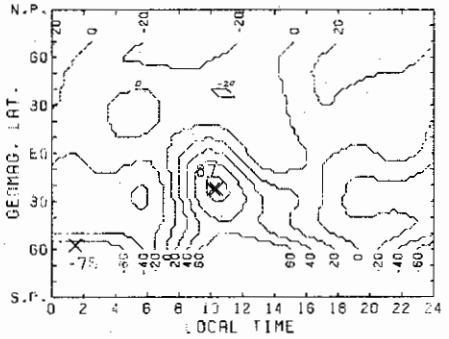

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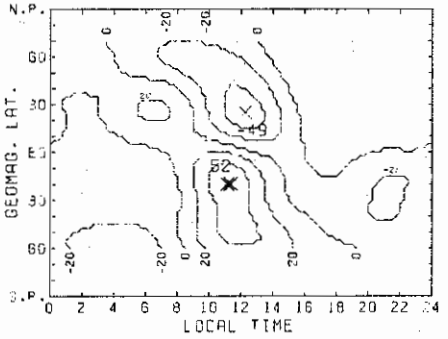

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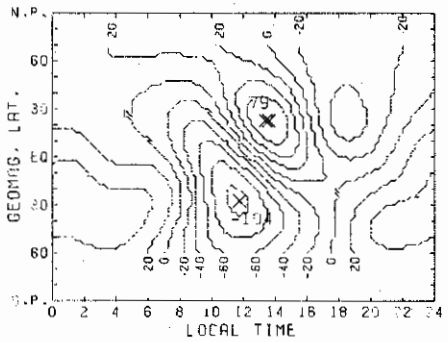

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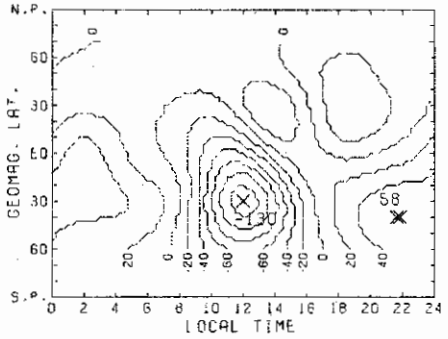

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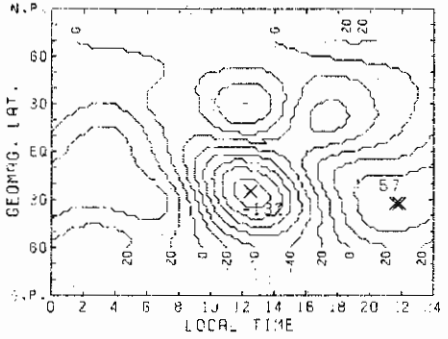

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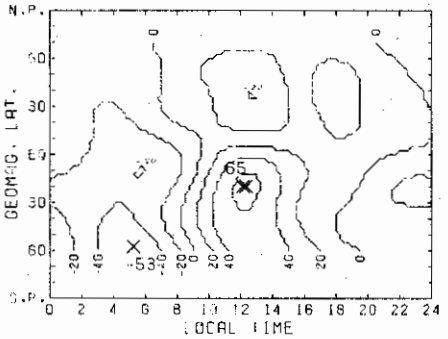

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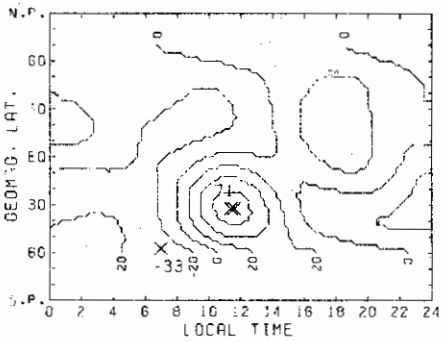

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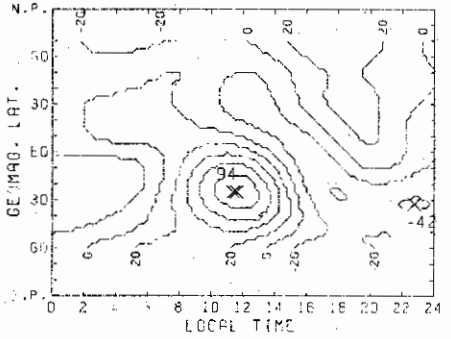

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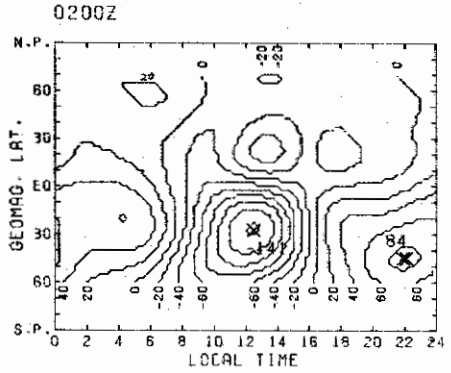

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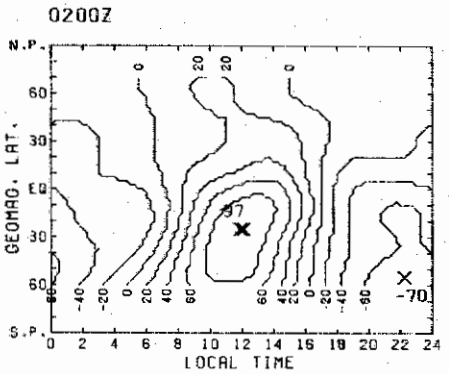

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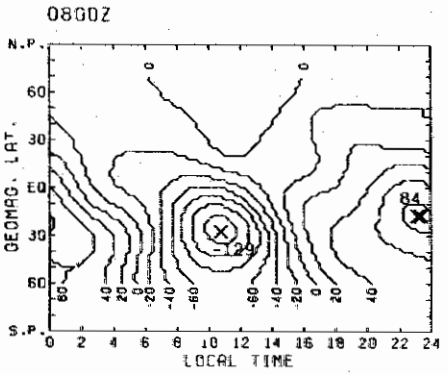

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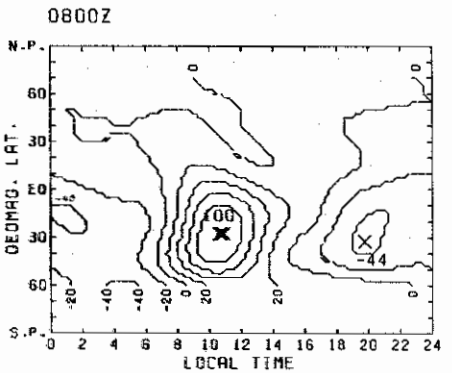

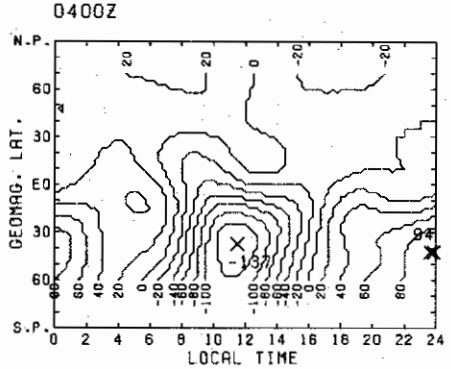

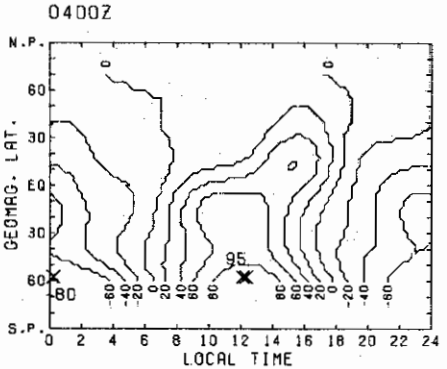

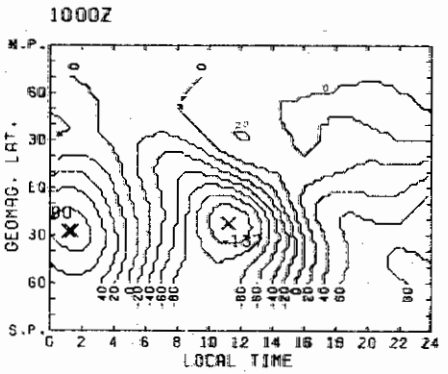

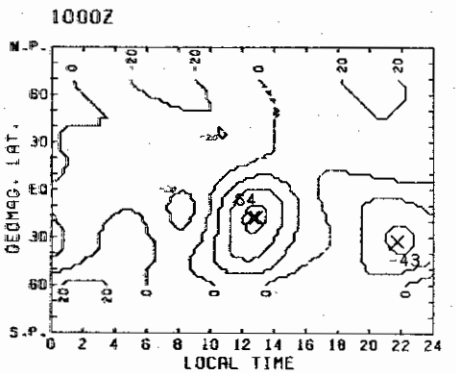

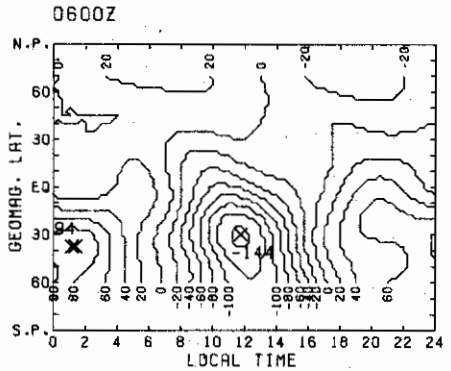

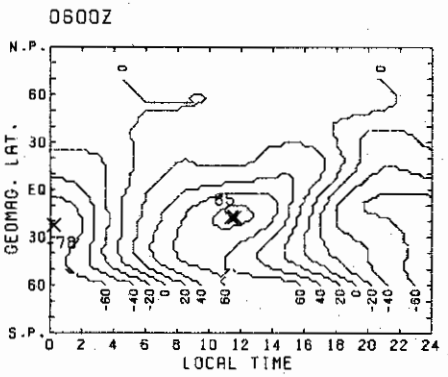

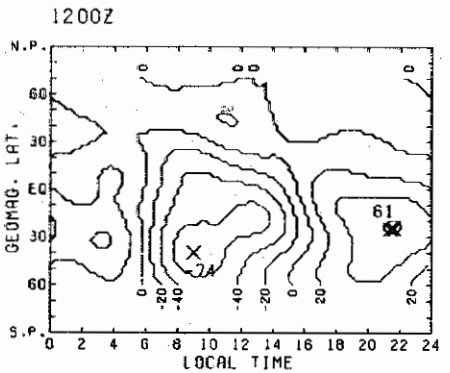

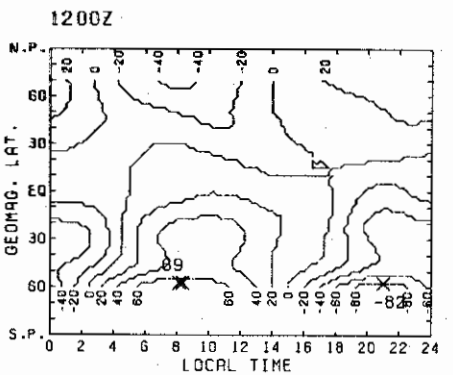

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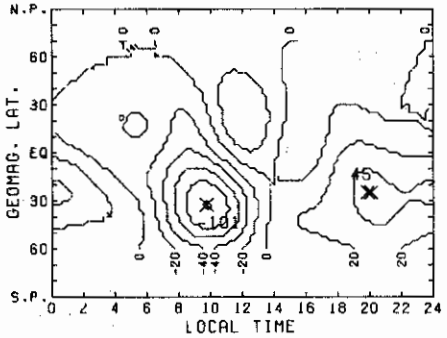

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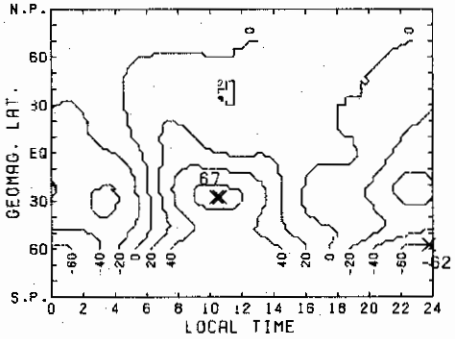

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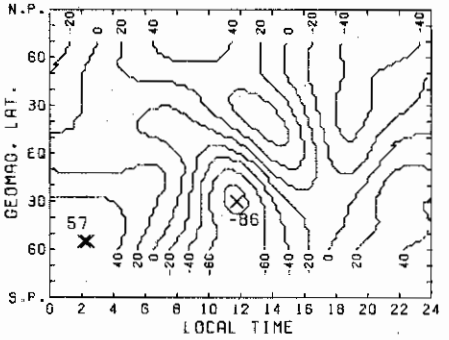

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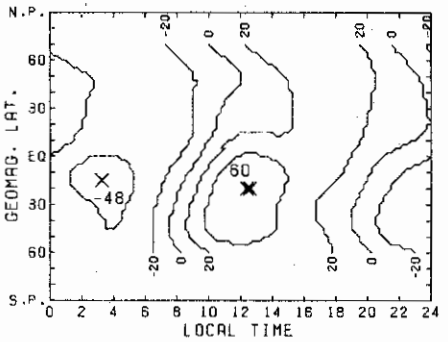

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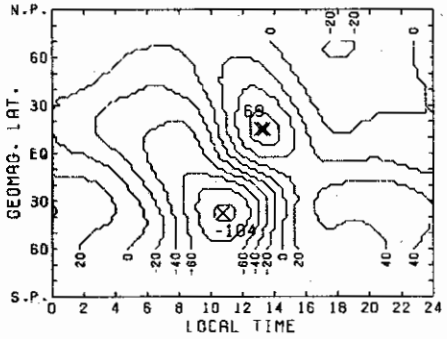

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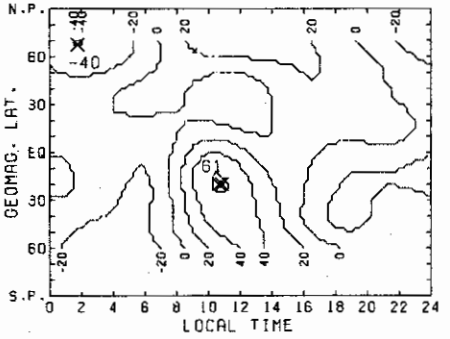

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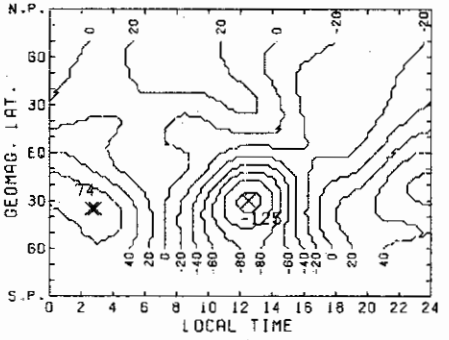

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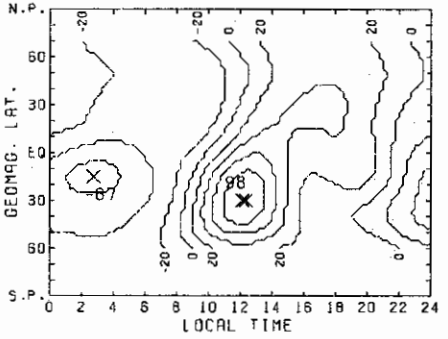

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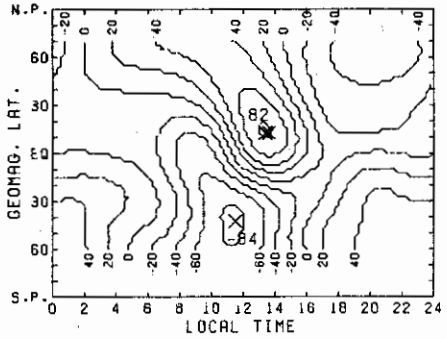

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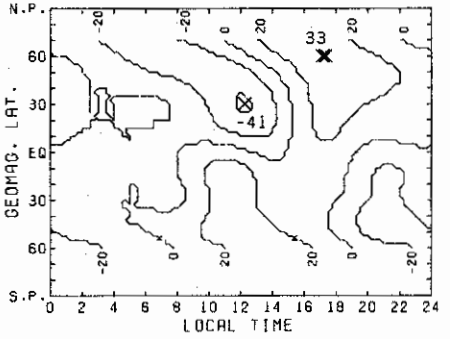

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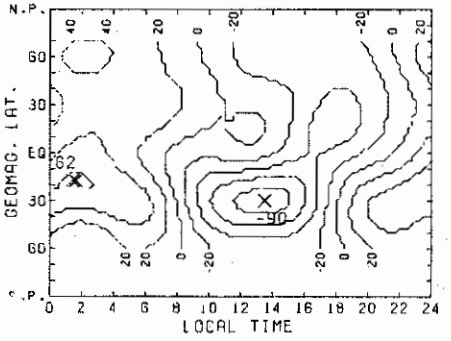

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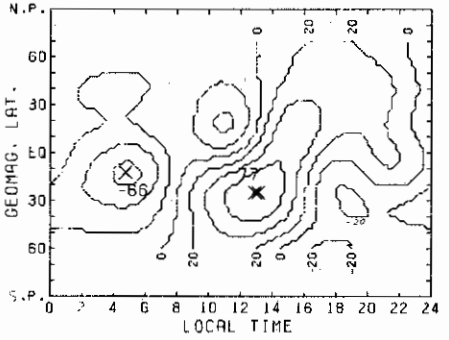

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EXTERNAL

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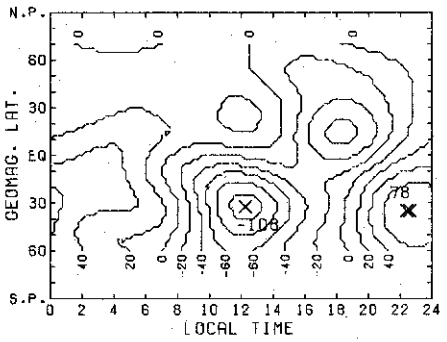

INTERNAL

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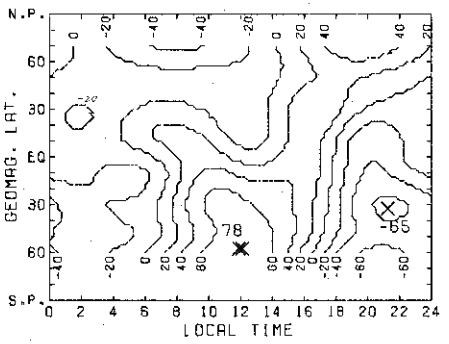

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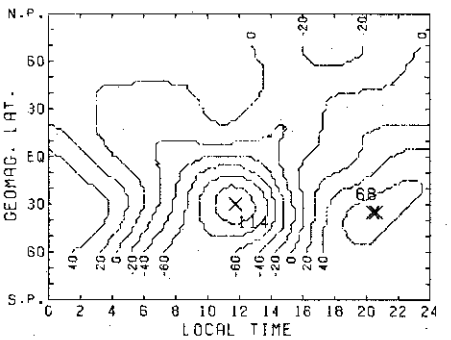

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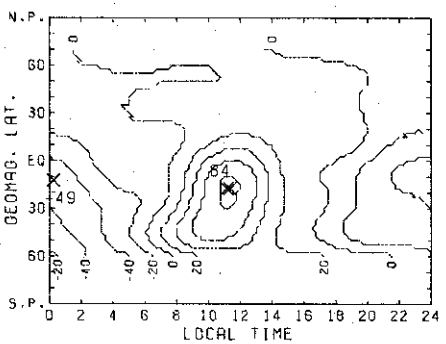

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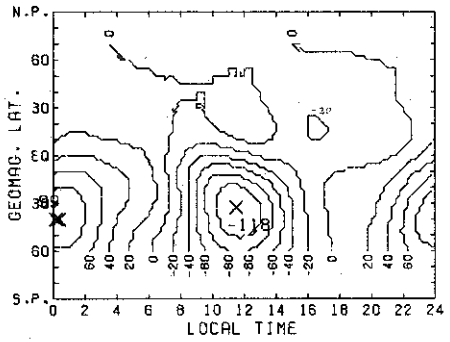

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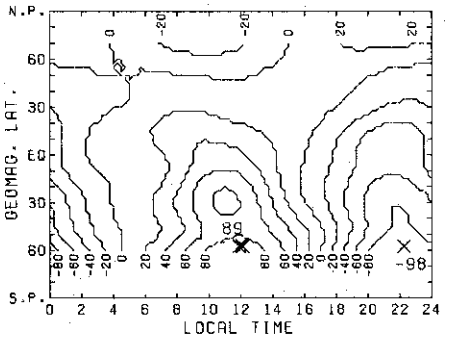

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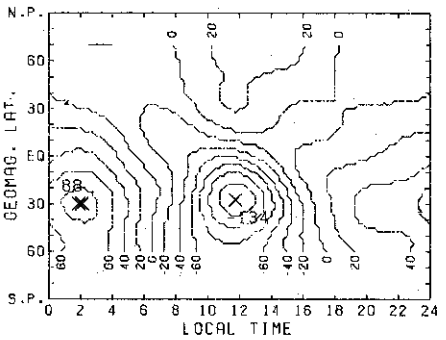

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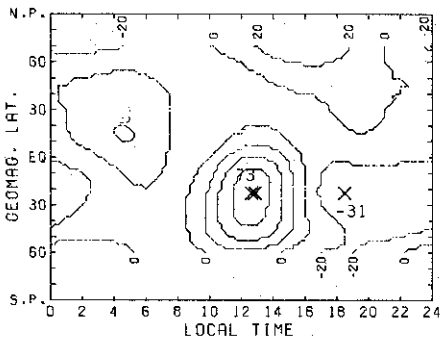

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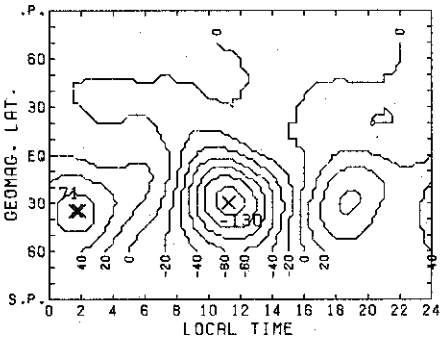

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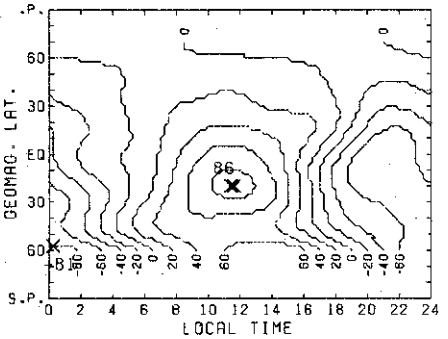

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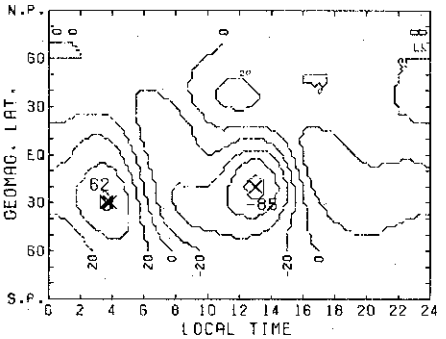

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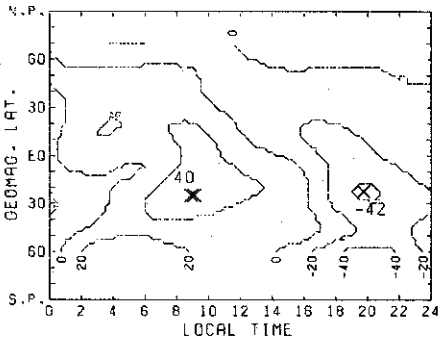

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EXTERNAL

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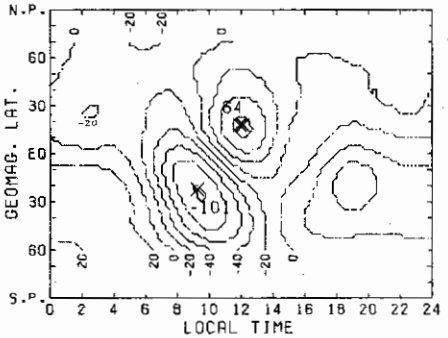

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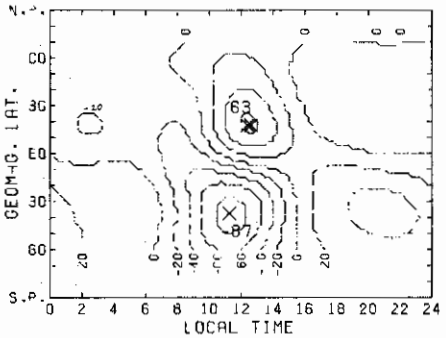

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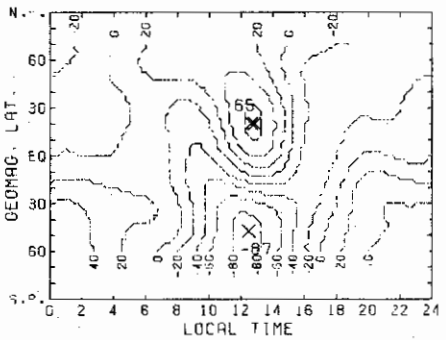

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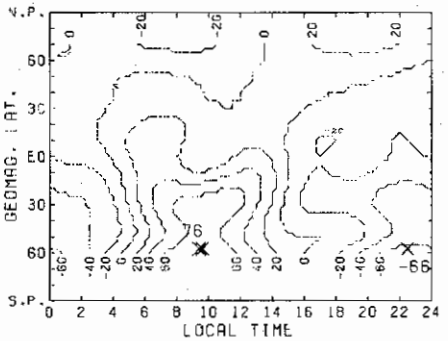

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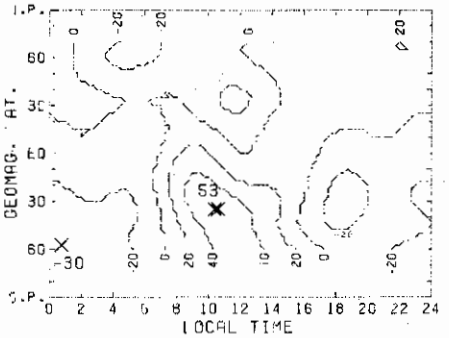

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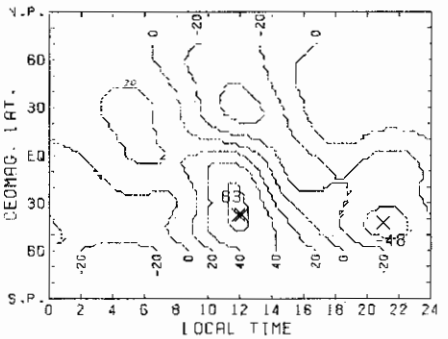

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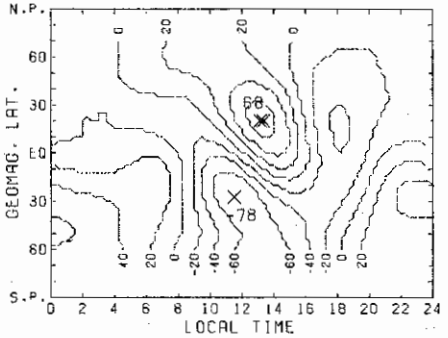

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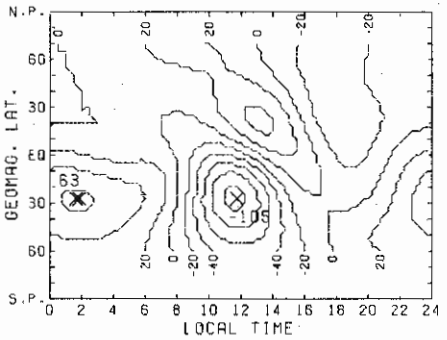

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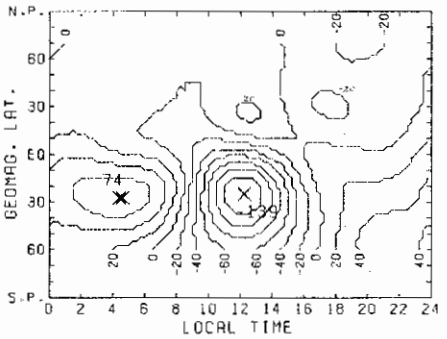

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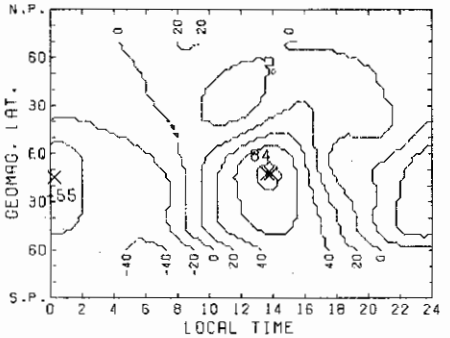

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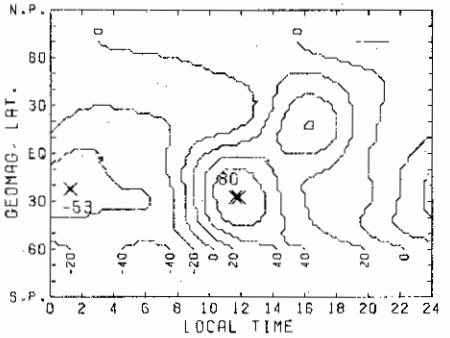

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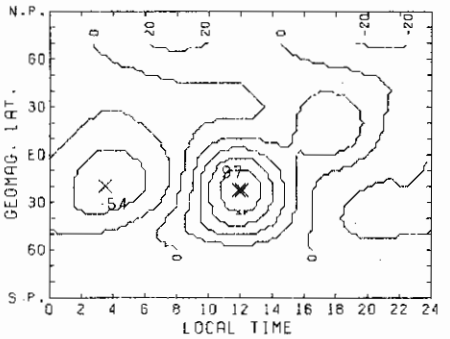

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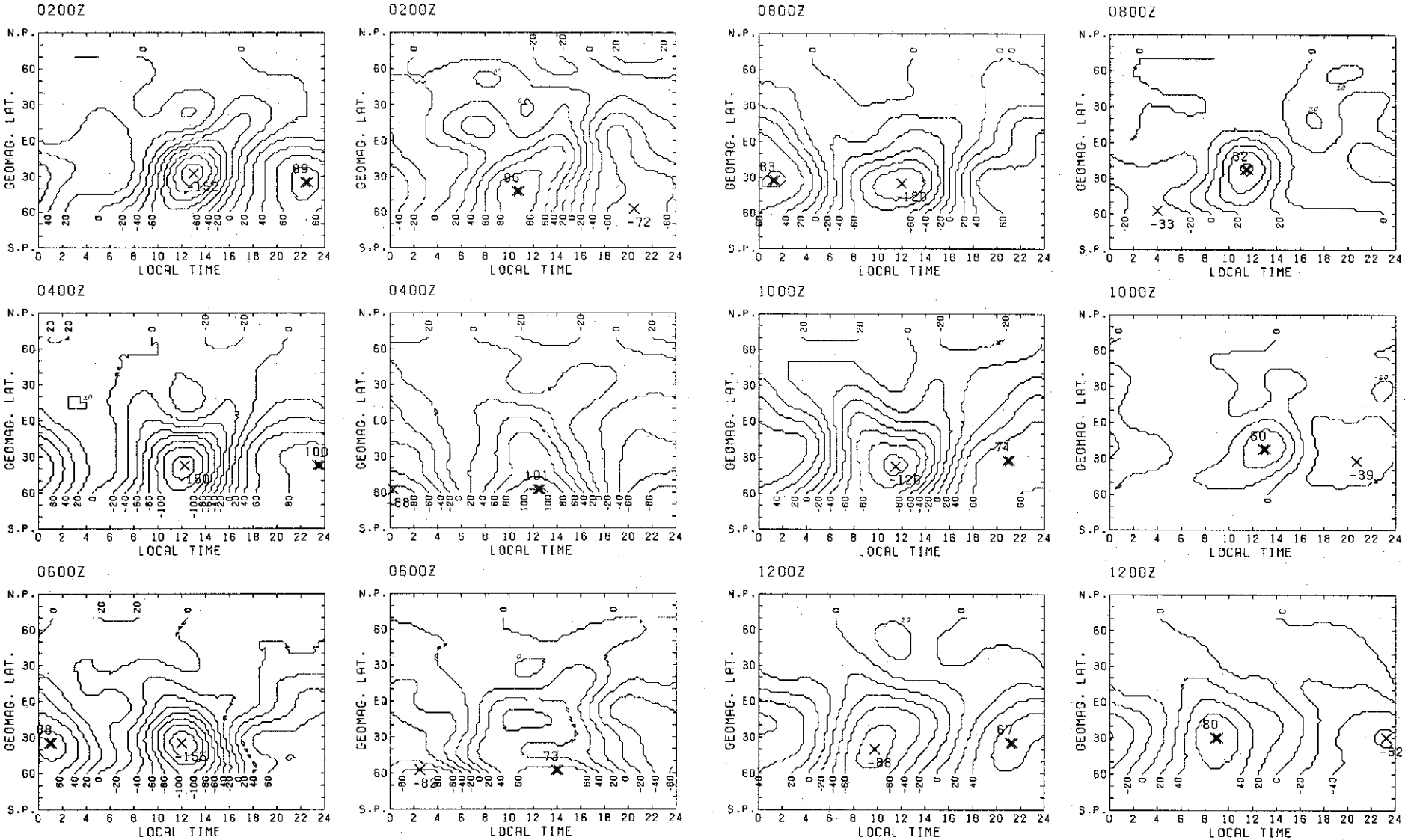

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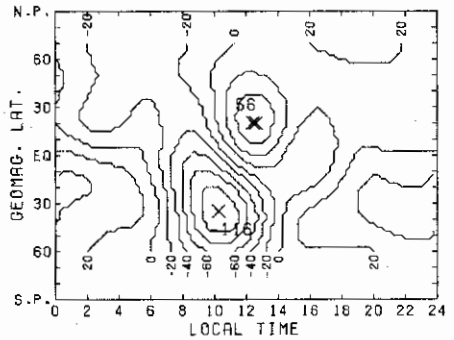

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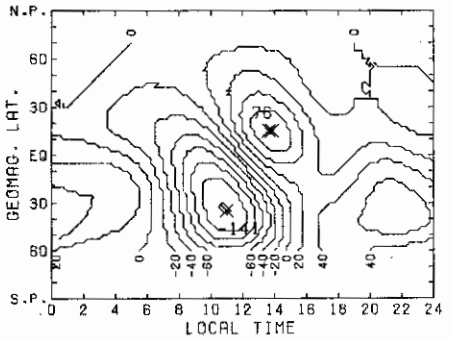

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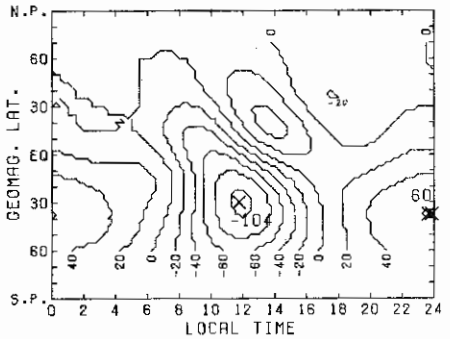

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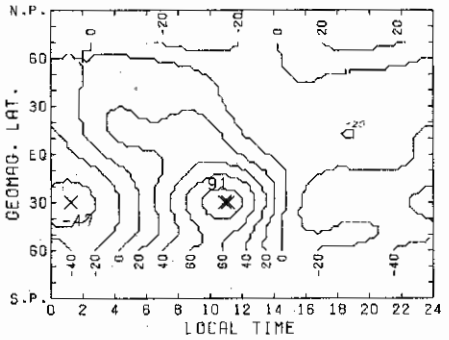

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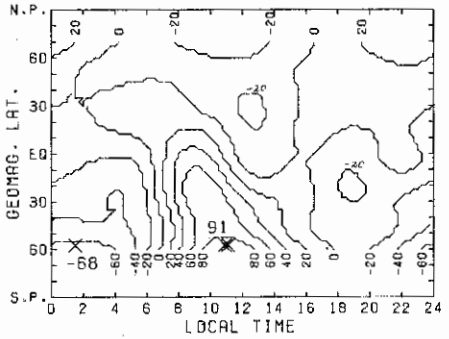

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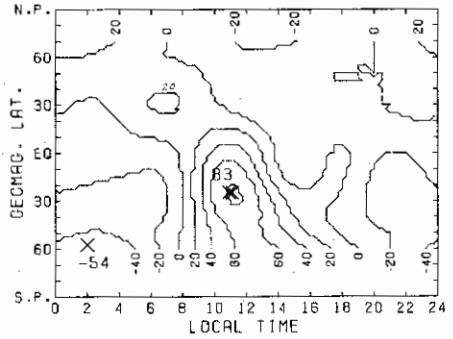

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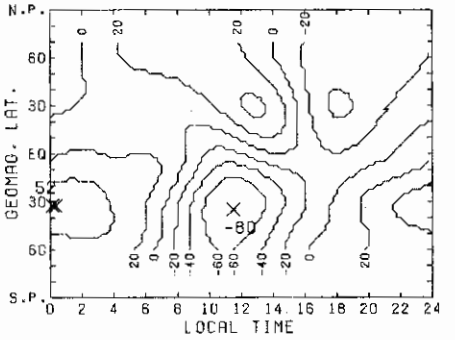

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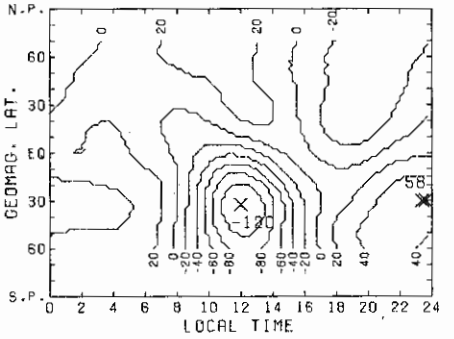

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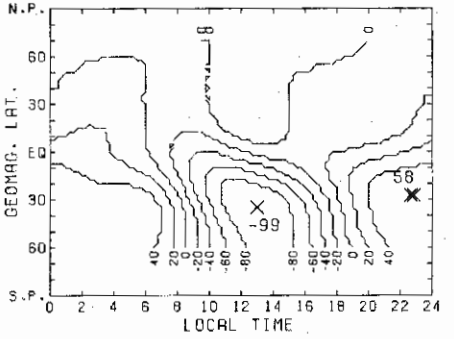

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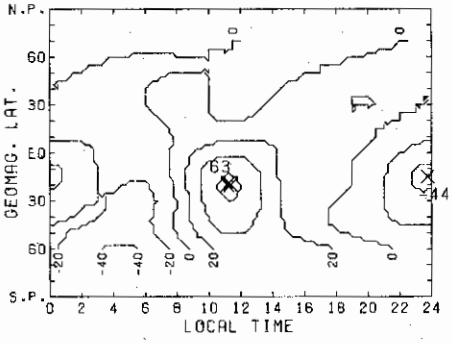

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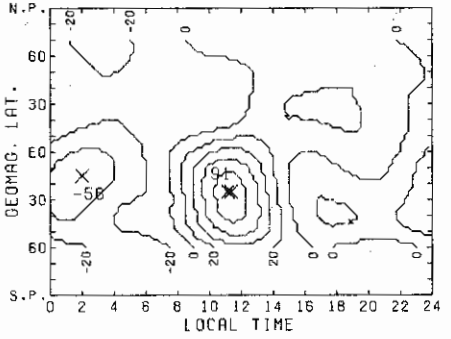

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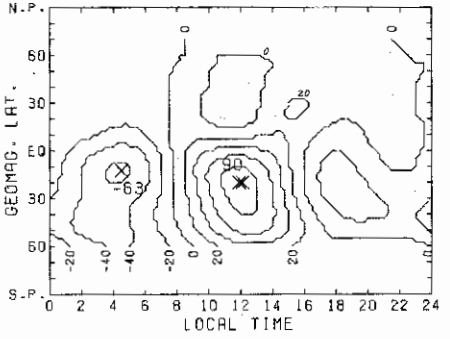

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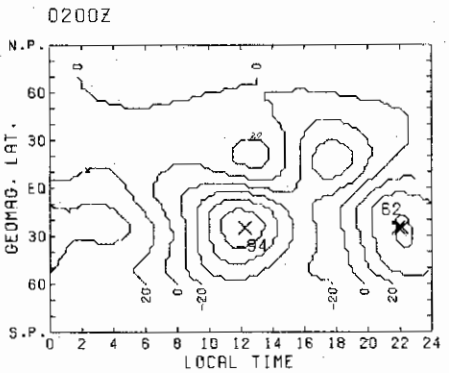

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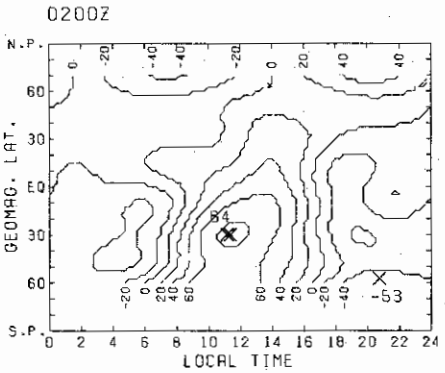

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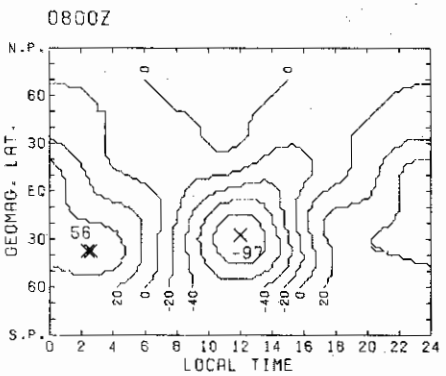

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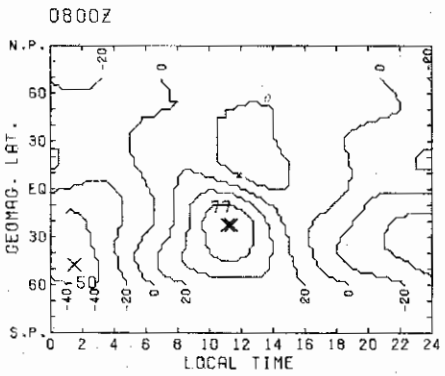

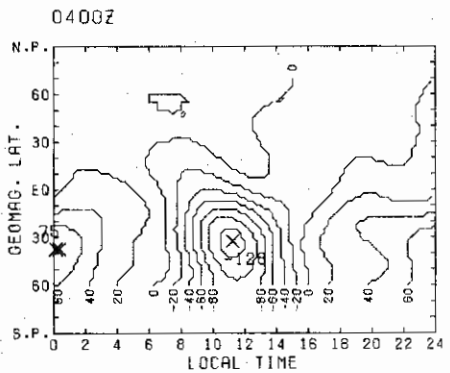

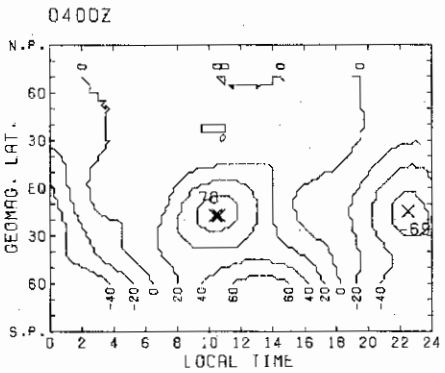

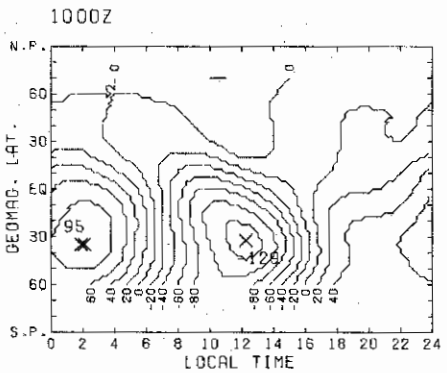

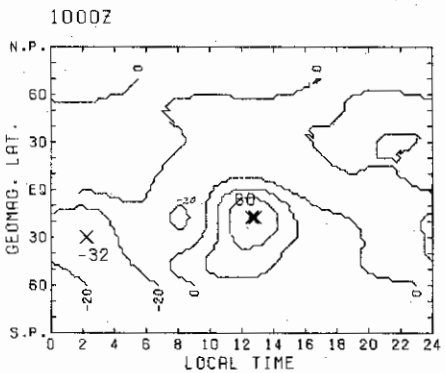

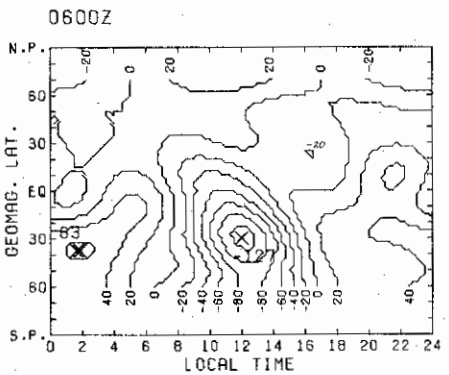

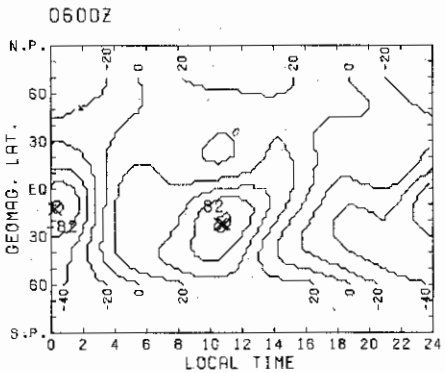

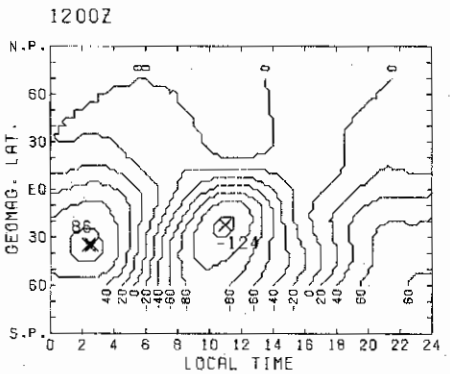

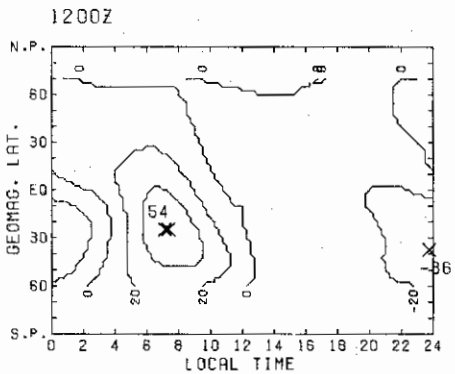

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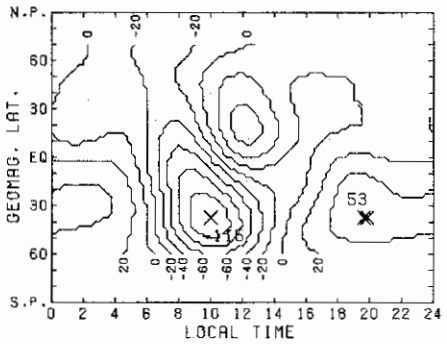

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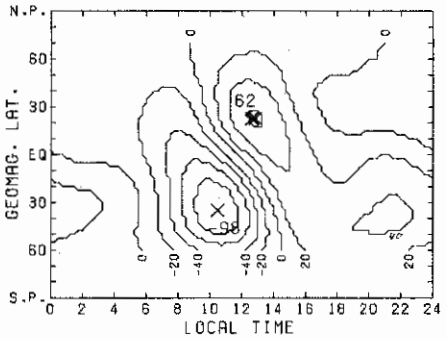

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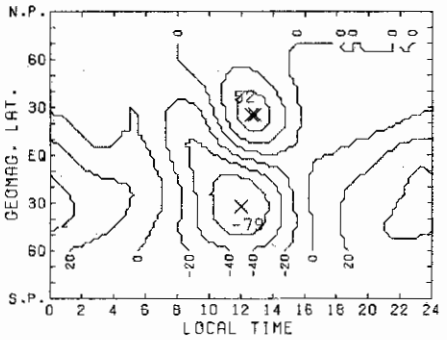

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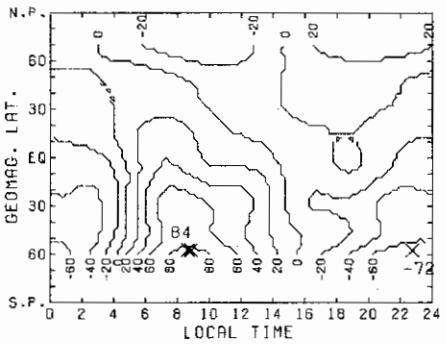

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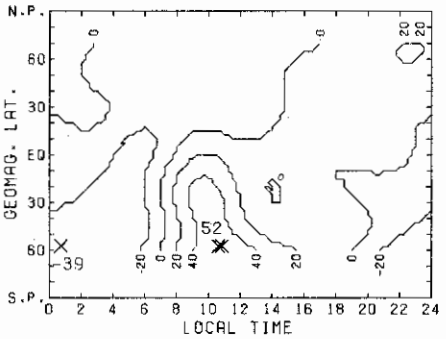

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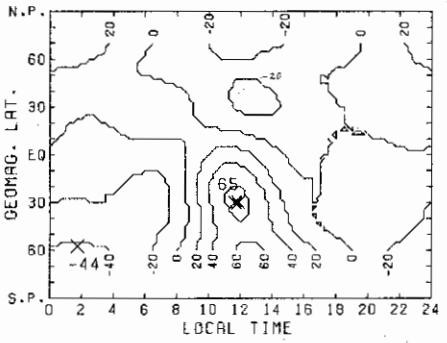

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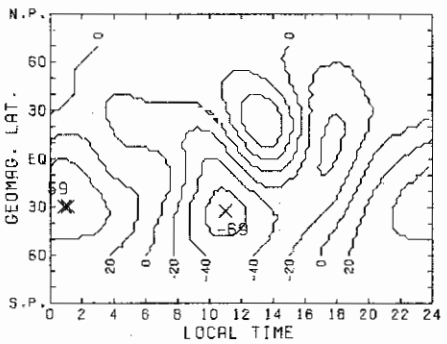

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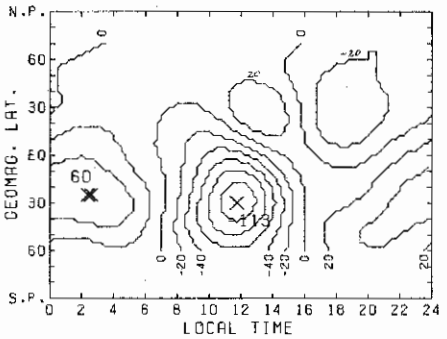

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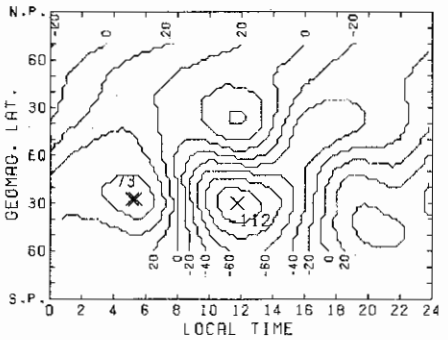

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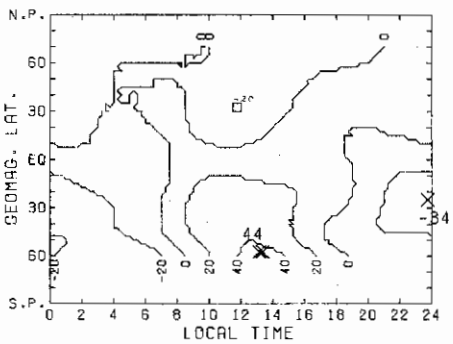

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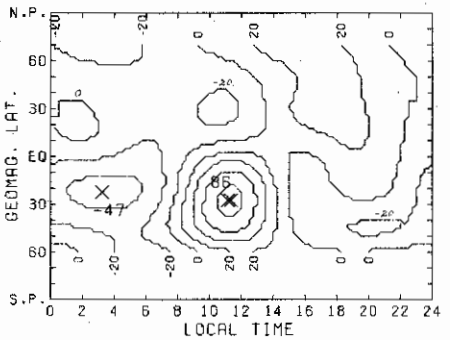

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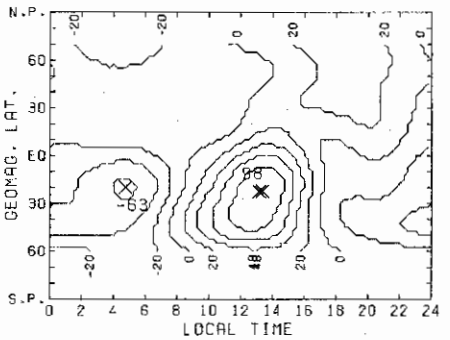

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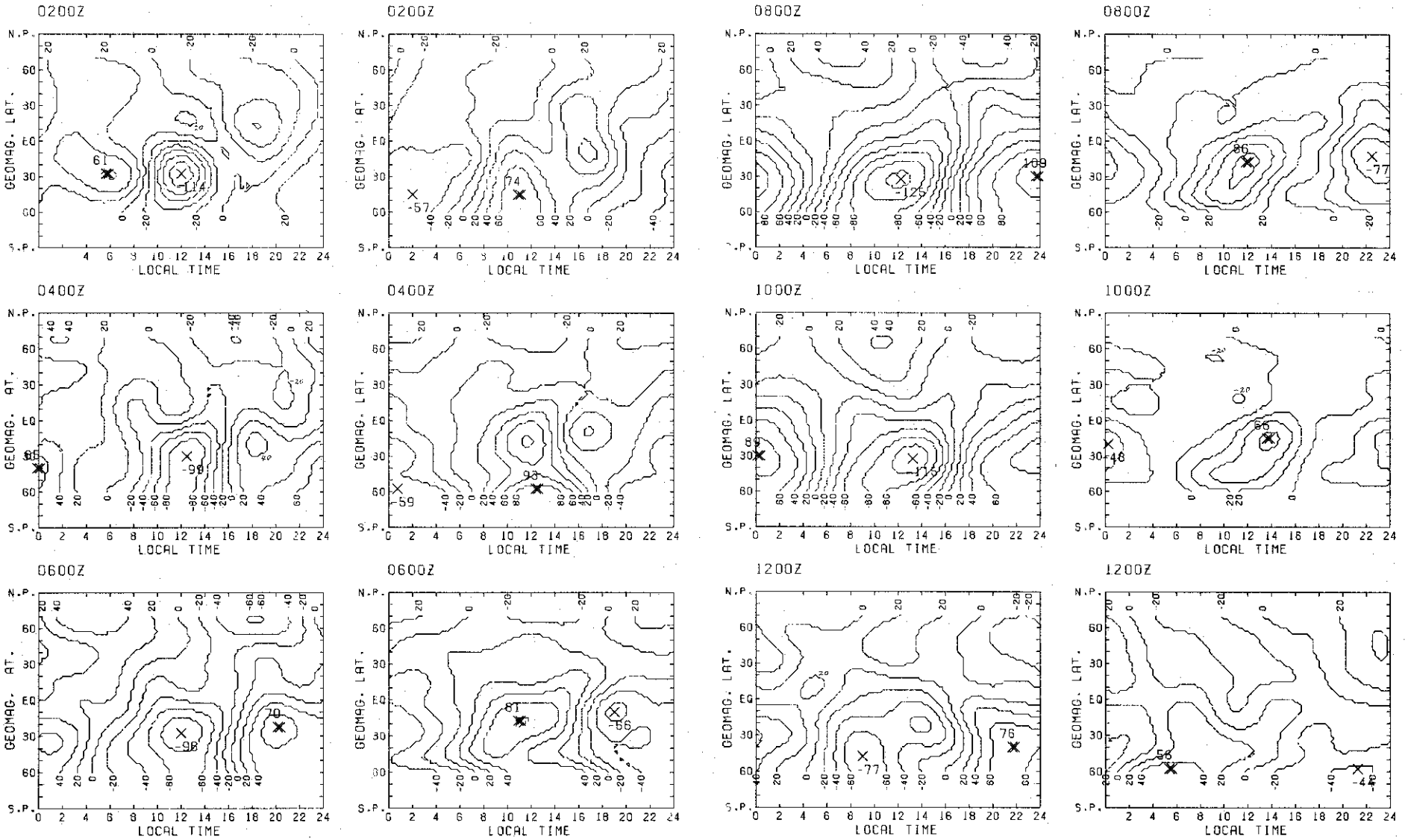

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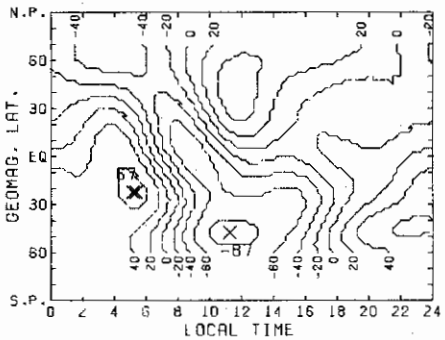

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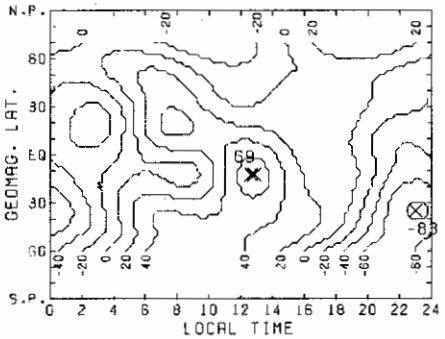

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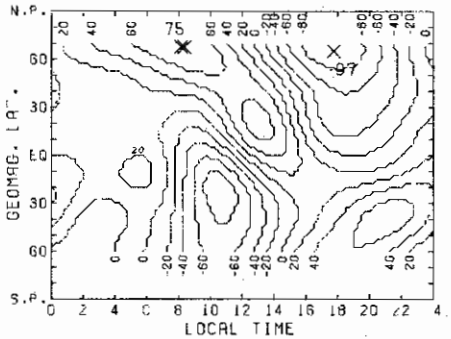

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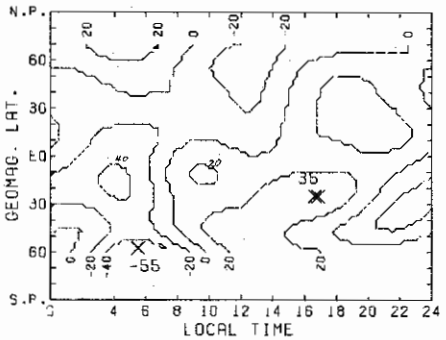

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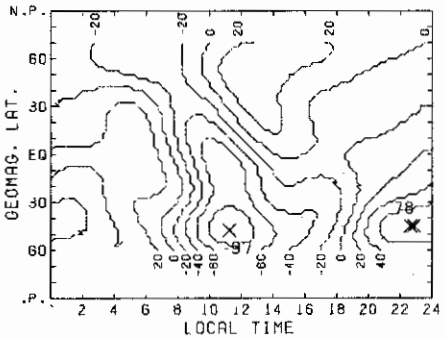

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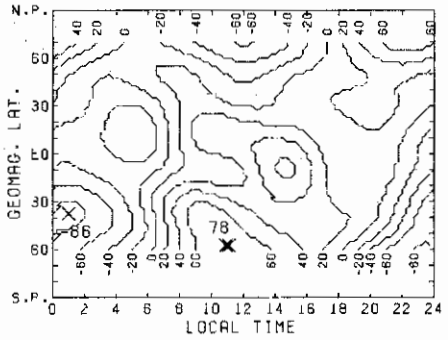

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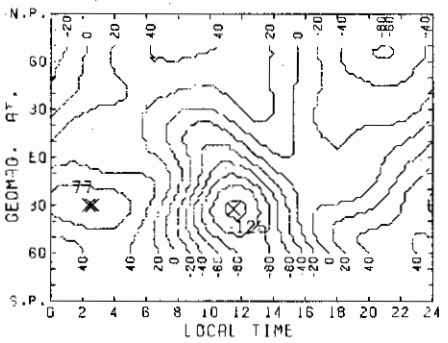

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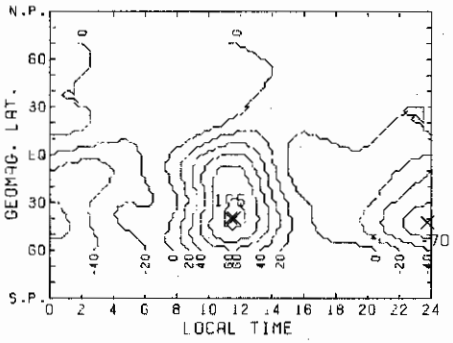

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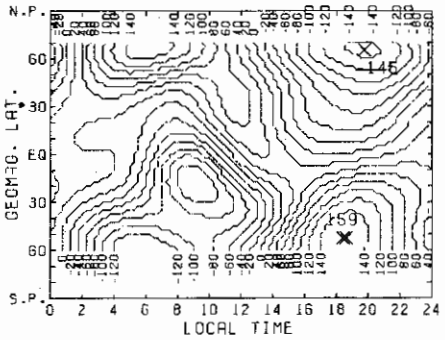

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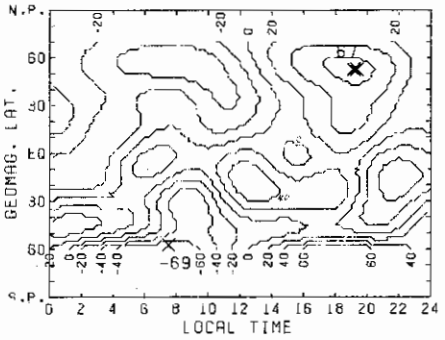

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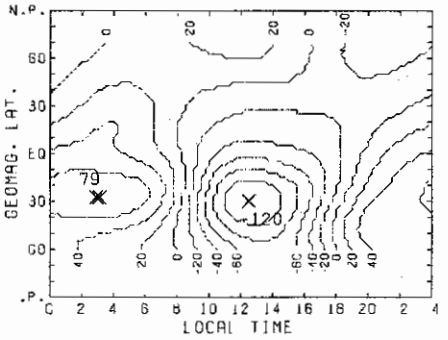

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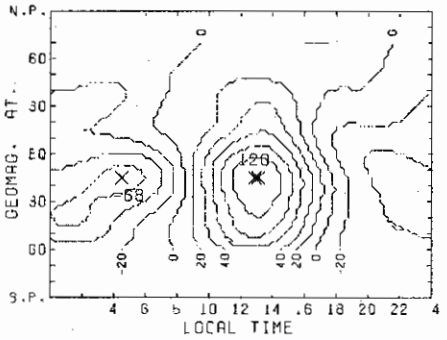

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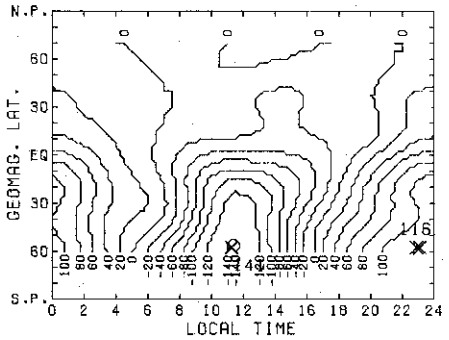

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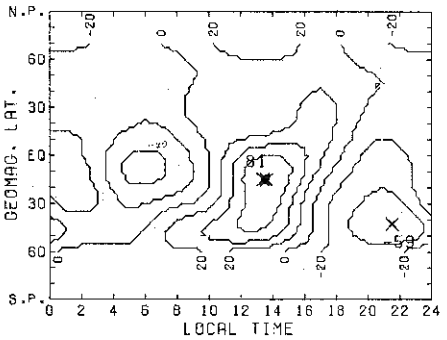

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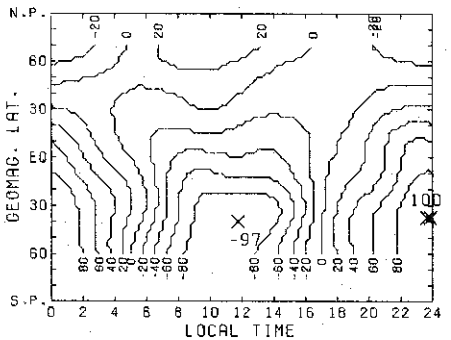

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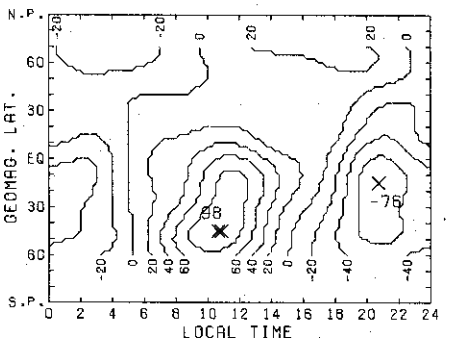

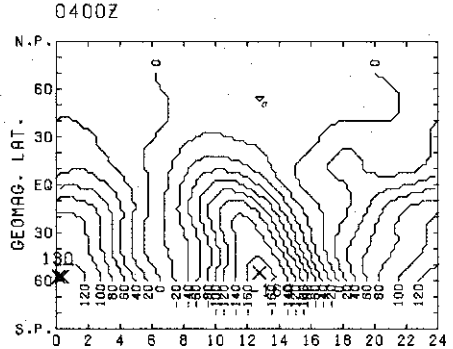

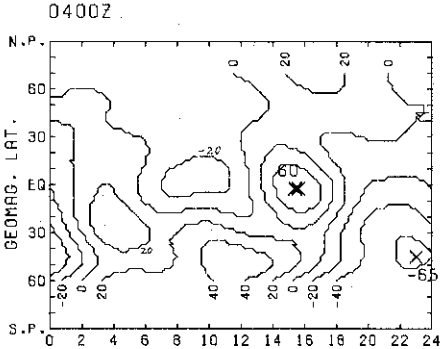

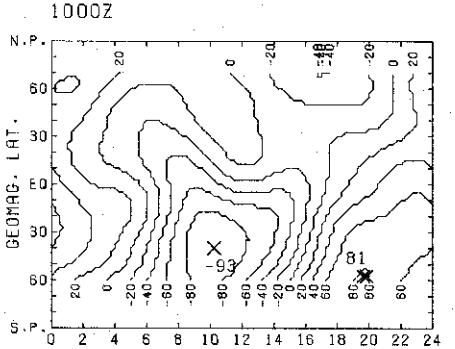

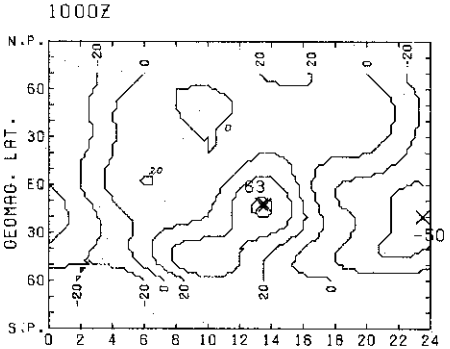

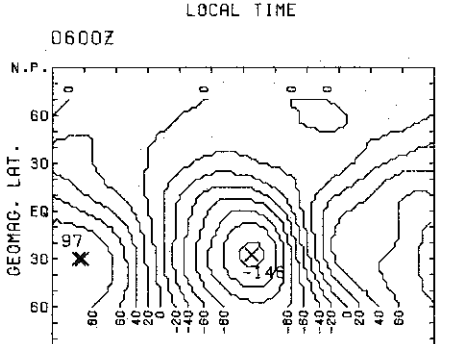

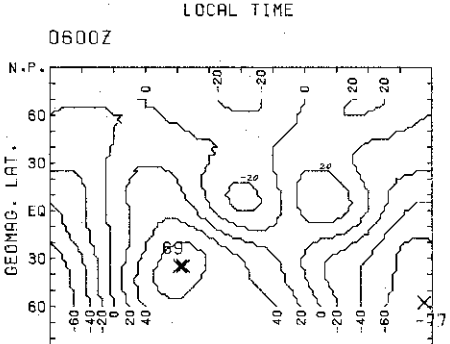

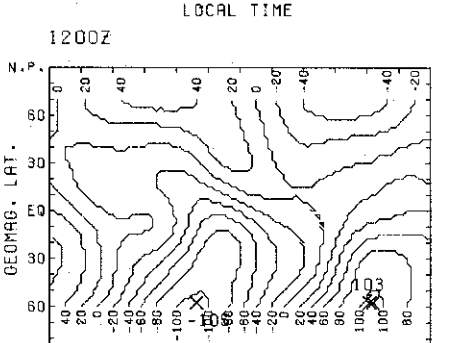

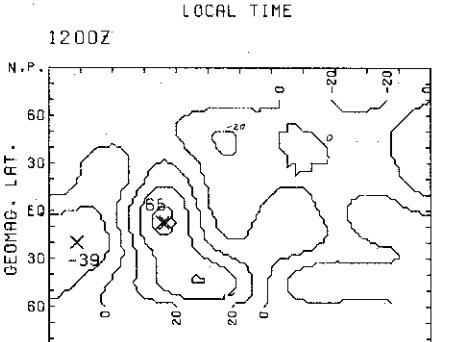

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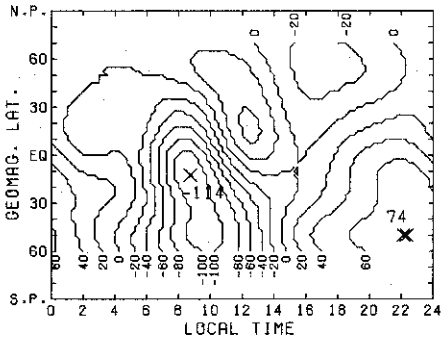

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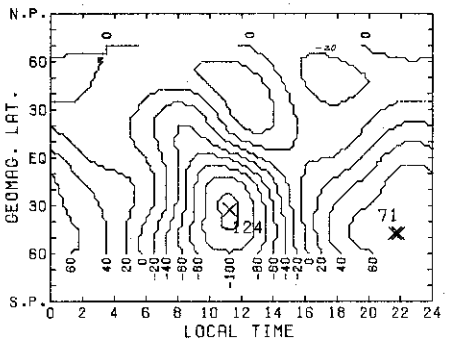

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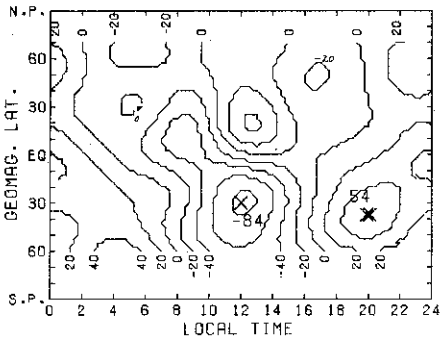

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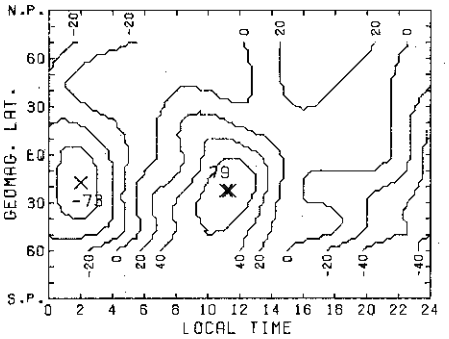

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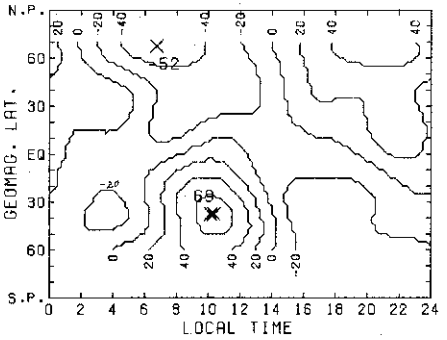

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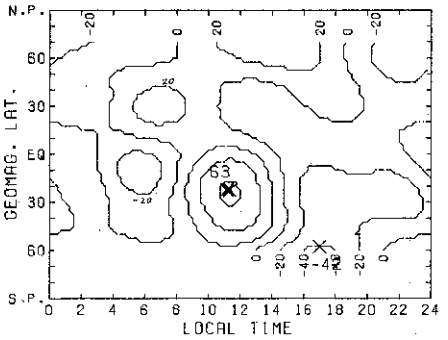

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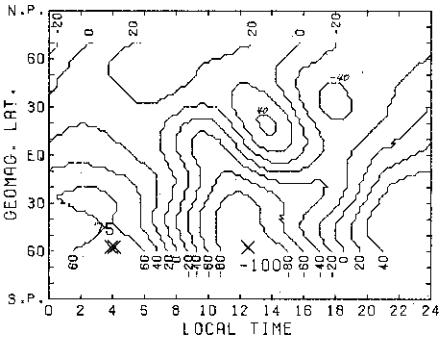

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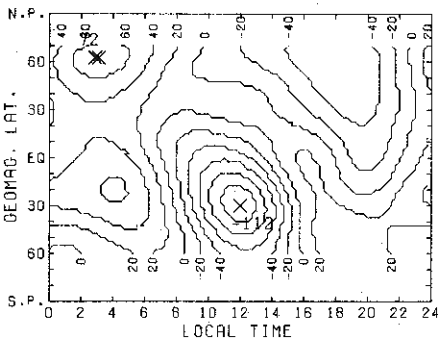

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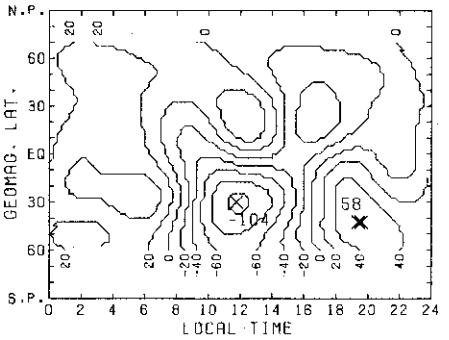

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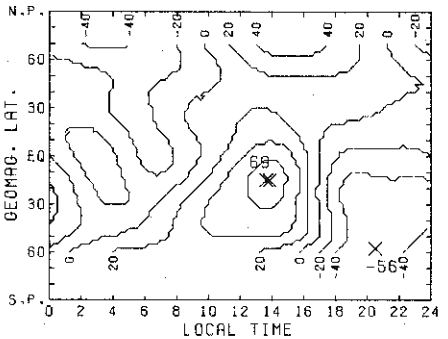

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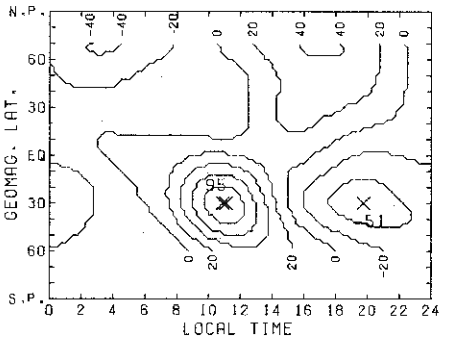

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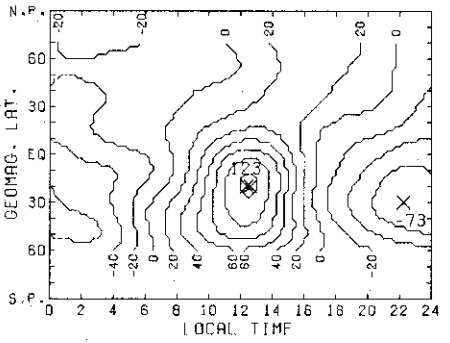

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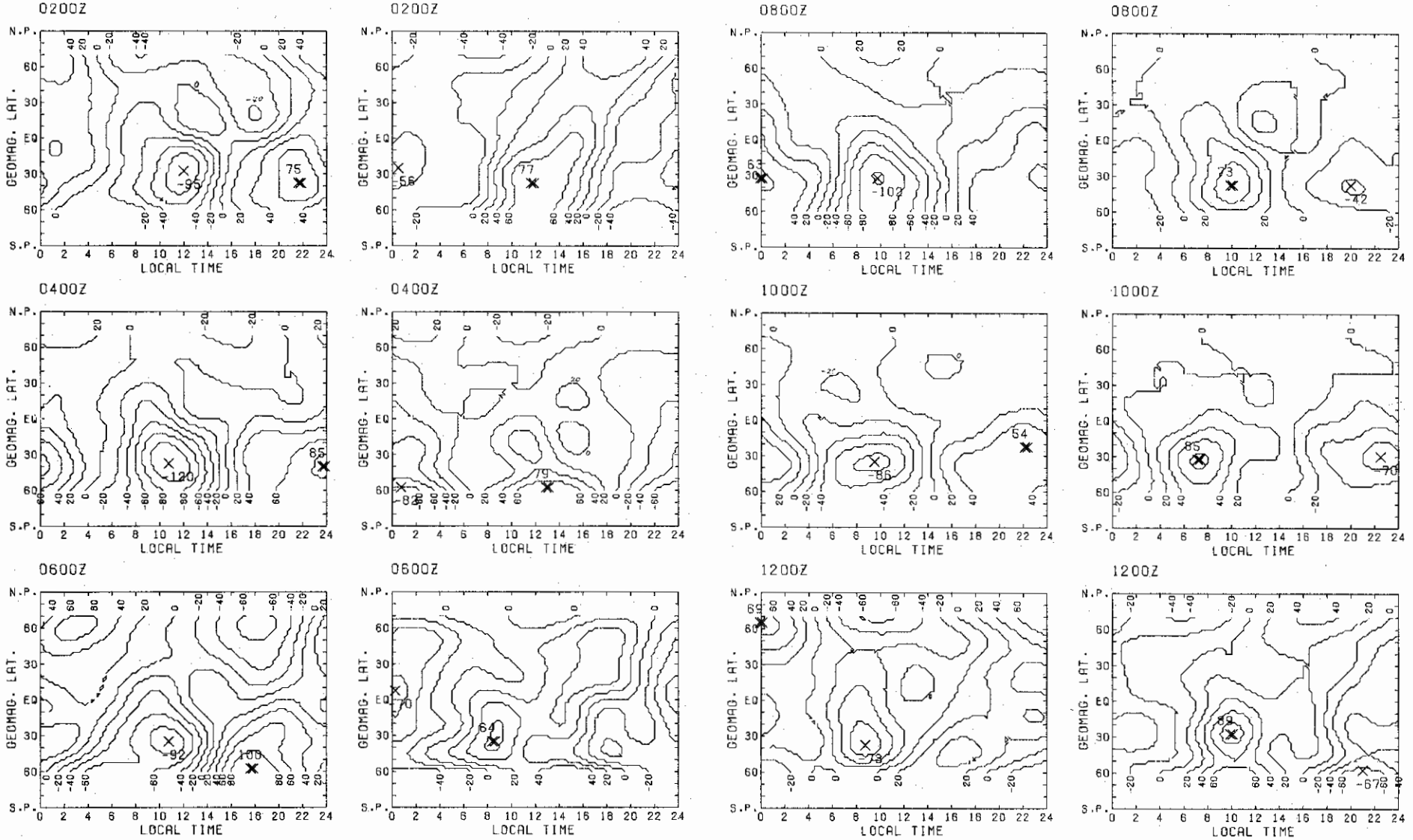

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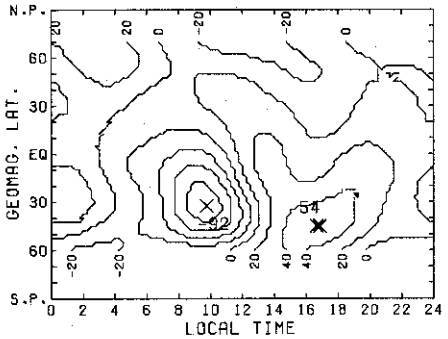

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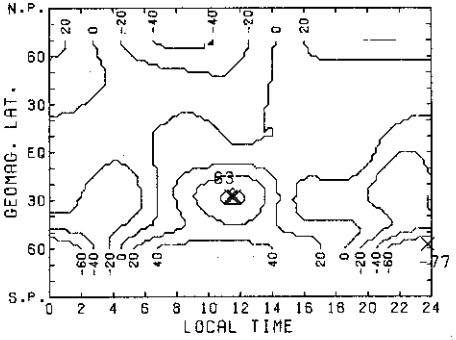

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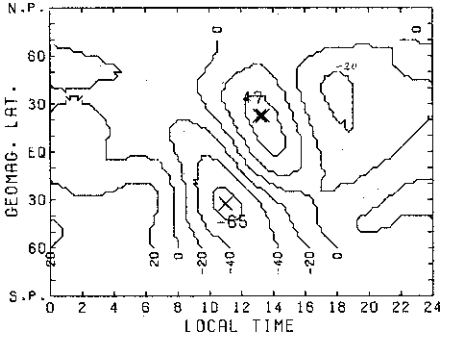

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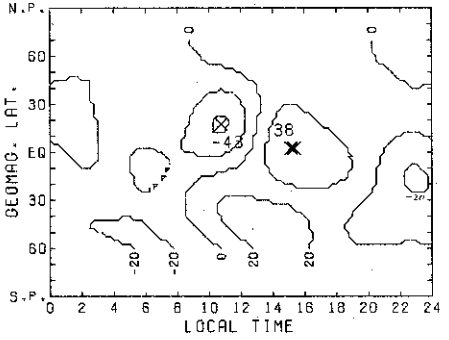

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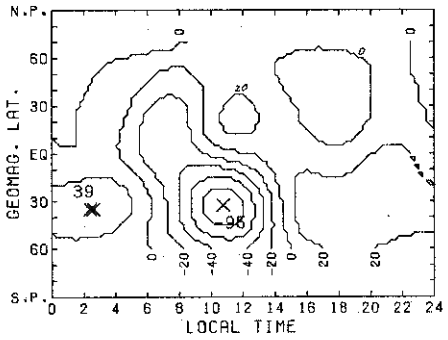

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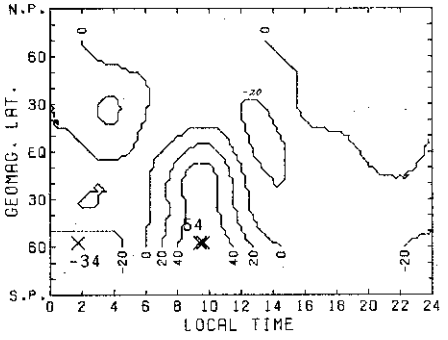

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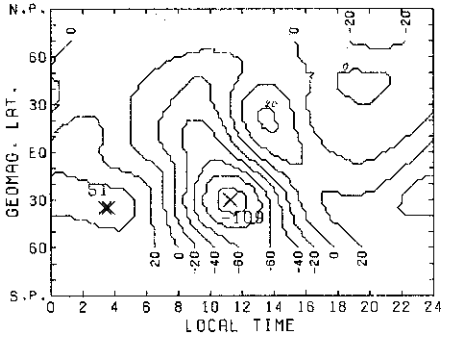

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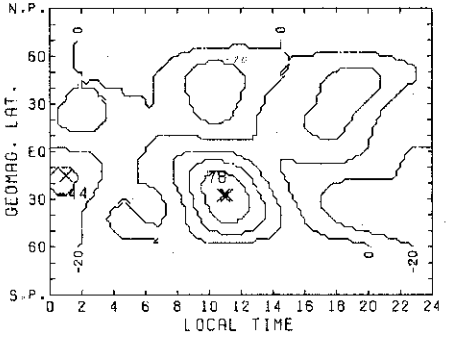

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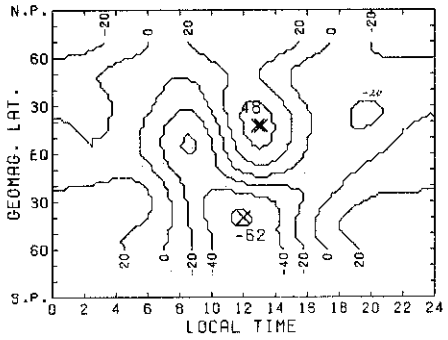

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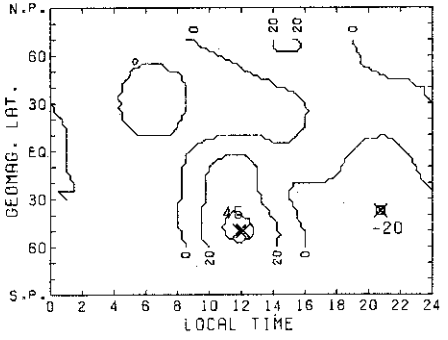

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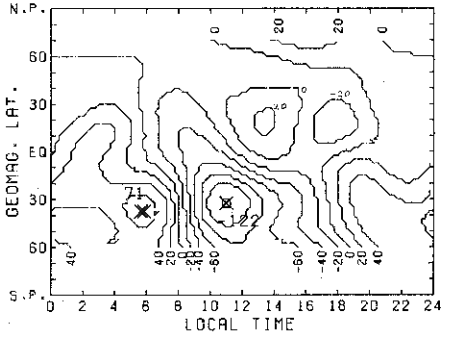

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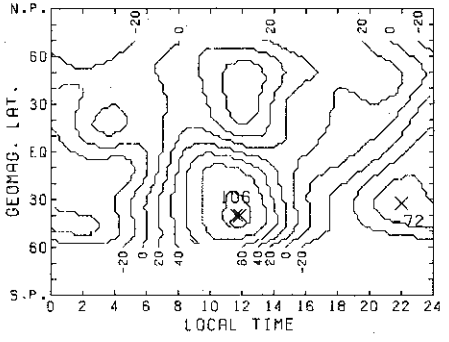

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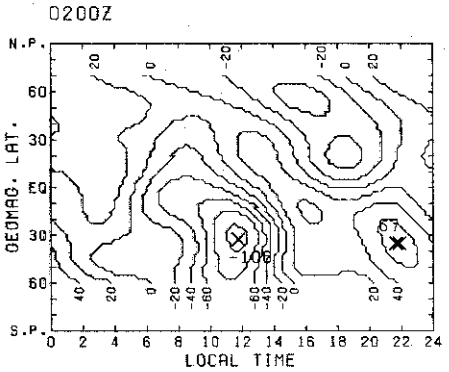

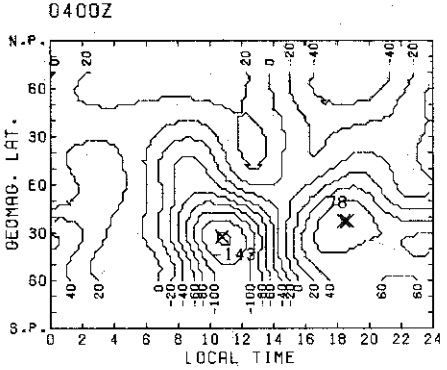

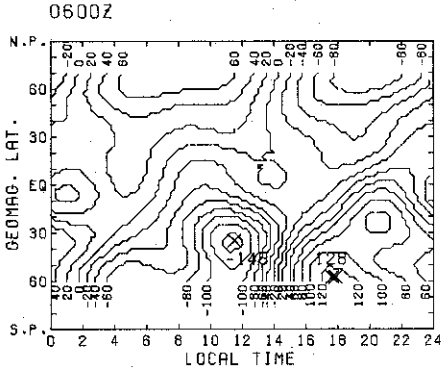

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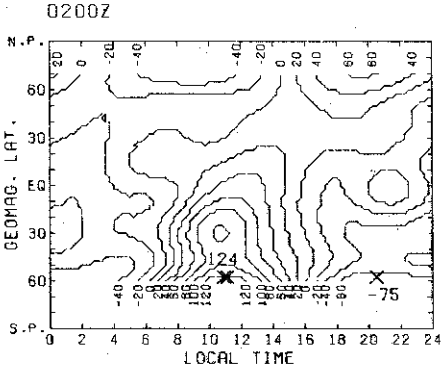

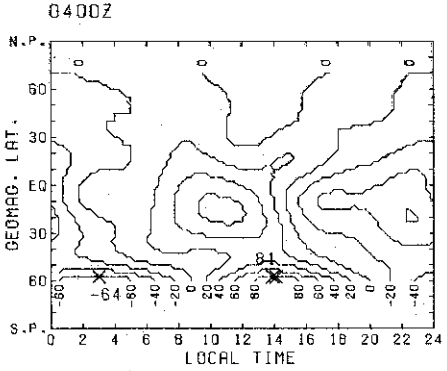

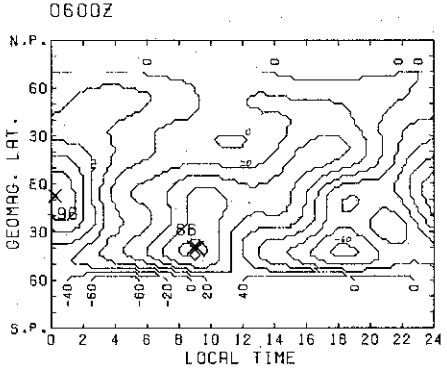

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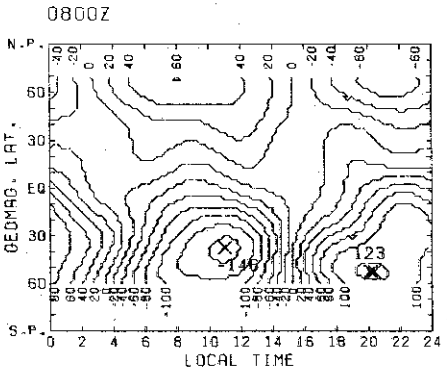

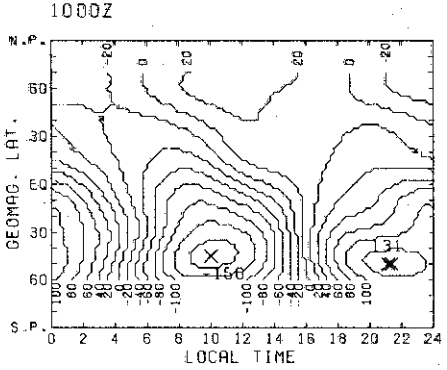

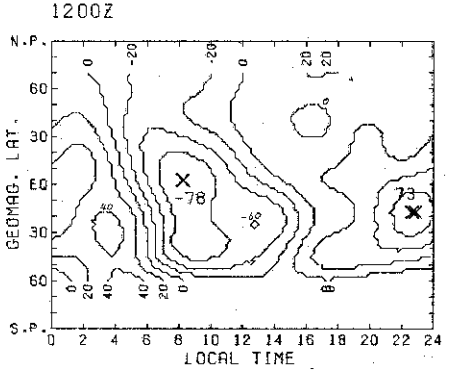

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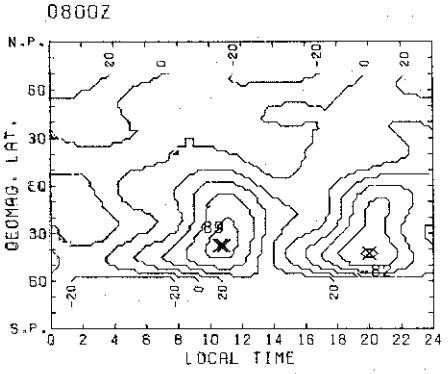

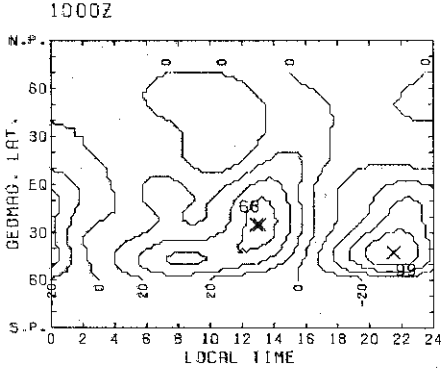

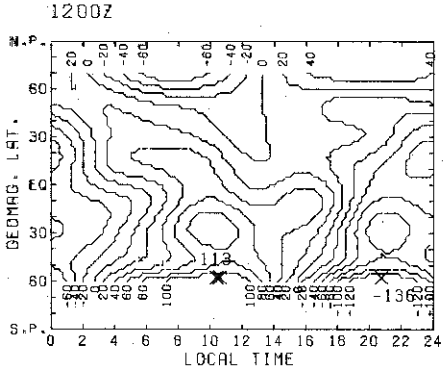

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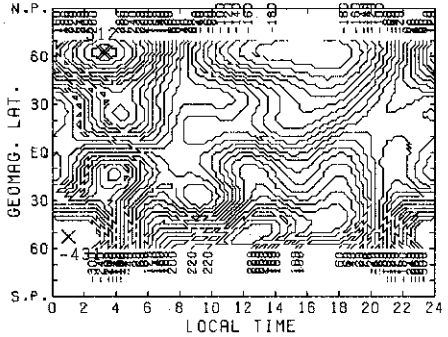

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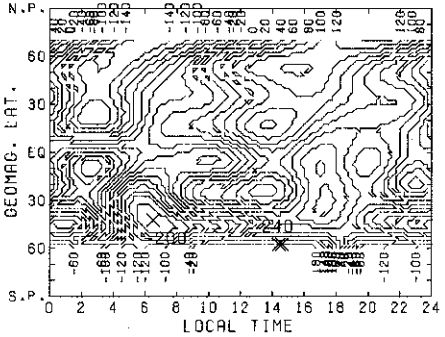

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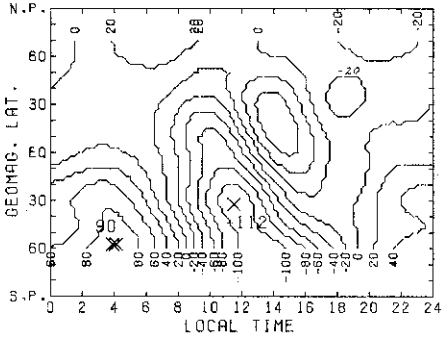

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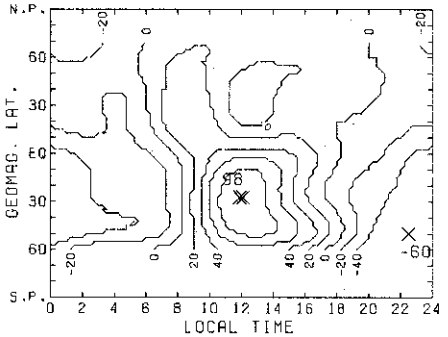

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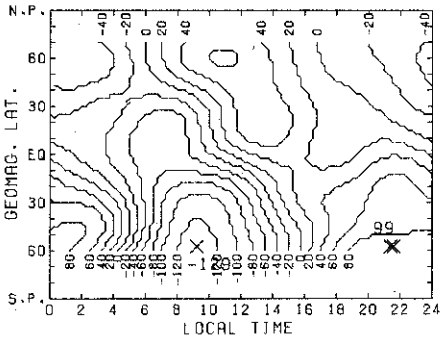

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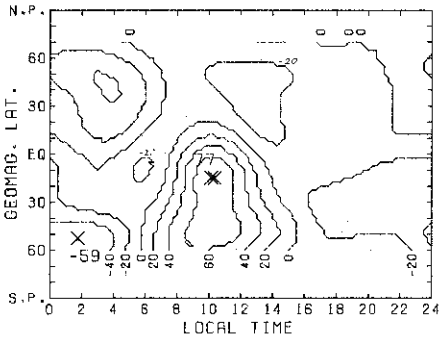

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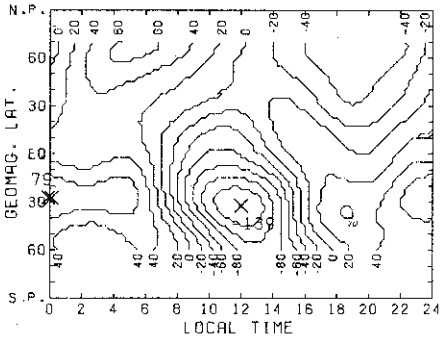

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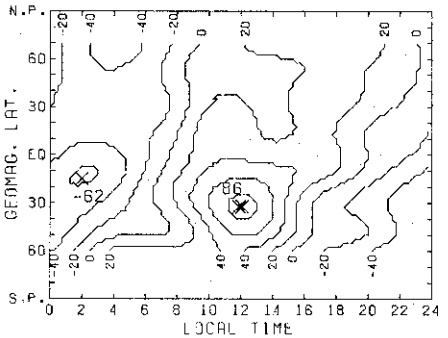

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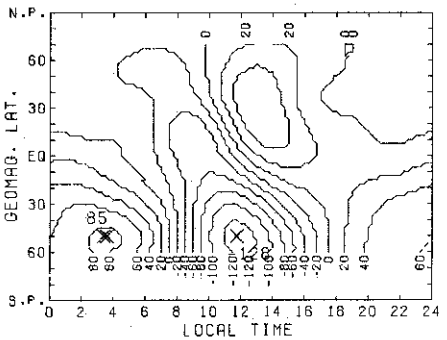

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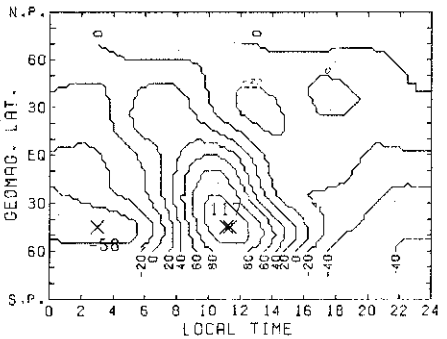

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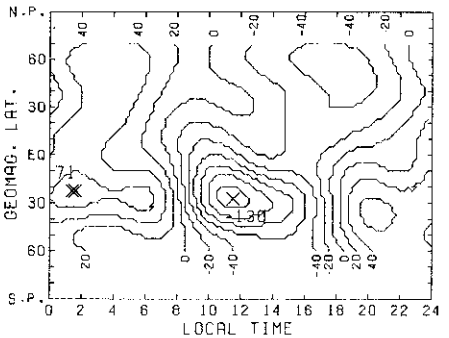

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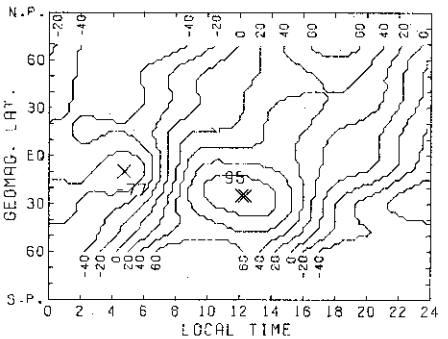

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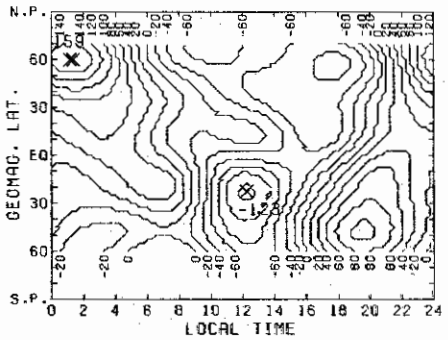

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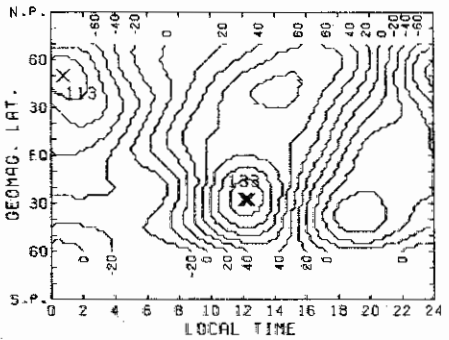

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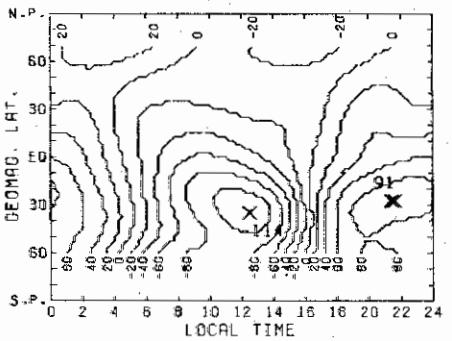

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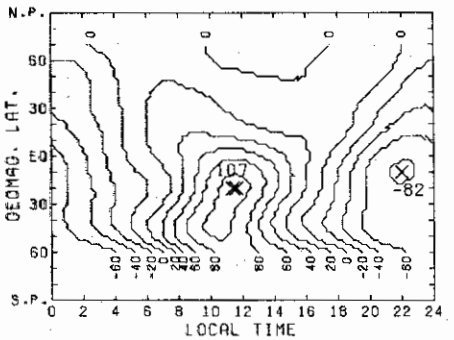

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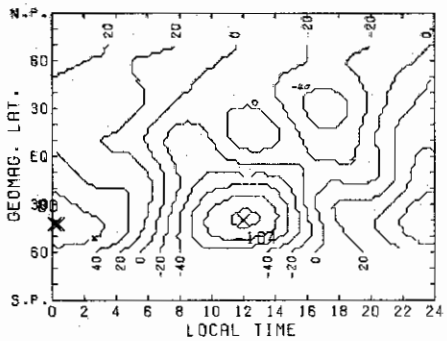

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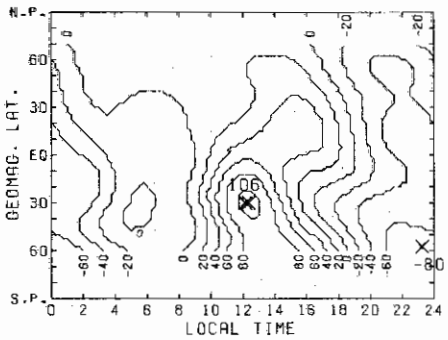

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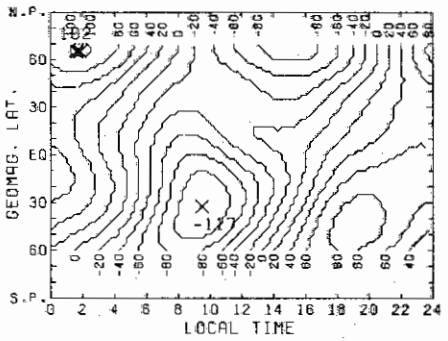

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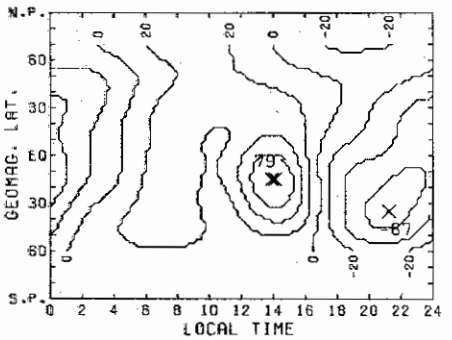

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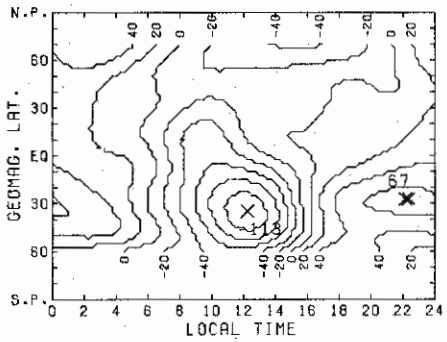

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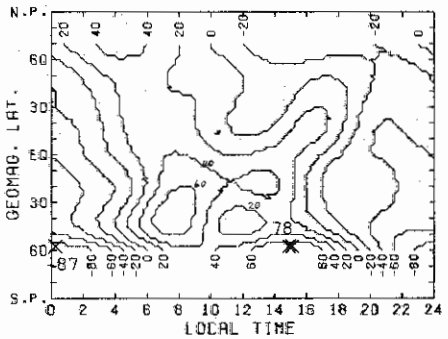

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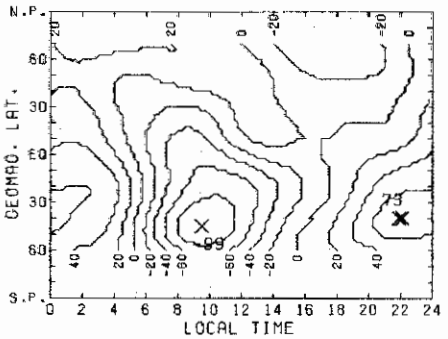

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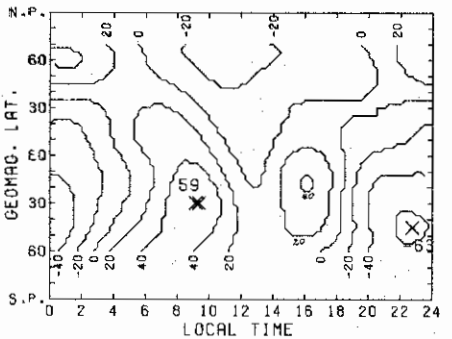

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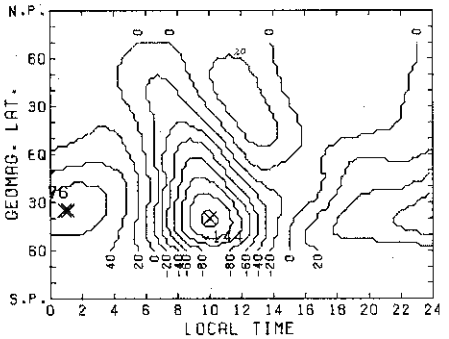

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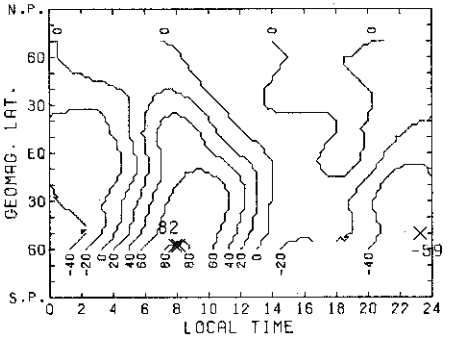

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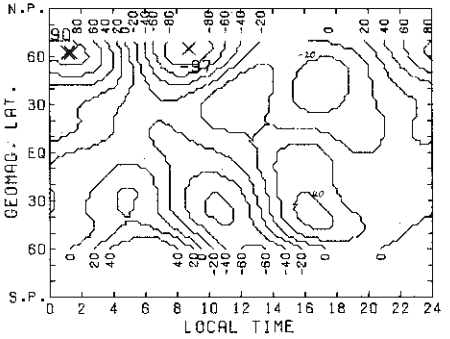

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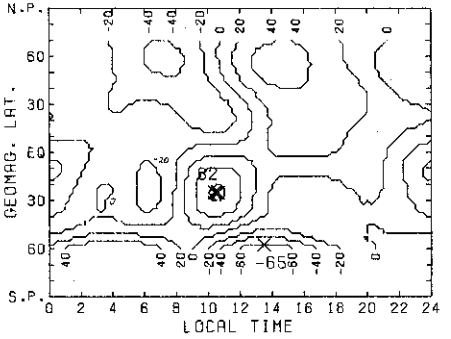

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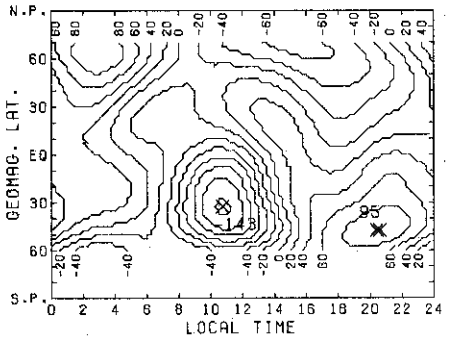

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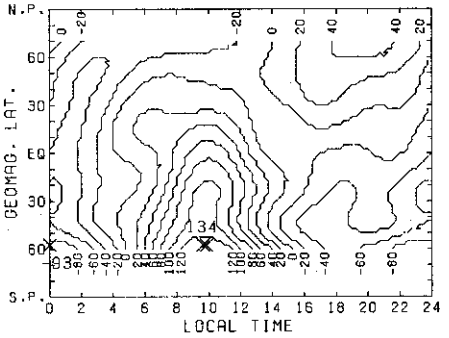

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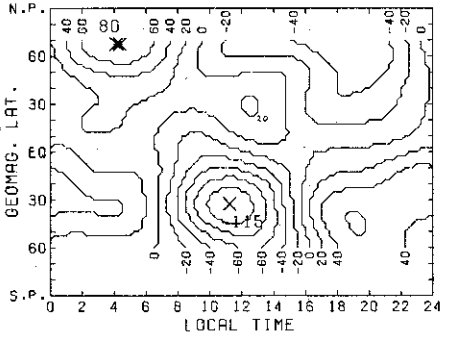

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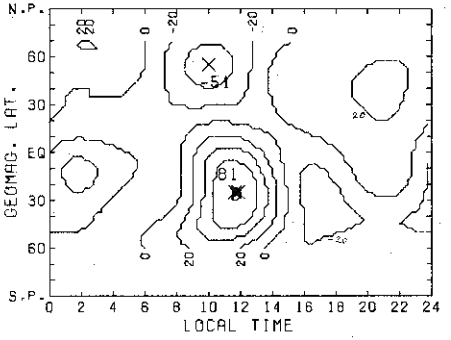

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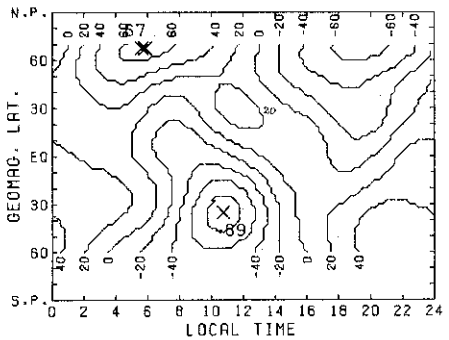

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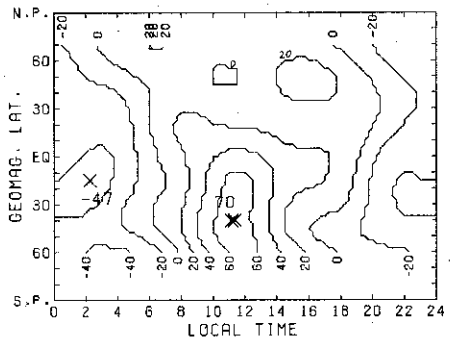

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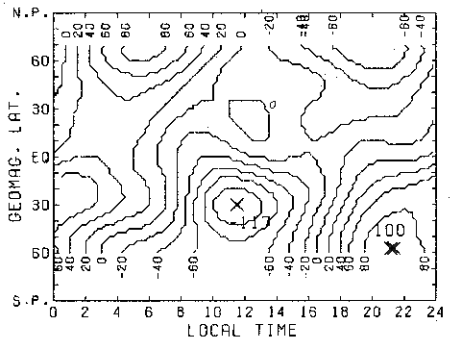

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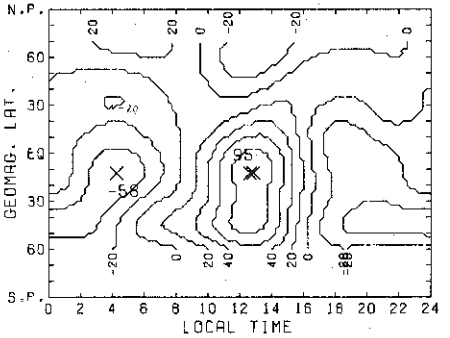

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EXTERNAL

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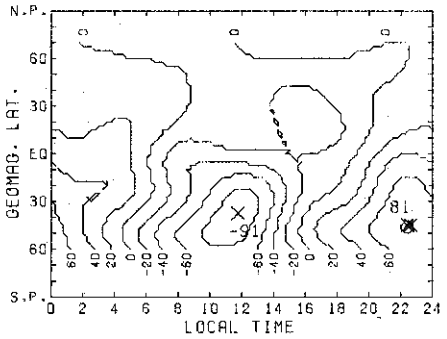

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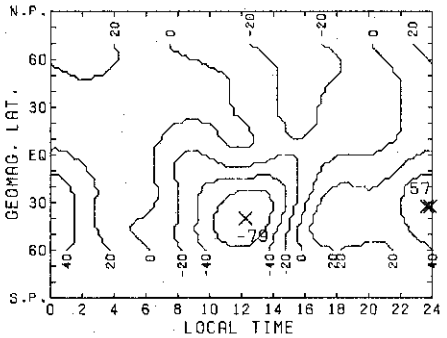

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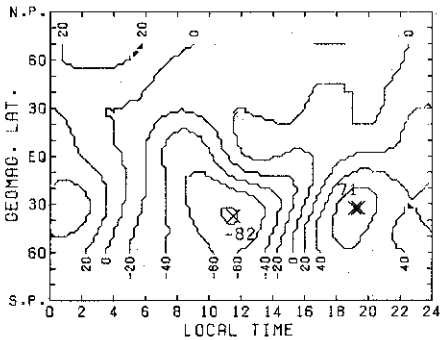

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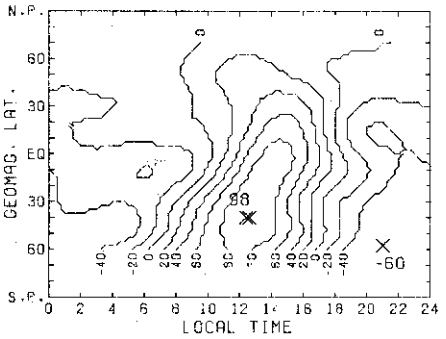

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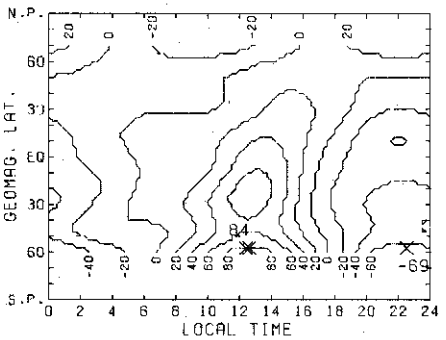

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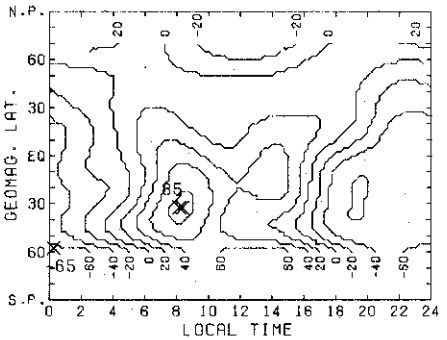

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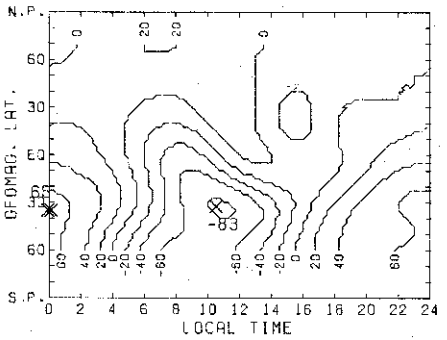

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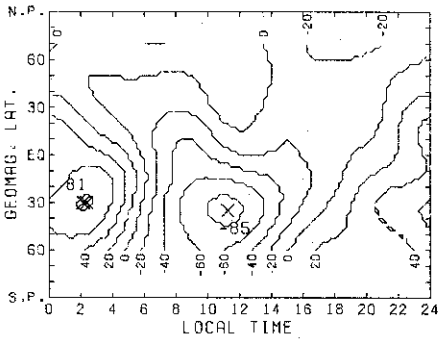

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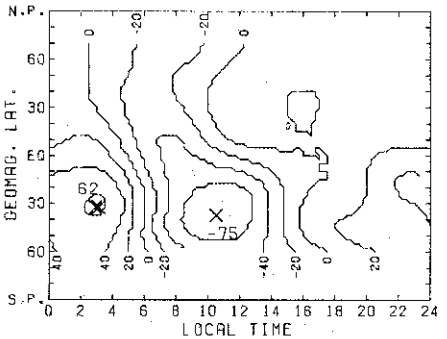

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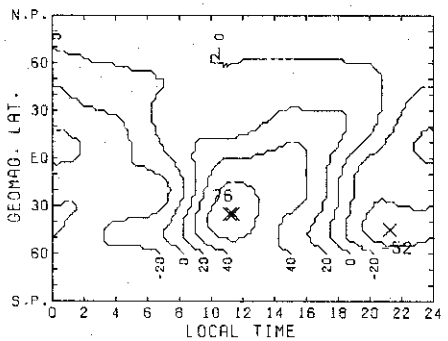

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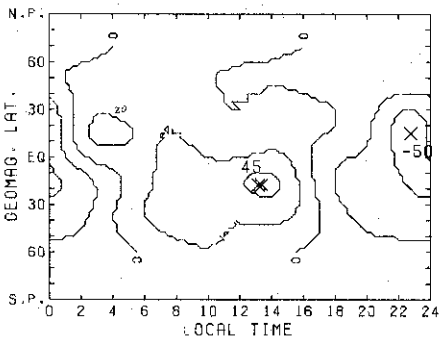

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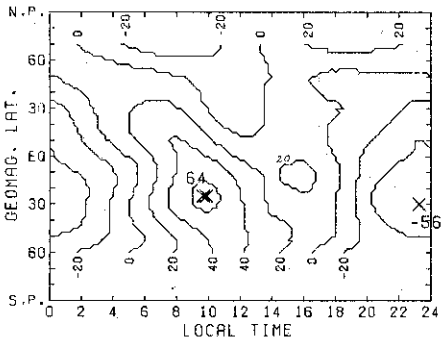

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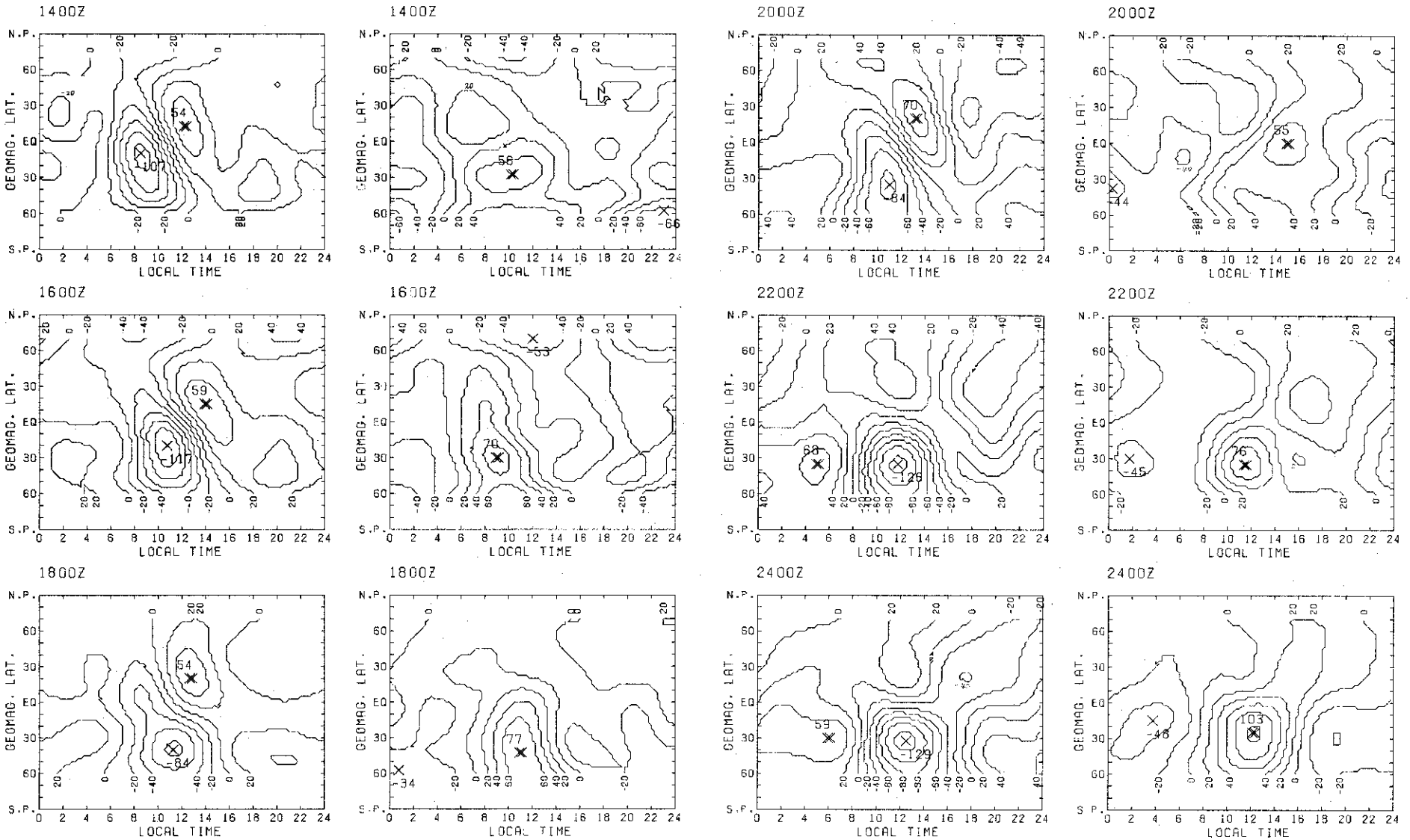

DEC. 19, 1964

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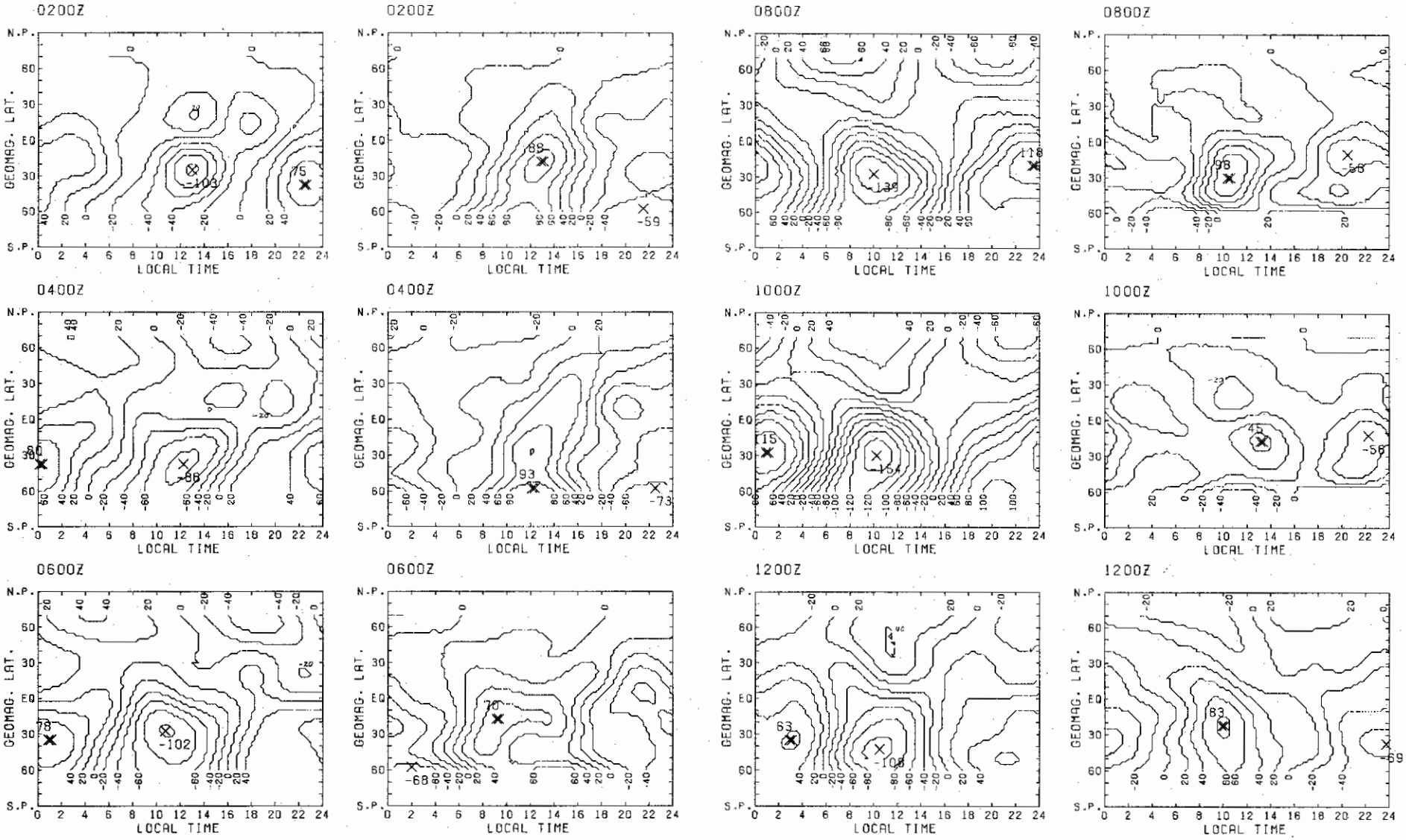

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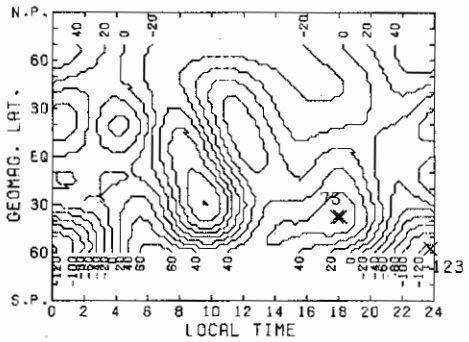

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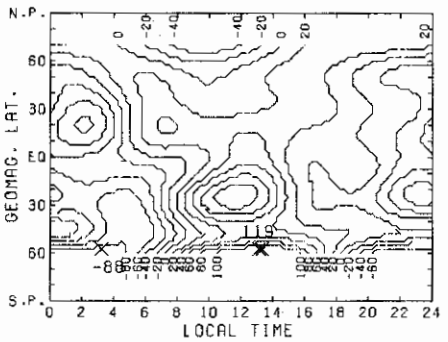

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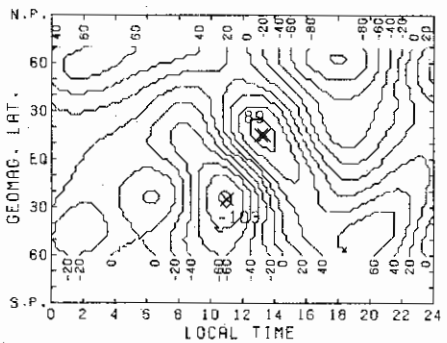

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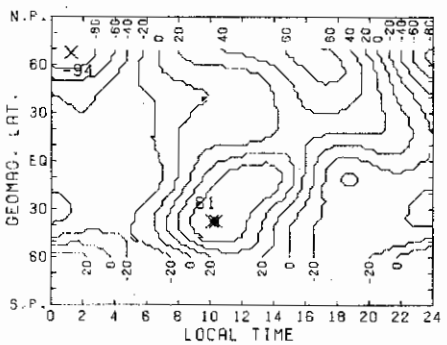

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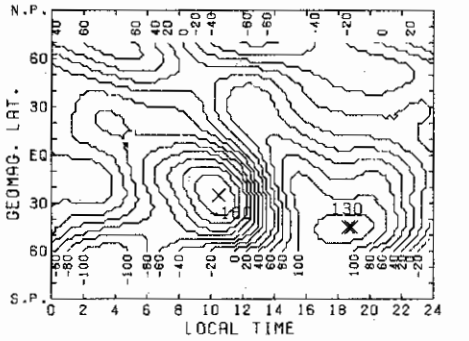

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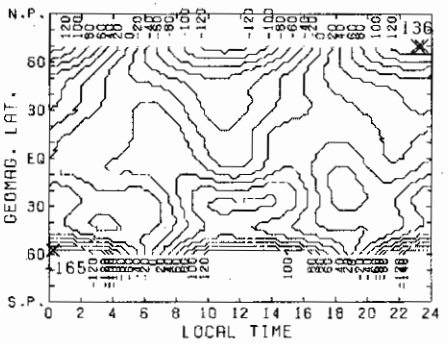

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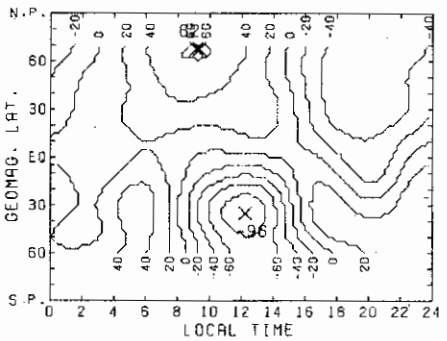

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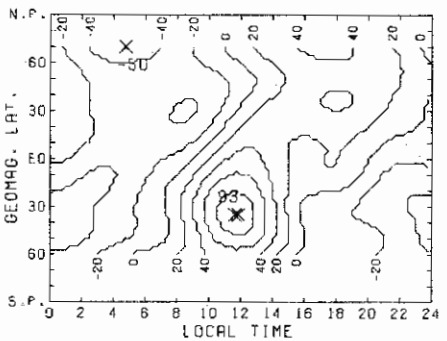

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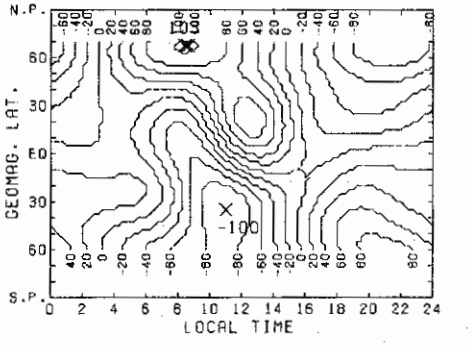

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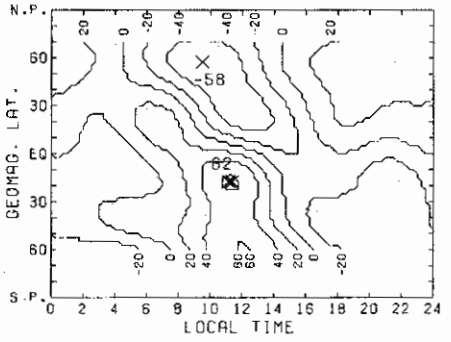

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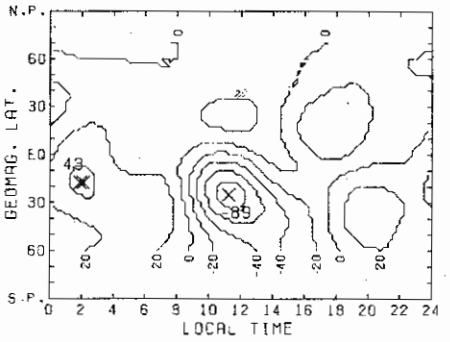

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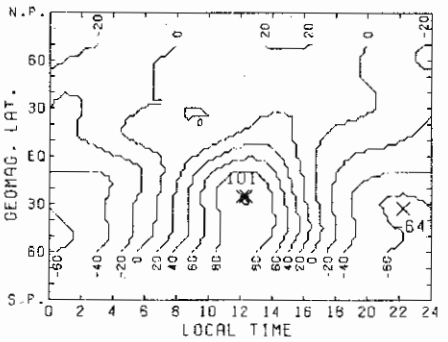

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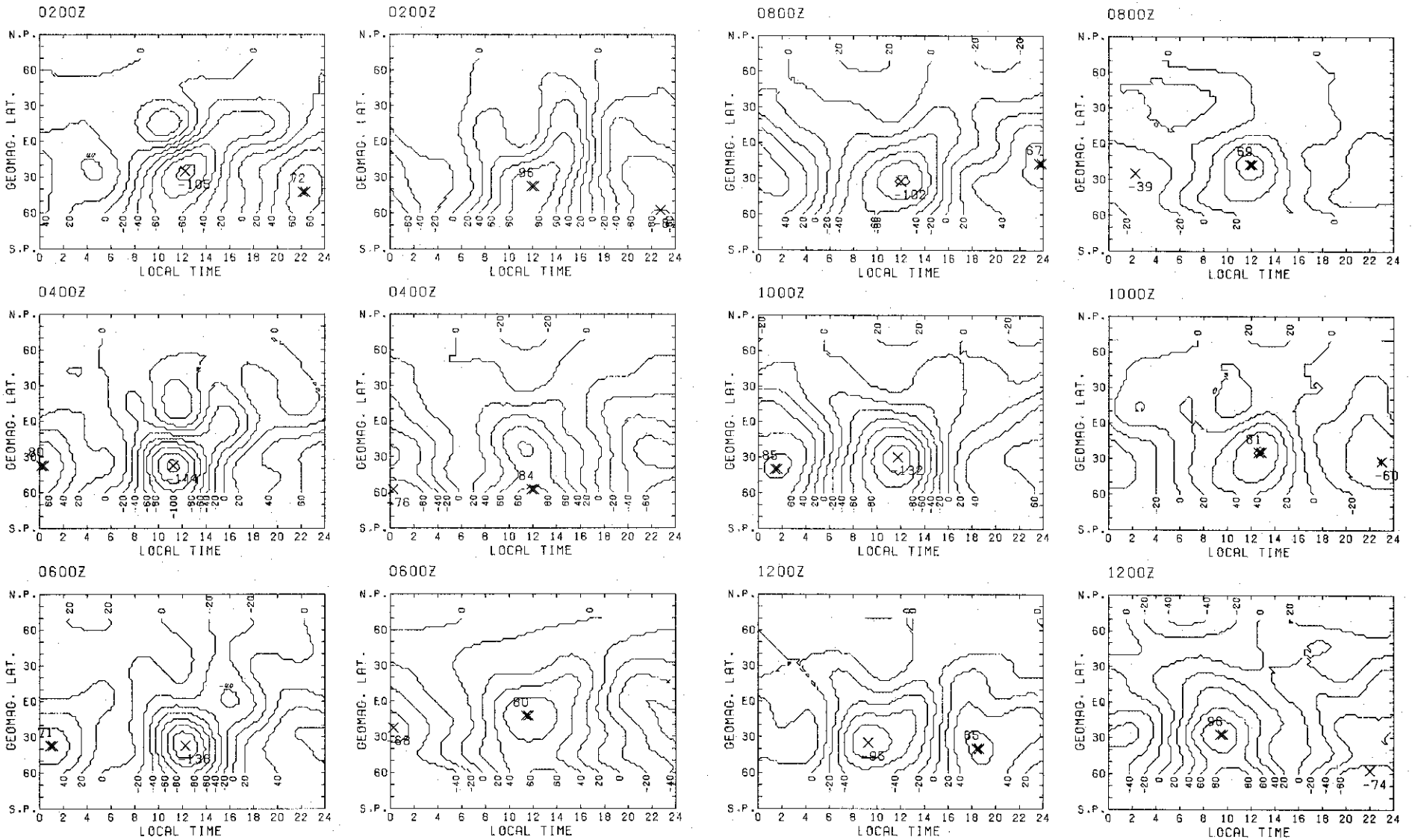

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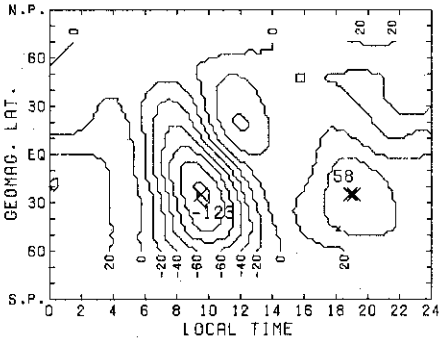

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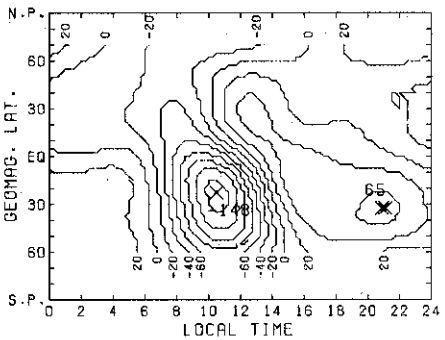

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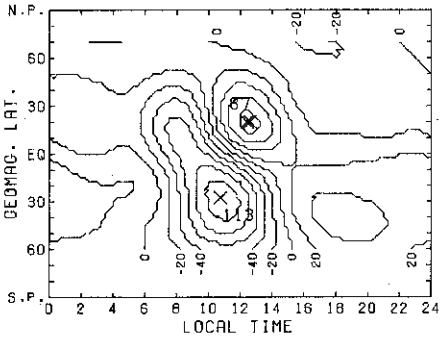

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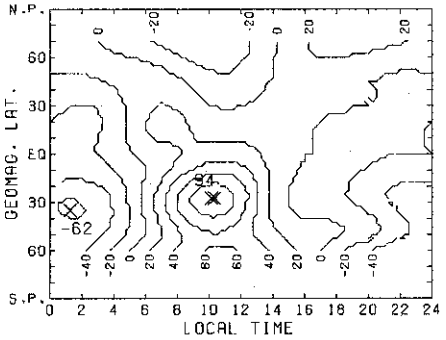

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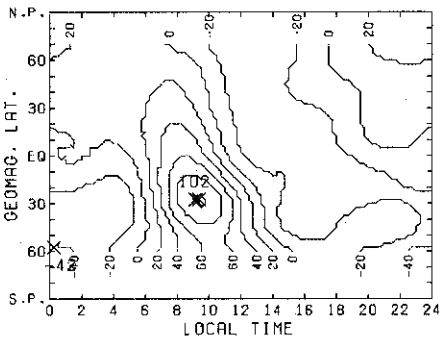

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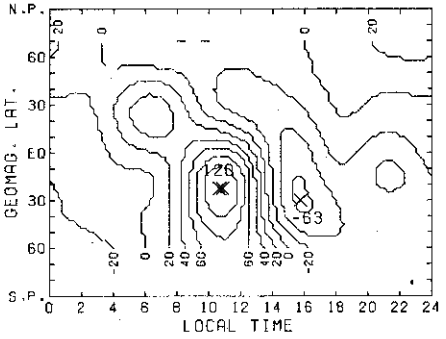

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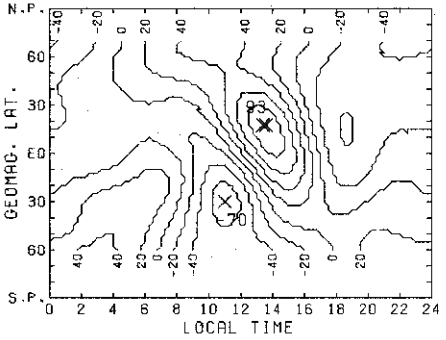

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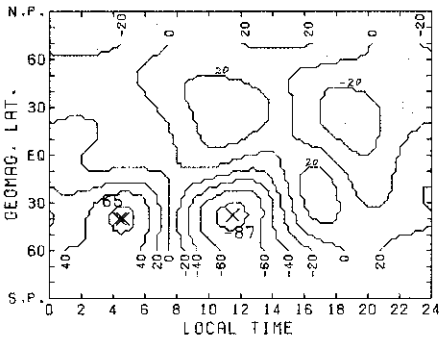

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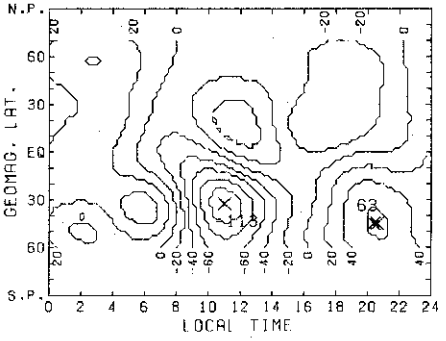

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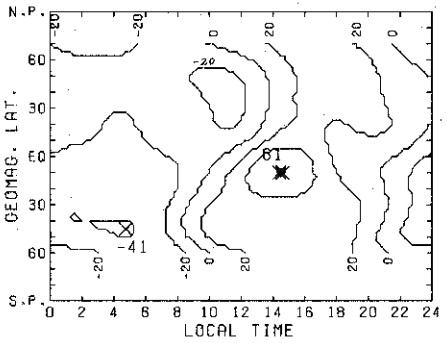

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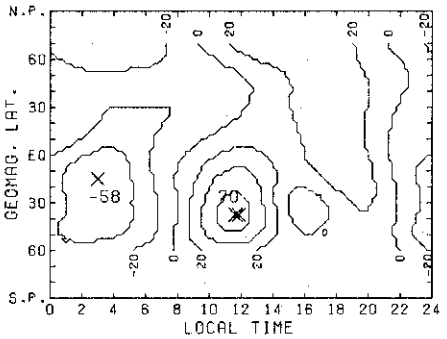

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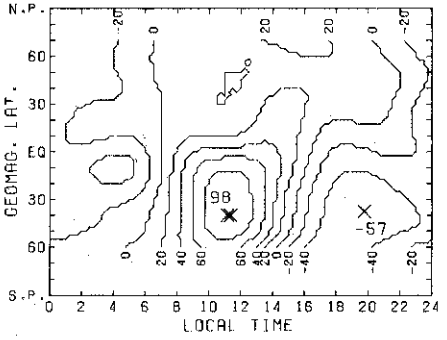

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EXTERNAL

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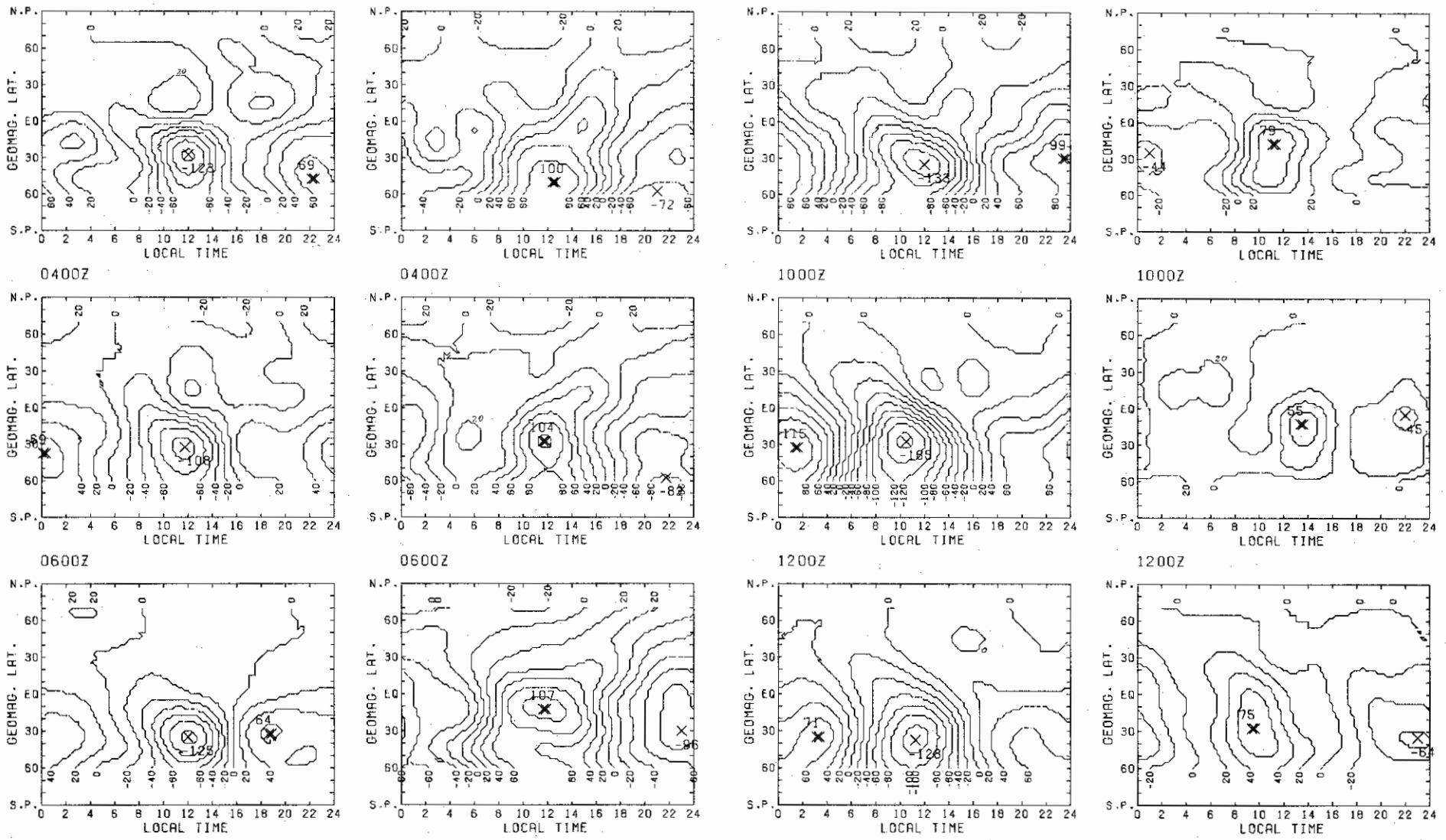
EXTERNAL

INTERNAL



DEC. 21, 1964

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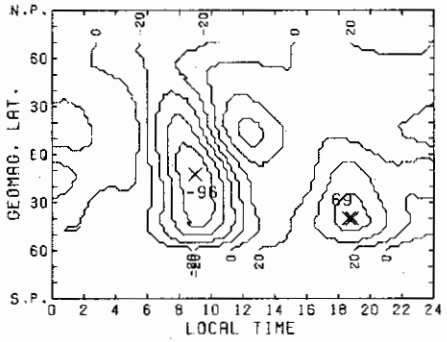

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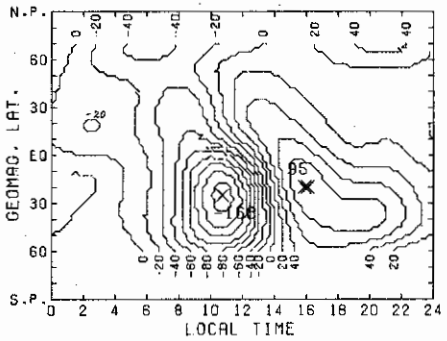

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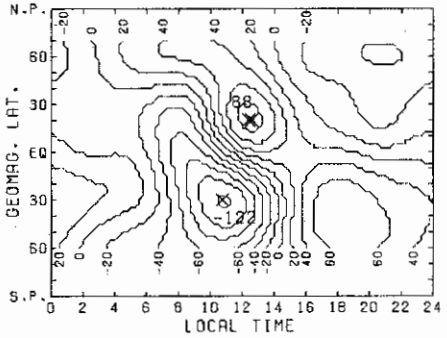

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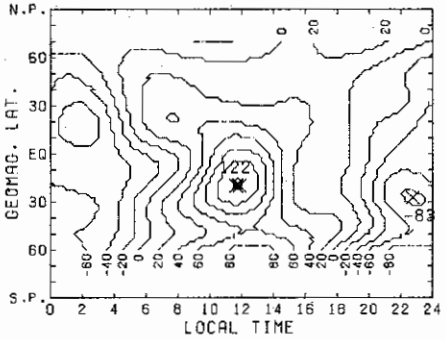

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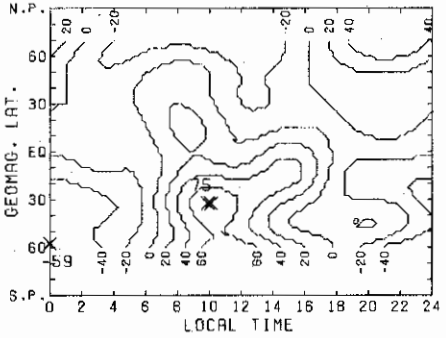

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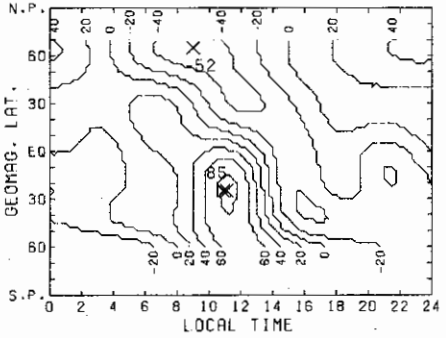

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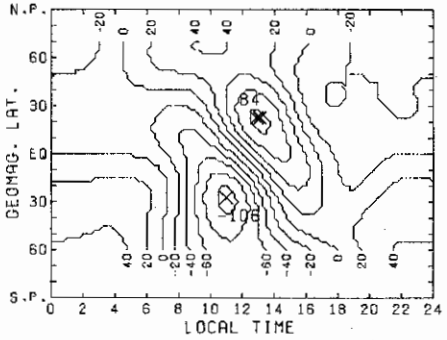

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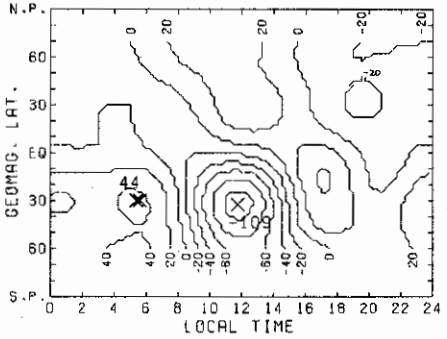

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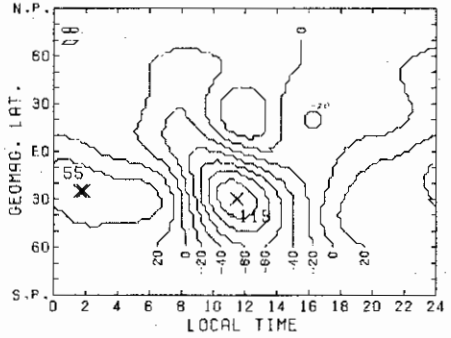

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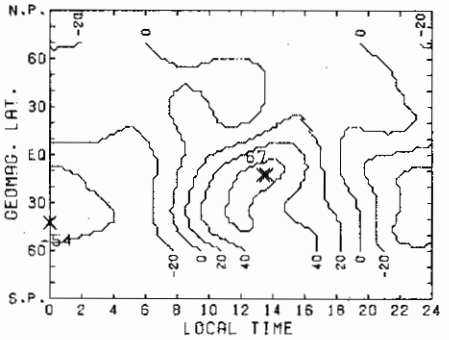

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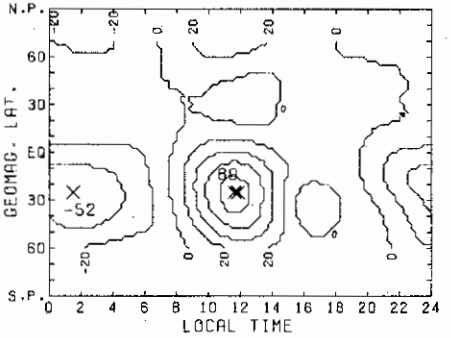

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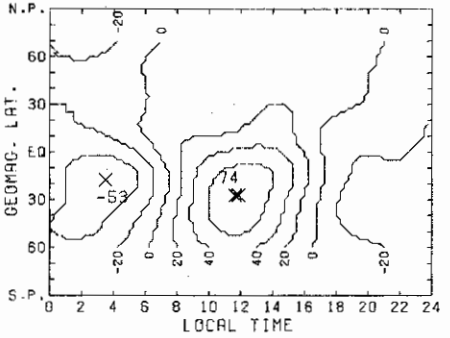

DEC. 22, 1964

EXTERNAL

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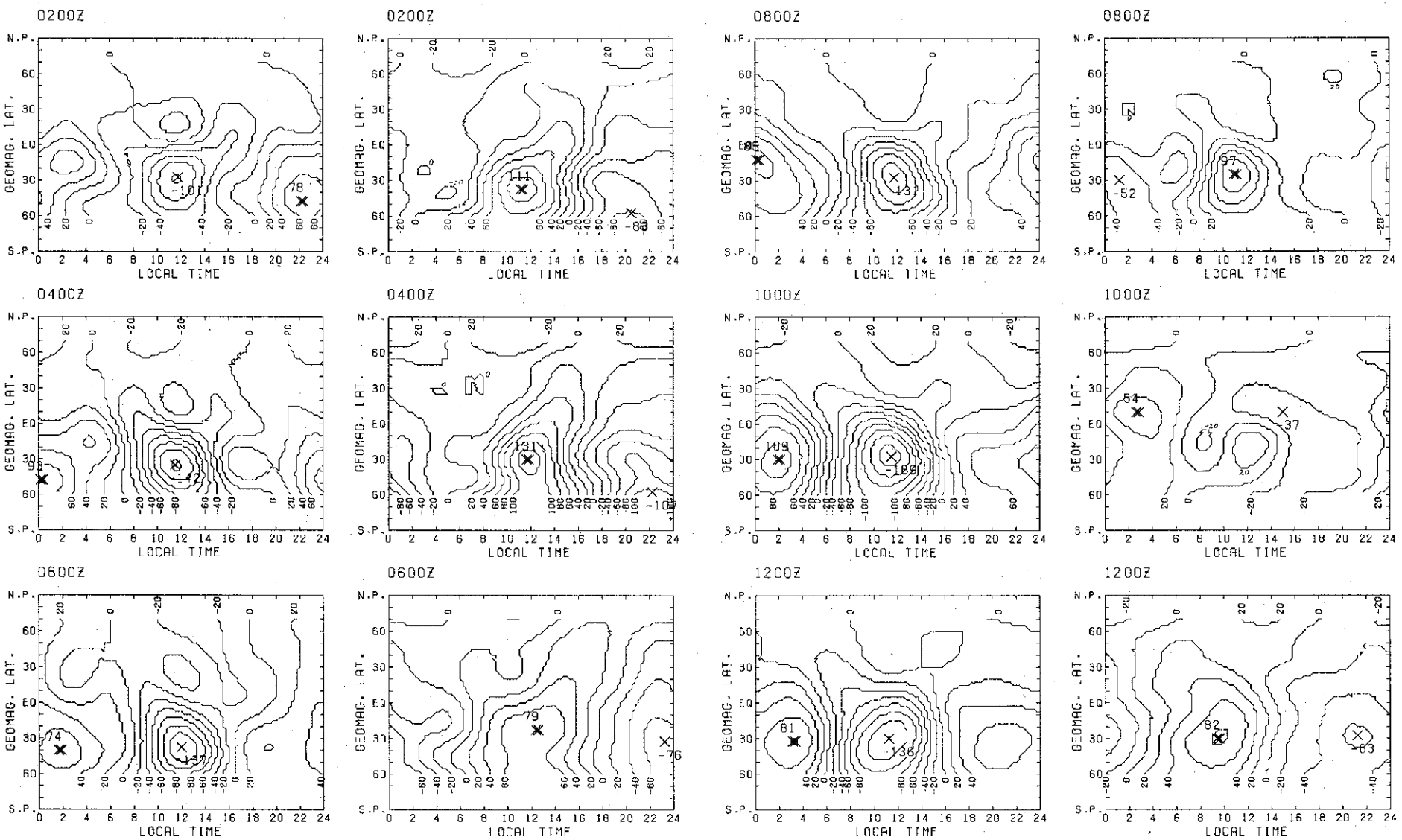

DEC. 22, 1964

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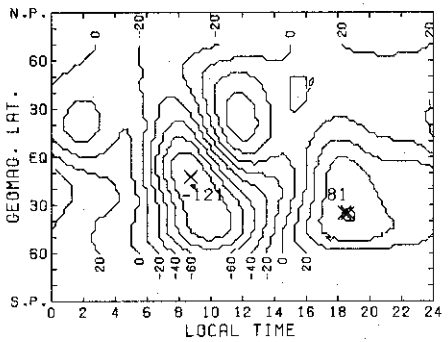

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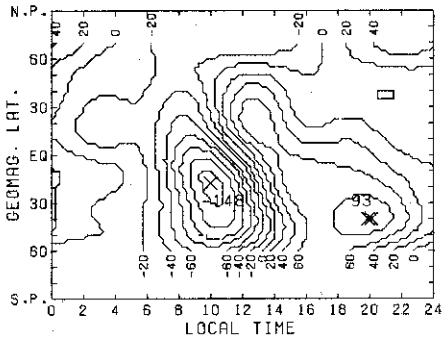

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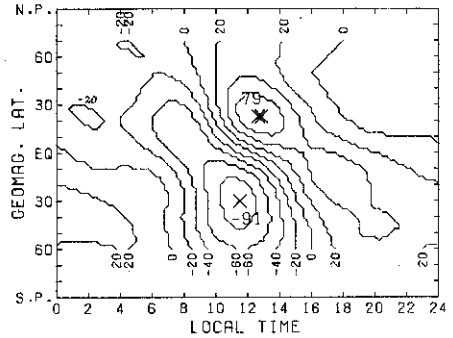

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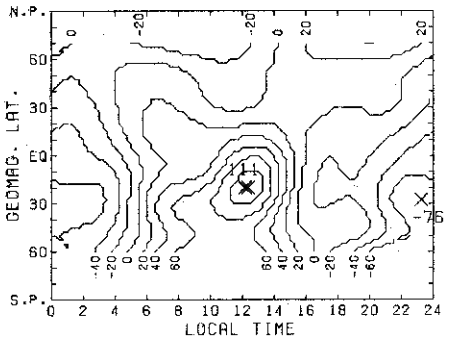

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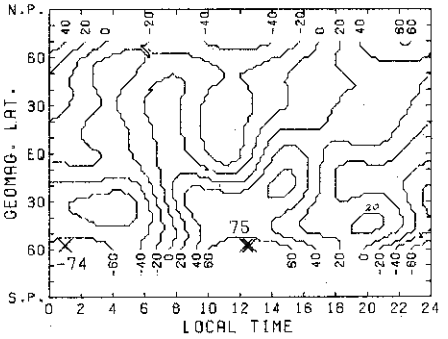

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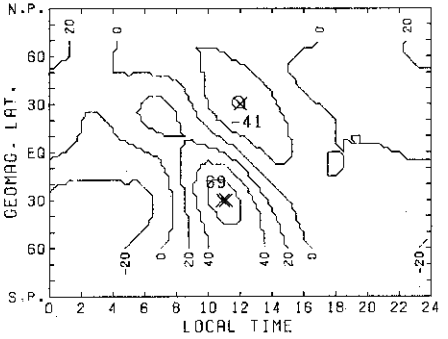

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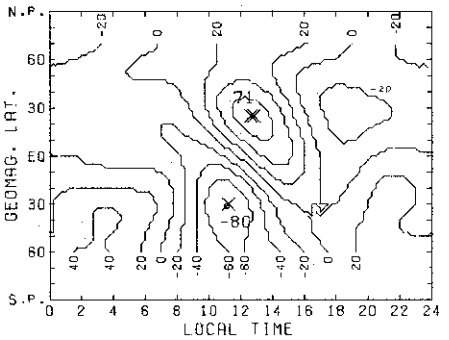

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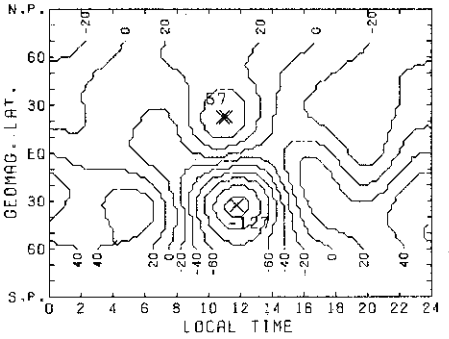

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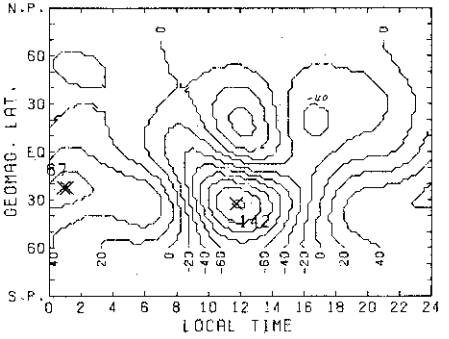

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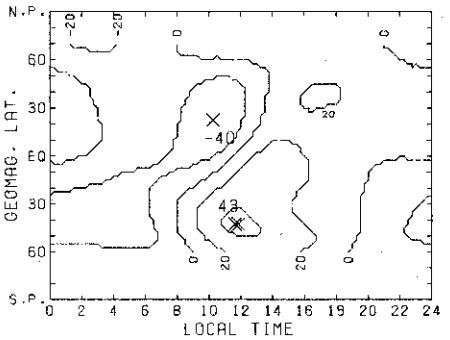

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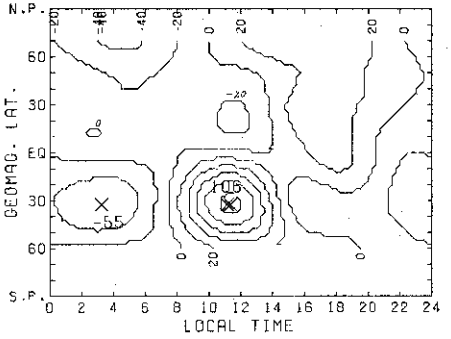

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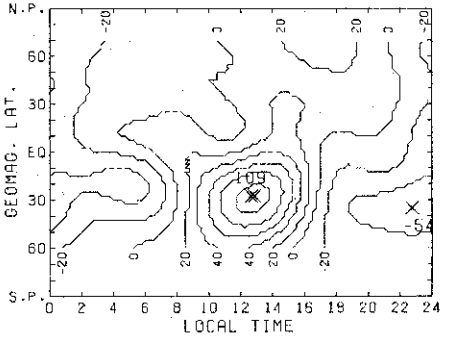

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EXTERNAL

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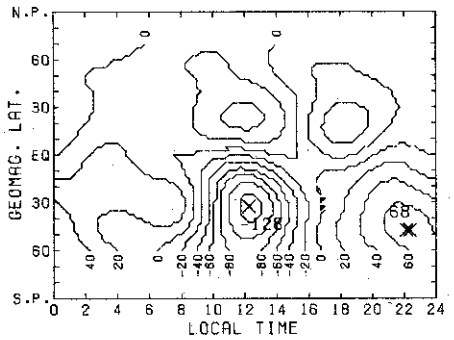

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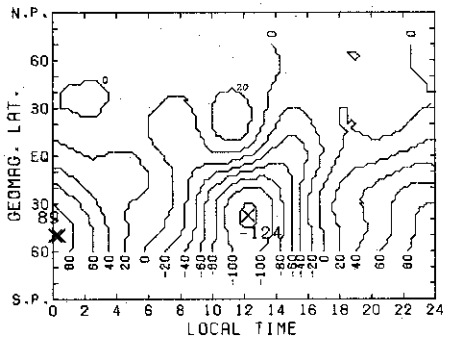

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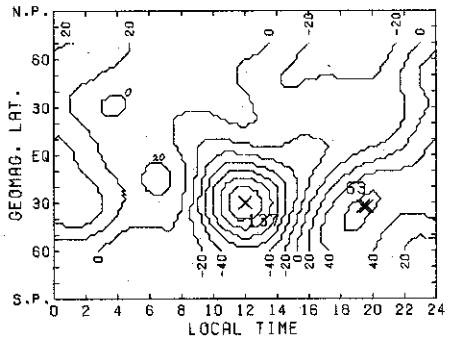

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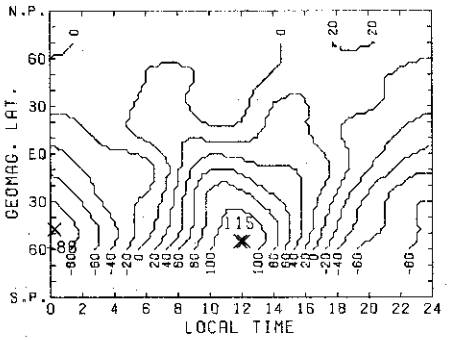

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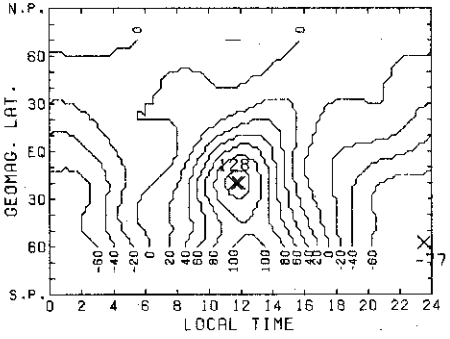

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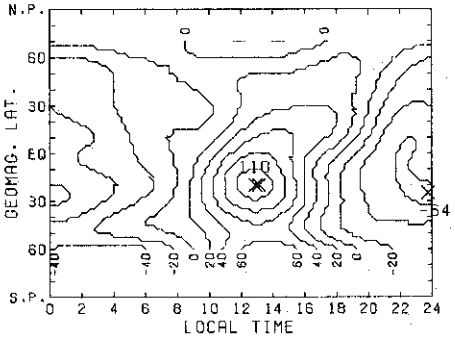

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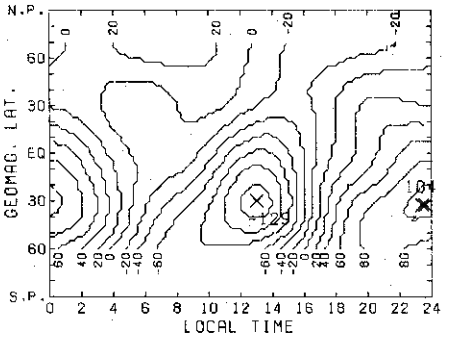

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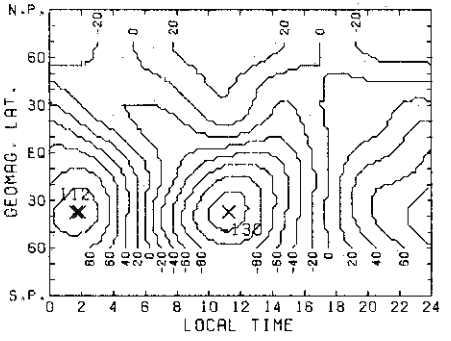

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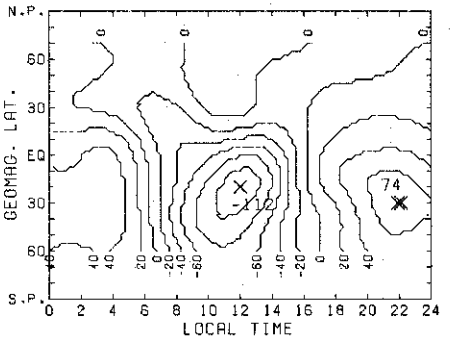

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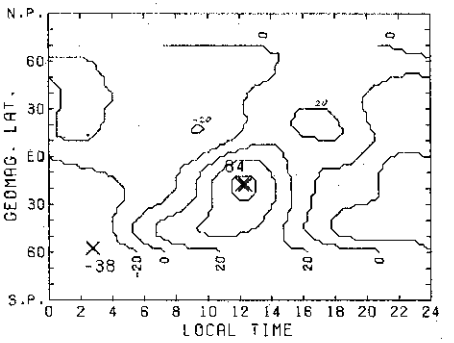

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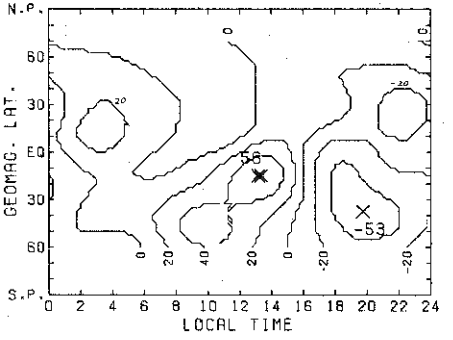

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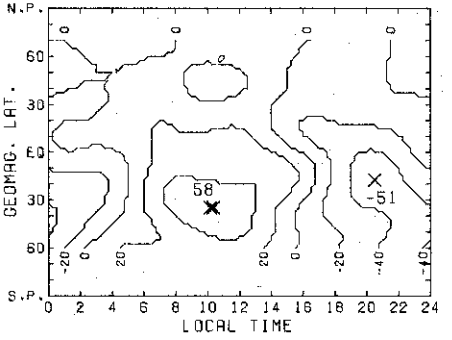

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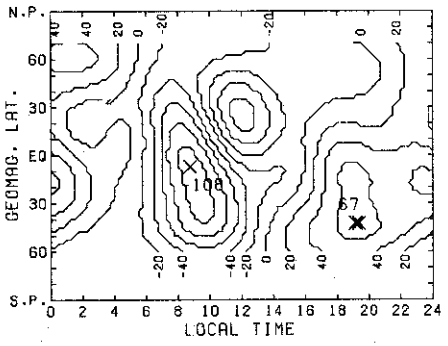

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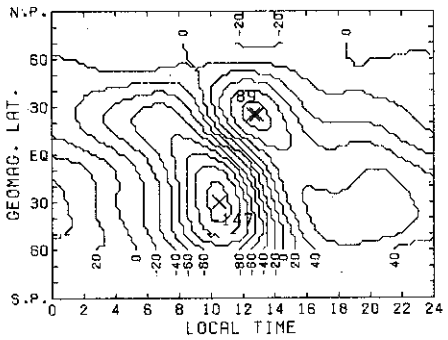

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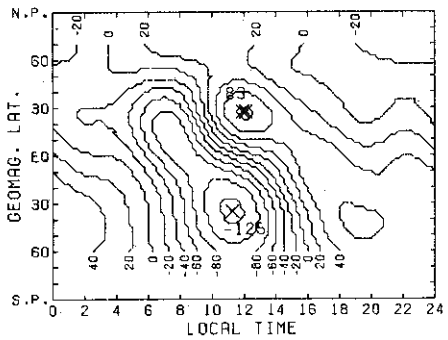

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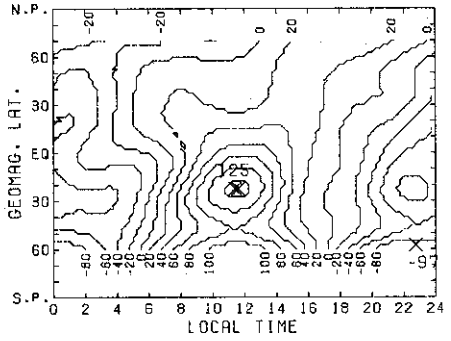

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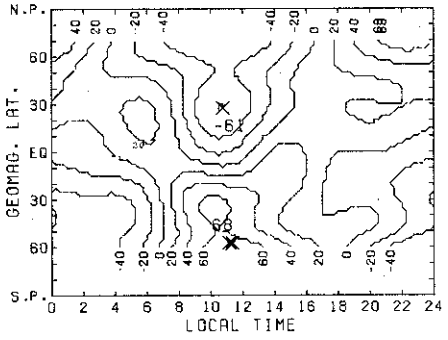

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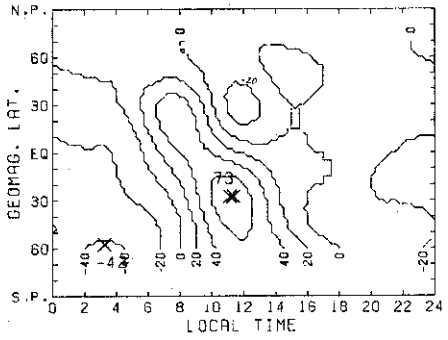

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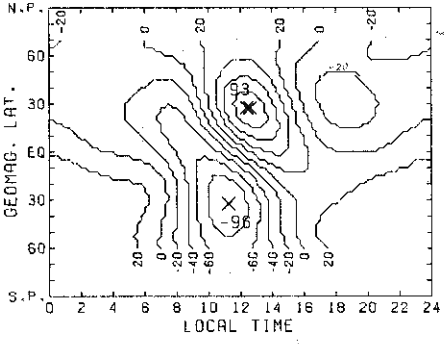

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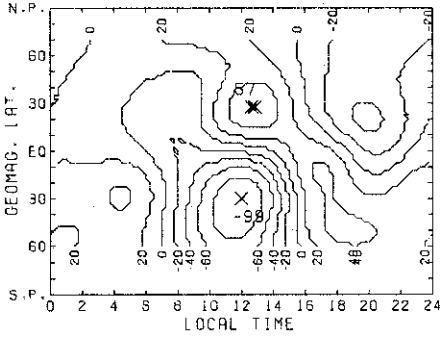

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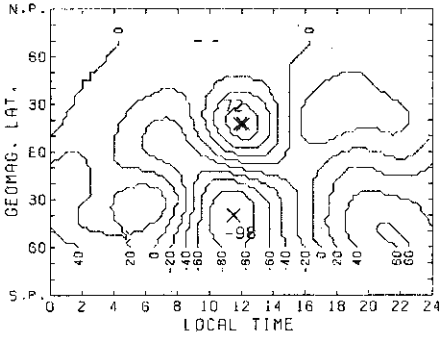

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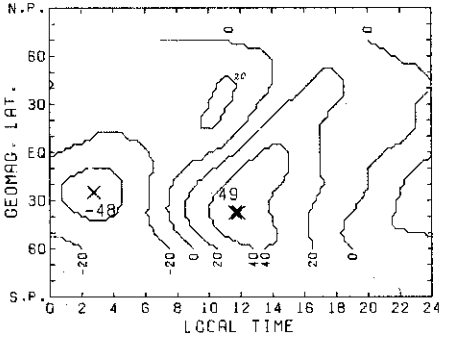

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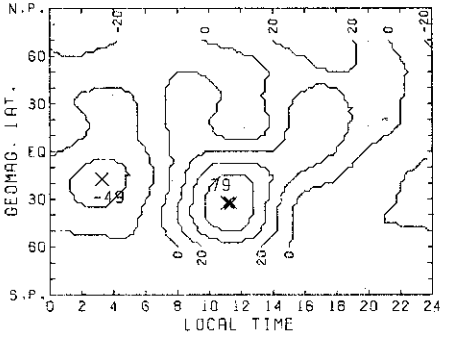

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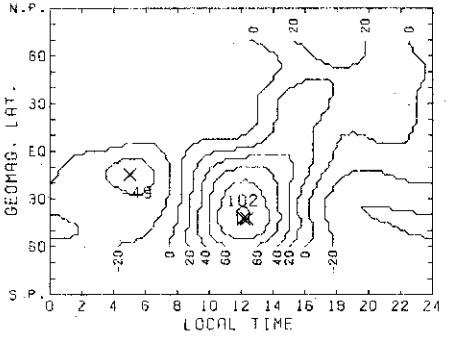

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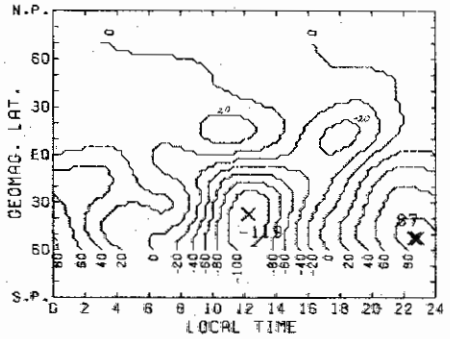

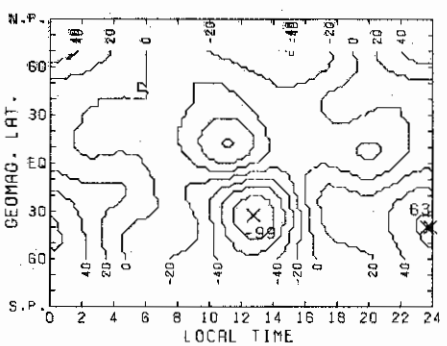

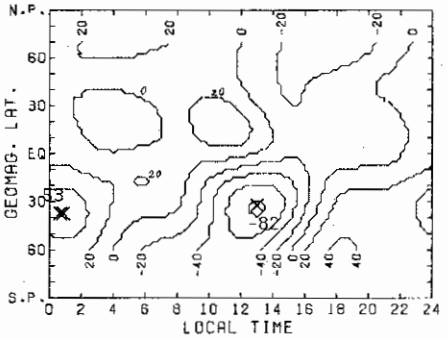

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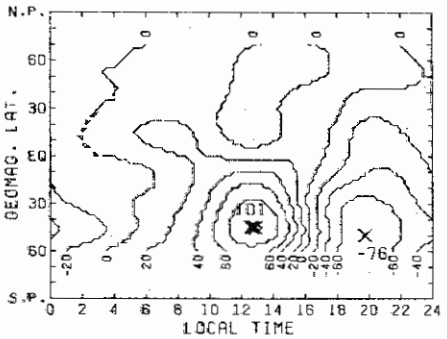

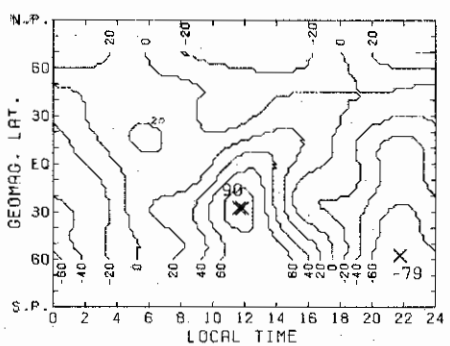

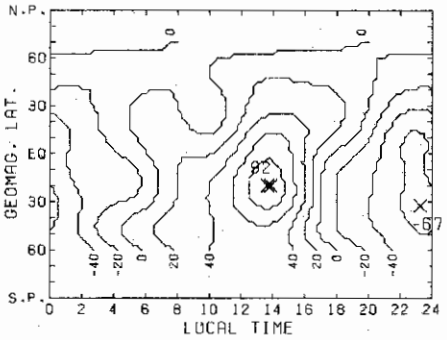

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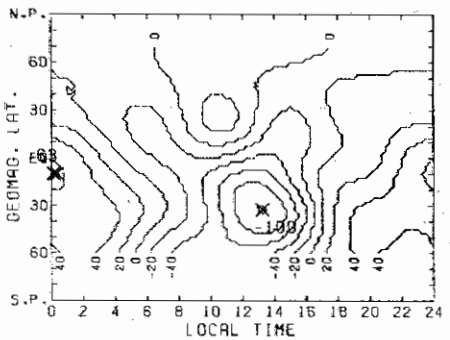

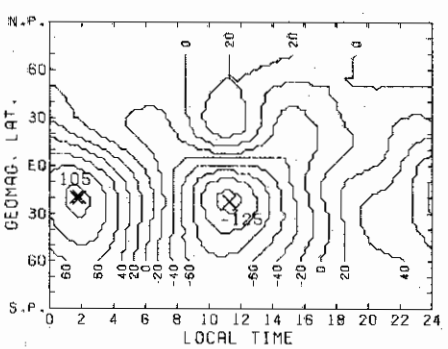

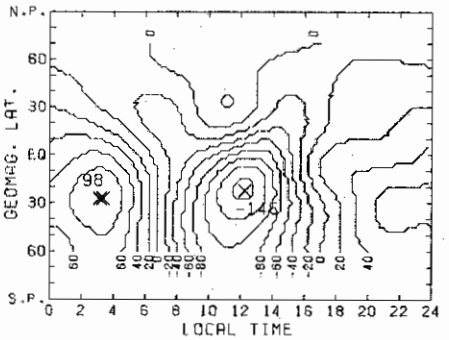

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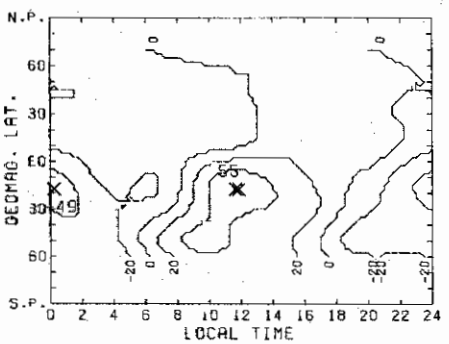

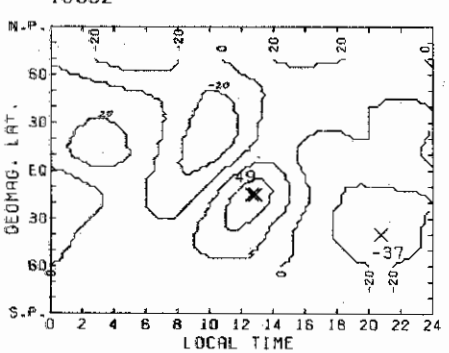

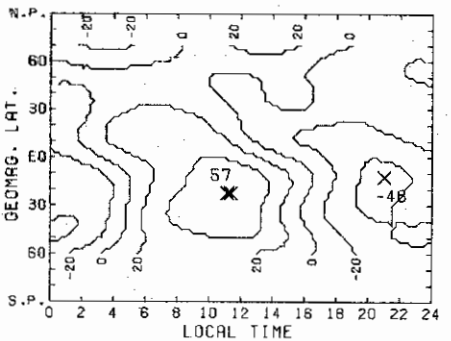

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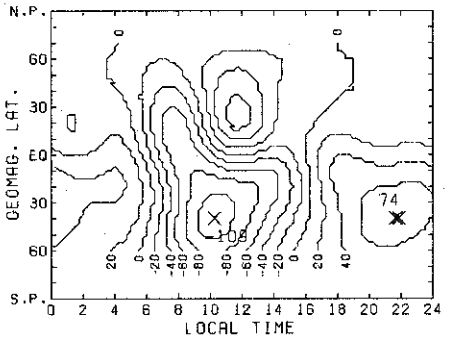

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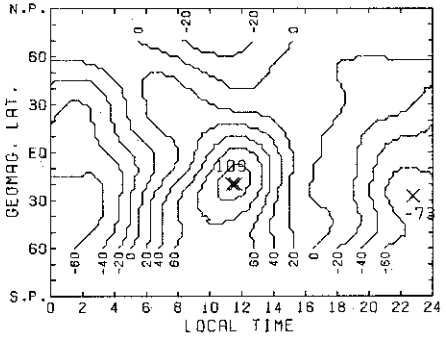

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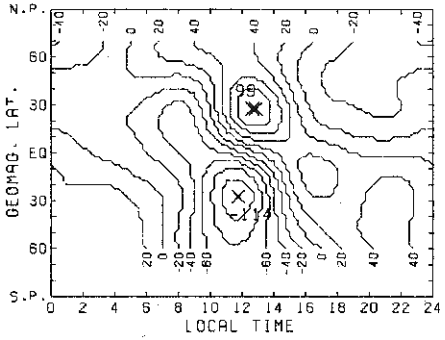

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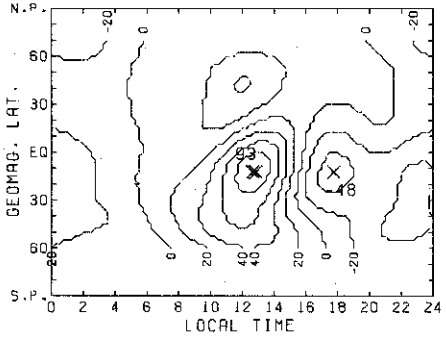

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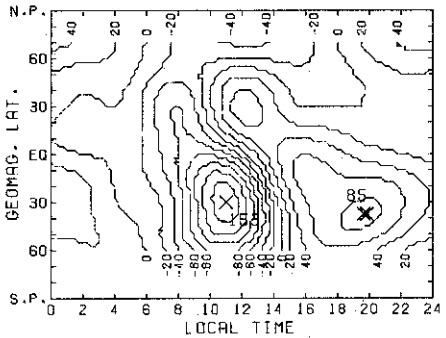

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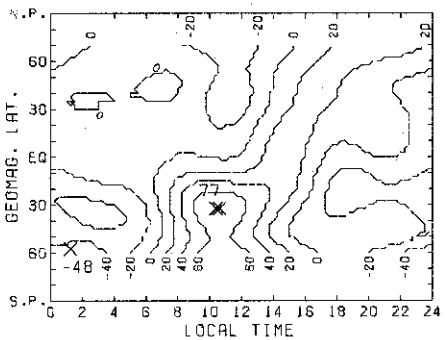

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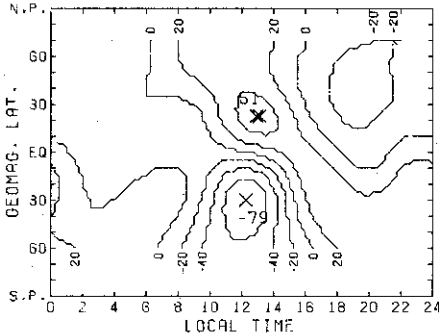

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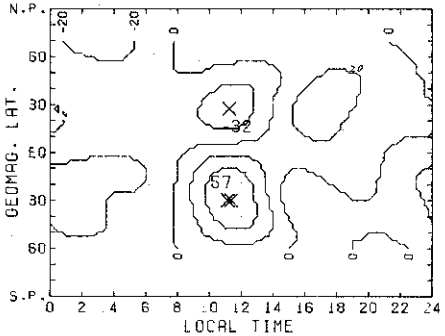

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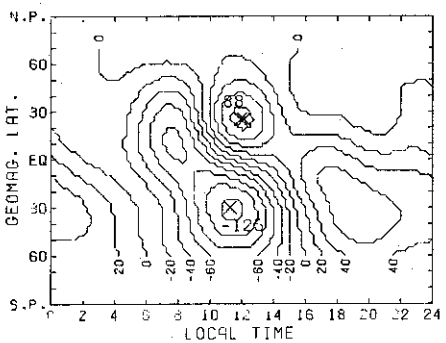

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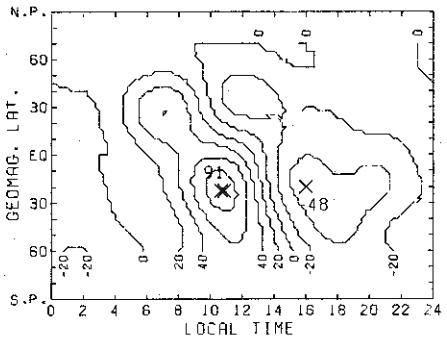

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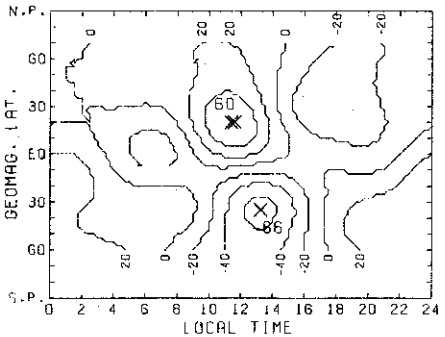

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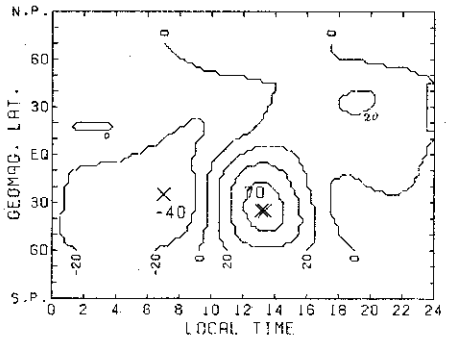

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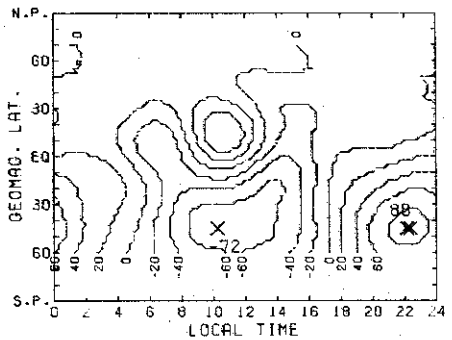

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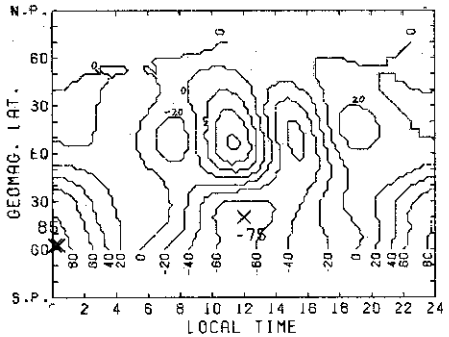

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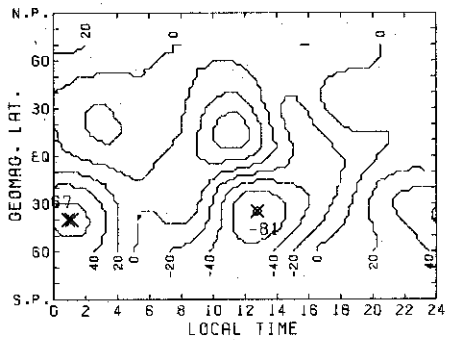

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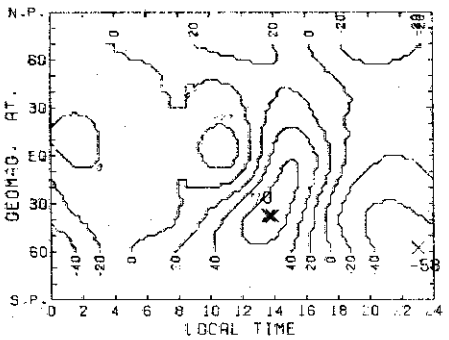

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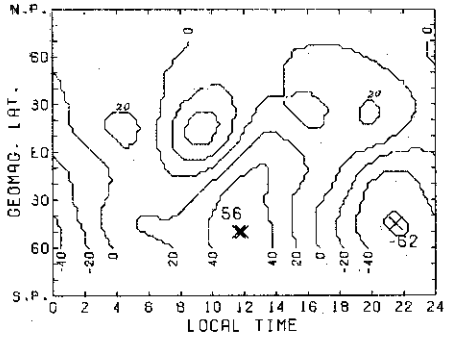

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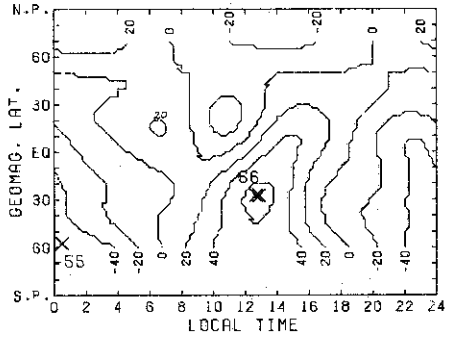

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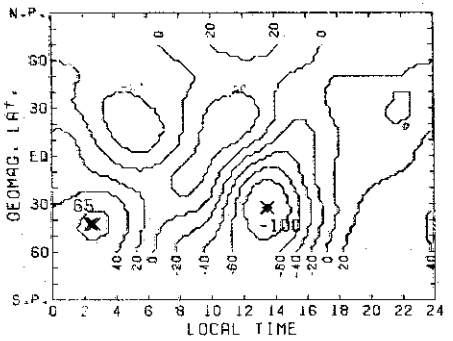

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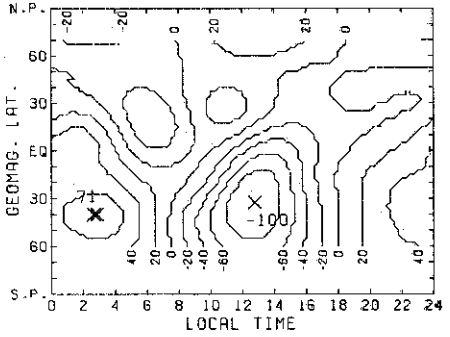

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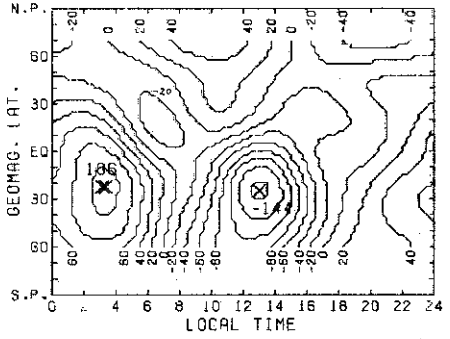

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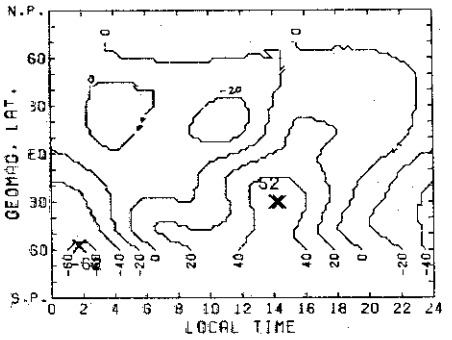

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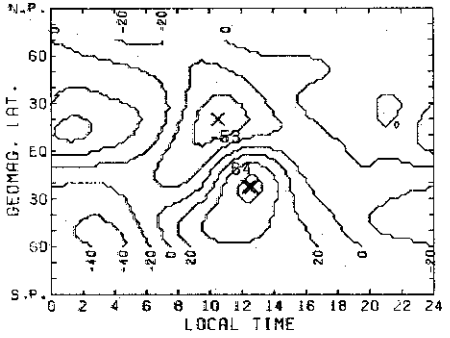

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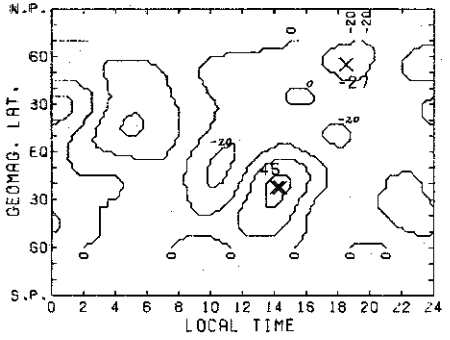

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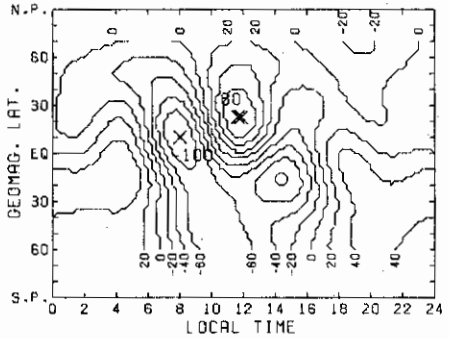

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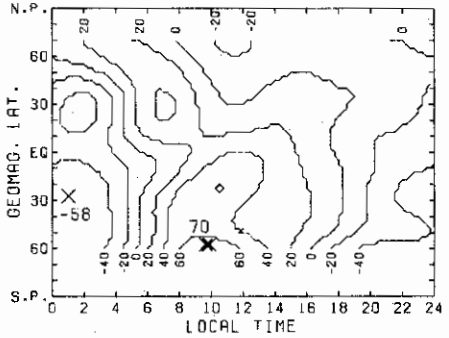

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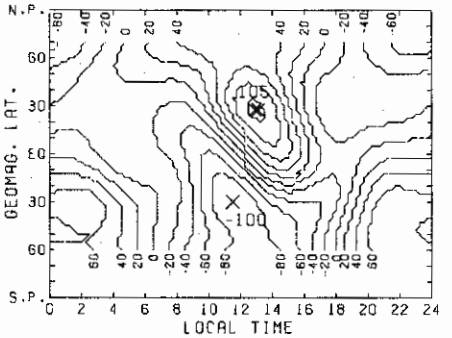

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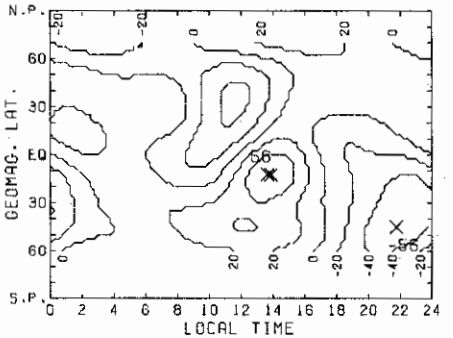

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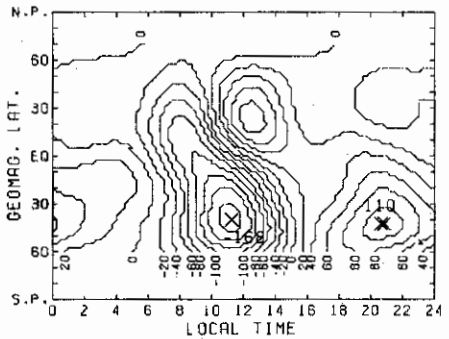

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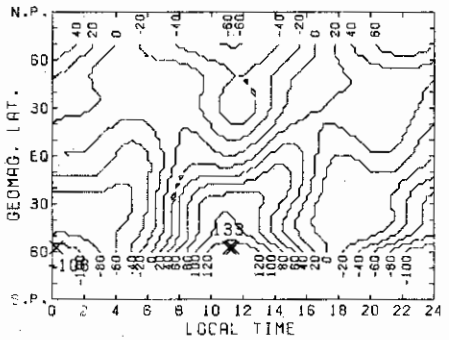

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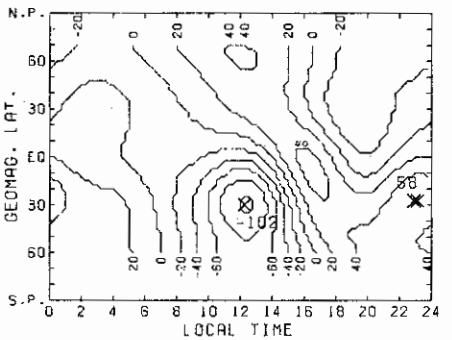

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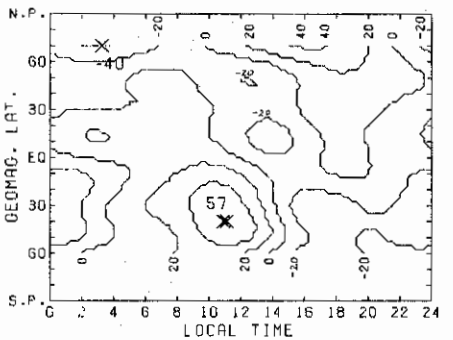

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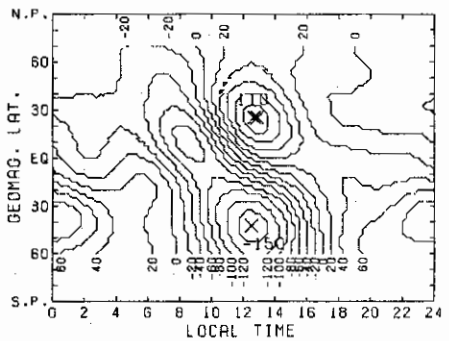

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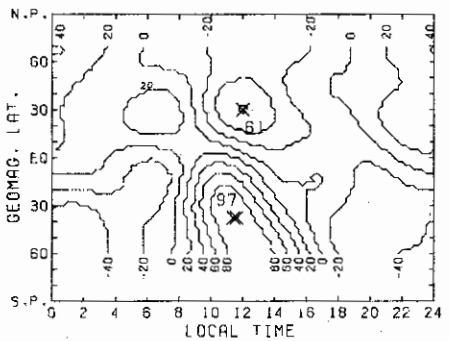

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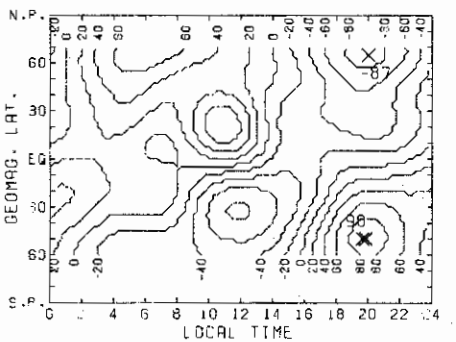

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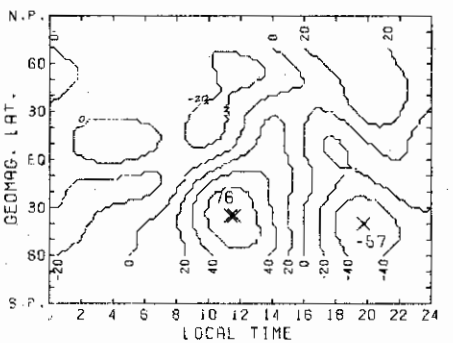

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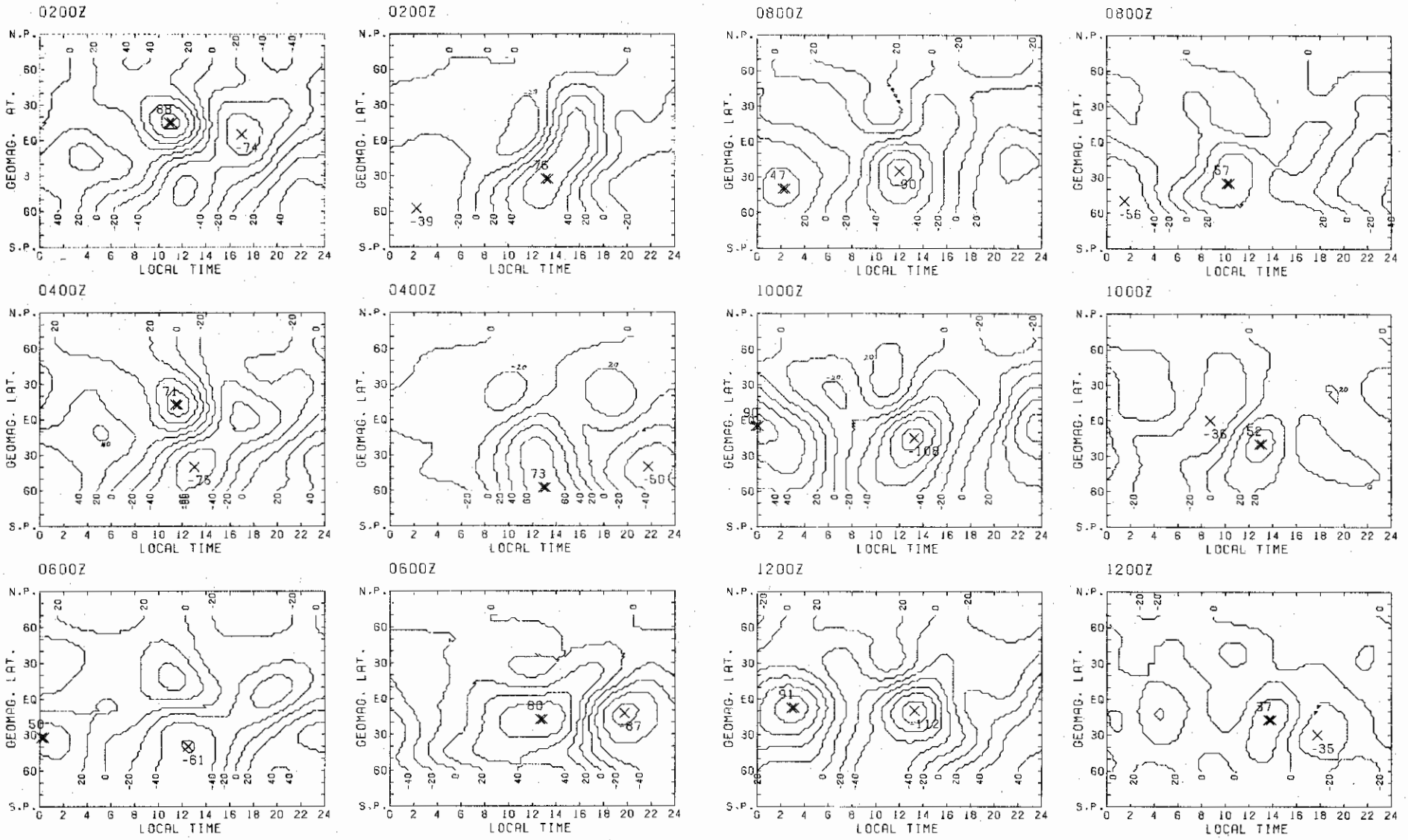

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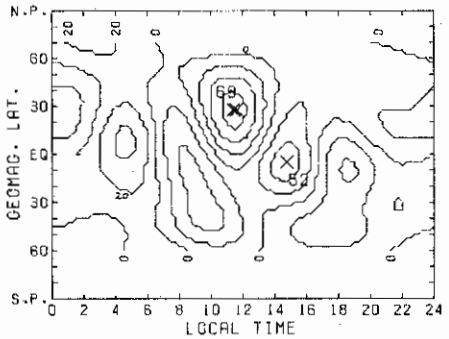

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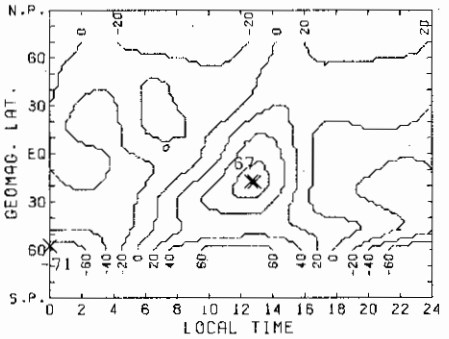

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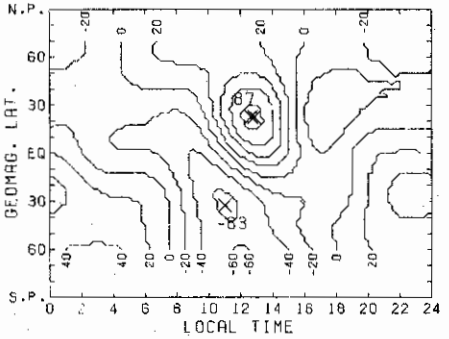

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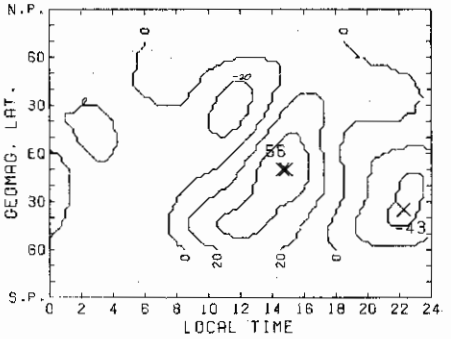

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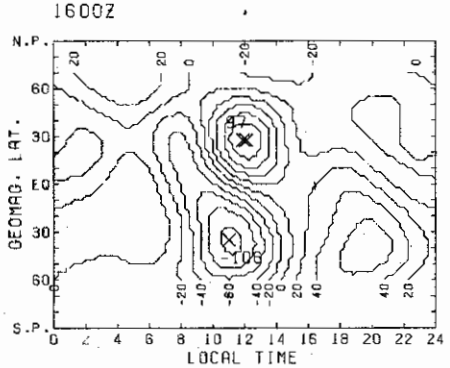

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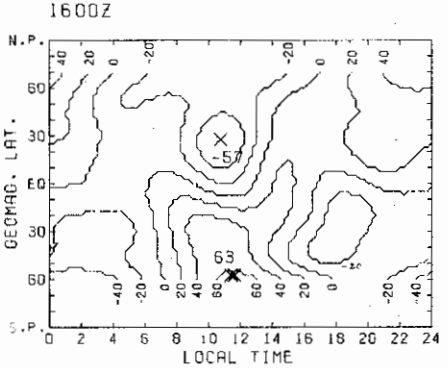

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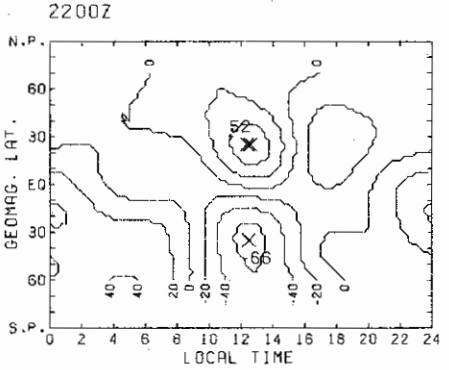

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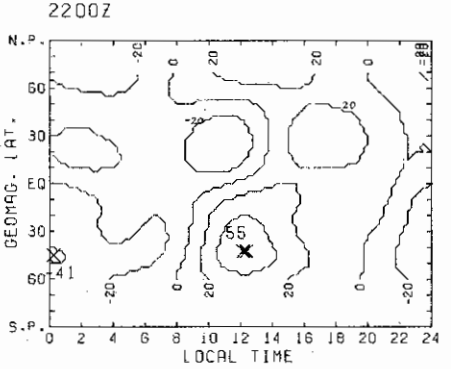

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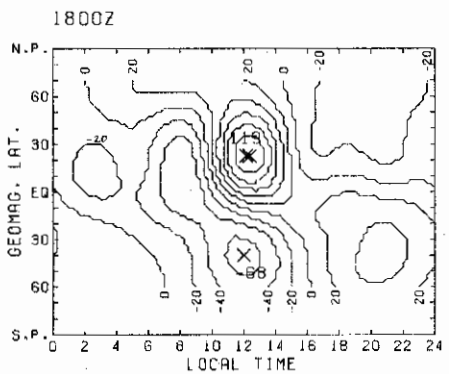

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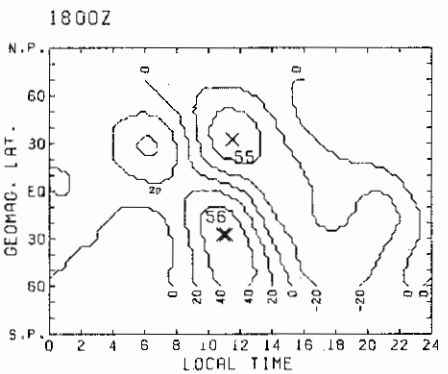

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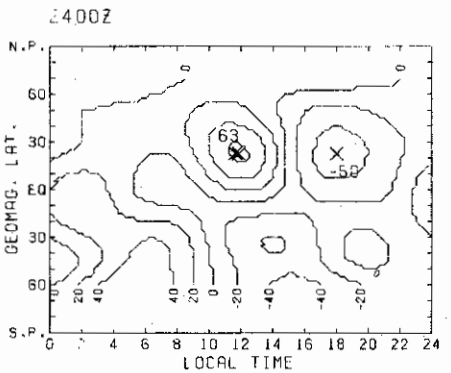

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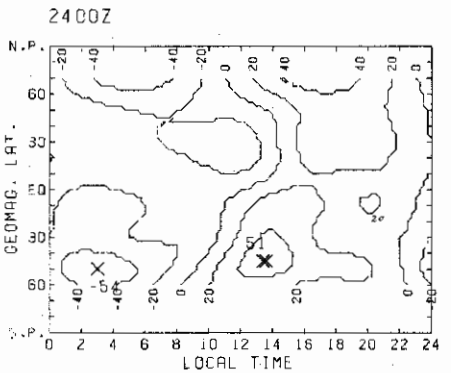

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EXTERNAL

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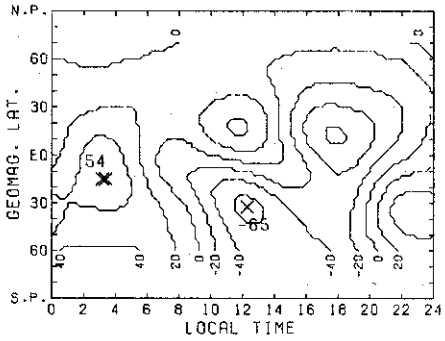

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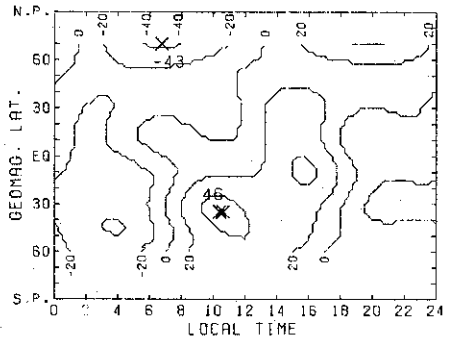

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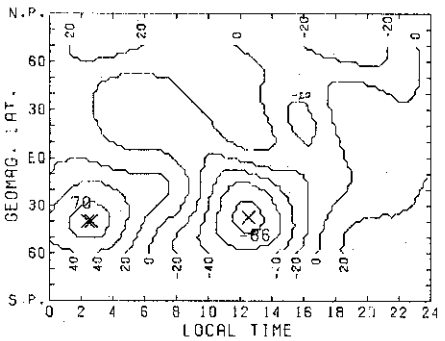

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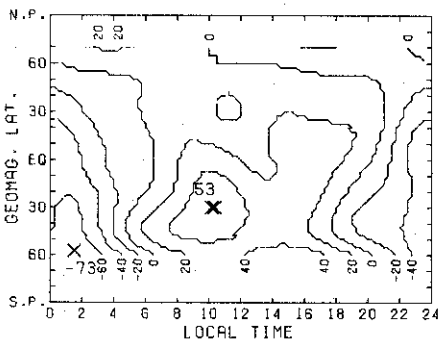

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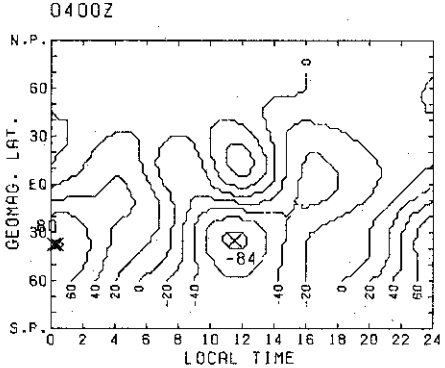

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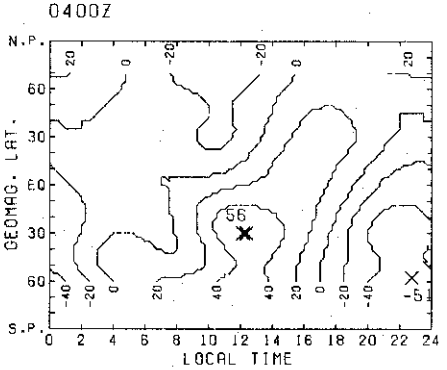

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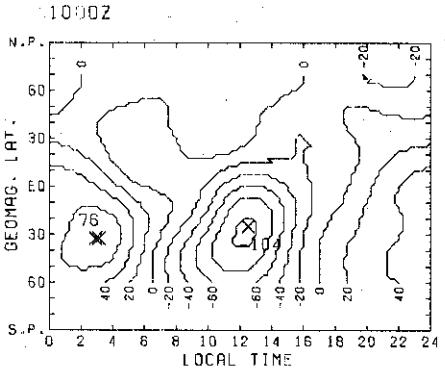

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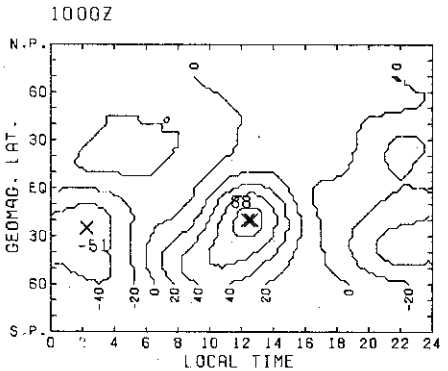

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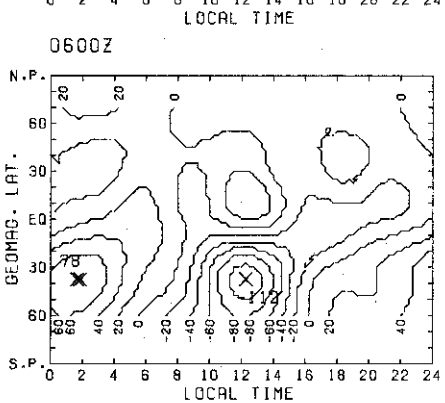

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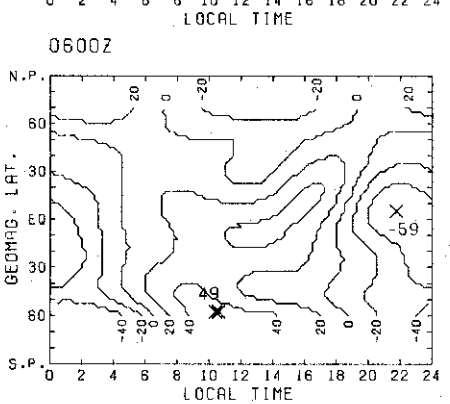

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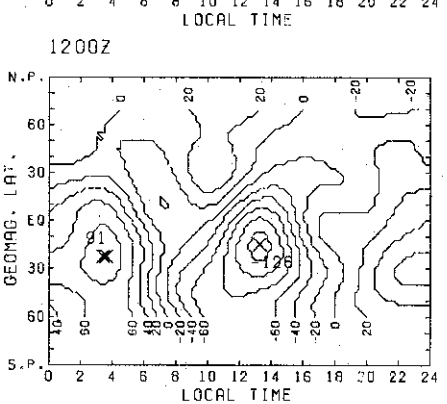

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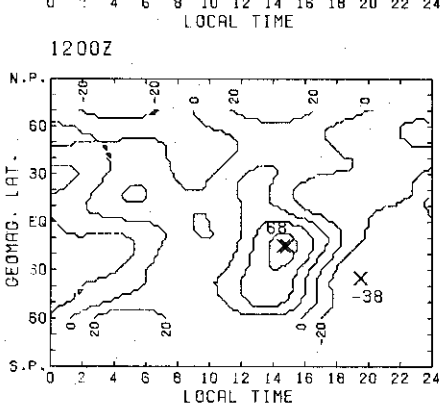

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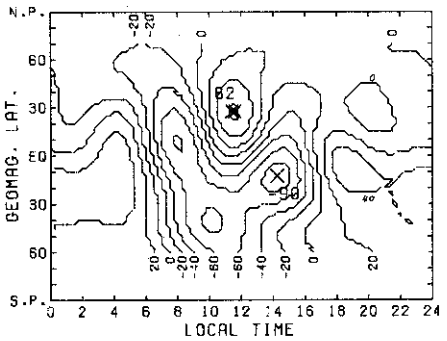

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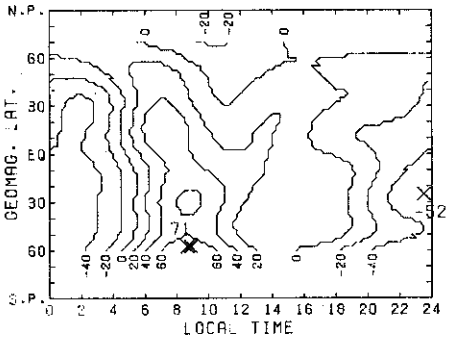

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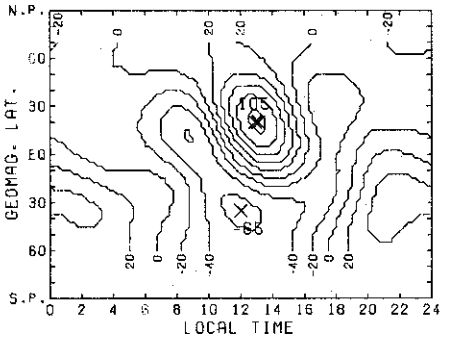

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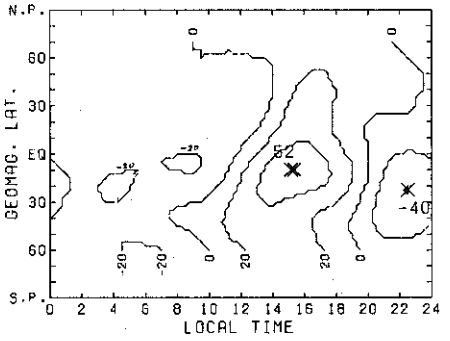

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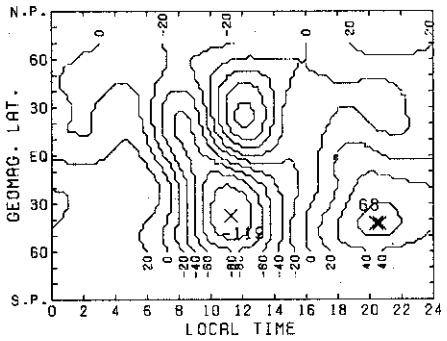

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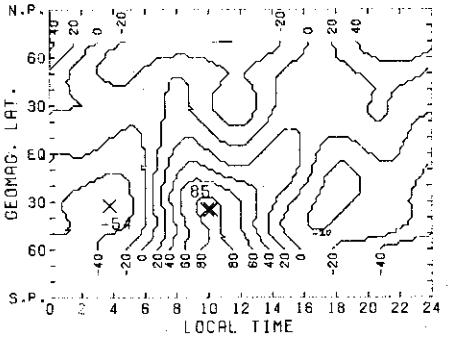

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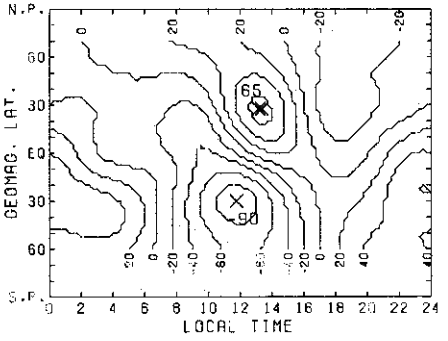

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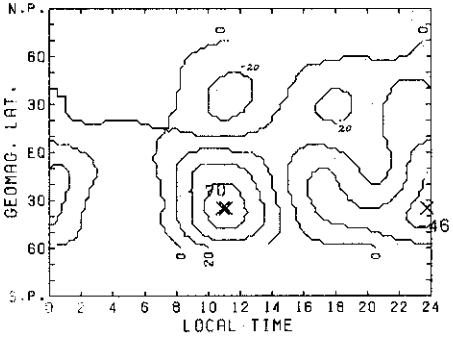

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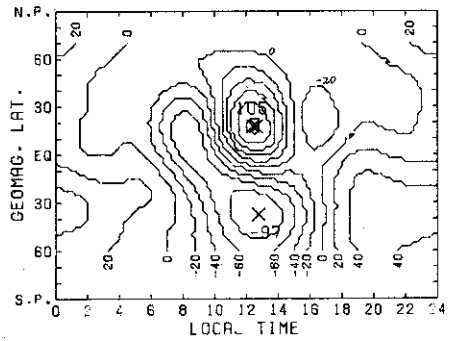

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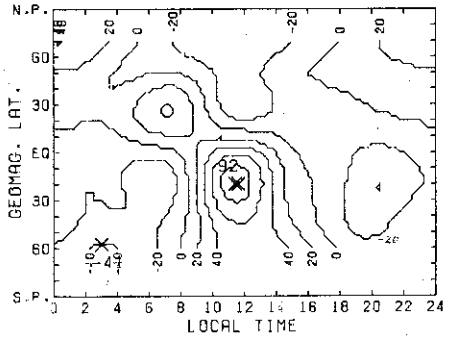

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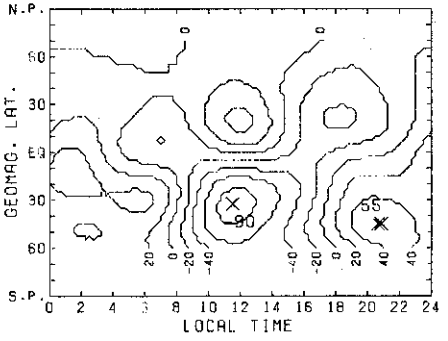

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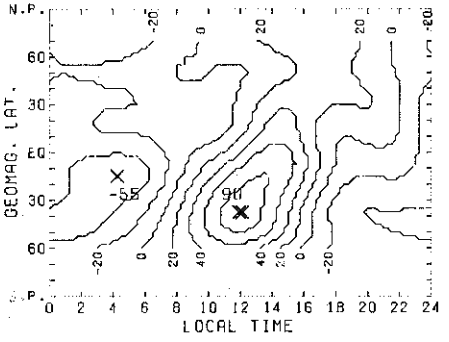

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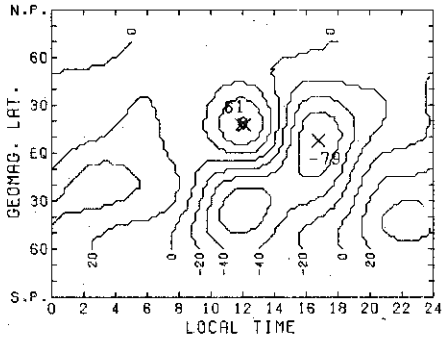

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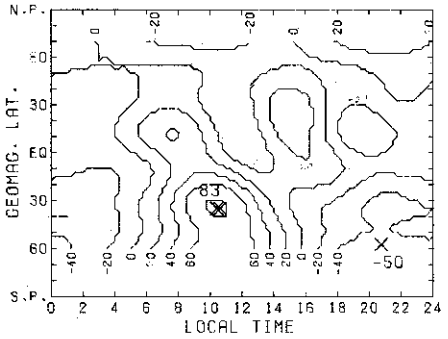

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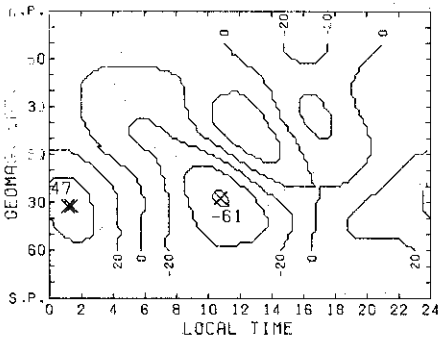

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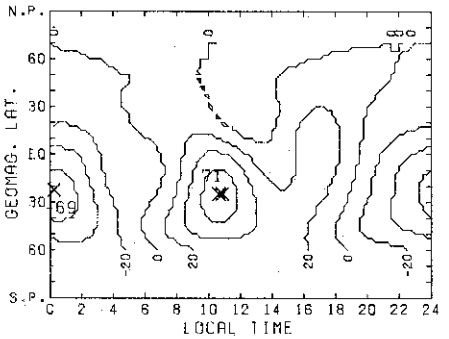

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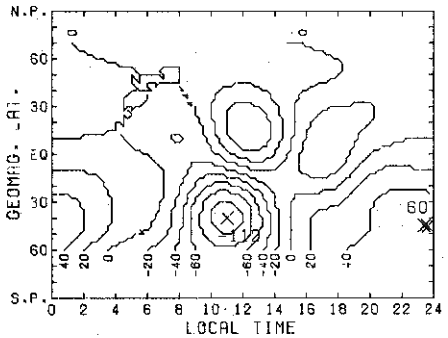

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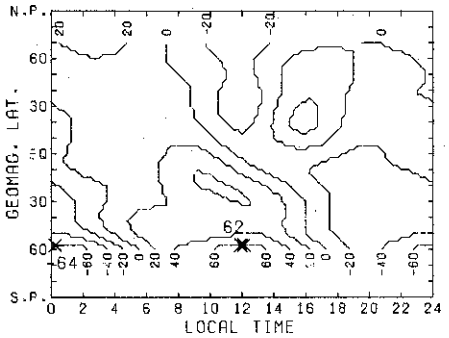

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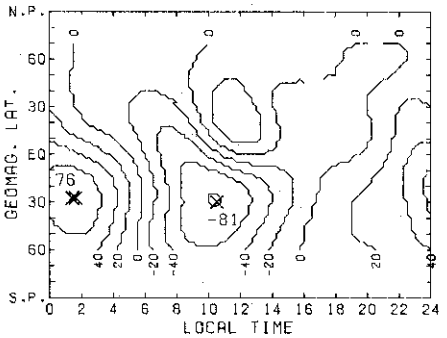

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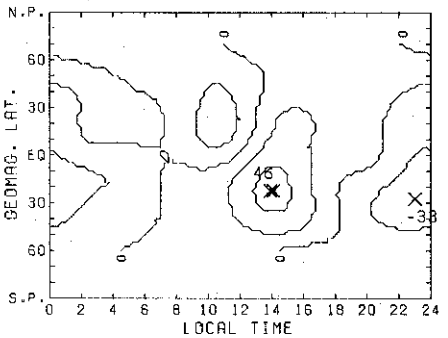

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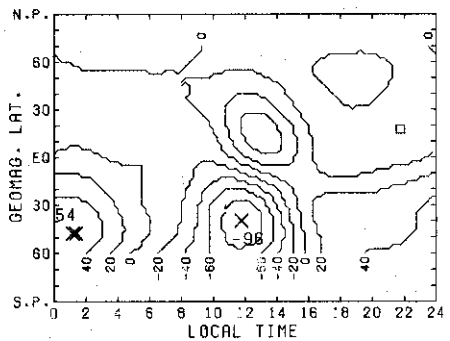

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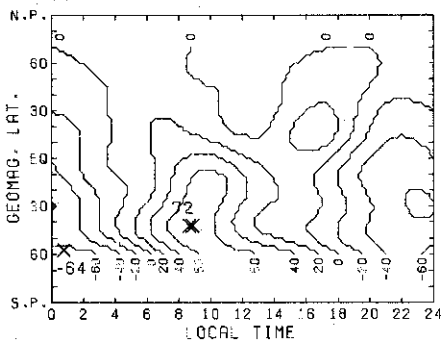

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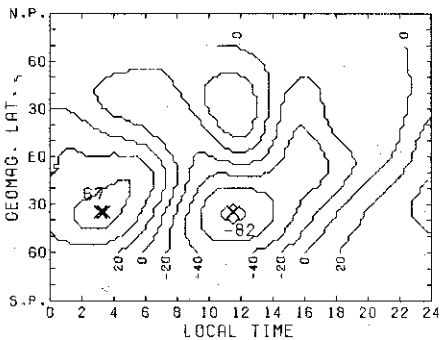

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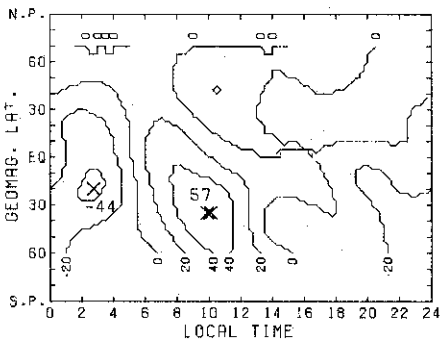

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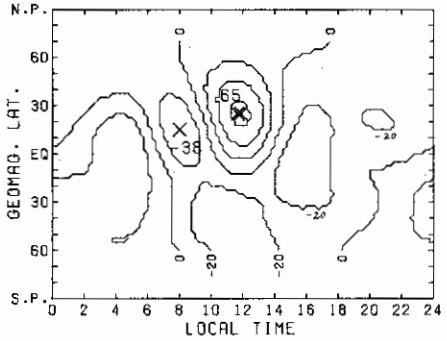

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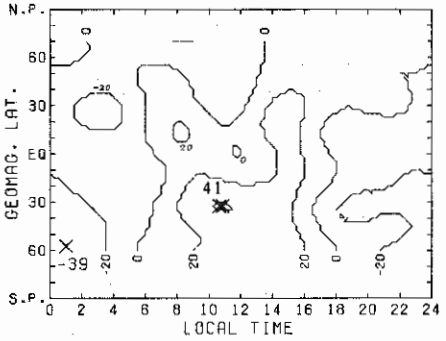

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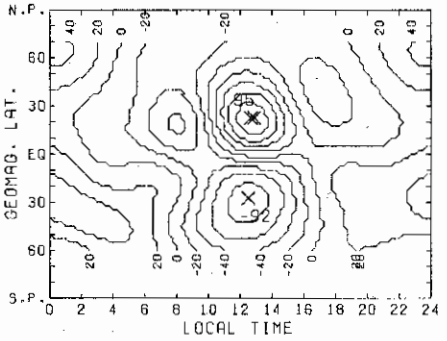

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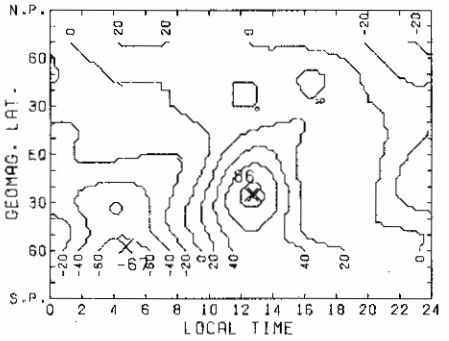

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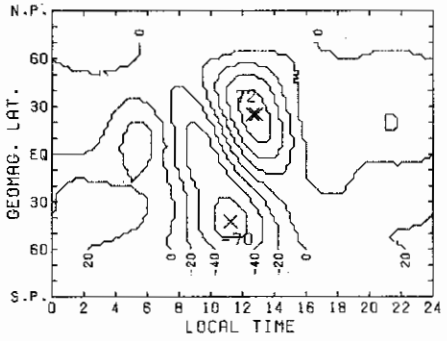

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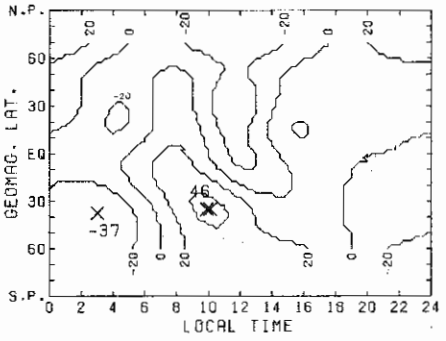

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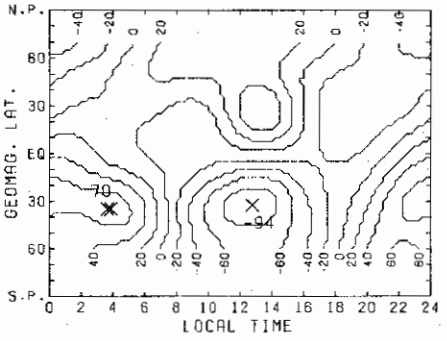

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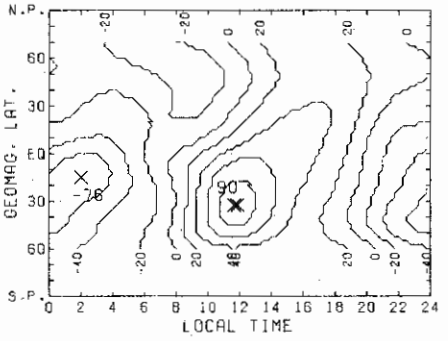

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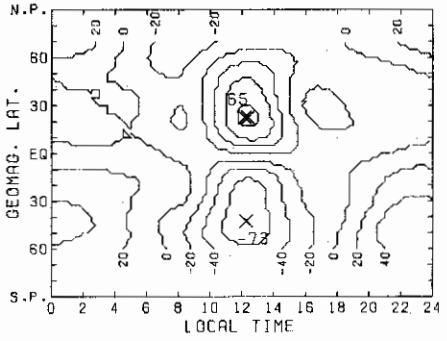

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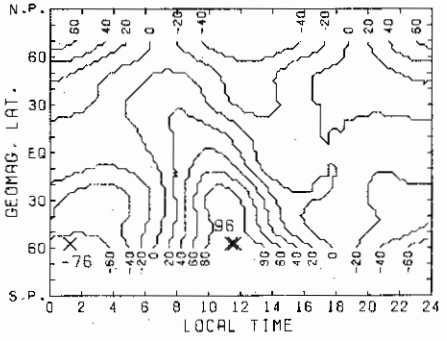

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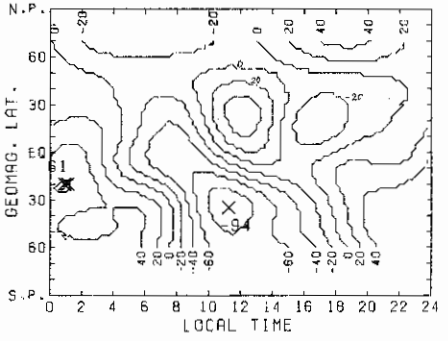

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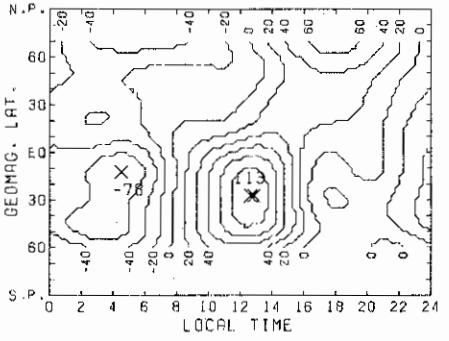

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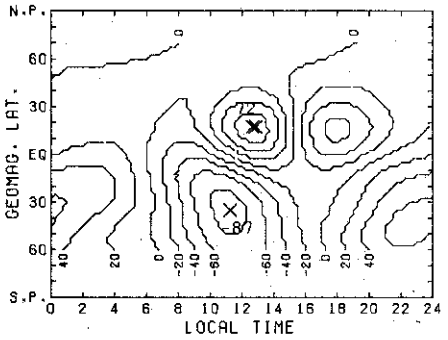

INTERNAL

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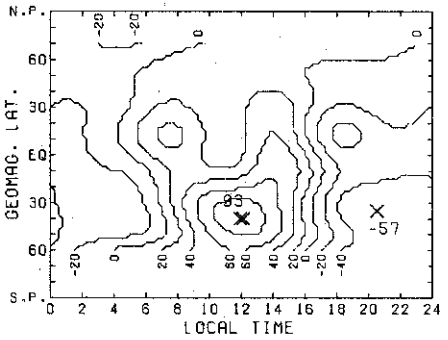

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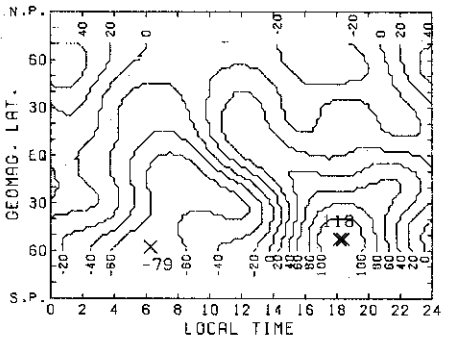

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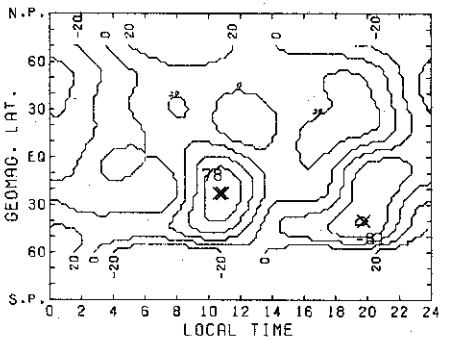

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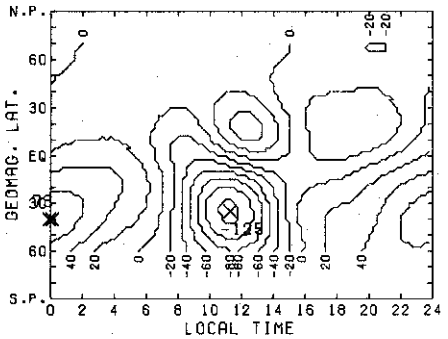

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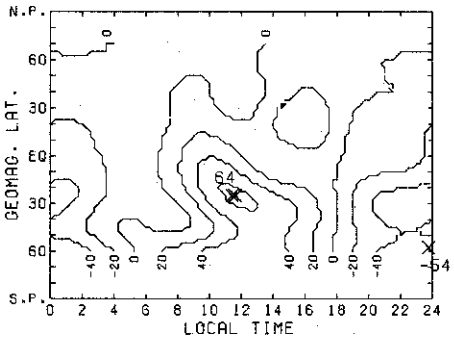

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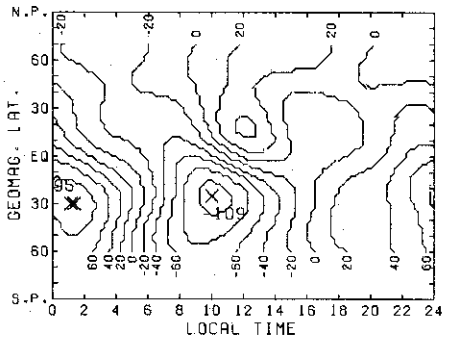

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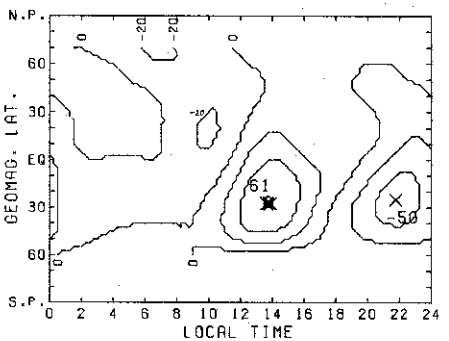

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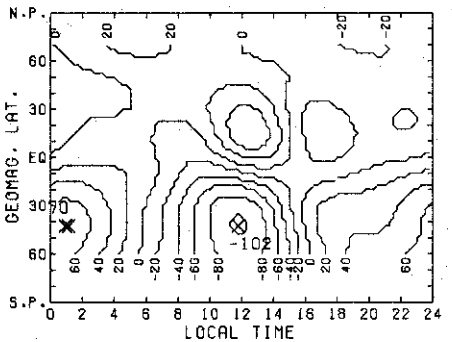

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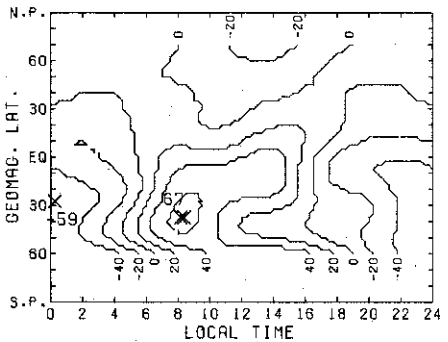

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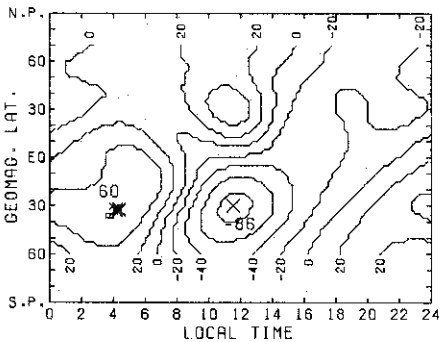

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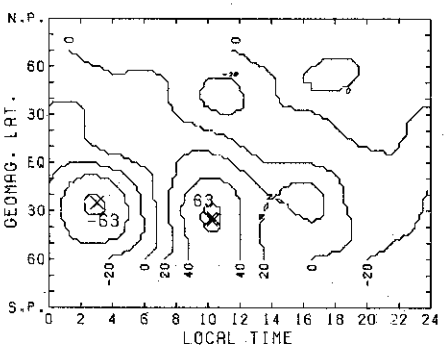

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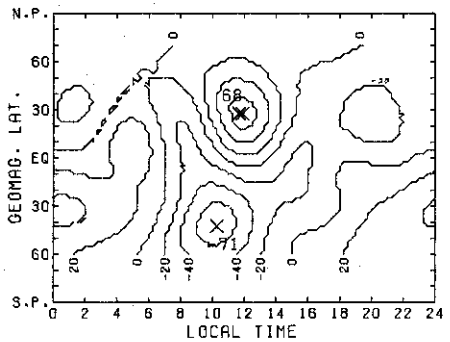

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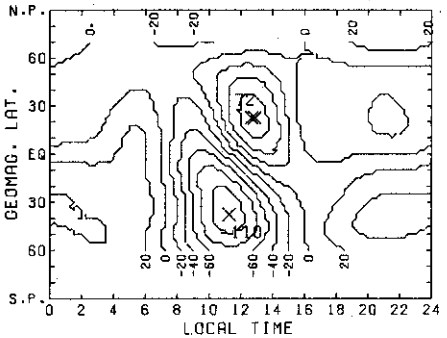

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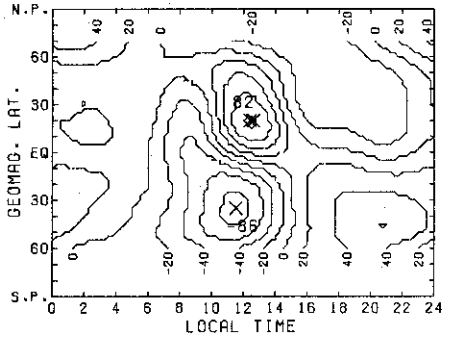

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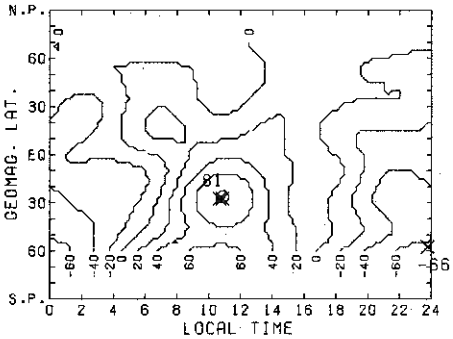

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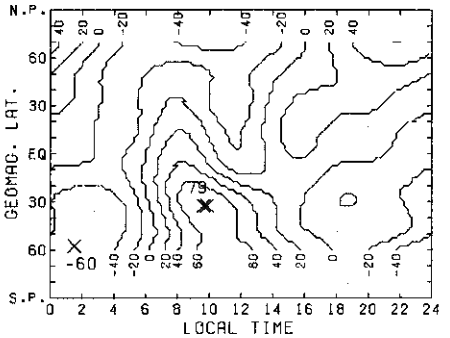

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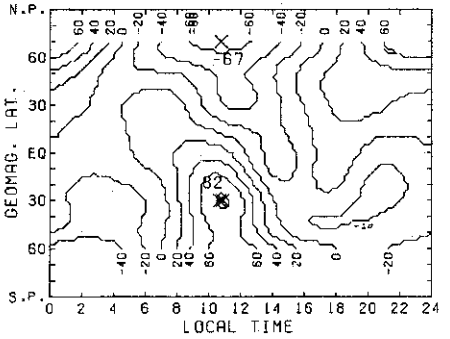

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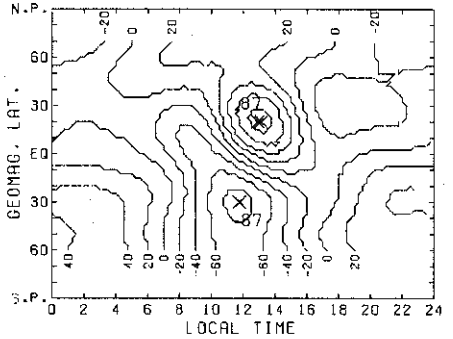

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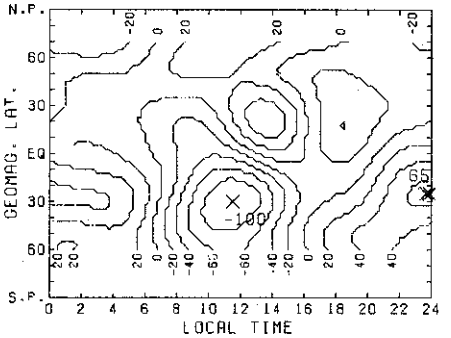

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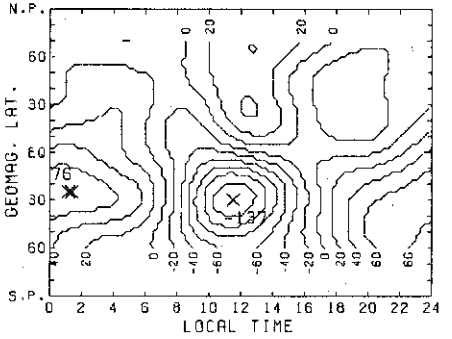

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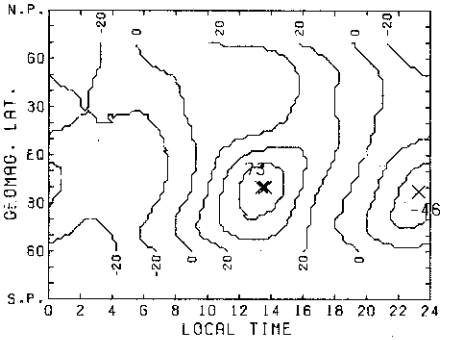

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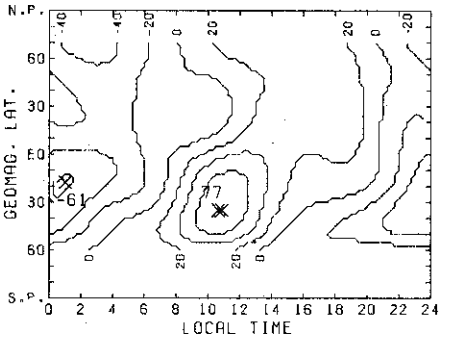

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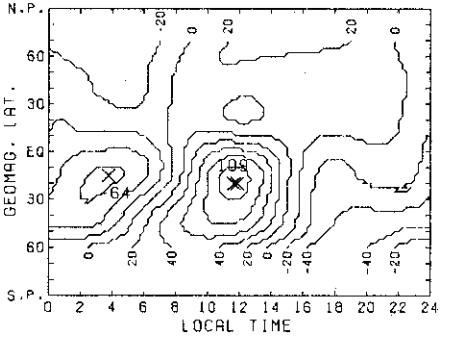

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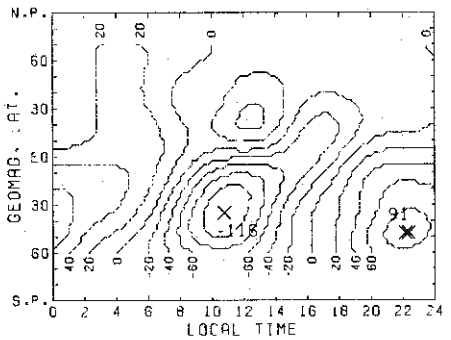

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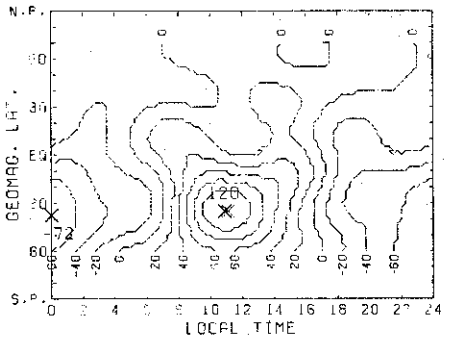

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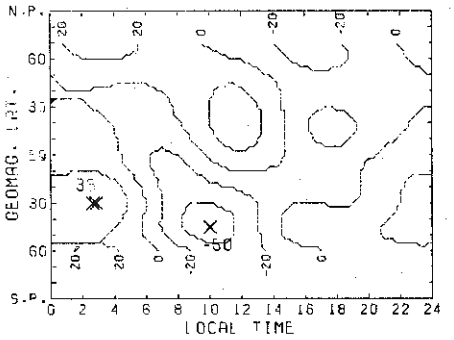

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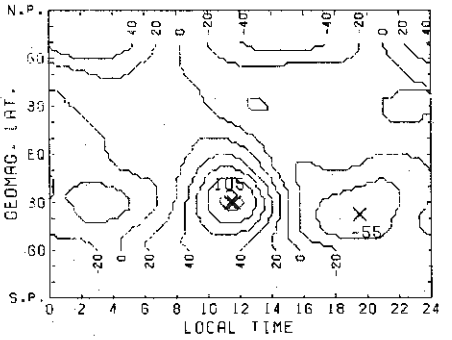

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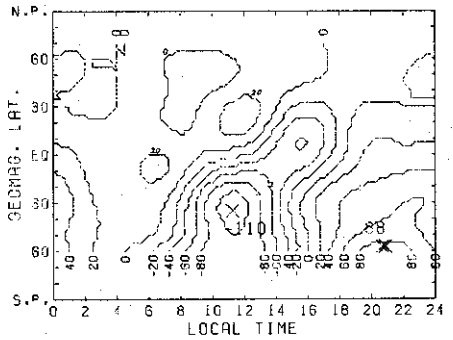

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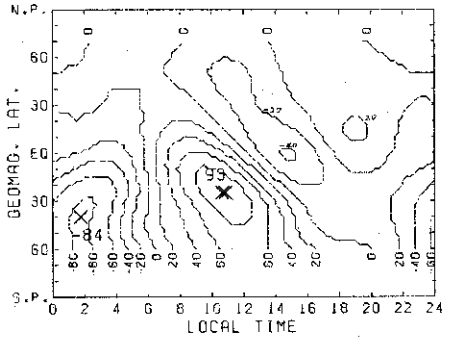

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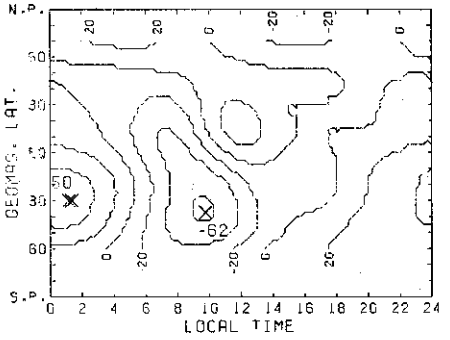

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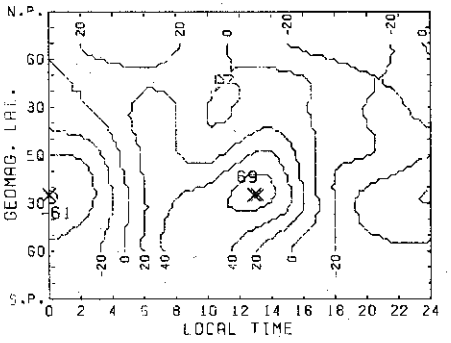

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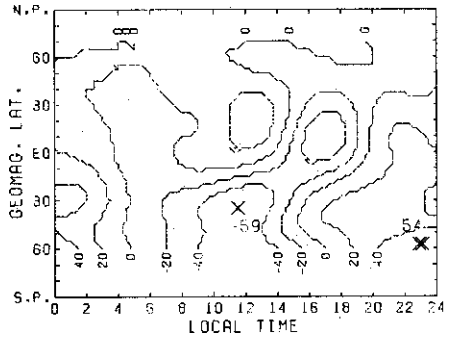

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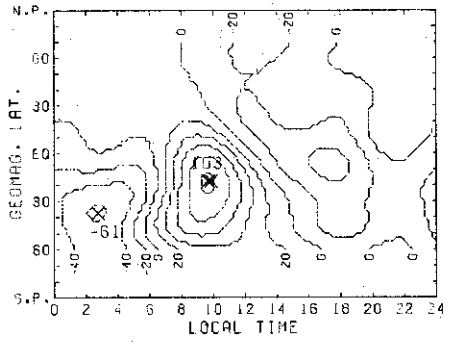

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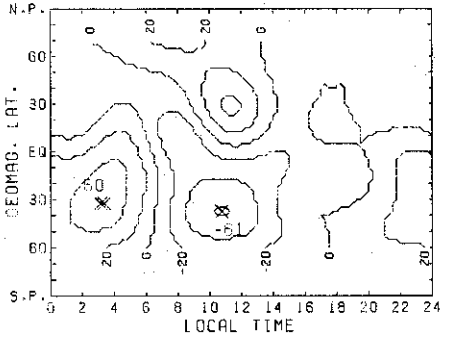

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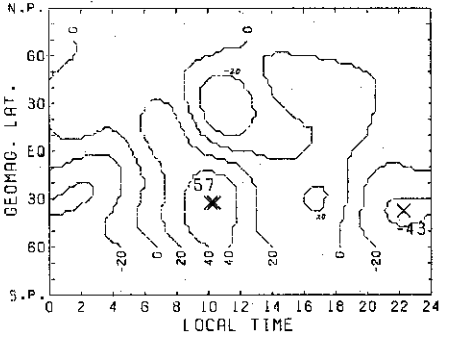

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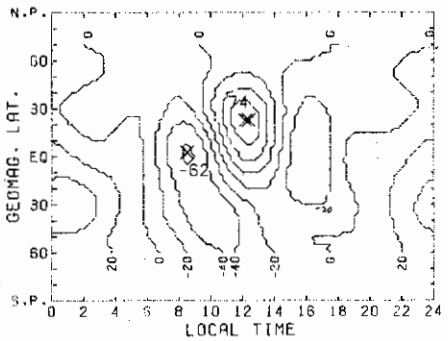

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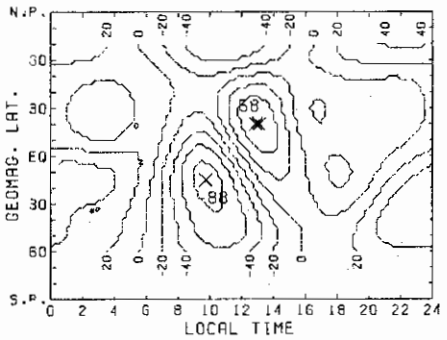

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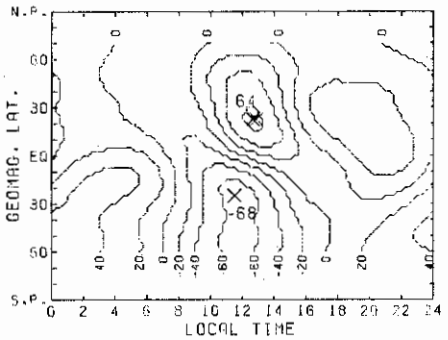

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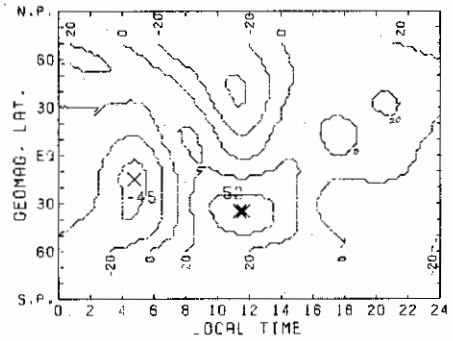

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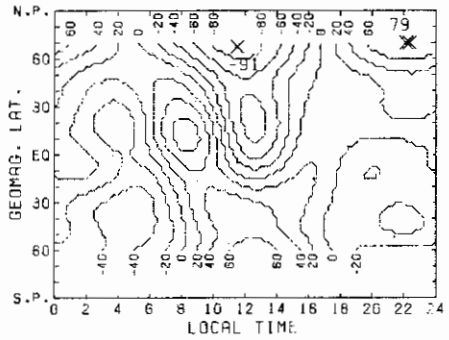

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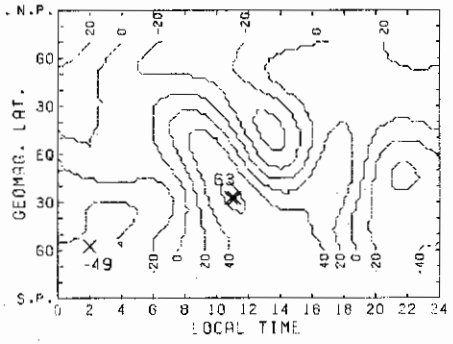

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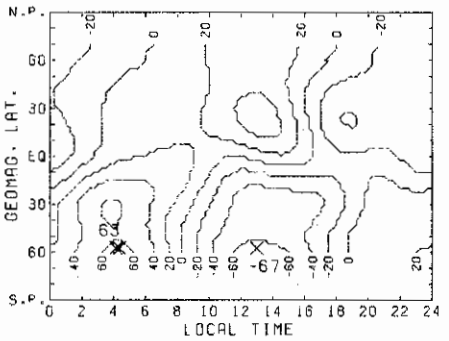

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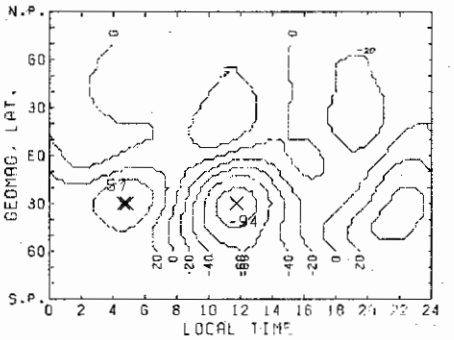

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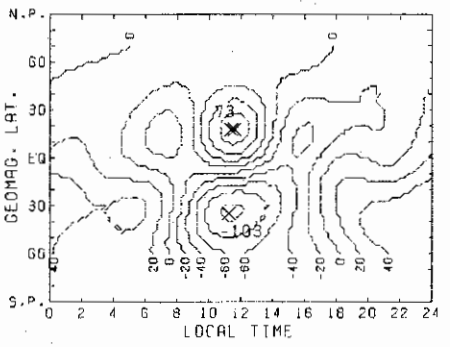

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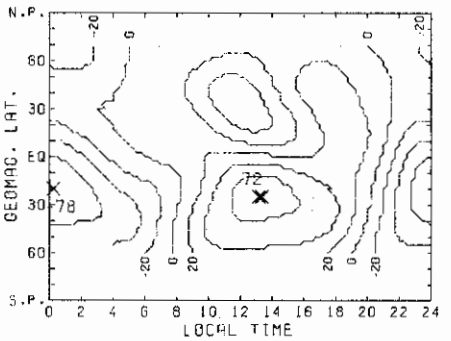

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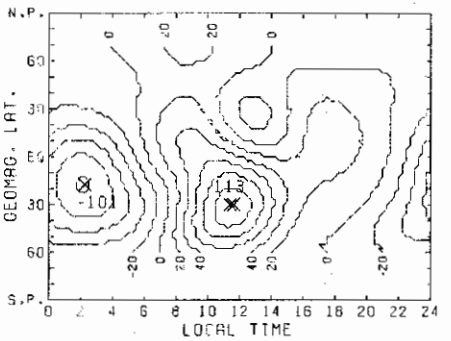

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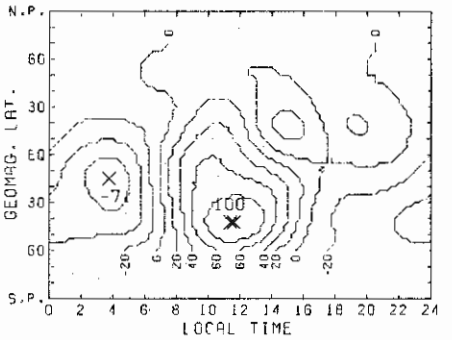

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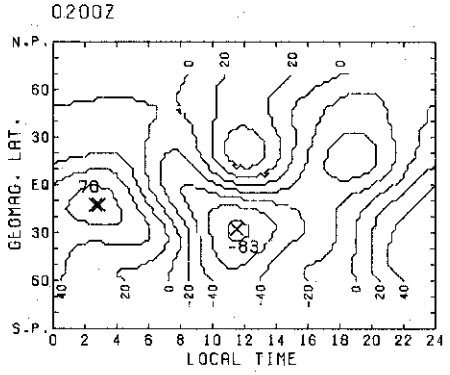

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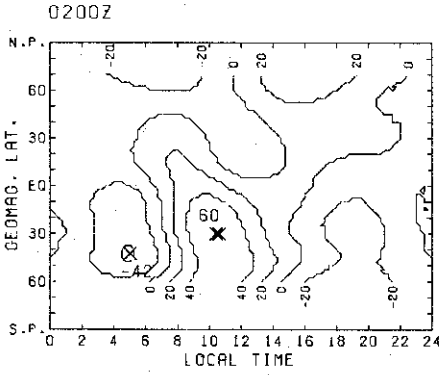

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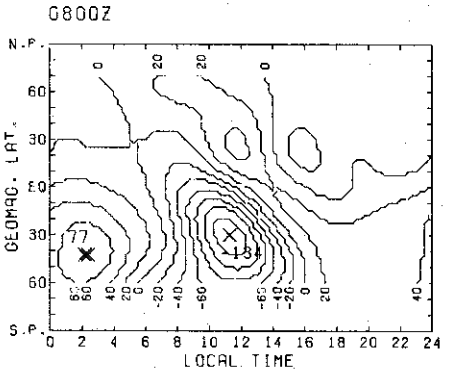

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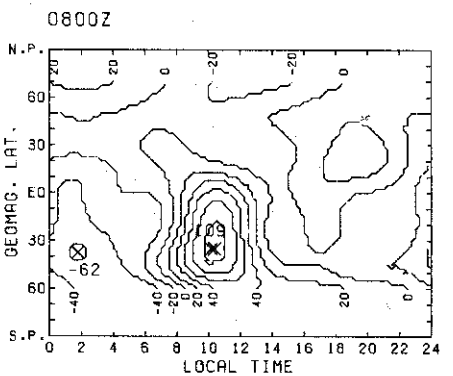

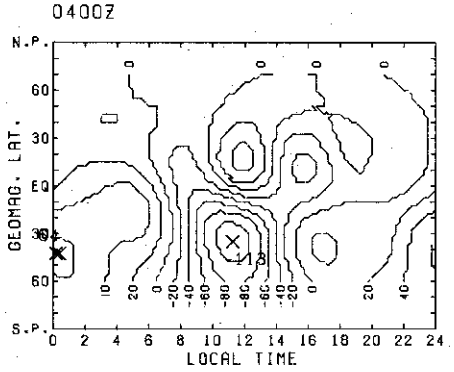

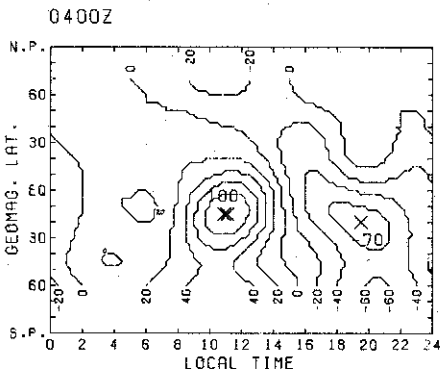

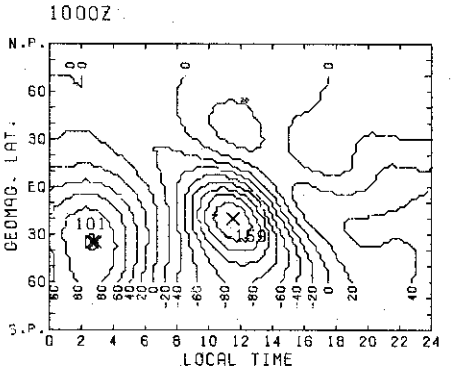

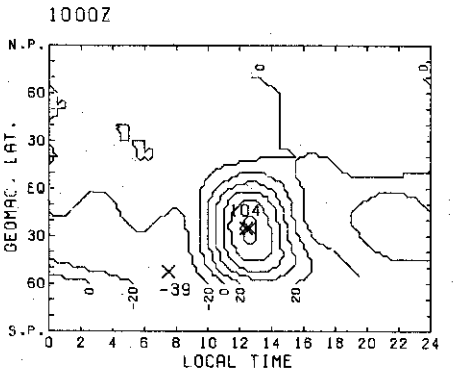

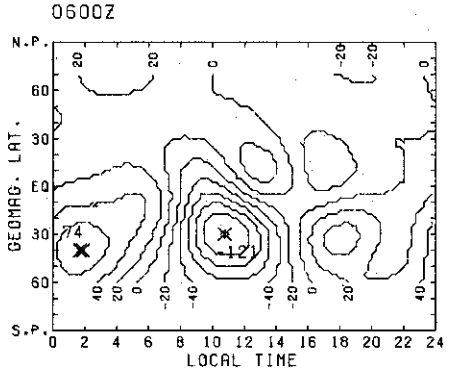

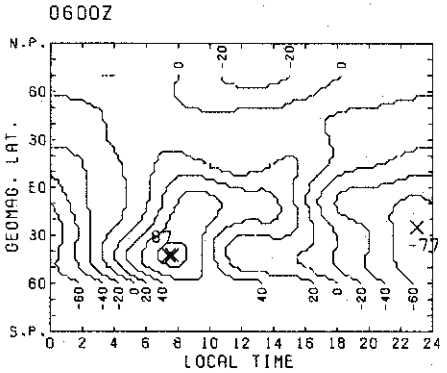

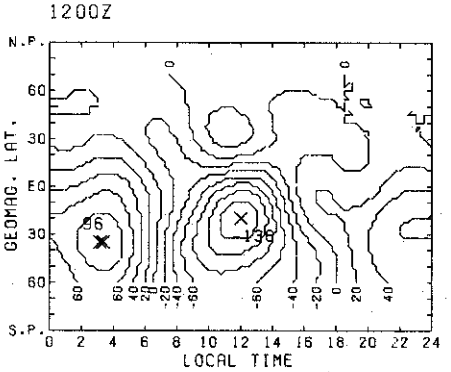

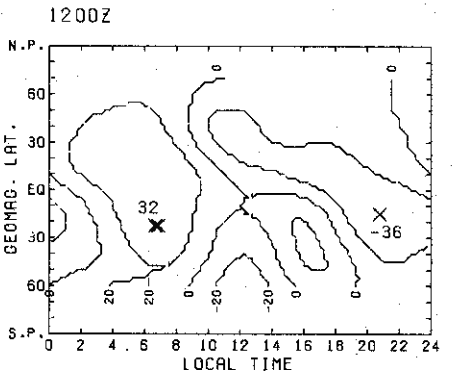

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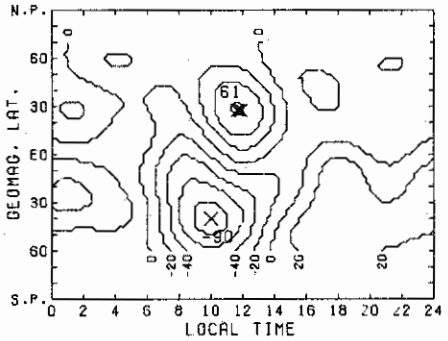

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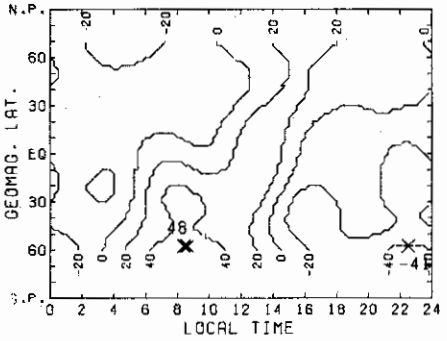

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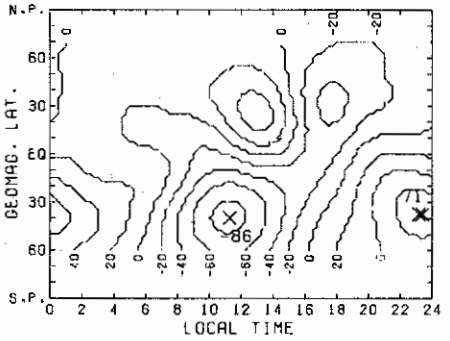

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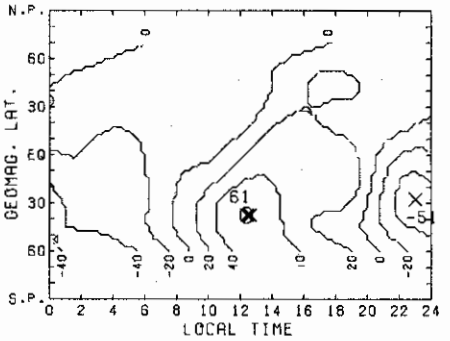

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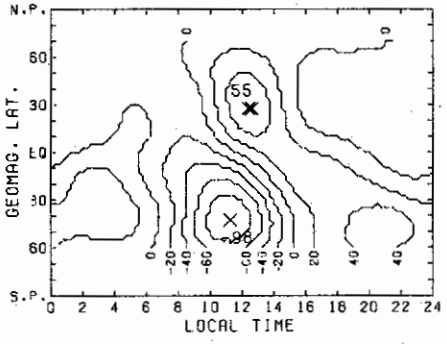

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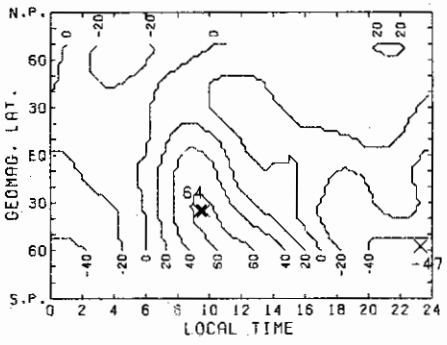

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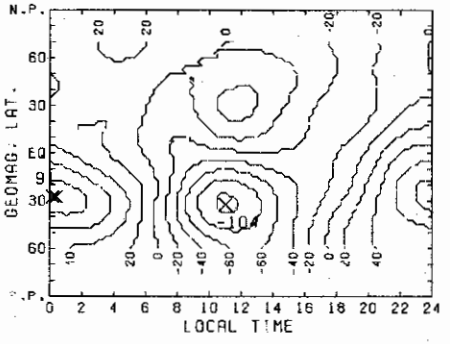

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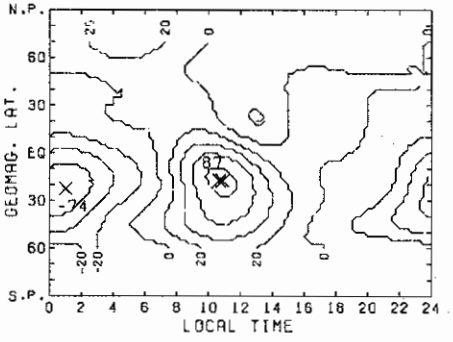

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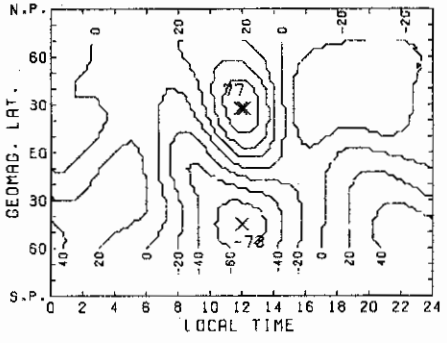

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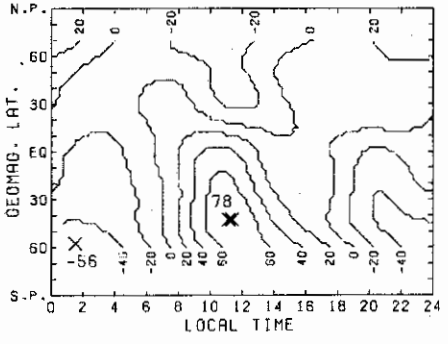

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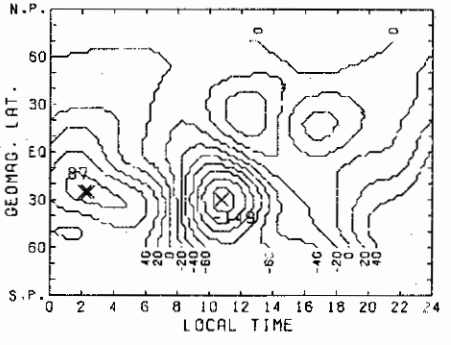

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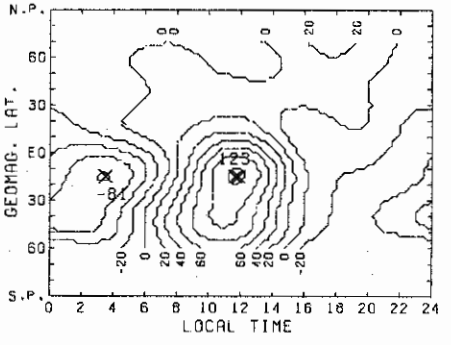


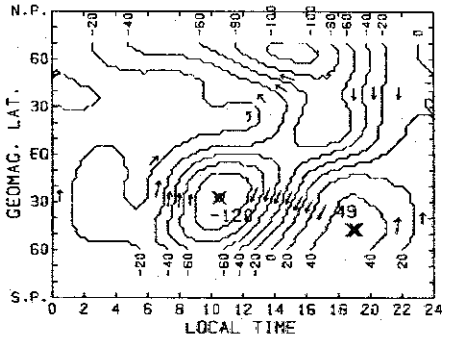
FIGURE 2

The external (left) and internal (right) parts of equivalent current systems at every two UT hours in December 1964, where midnight values are used as datum lines of the daily geomagnetic variations.

DEC. 1 ,1964

EXTERNAL

0200Z



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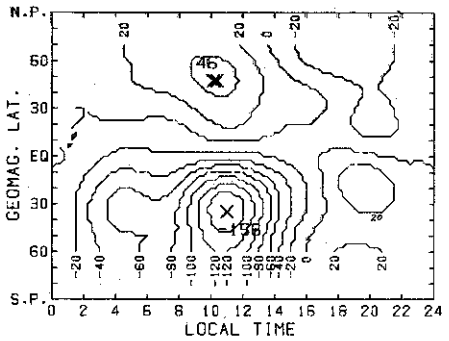

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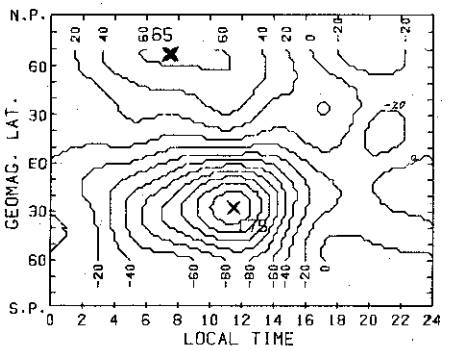

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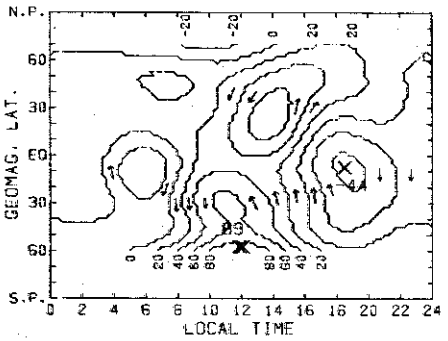

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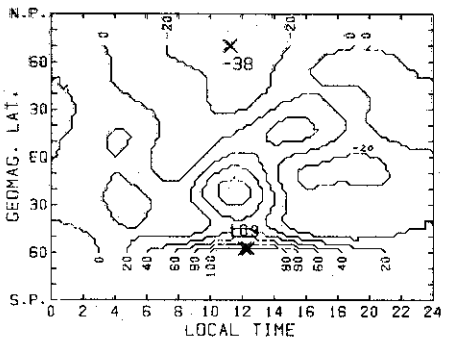

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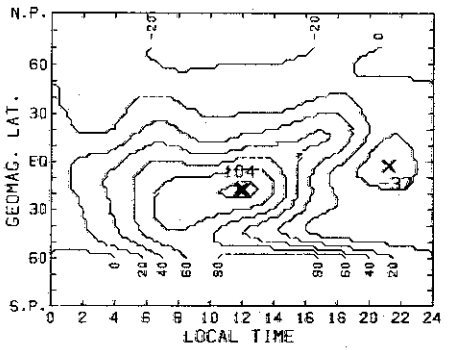

DEC. 1 ,1964

EXTERNAL

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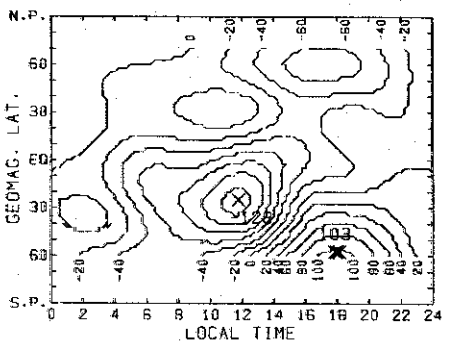

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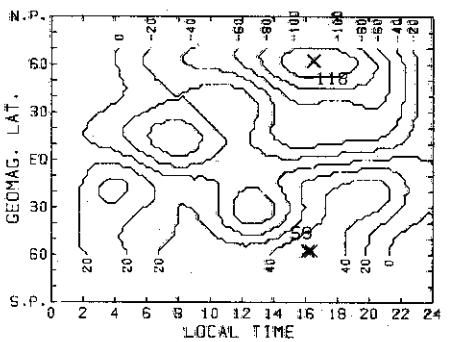

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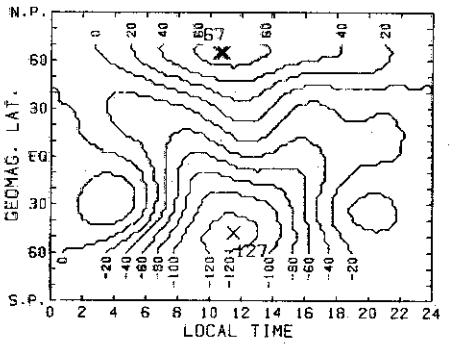

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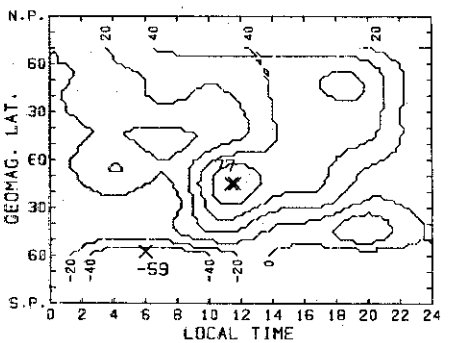

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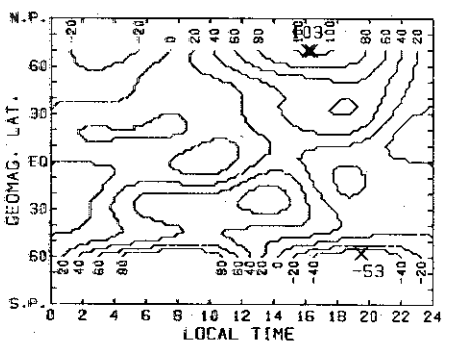

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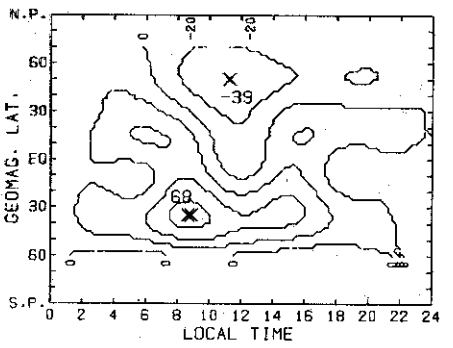

DEC. 1 ,1964

EXTERNAL

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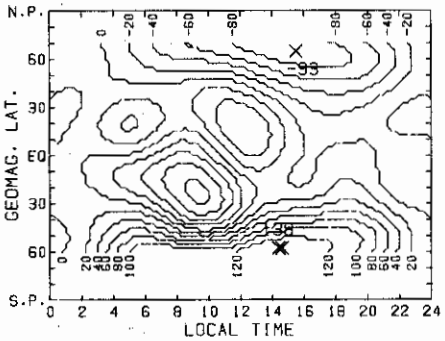

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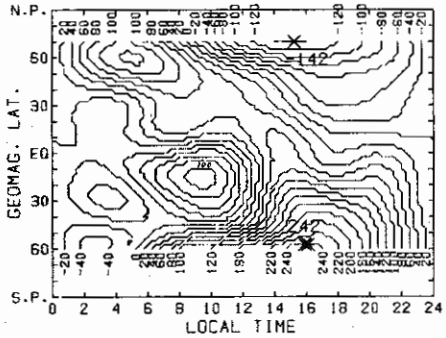

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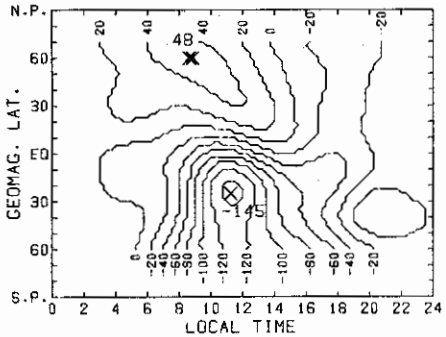

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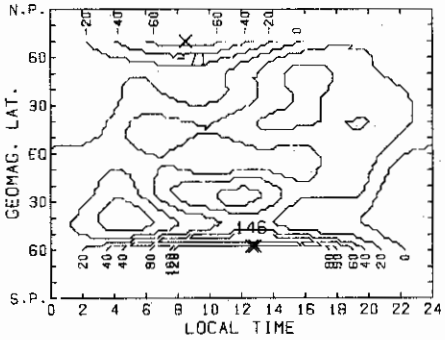

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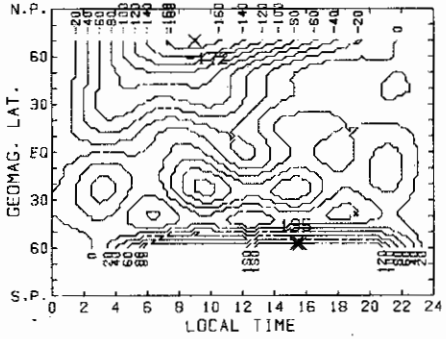

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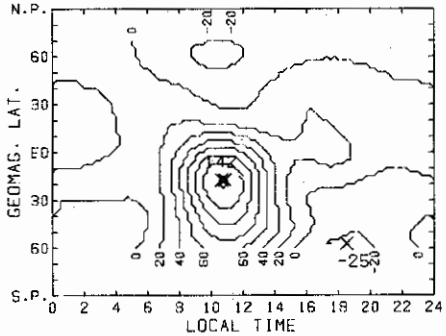

DEC. 1 ,1964

EXTERNAL

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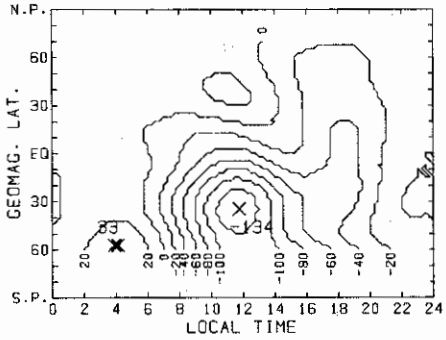

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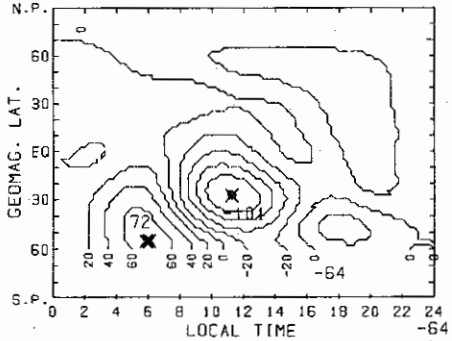

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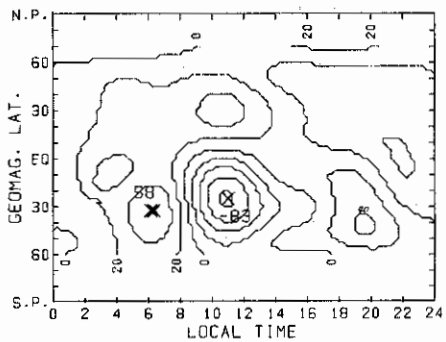

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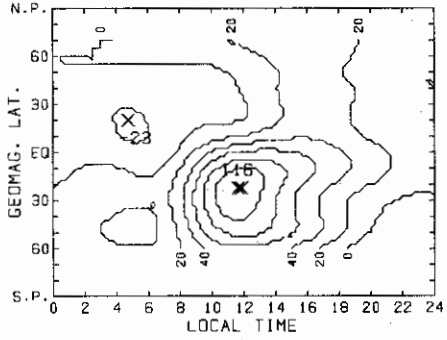

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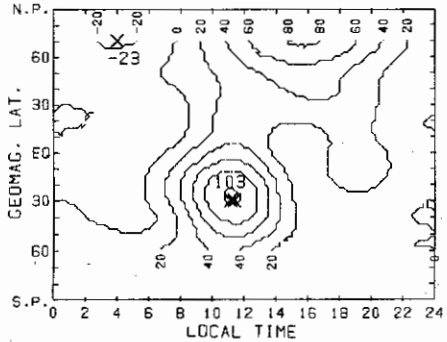

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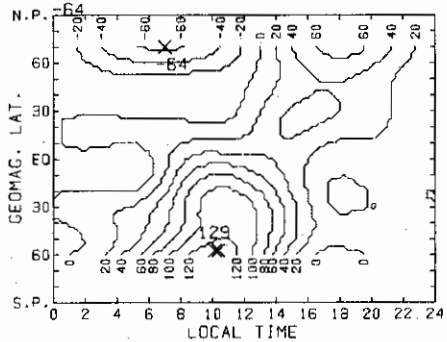

DEC. 2, 1964

EXTERNAL

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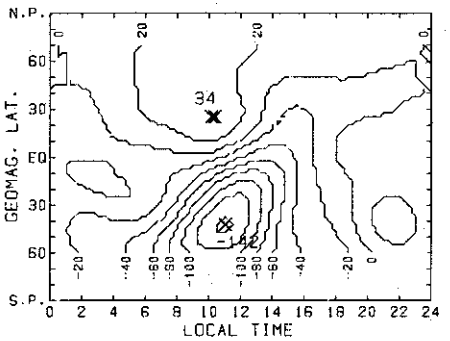

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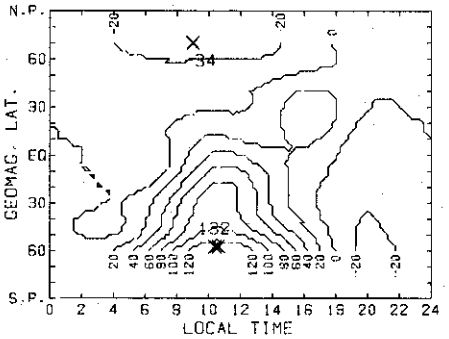

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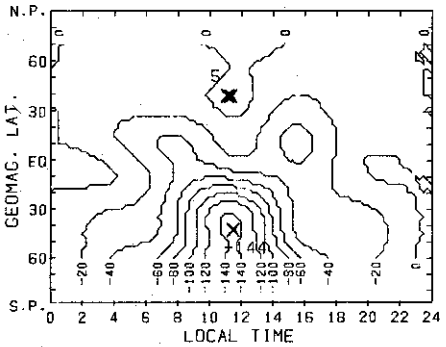

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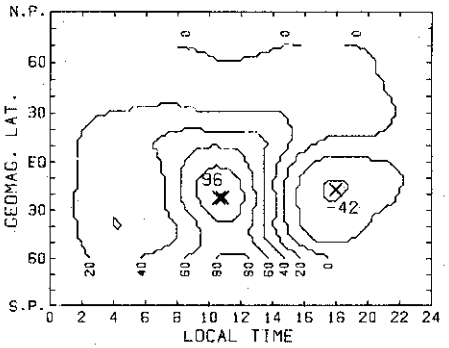

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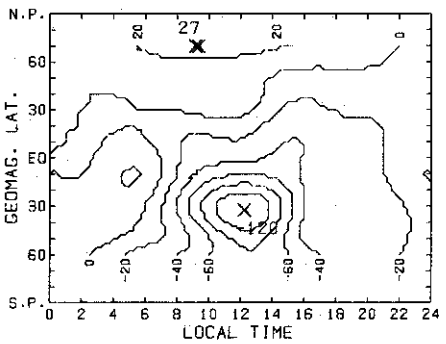

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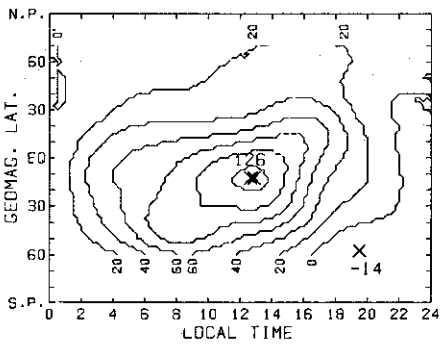

DEC. 2, 1964

EXTERNAL

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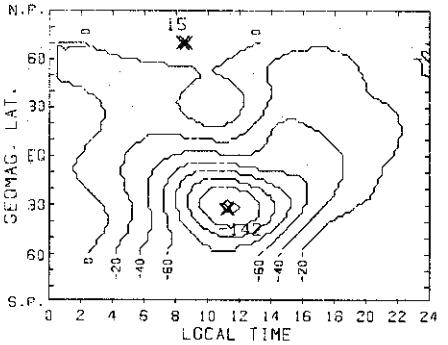

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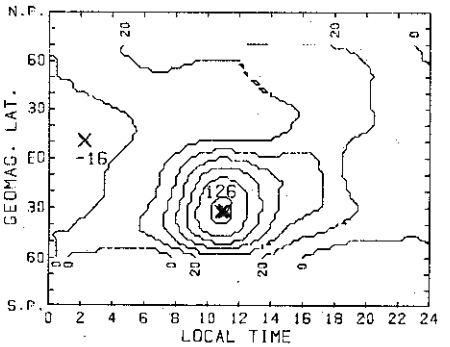

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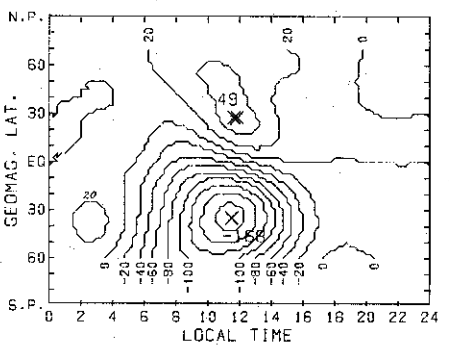

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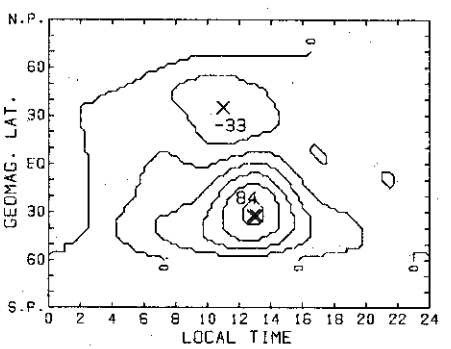

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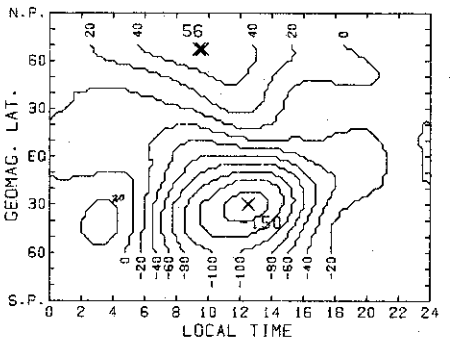

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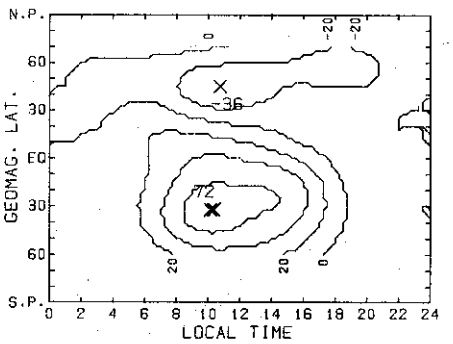

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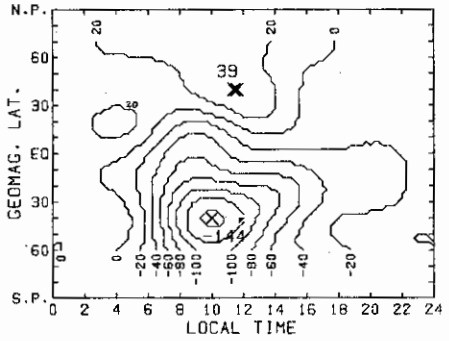

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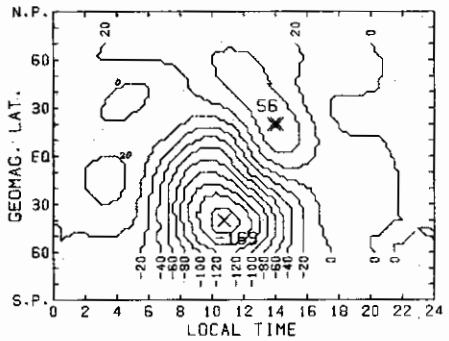

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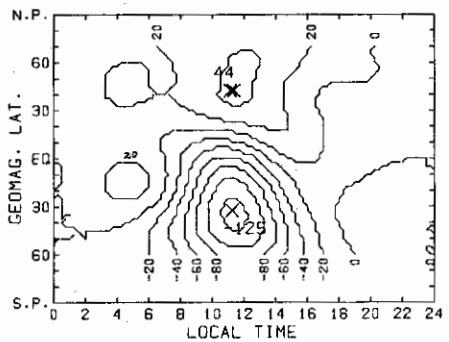

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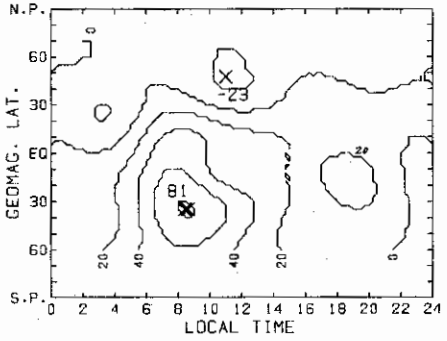

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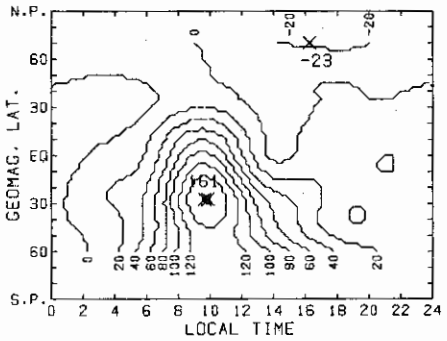

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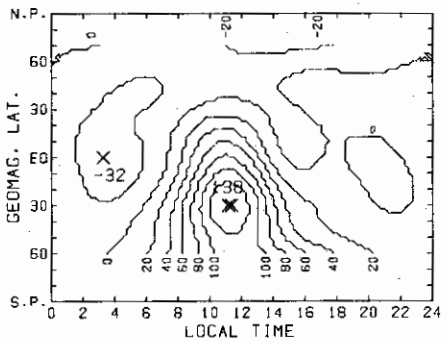

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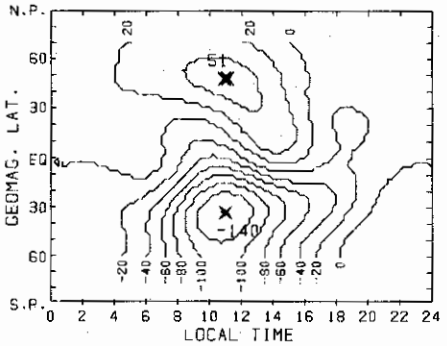

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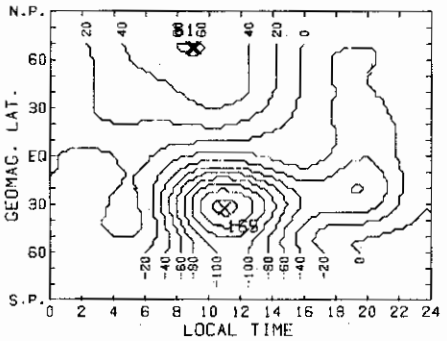

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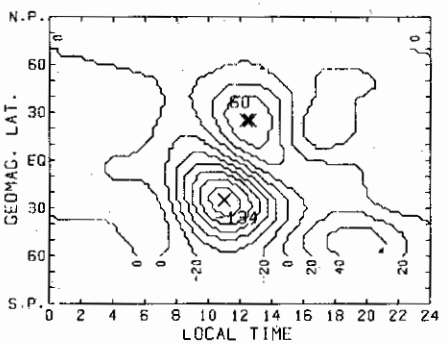

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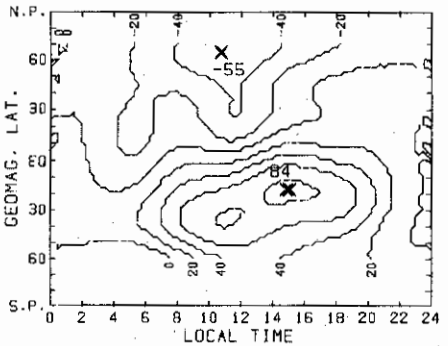

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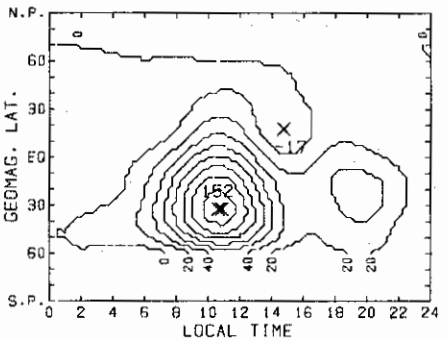

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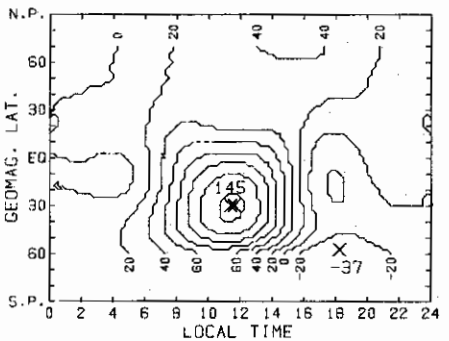

DEC. 3.1964

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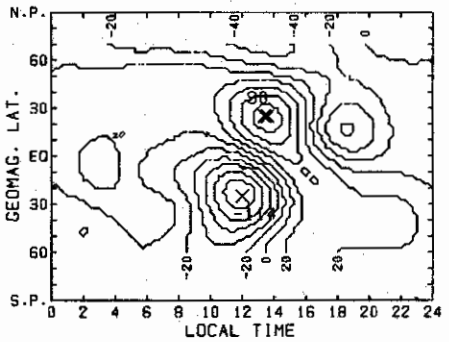

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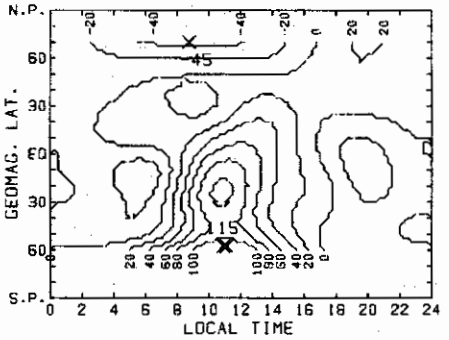
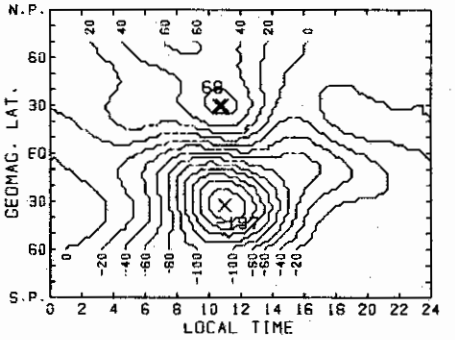


EXTERNAL



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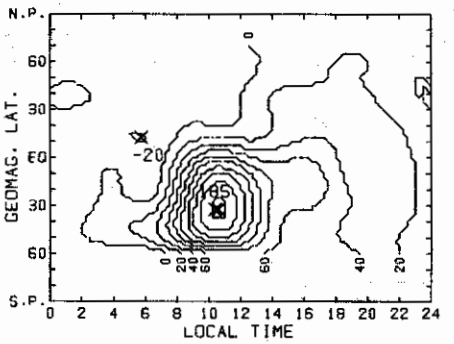

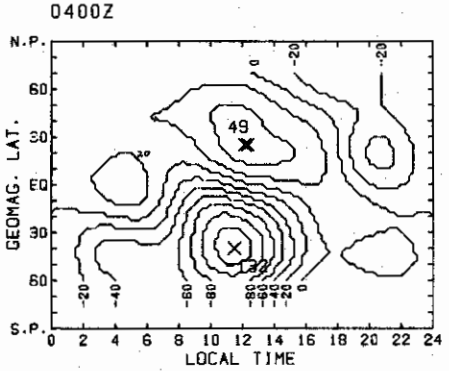

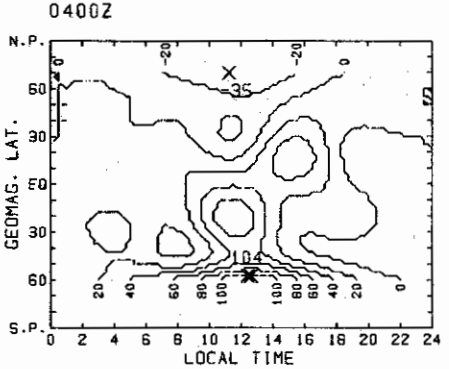

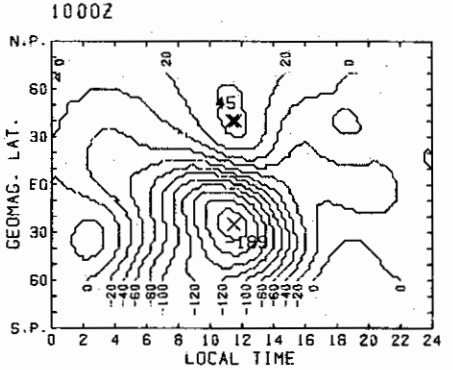

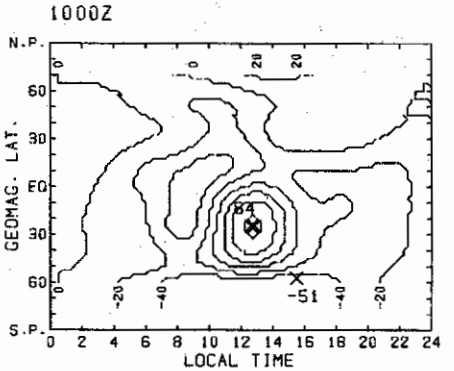

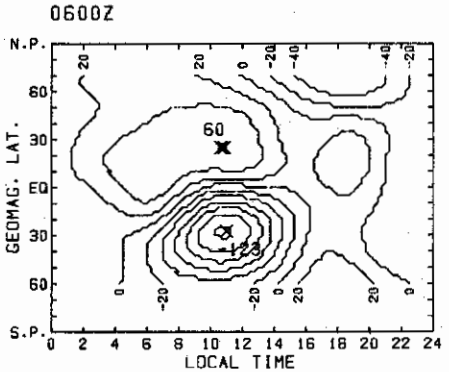

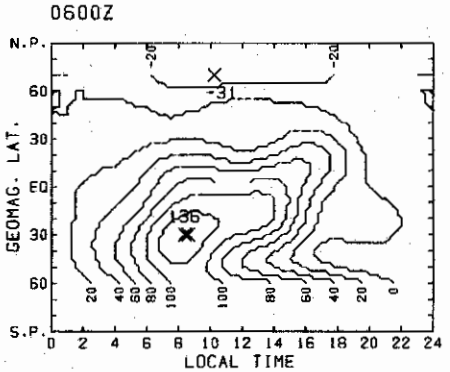

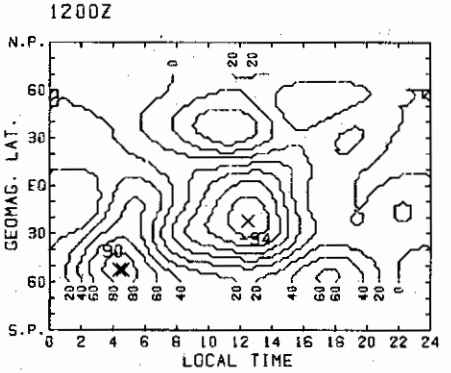

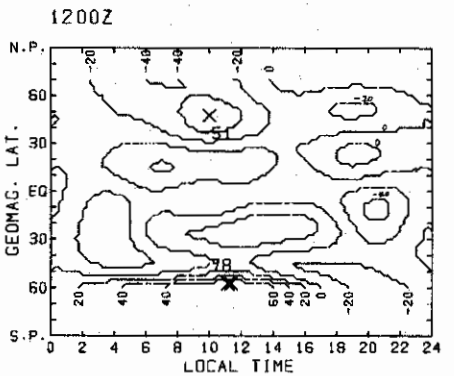

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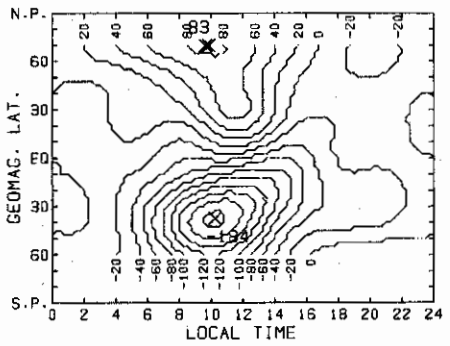

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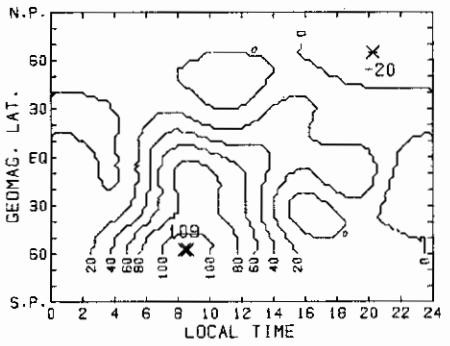

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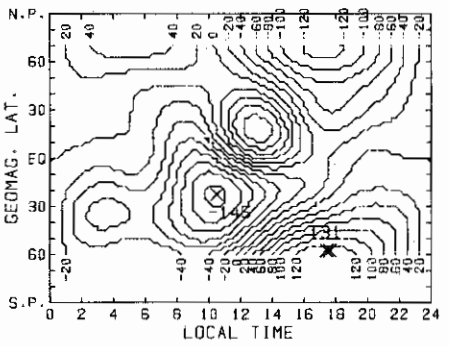

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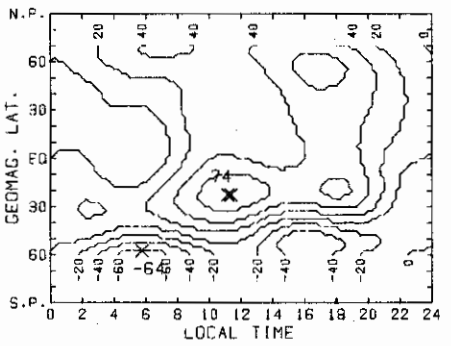

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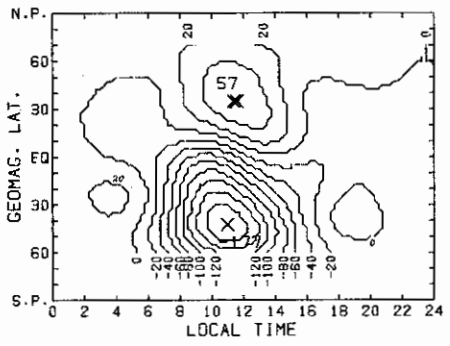

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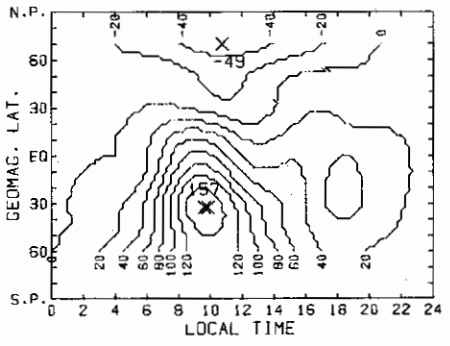

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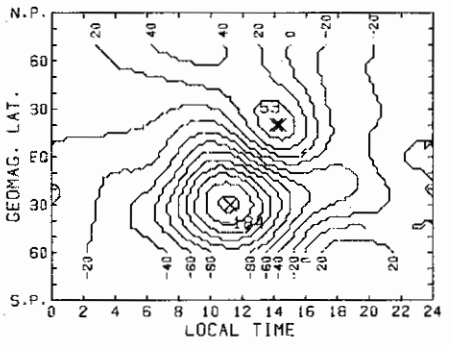

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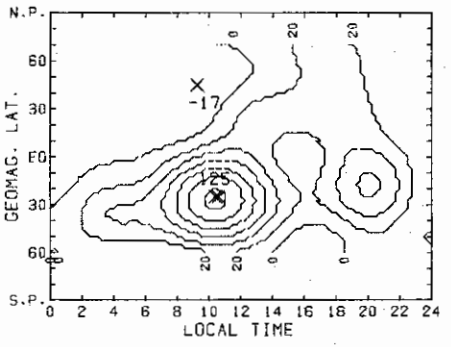

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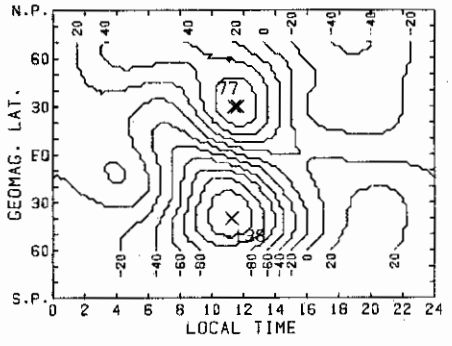

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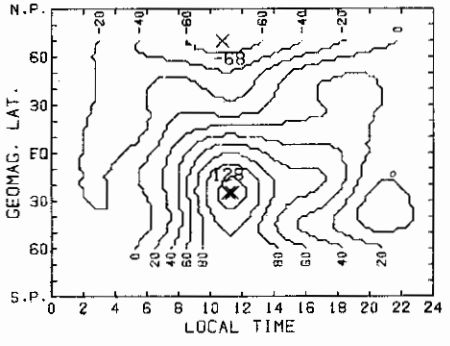

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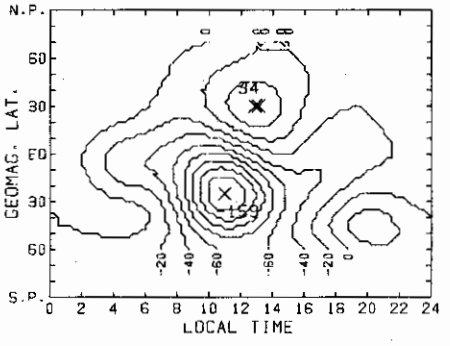

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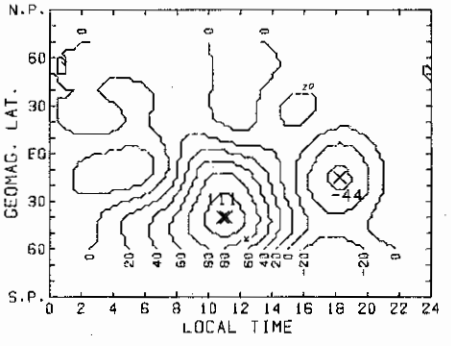

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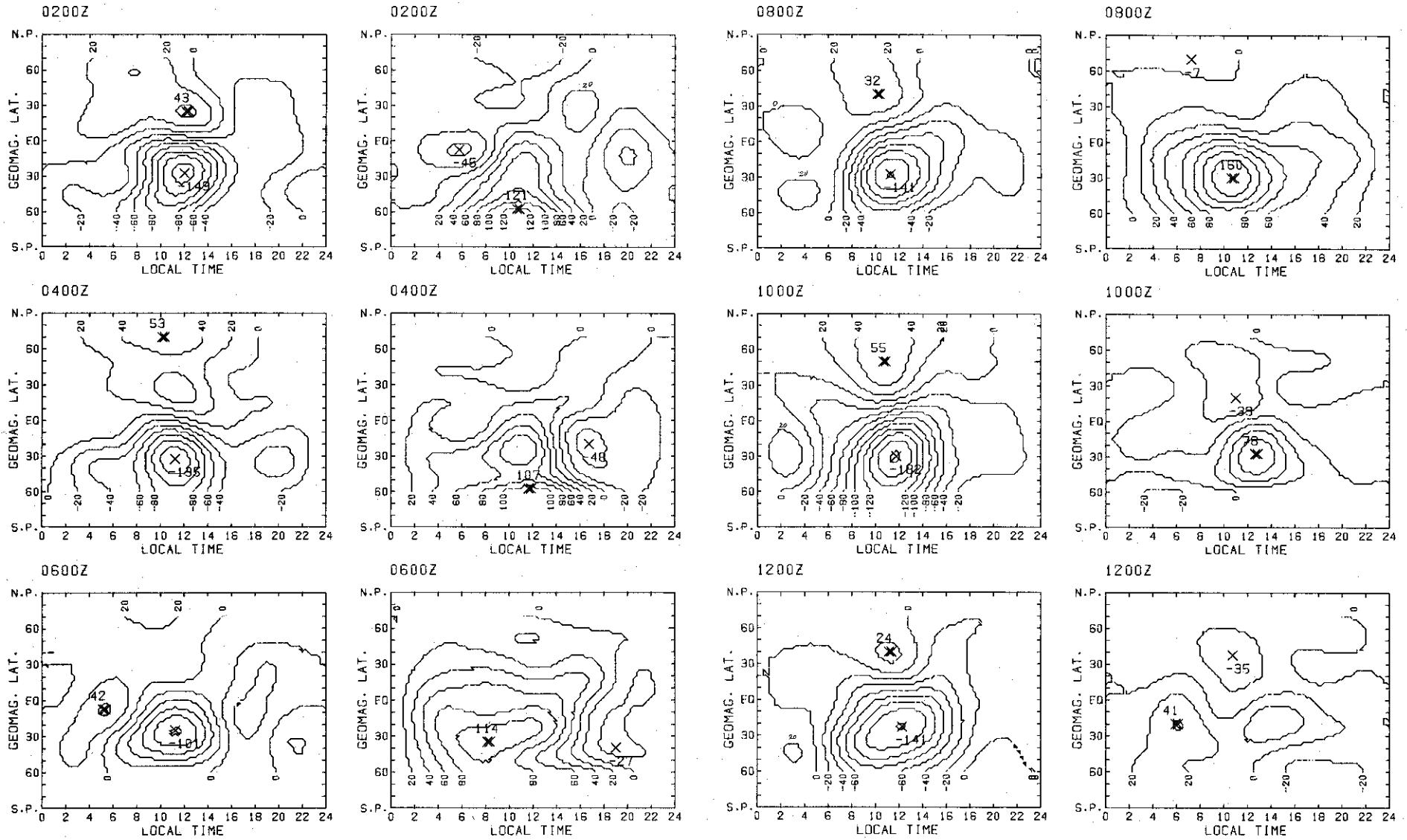
EXTERNAL

INTERNAL

EXTERNAL

INTERNAL



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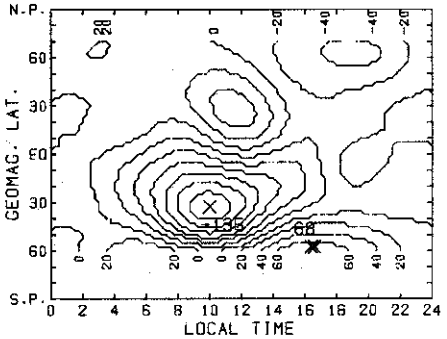

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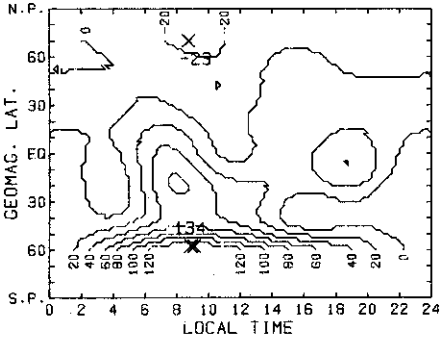

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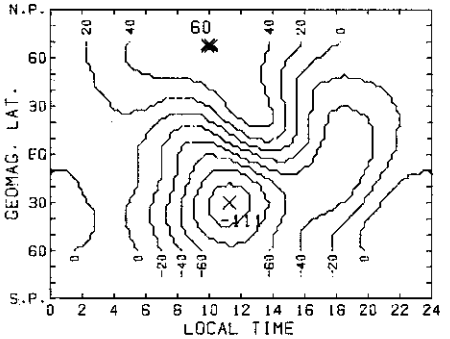

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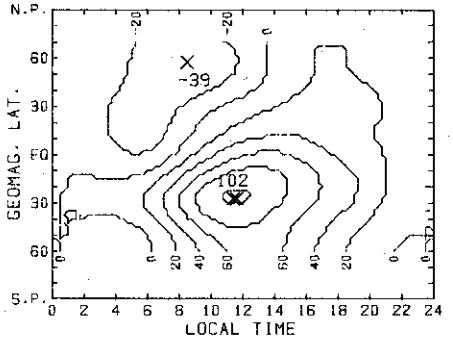

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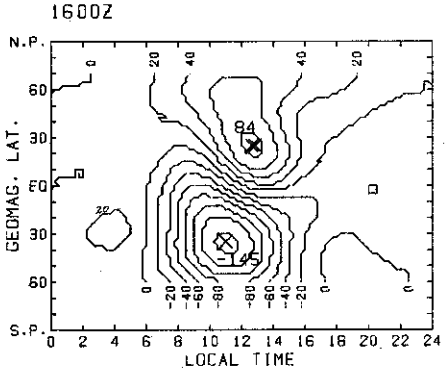

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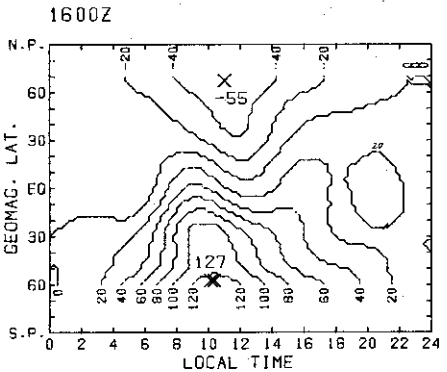

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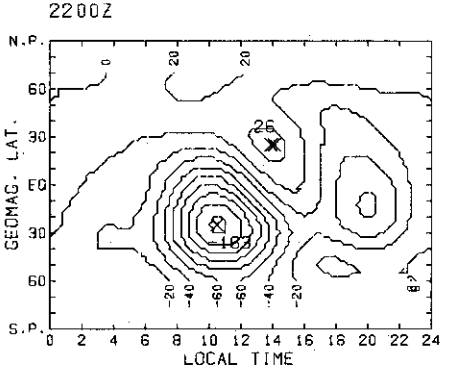

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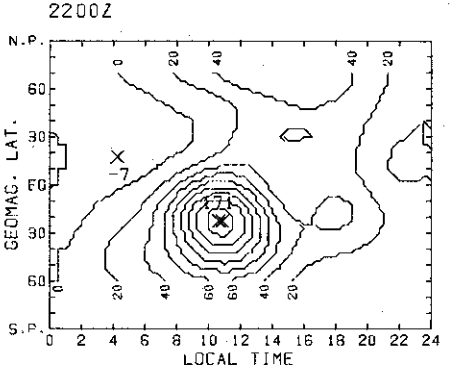

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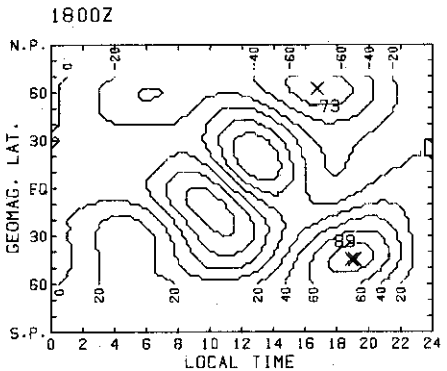

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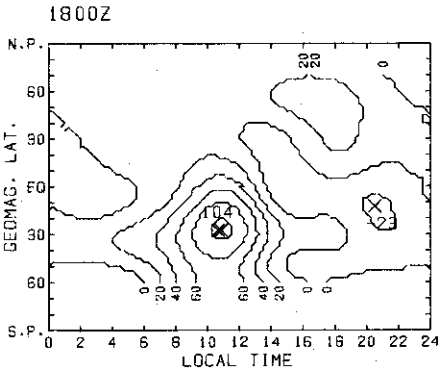

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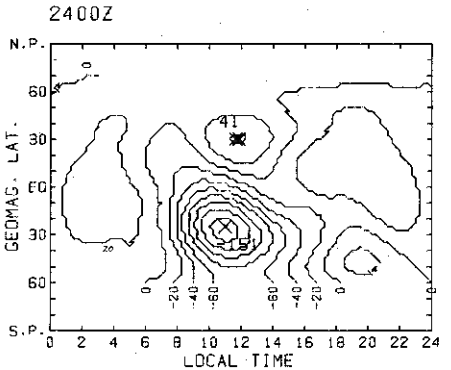

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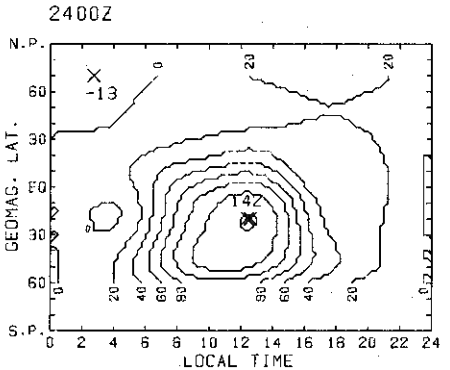

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EXTERNAL

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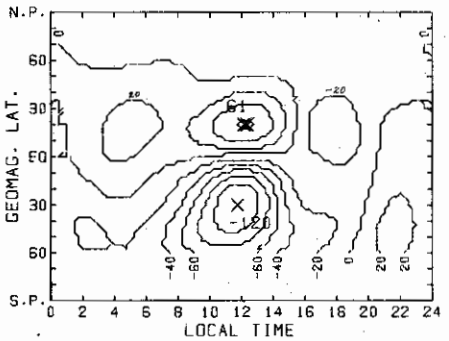

INTERNAL

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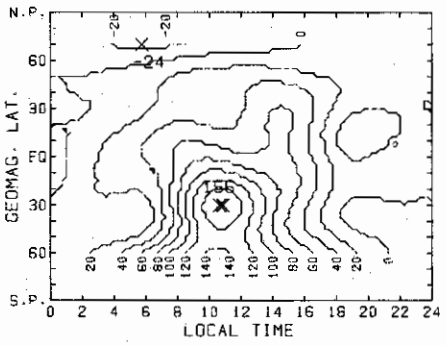

EXTERNAL

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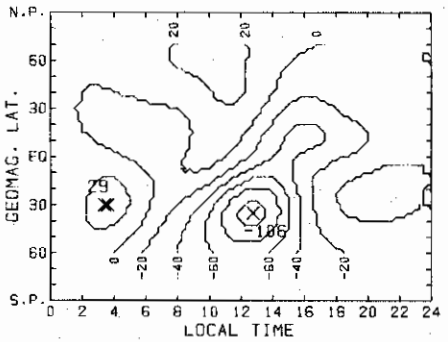

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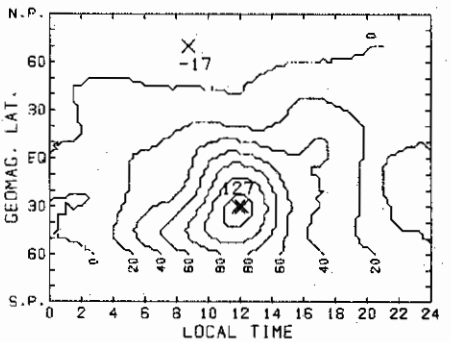

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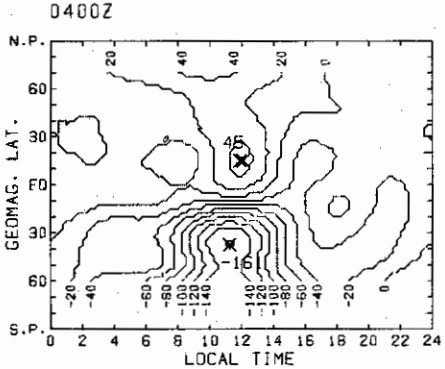

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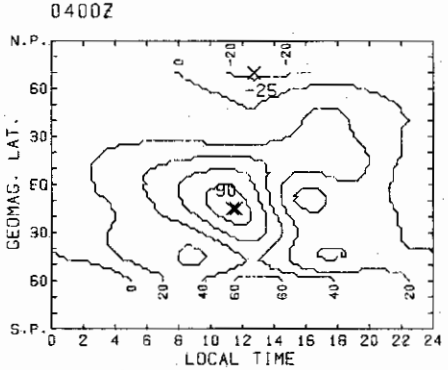

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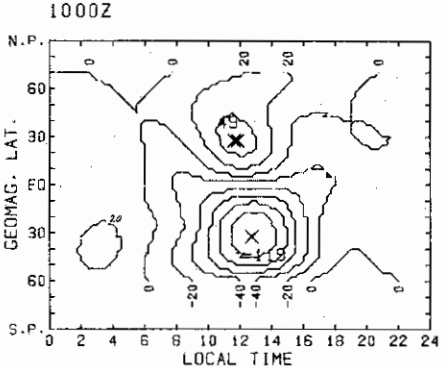

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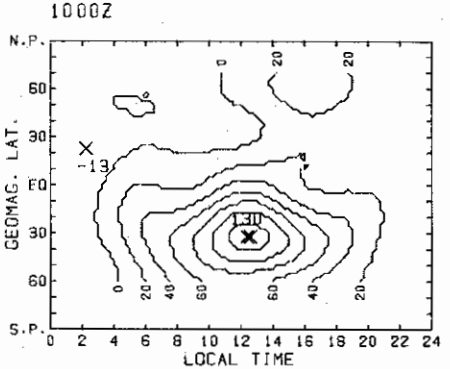

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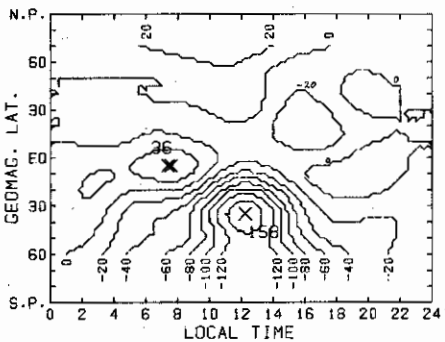

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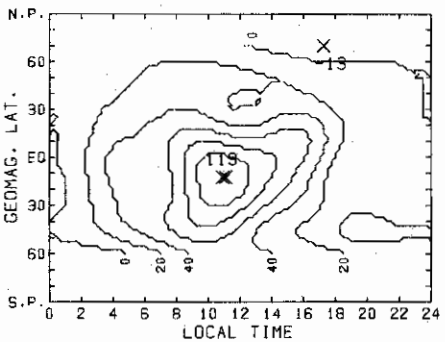

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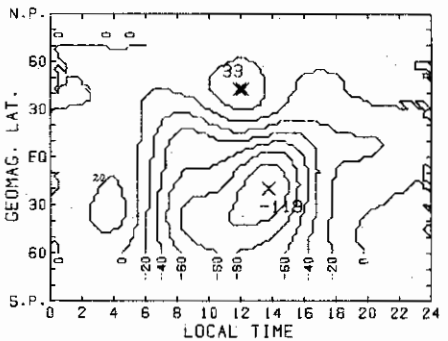

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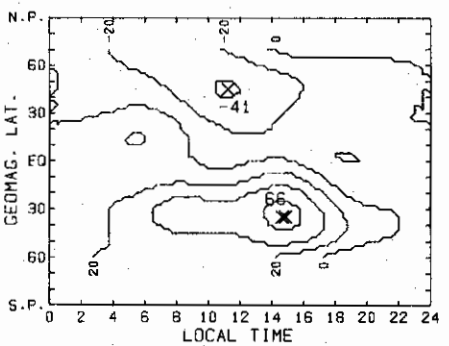

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EXTERNAL

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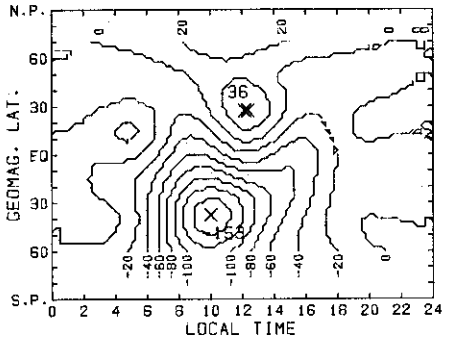

INTERNAL

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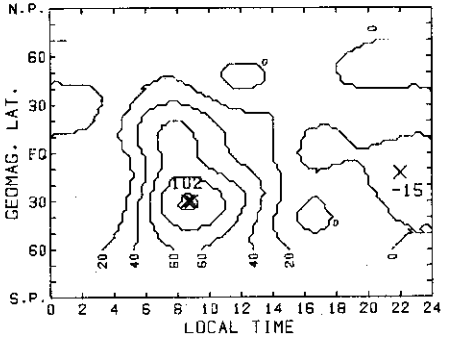

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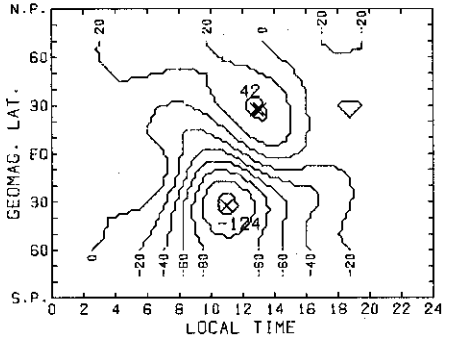

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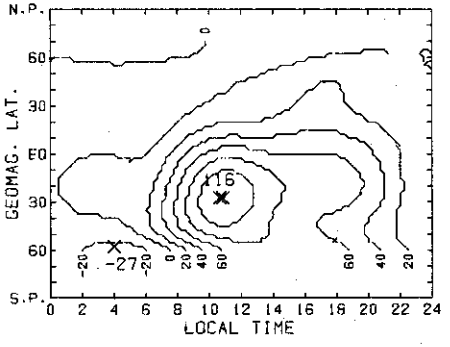

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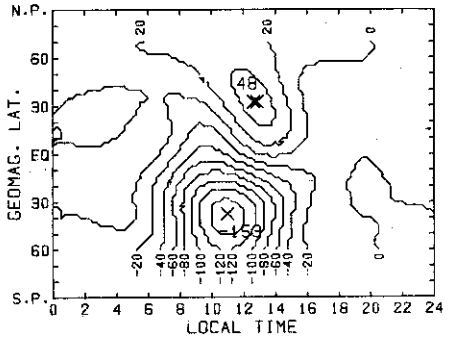

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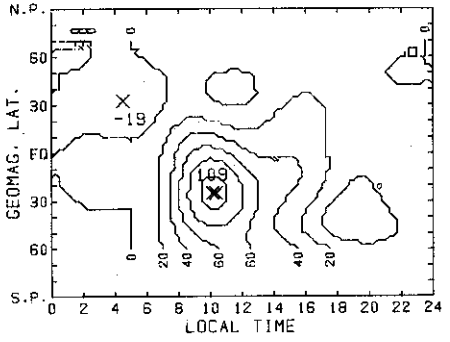

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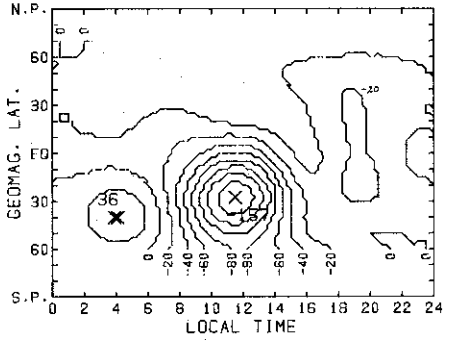

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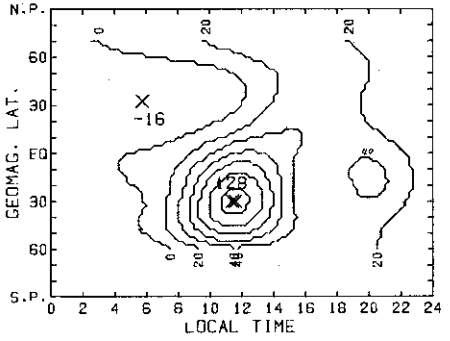

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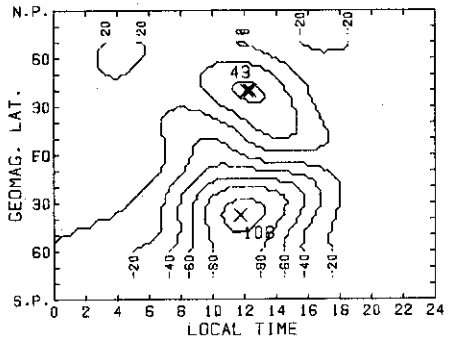

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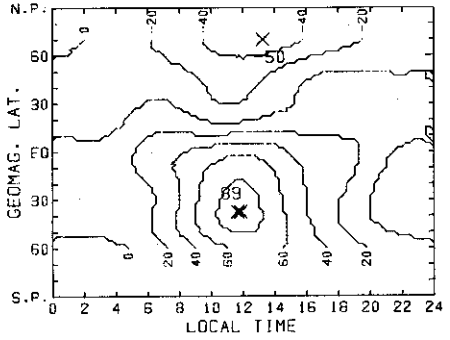

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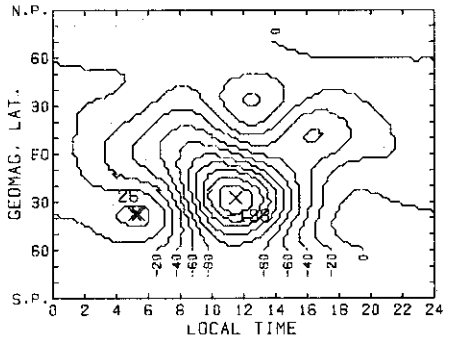

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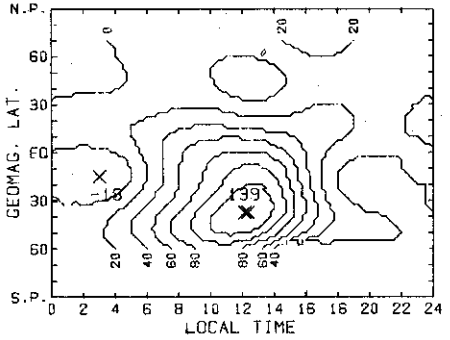

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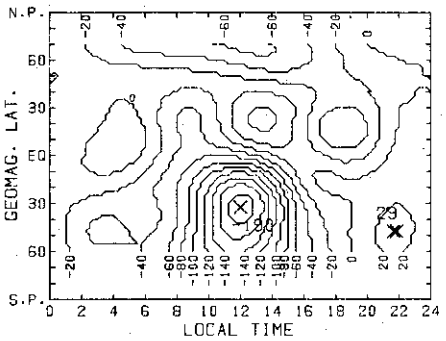

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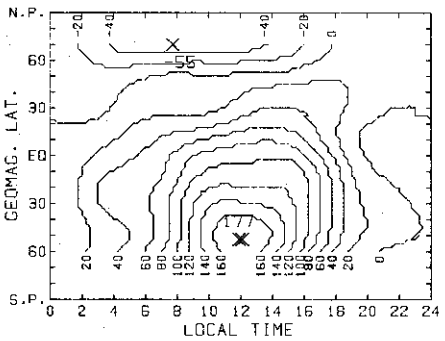

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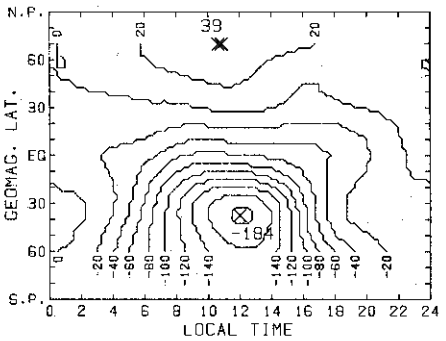

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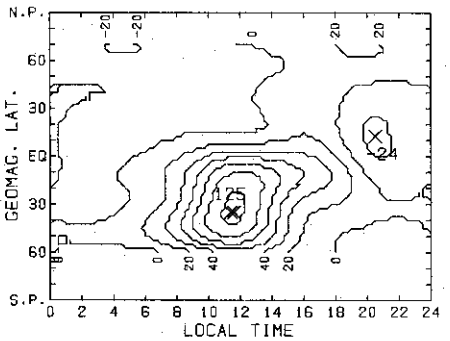

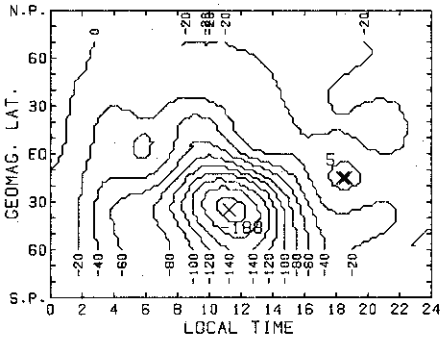

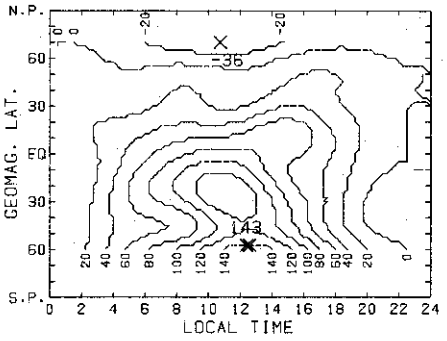

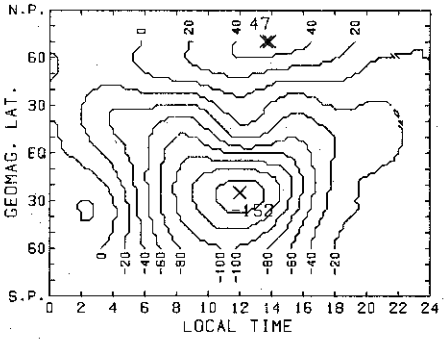

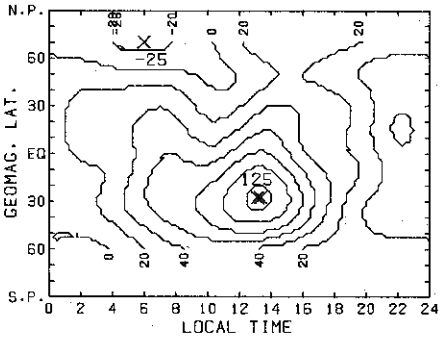

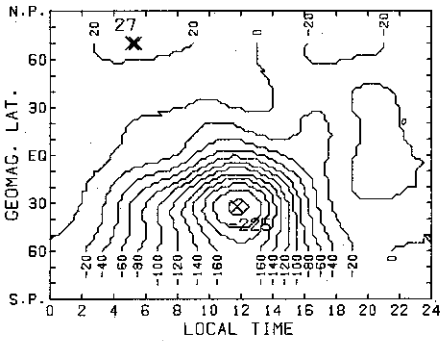

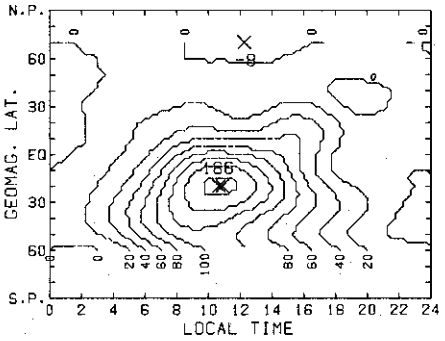

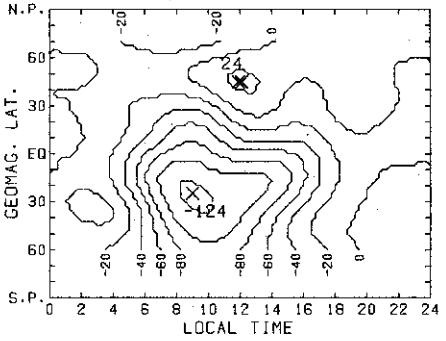

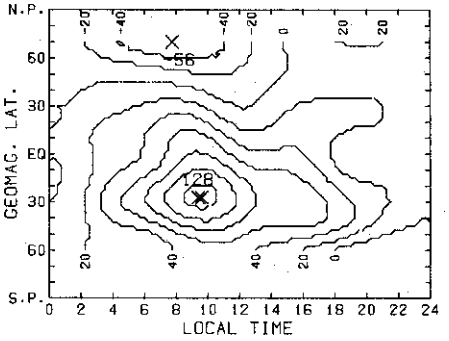

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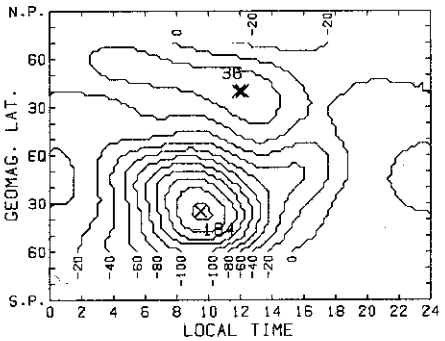

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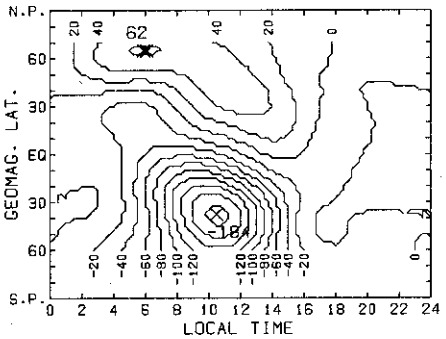

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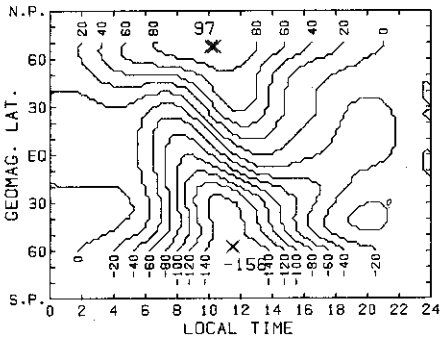

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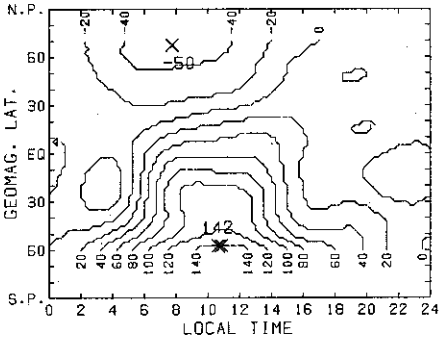

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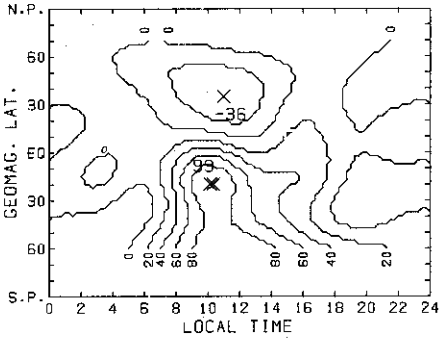

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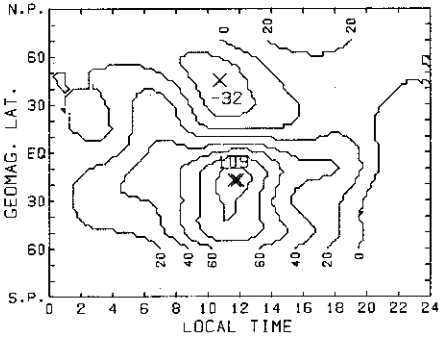

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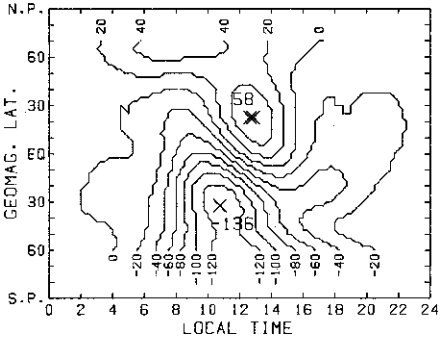

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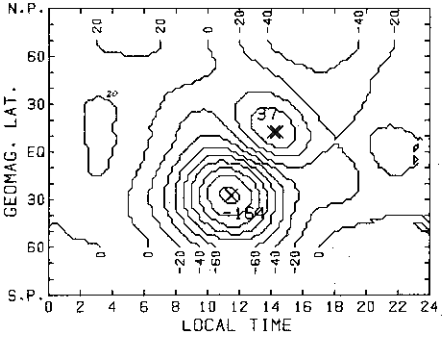

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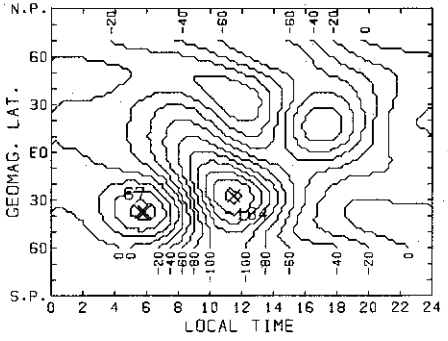

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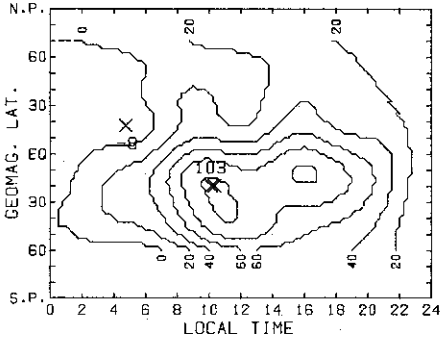

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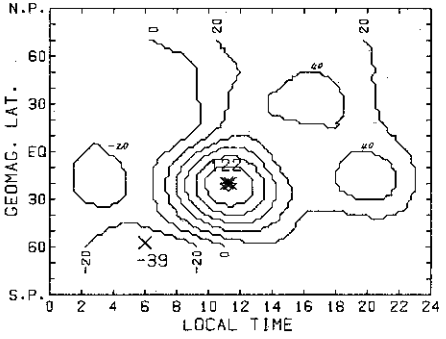

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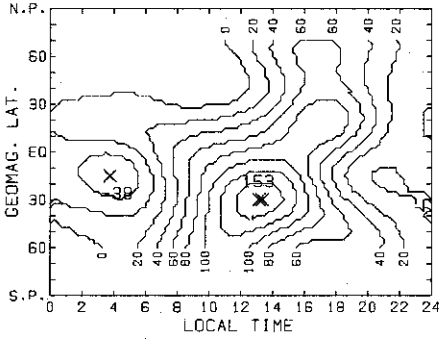

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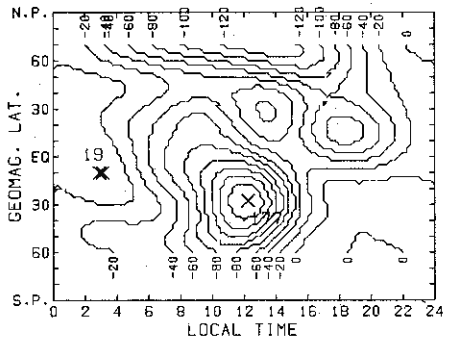

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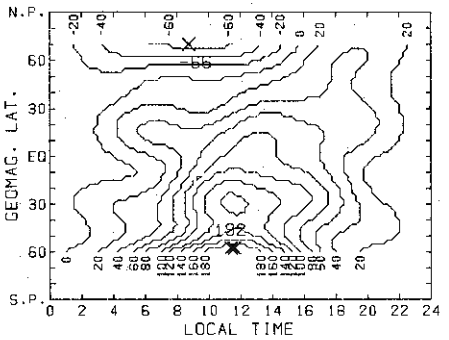

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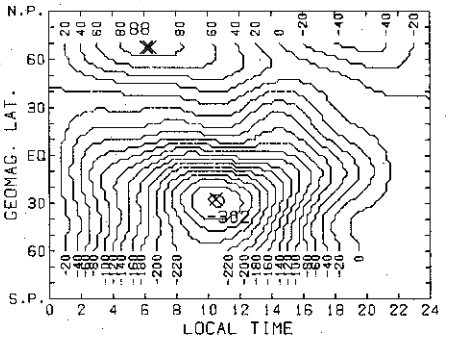

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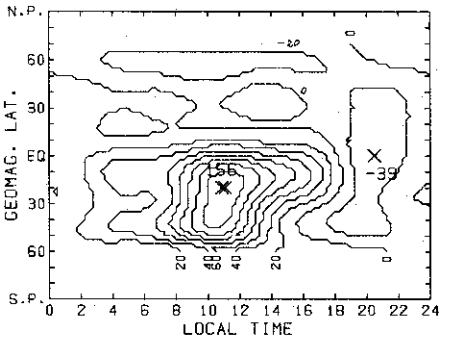

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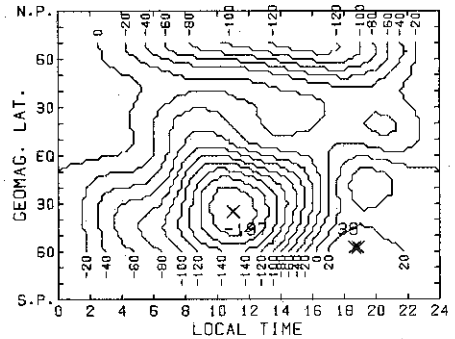

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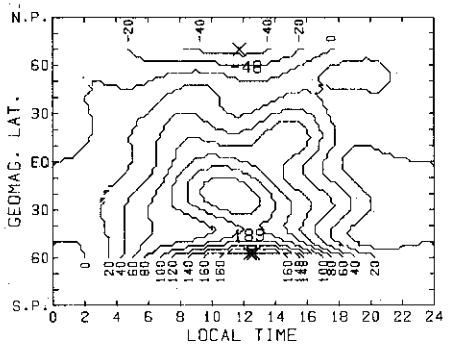

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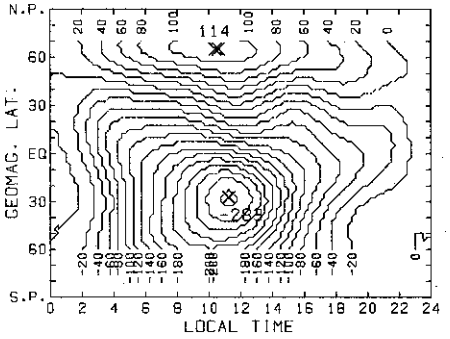

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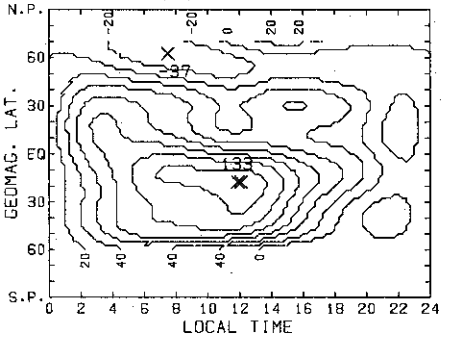

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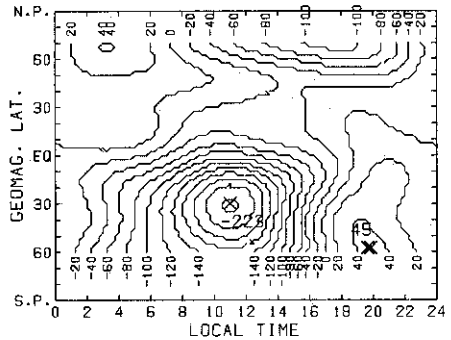

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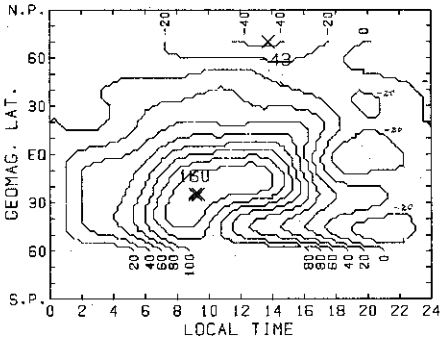

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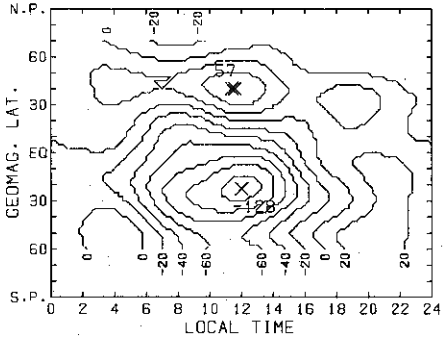

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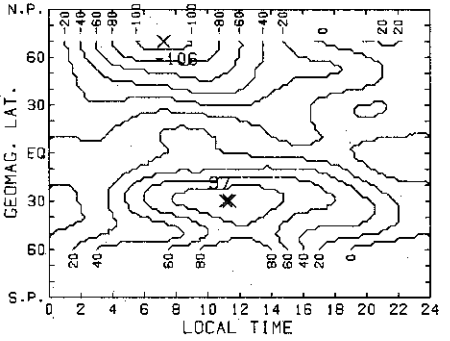

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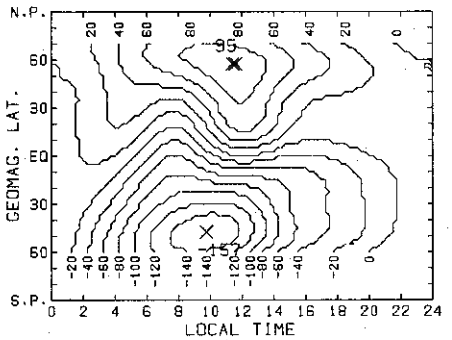

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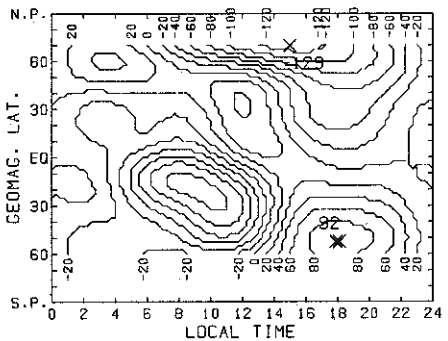

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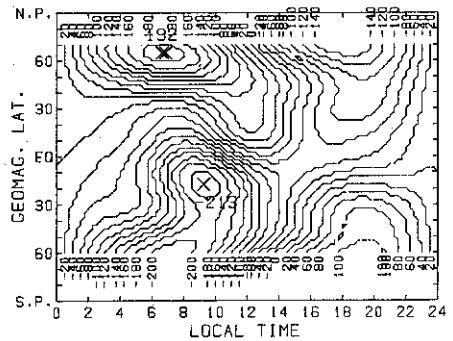

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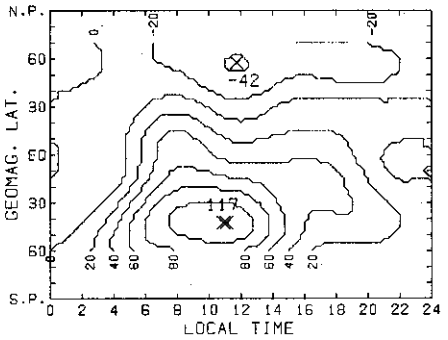

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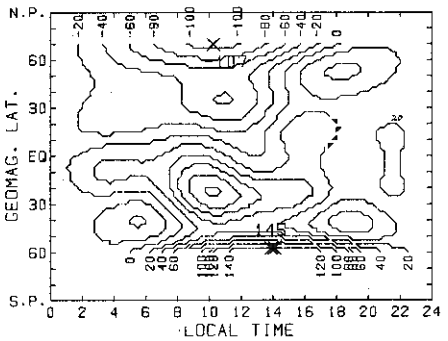

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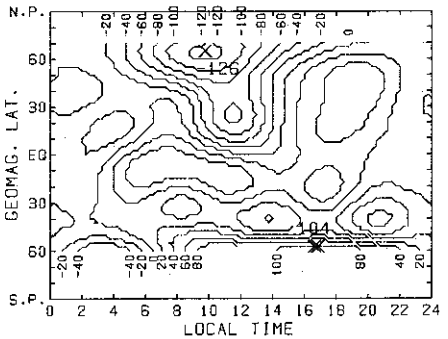

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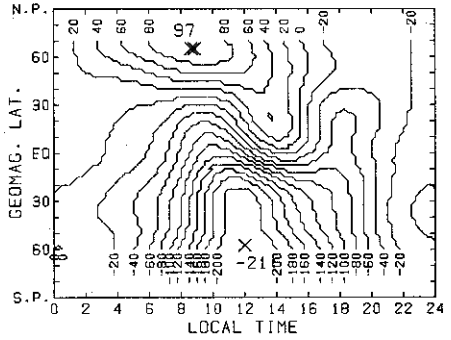

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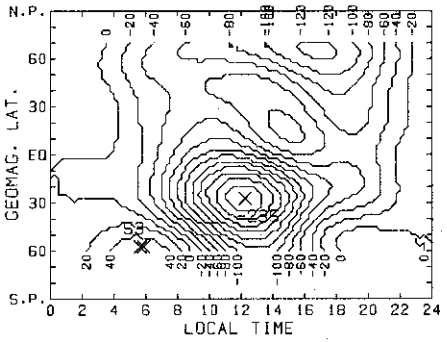

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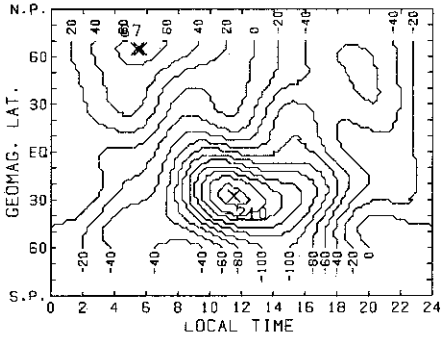

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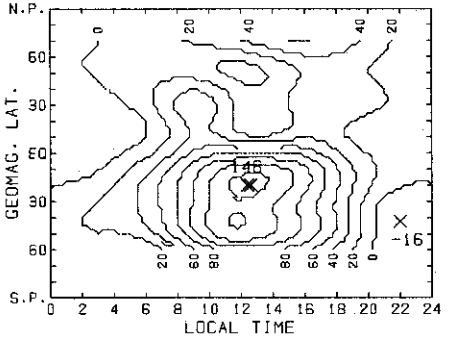

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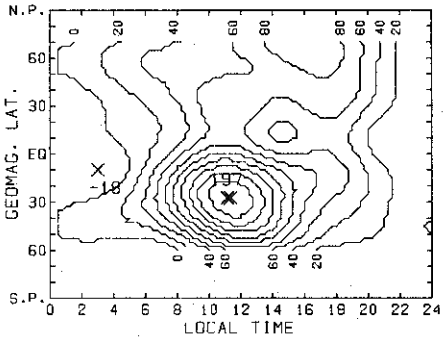

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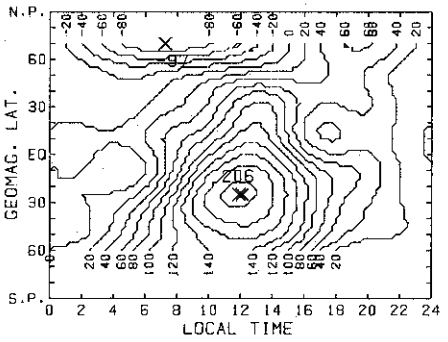

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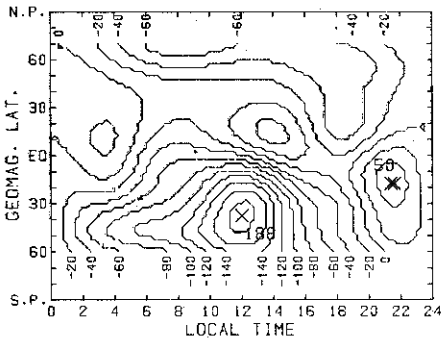

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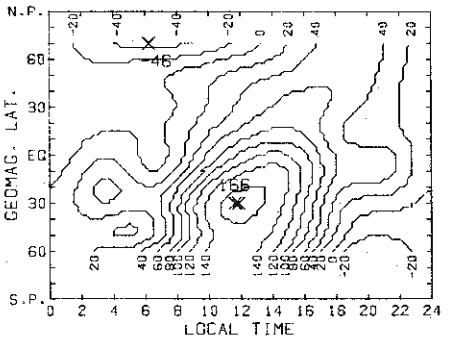

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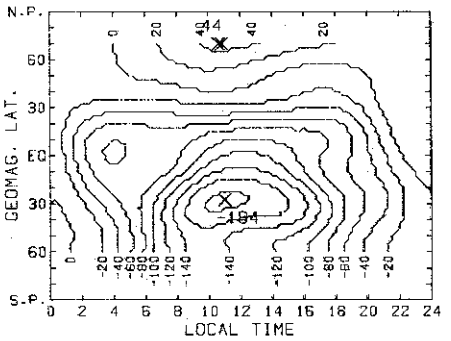

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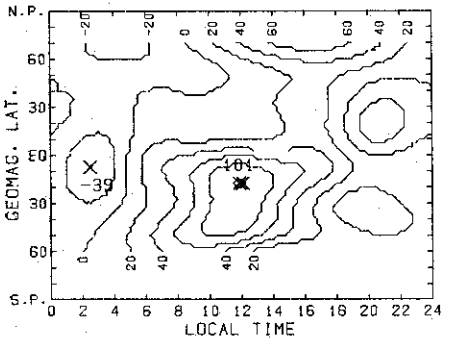

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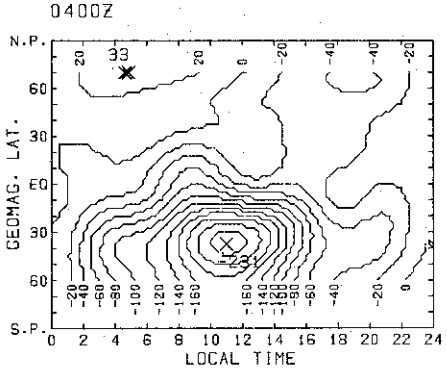

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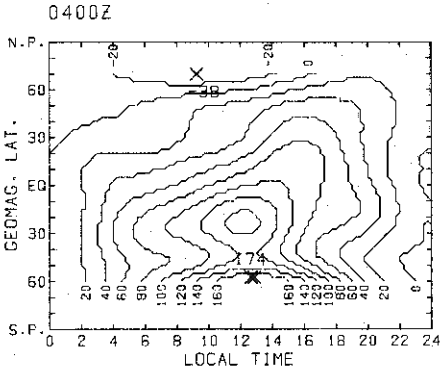

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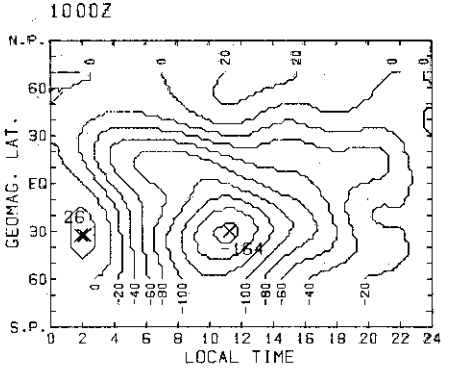

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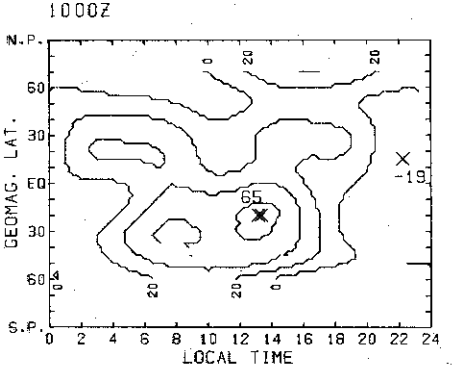

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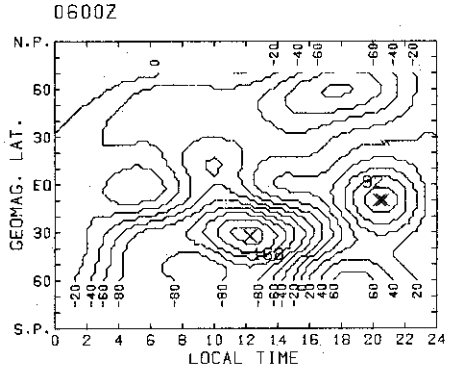

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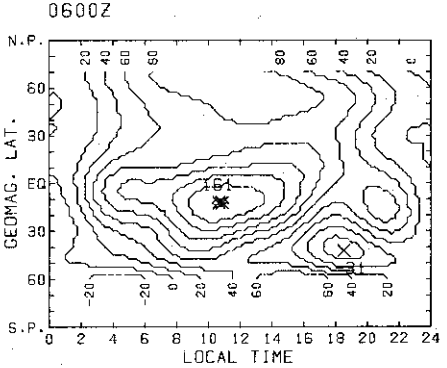

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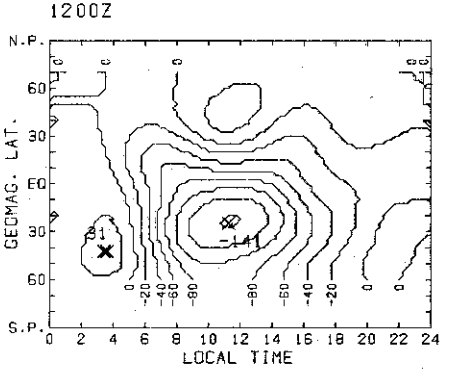

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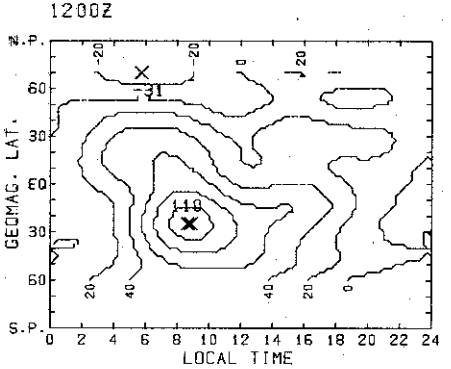

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EXTERNAL

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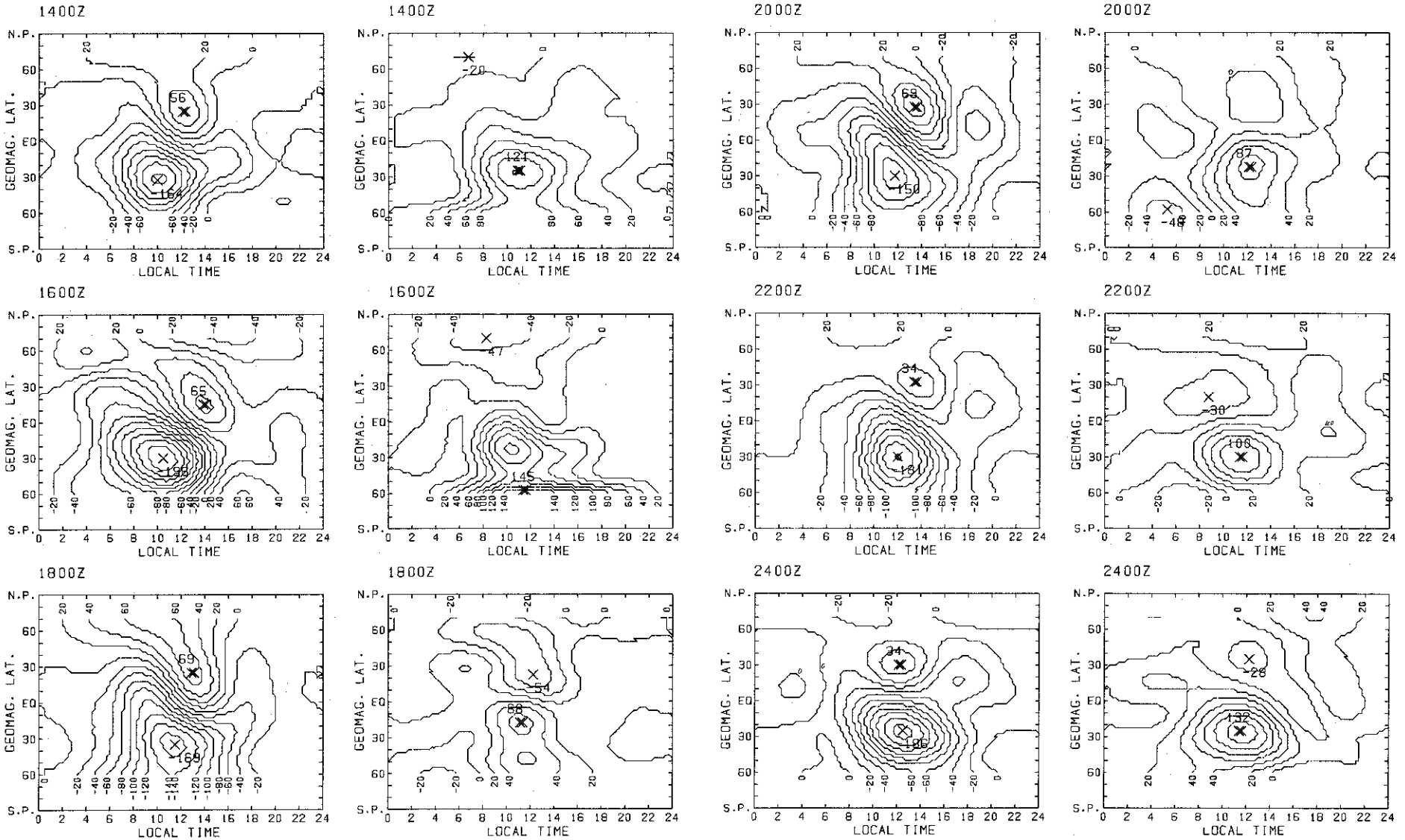

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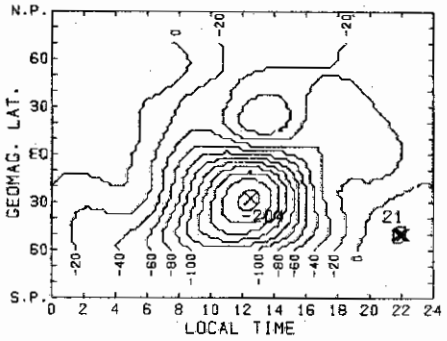

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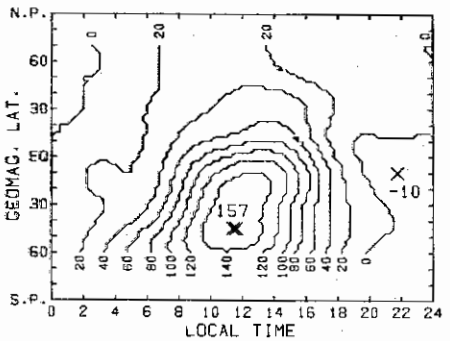

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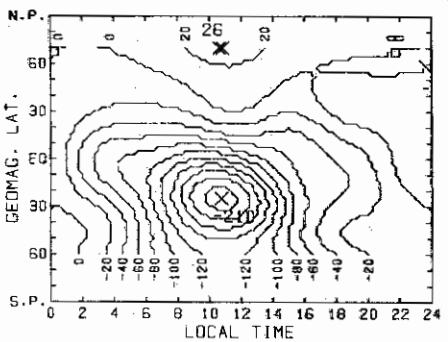

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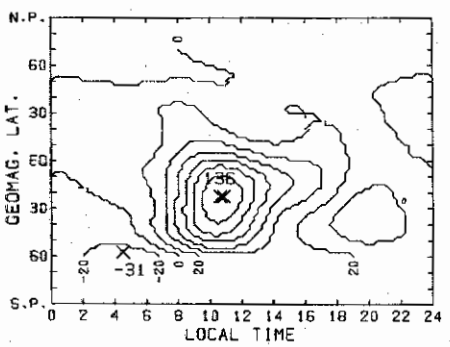

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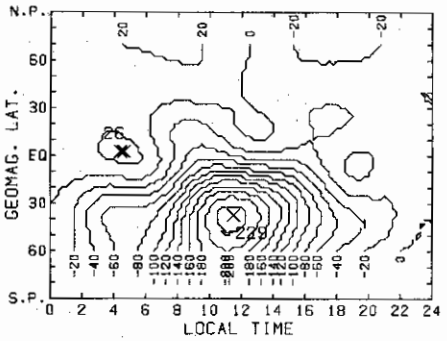

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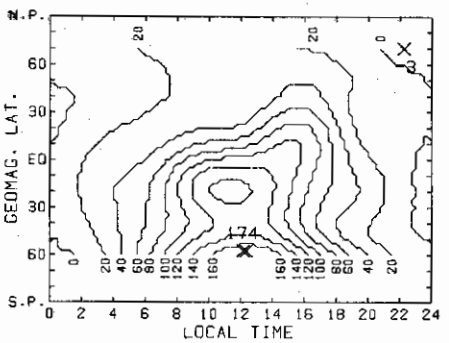

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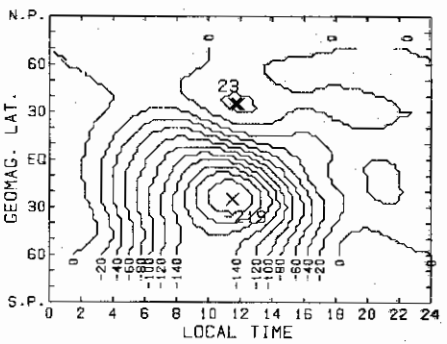

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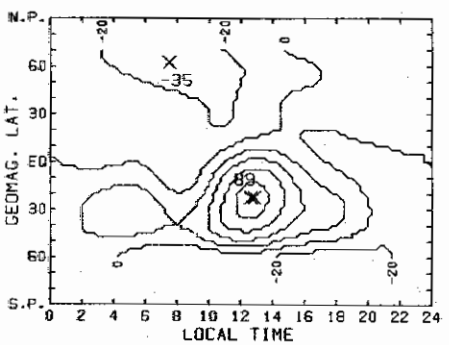

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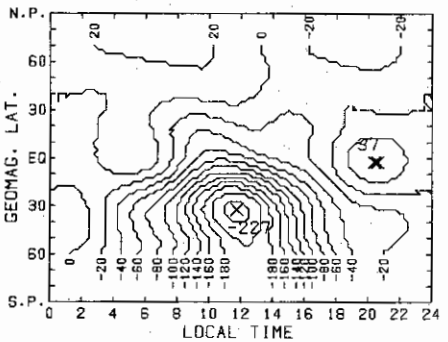

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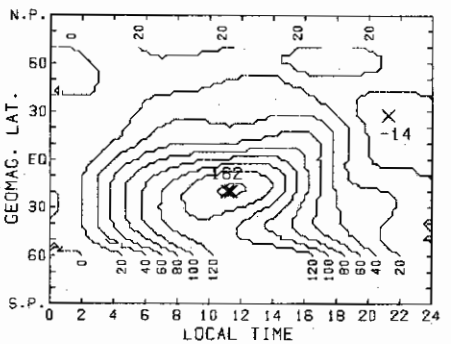

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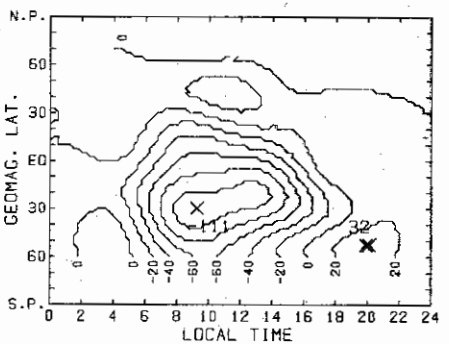

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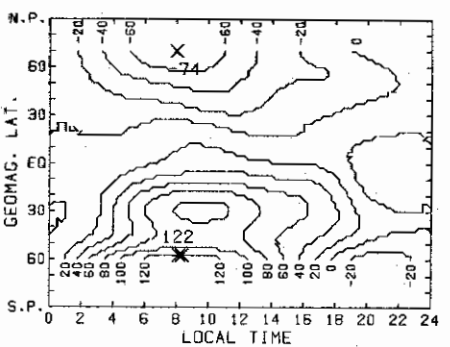

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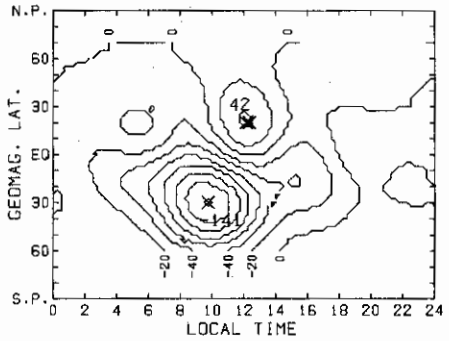

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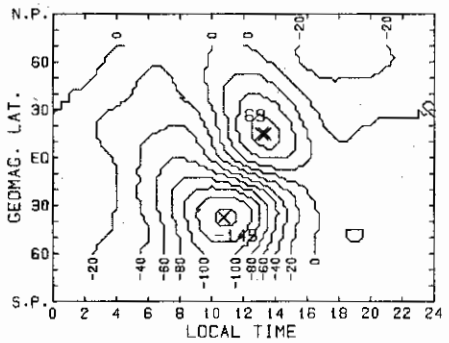

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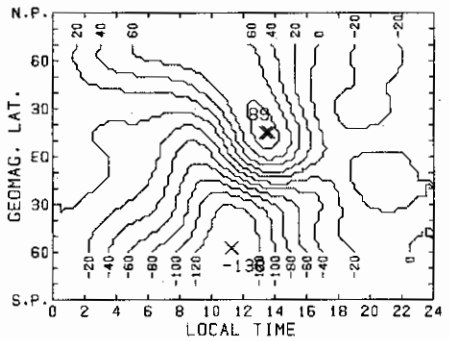

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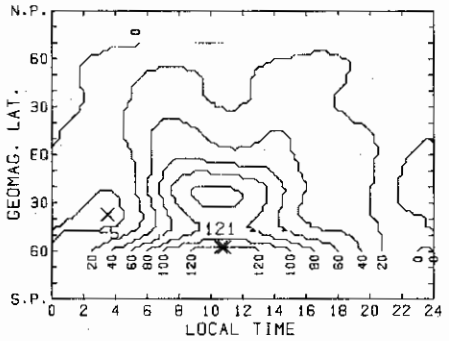

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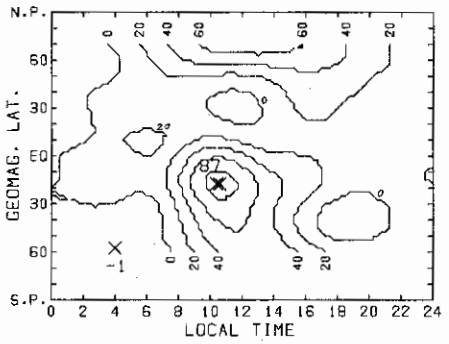

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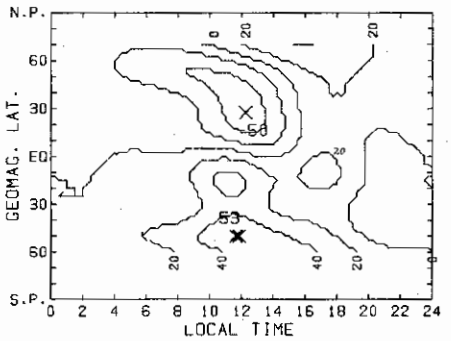

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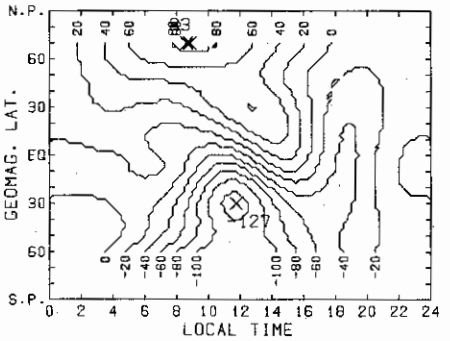

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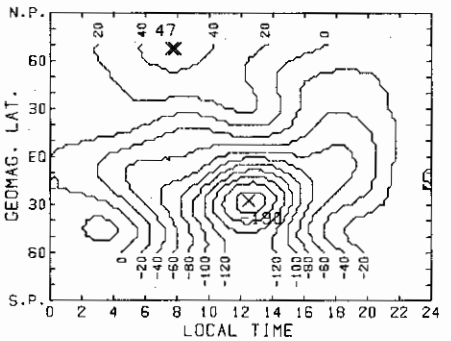

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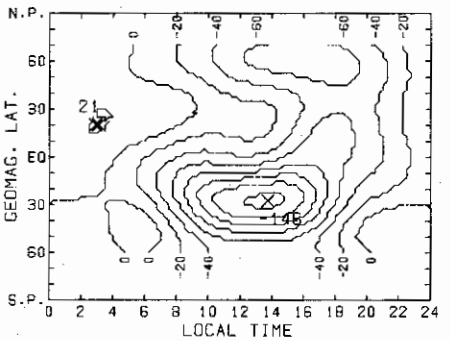

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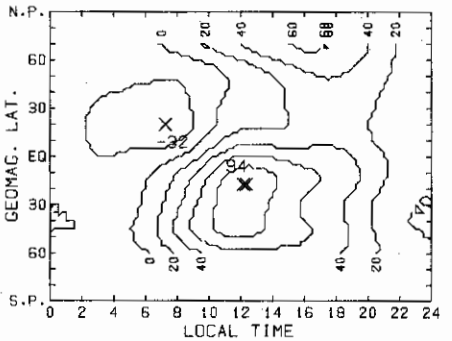

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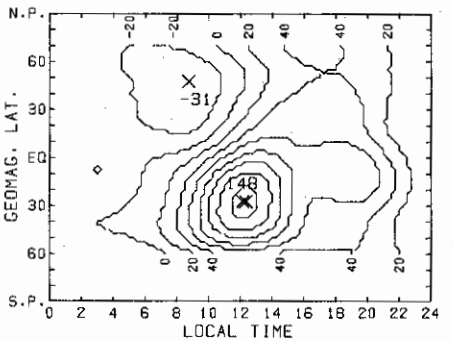

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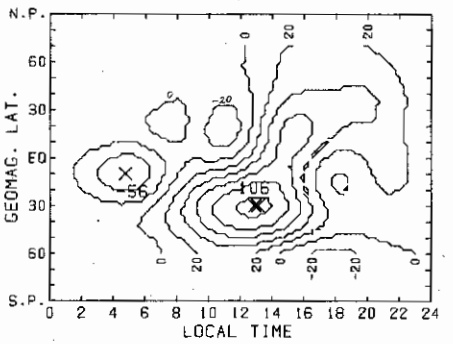

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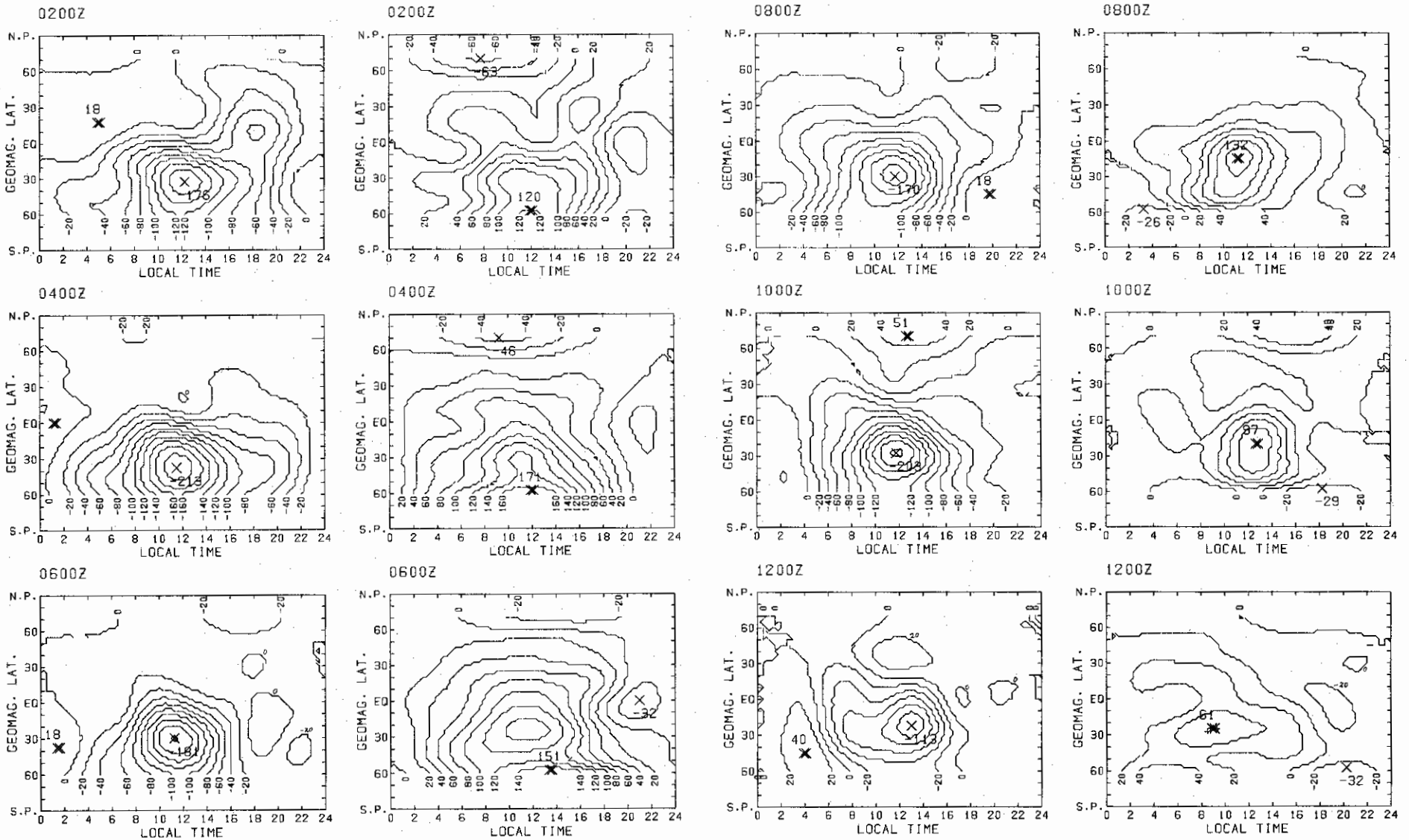

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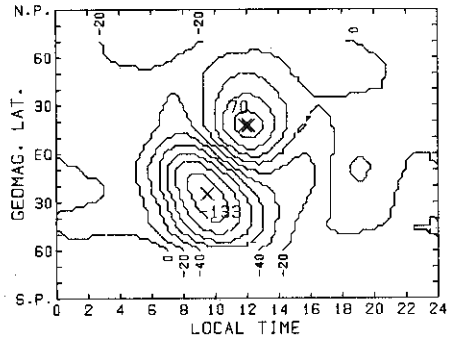

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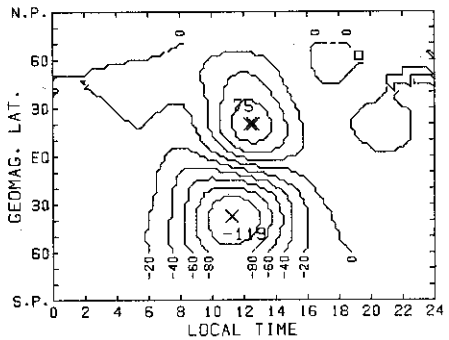

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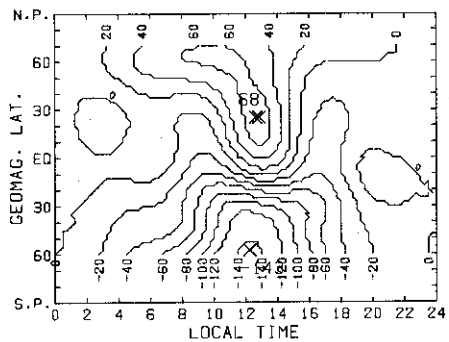

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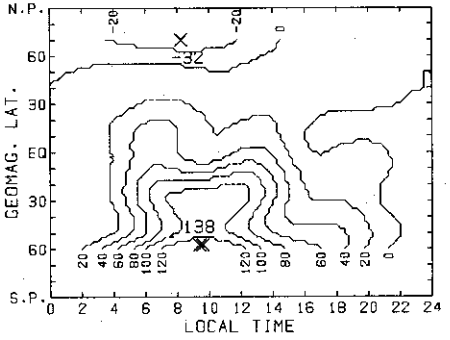

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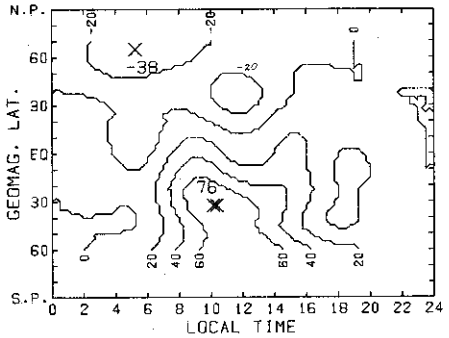

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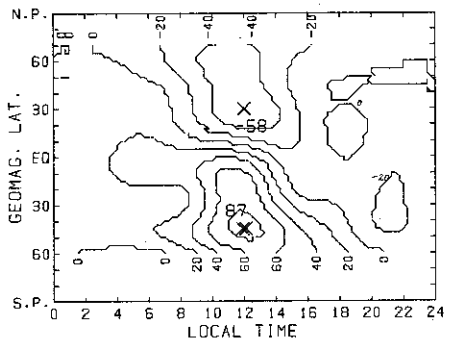

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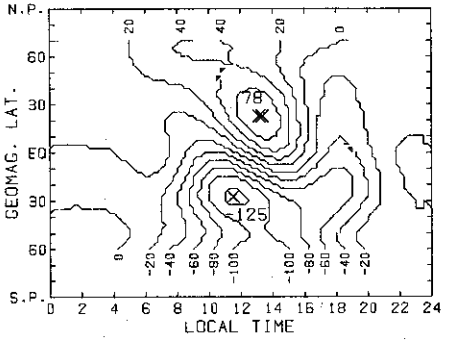

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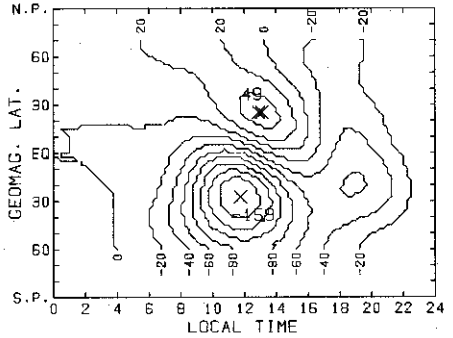

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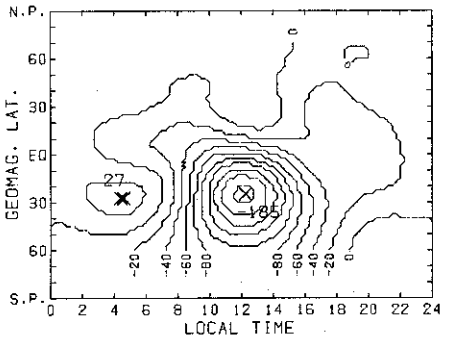

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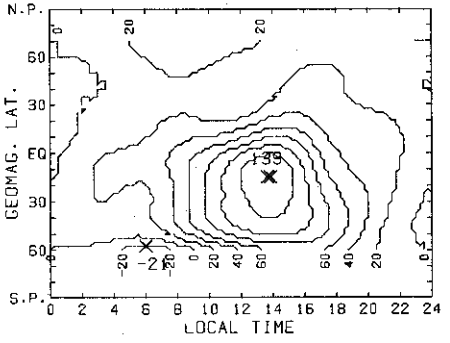

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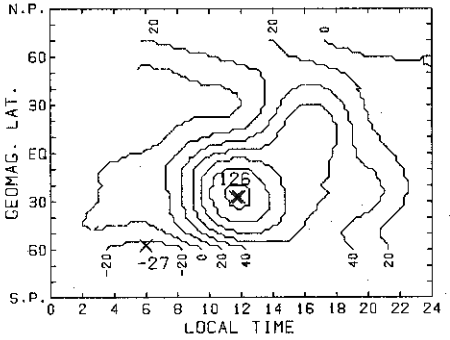

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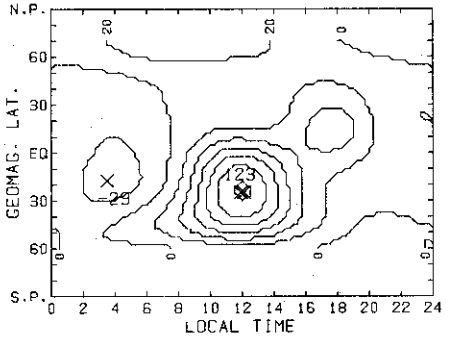

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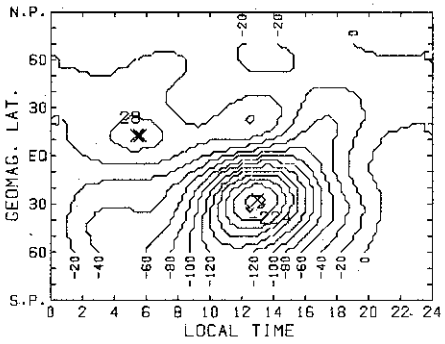

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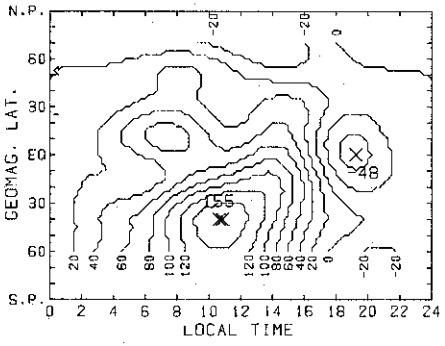

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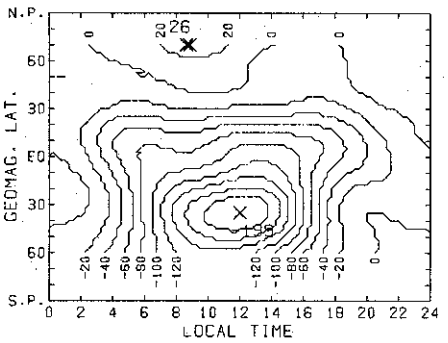

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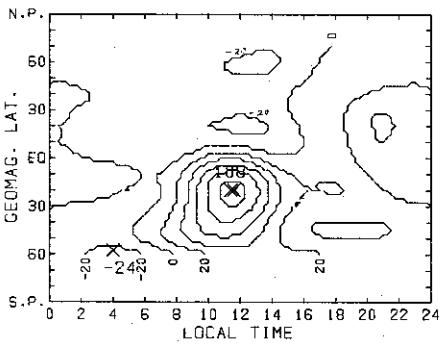

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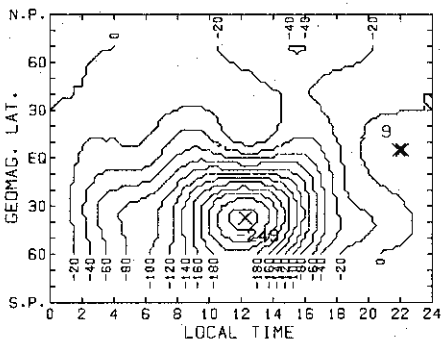

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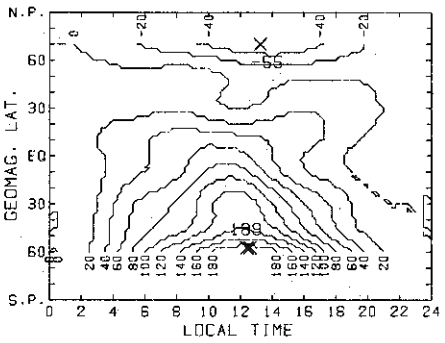

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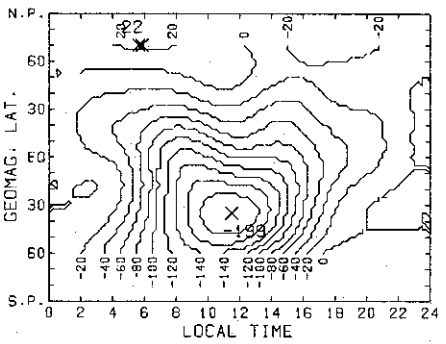

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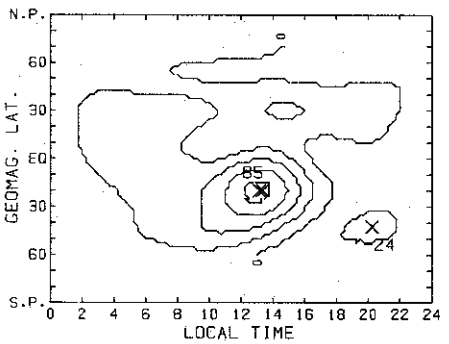

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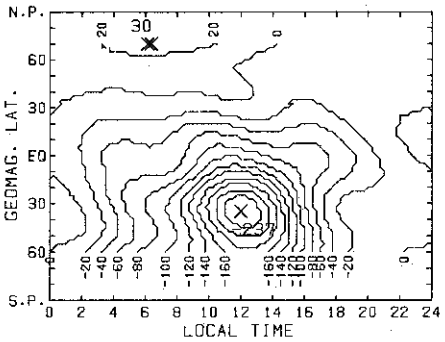

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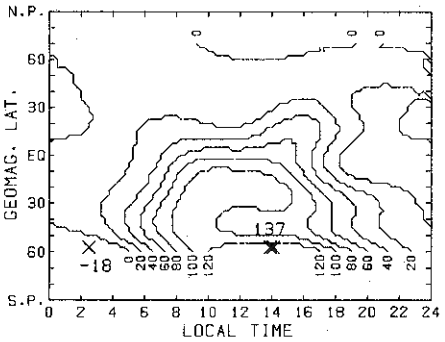

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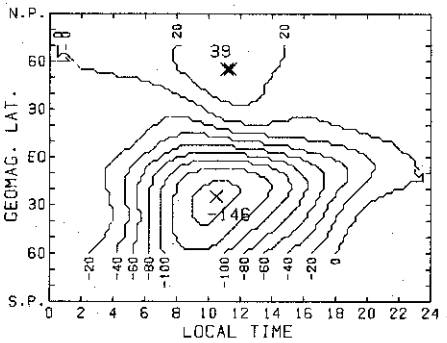

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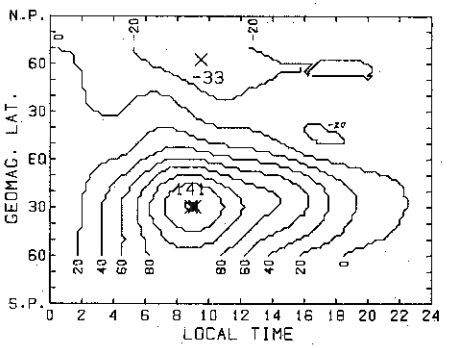

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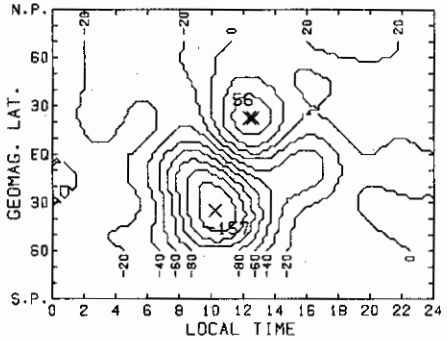

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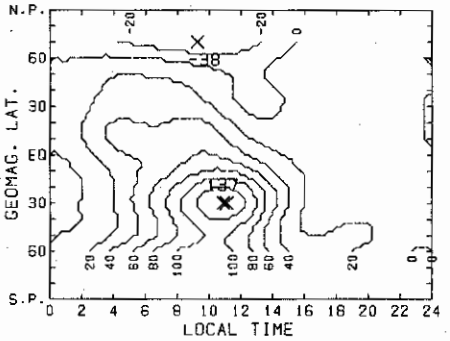

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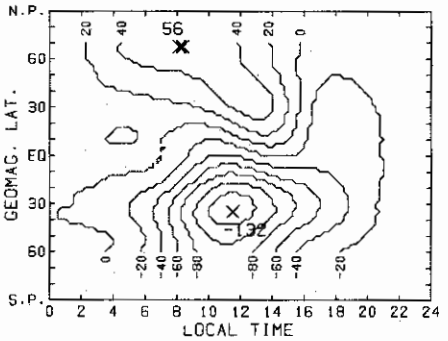

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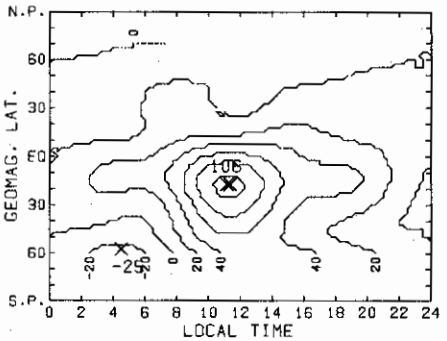

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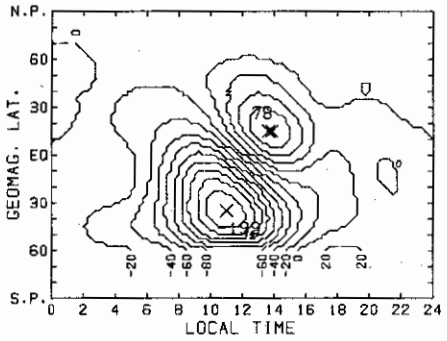

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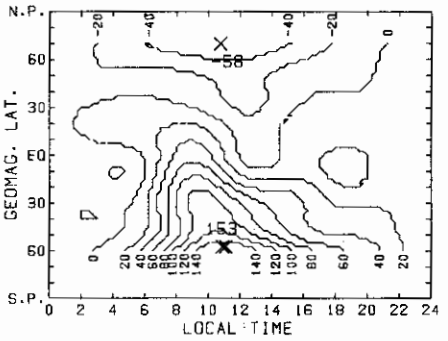

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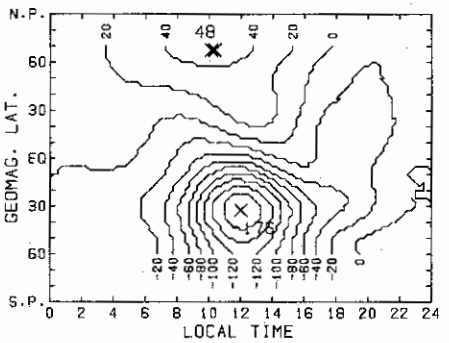

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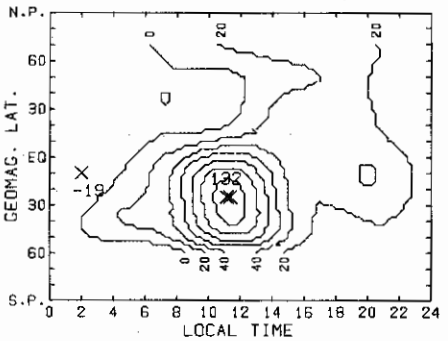

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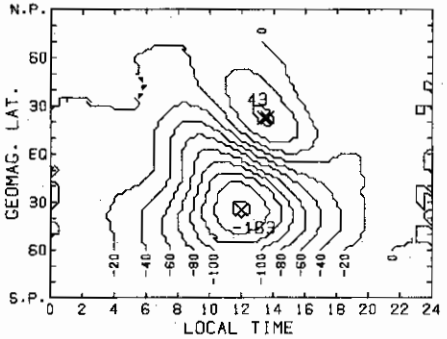

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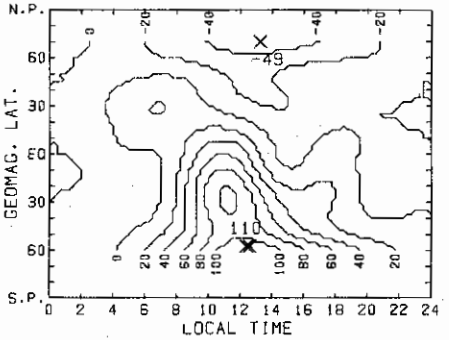

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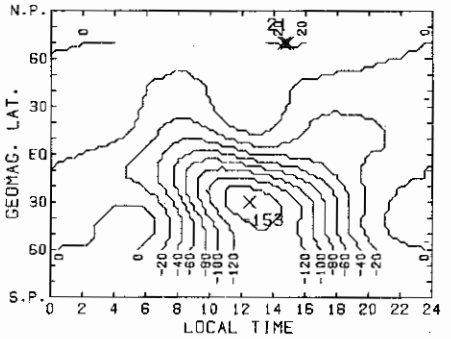

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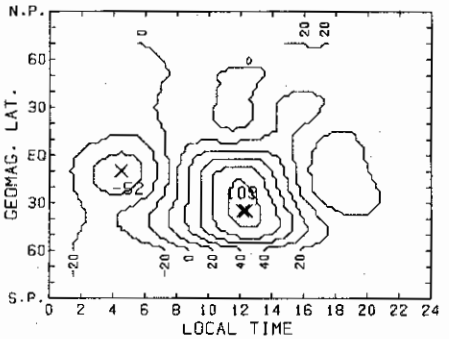

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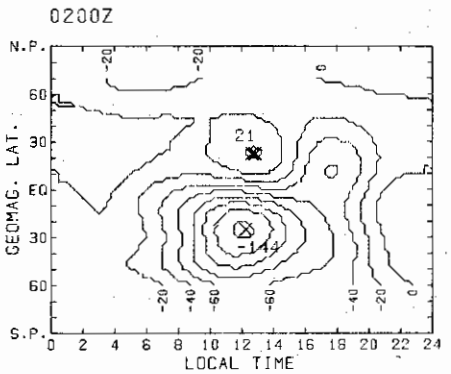

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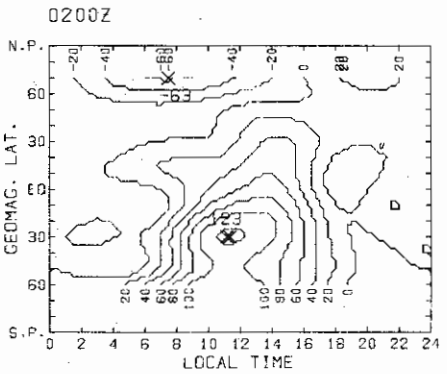

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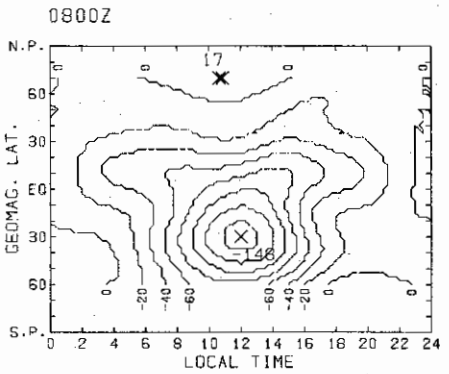

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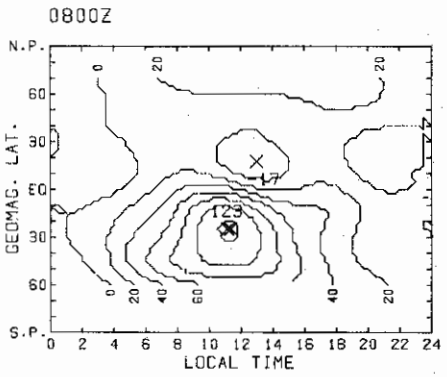

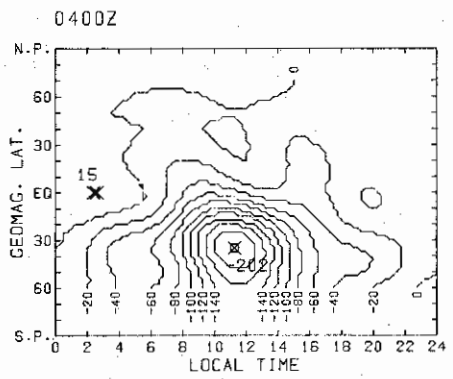

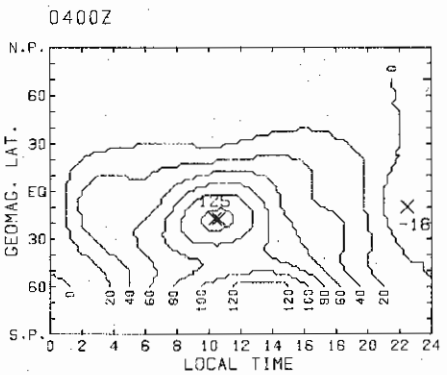

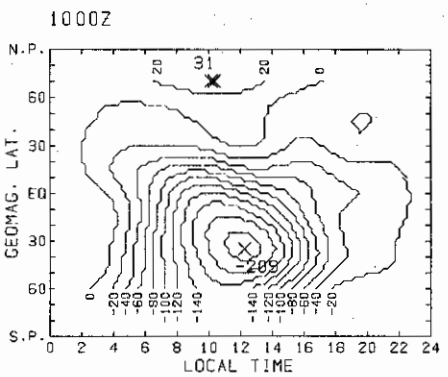

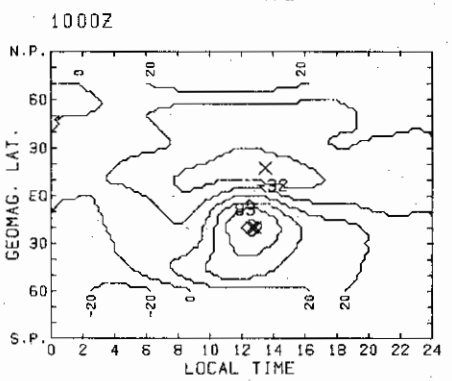

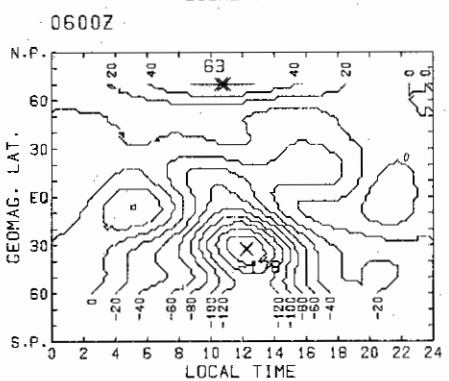

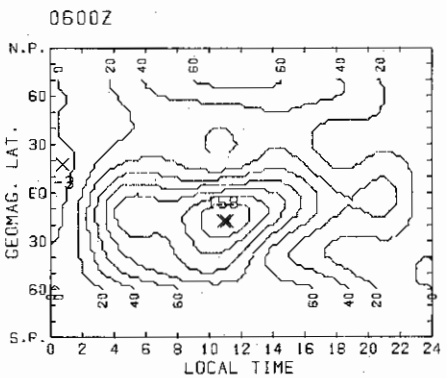

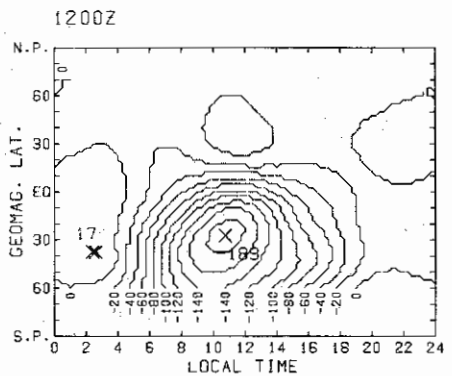

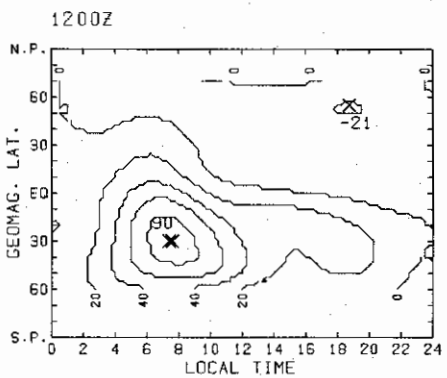

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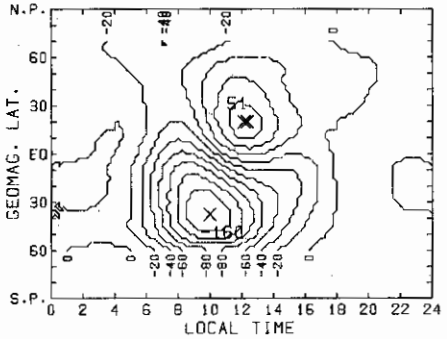

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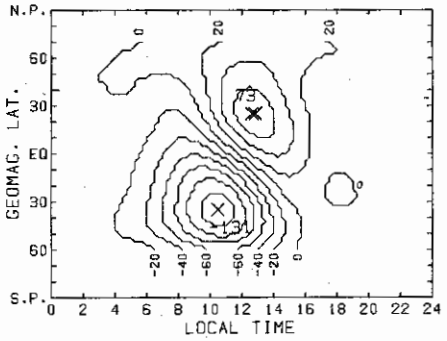

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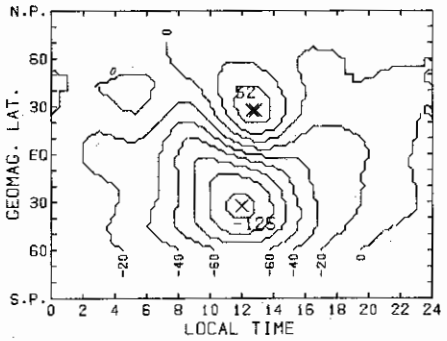

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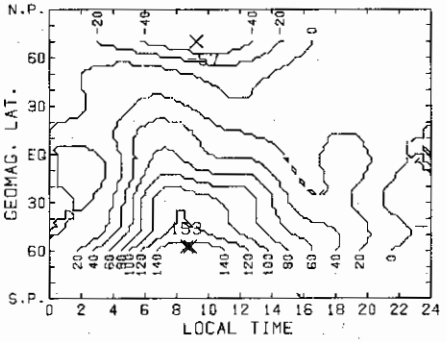

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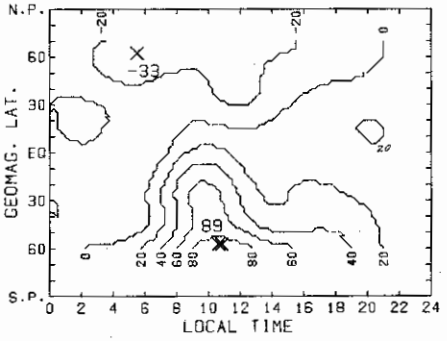

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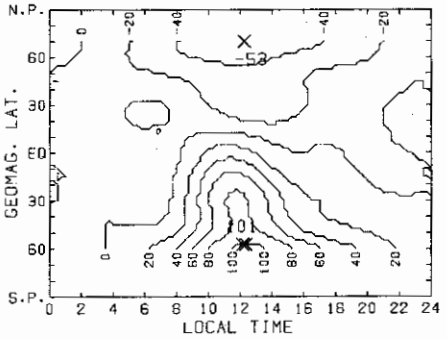

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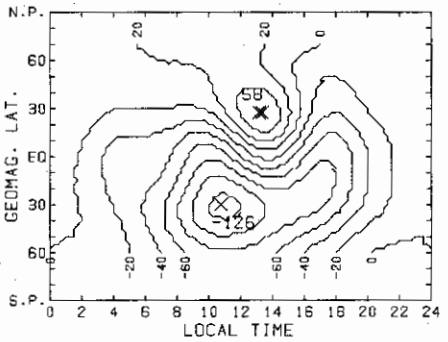

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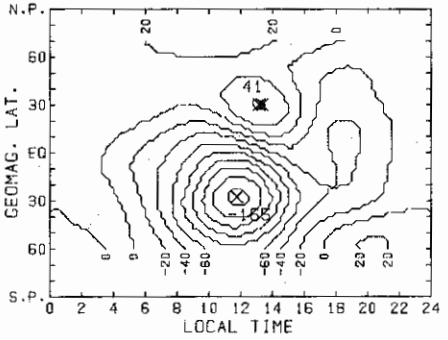

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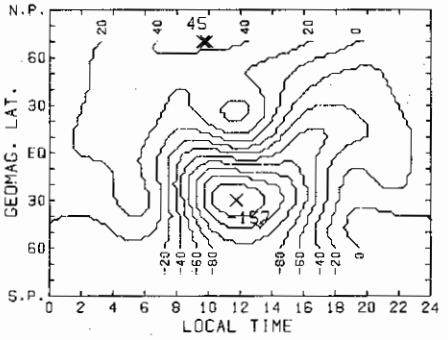

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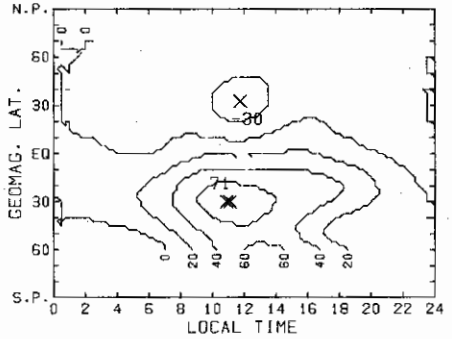

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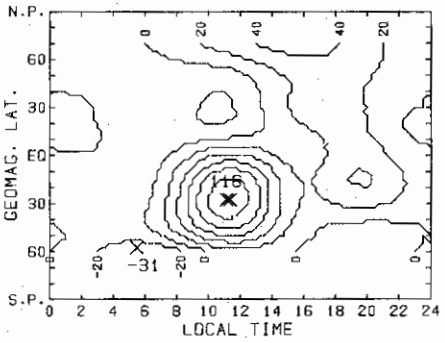

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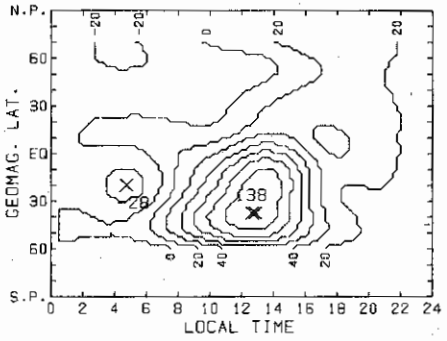

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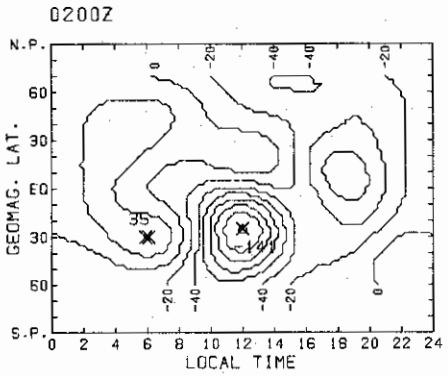

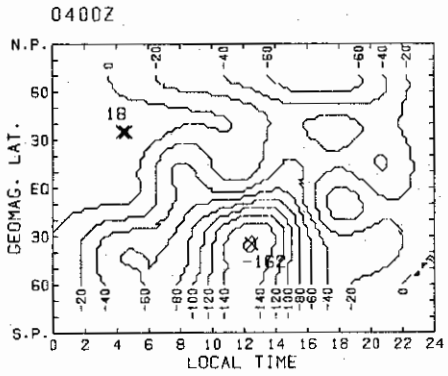

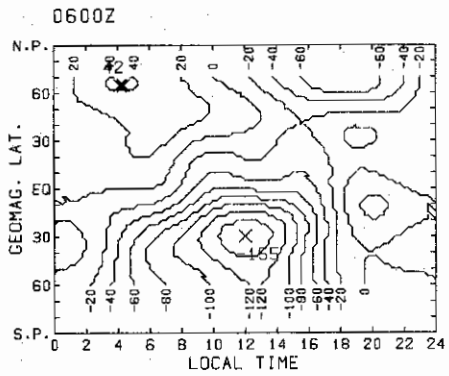

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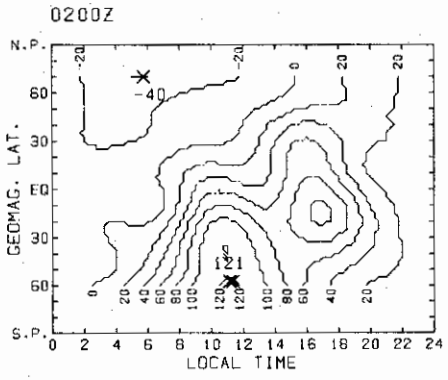

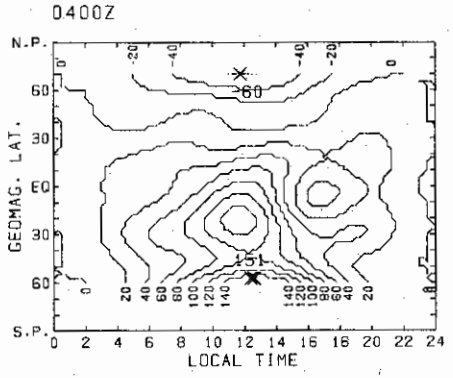

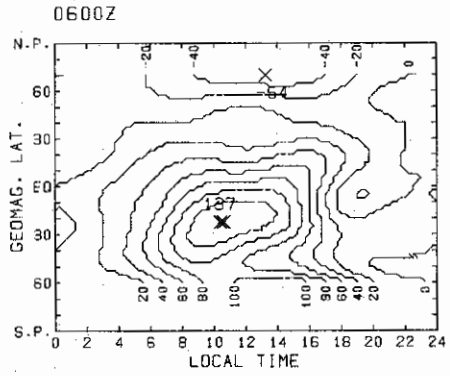

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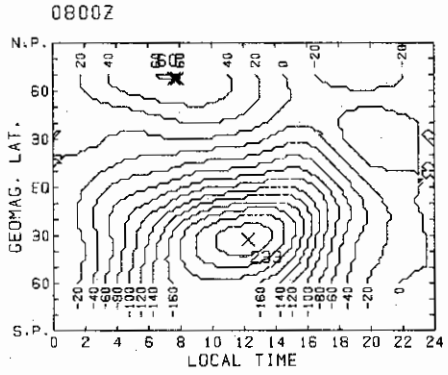

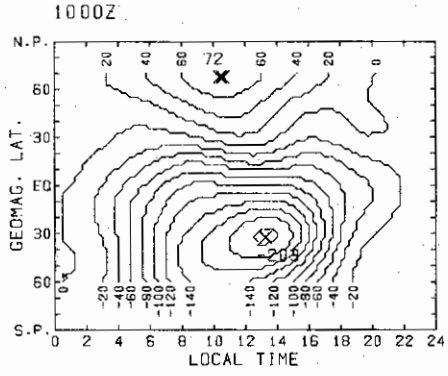

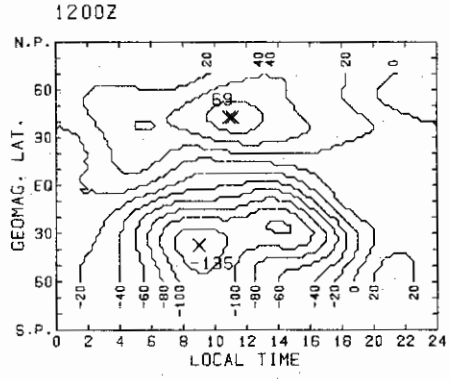

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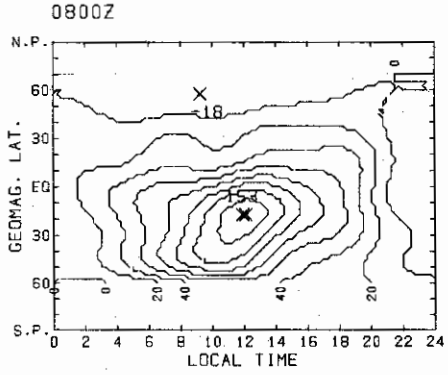

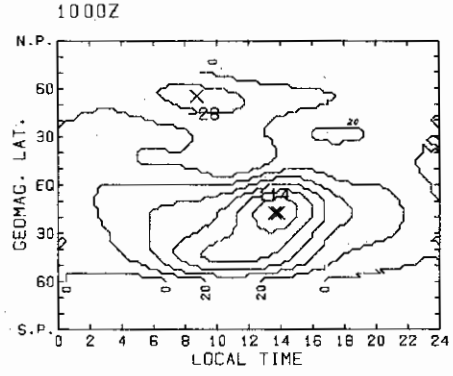

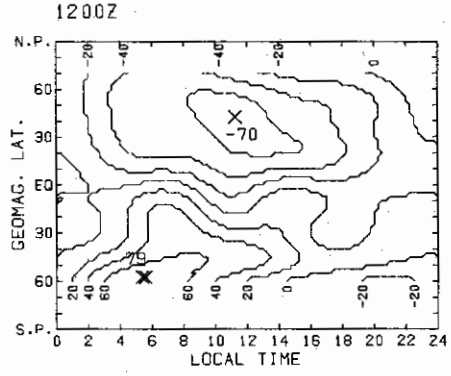

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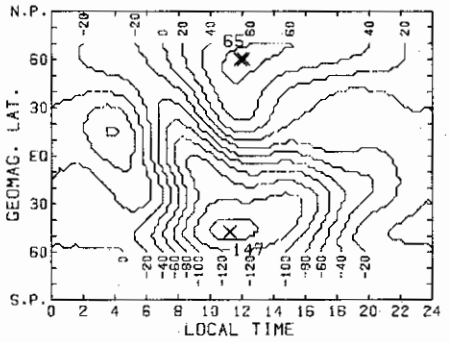

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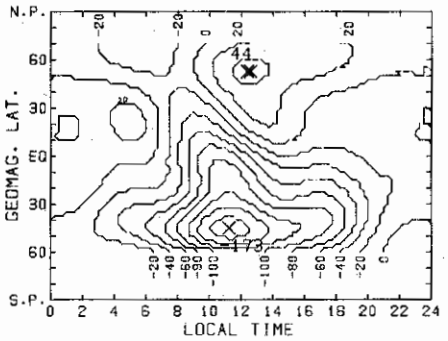

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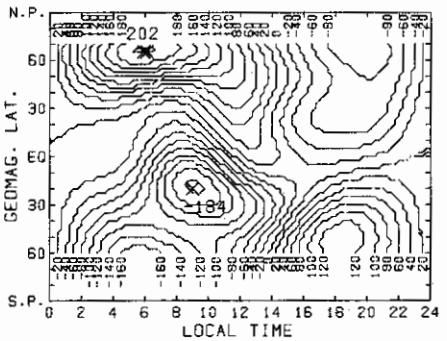

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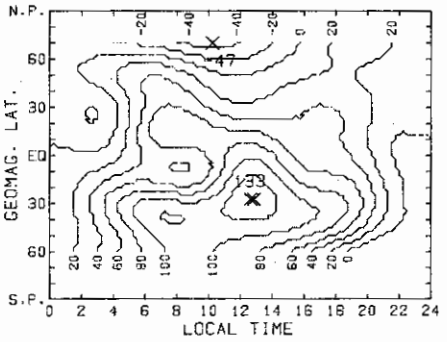

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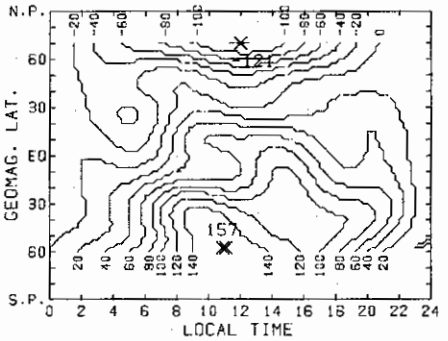

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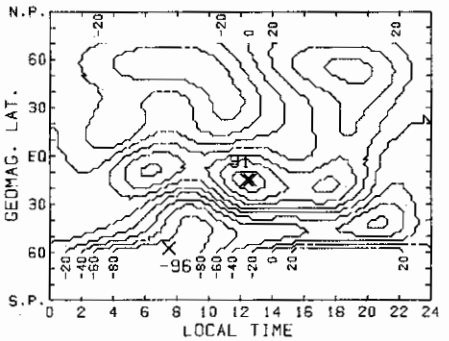

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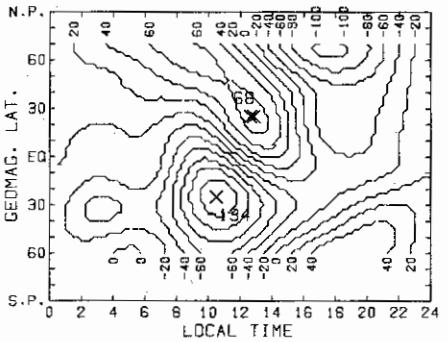

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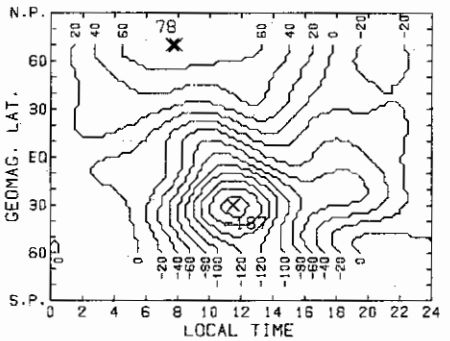

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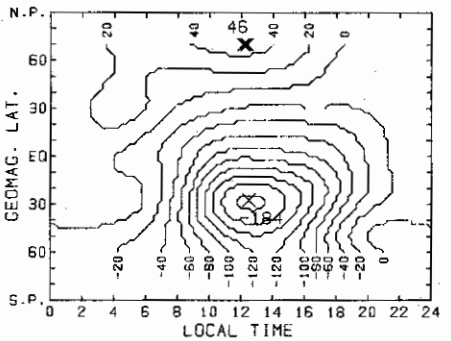

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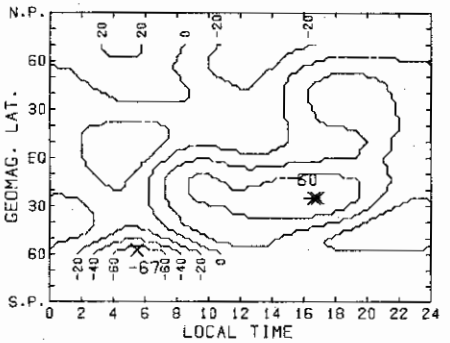

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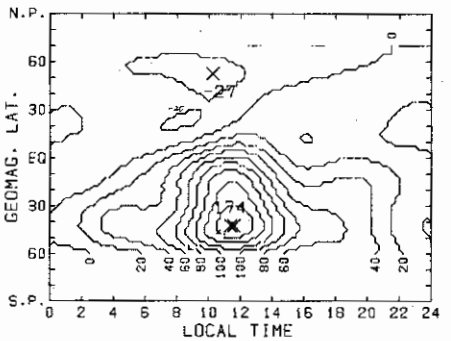

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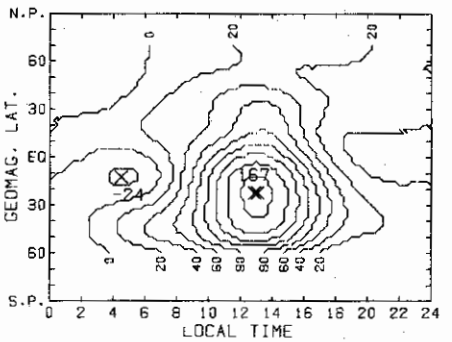

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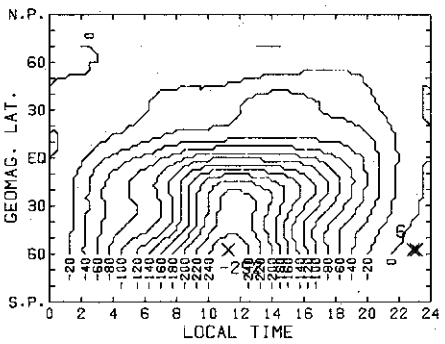

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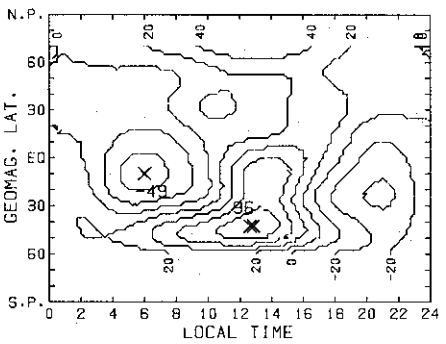

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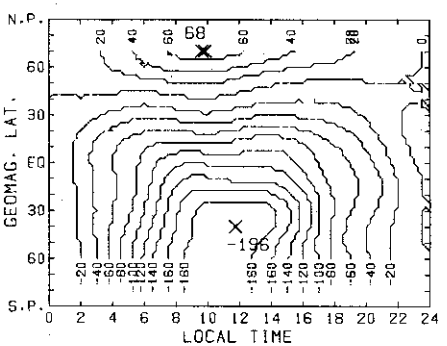

INTERNAL

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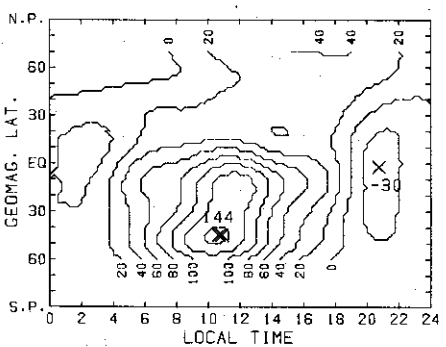
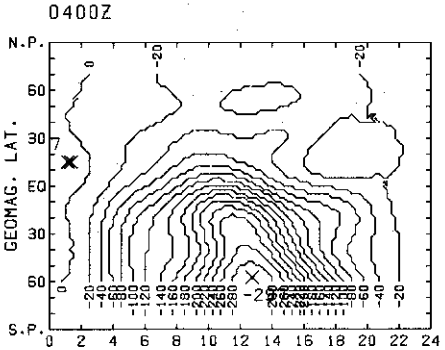


0400Z



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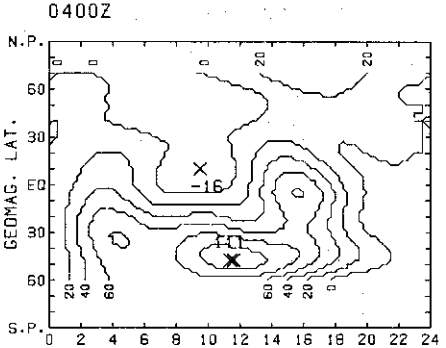

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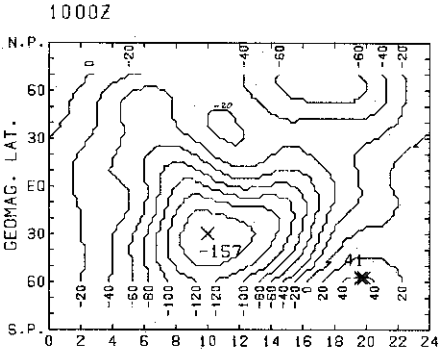

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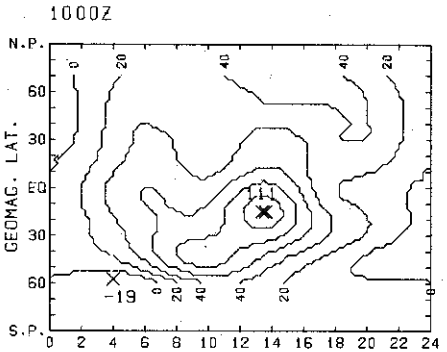

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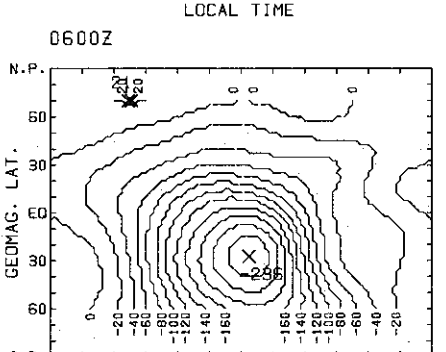

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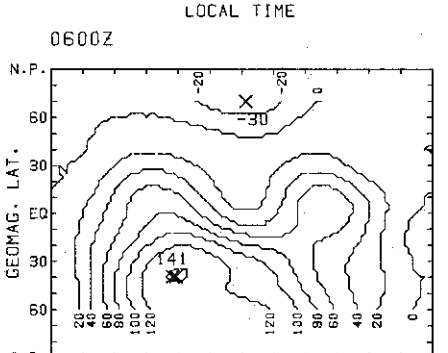

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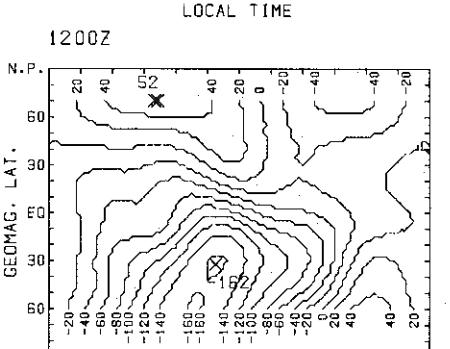

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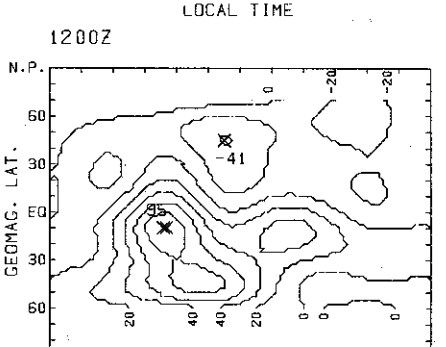

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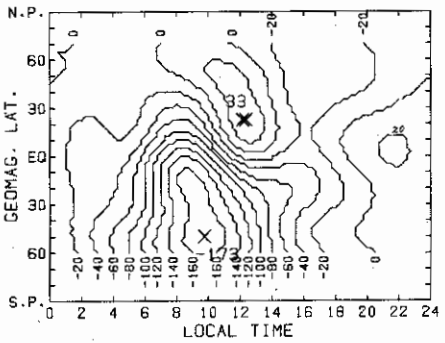
EXTERNAL

1400Z



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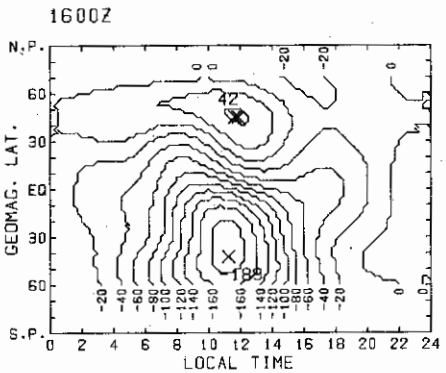

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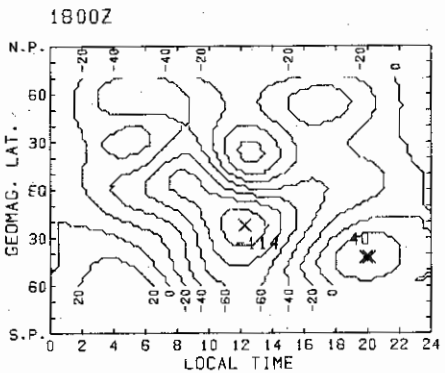

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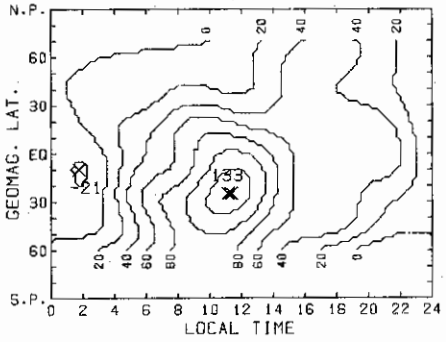

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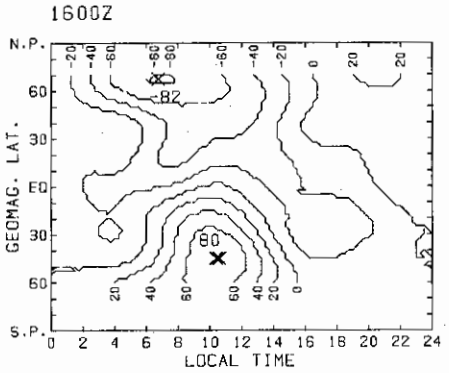

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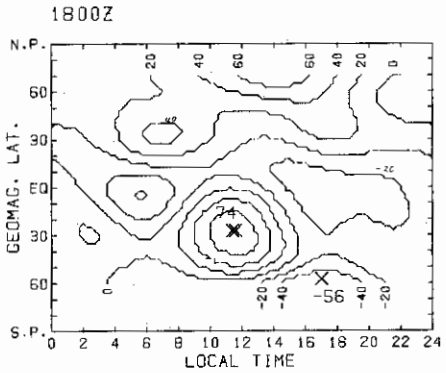

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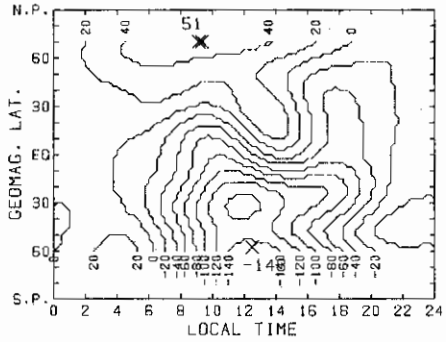

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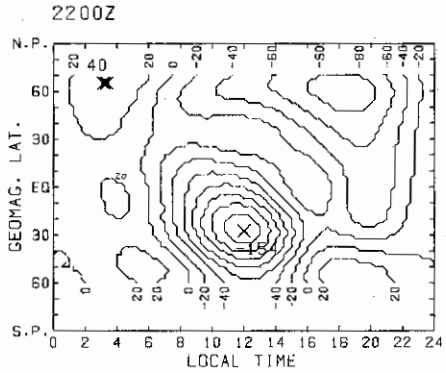

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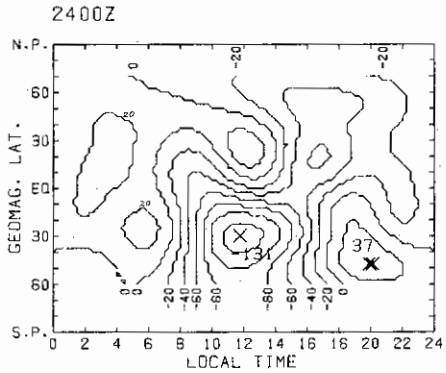

INTERNAL

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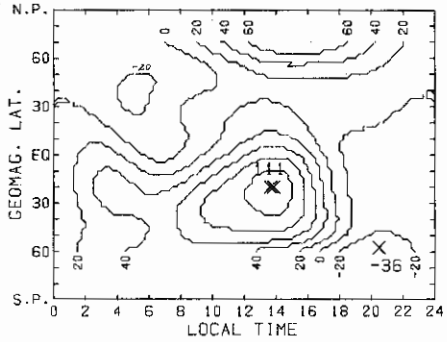

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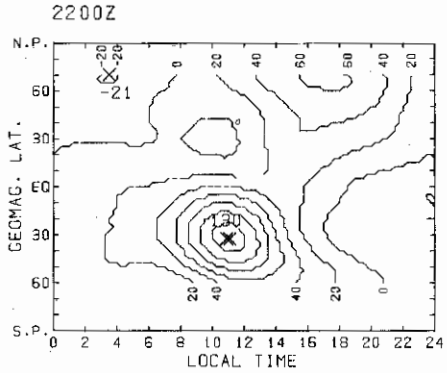

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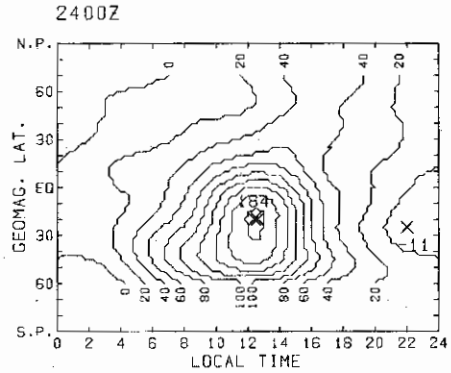

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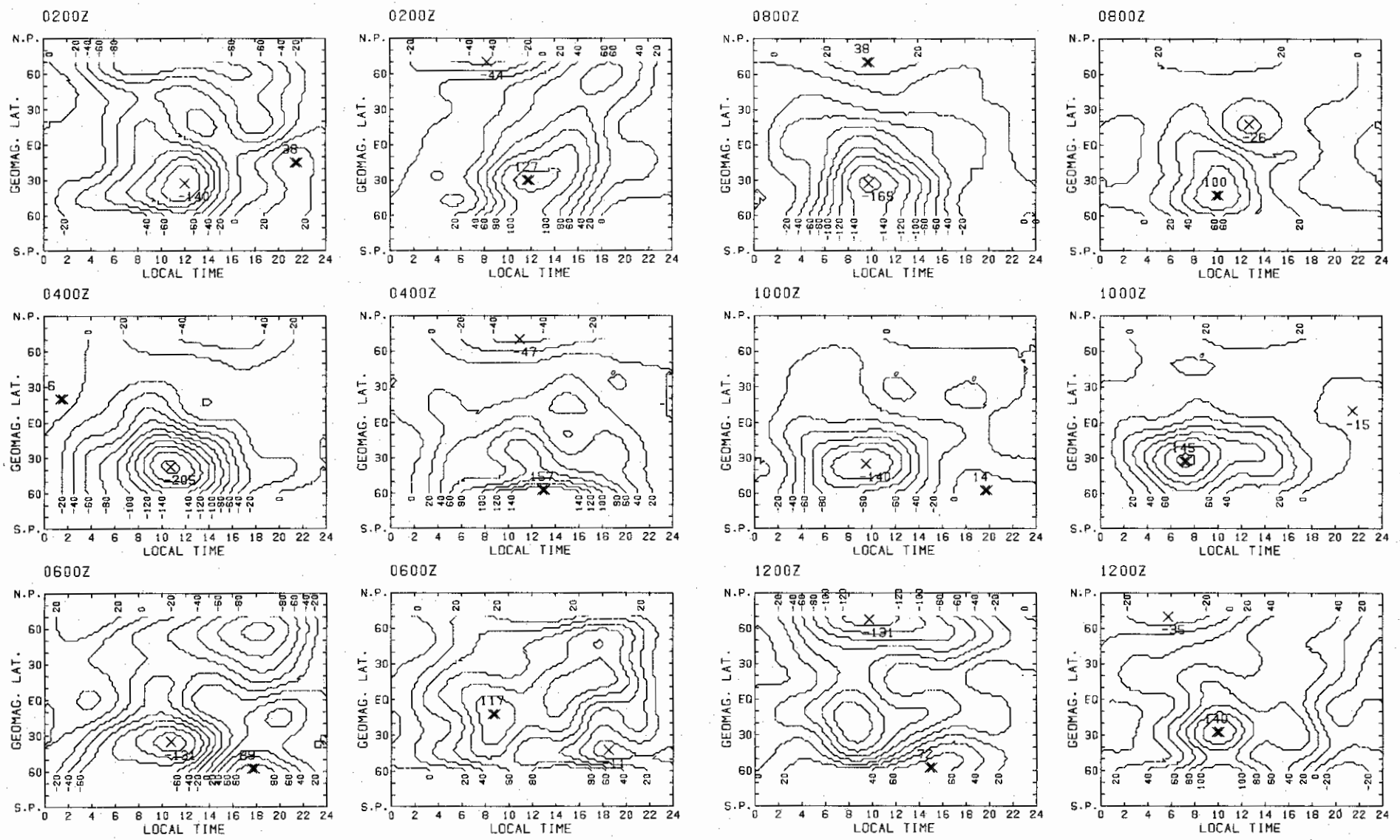
EXTERNAL

INTERNAL

EXTERNAL

INTERNAL



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EXTERNAL

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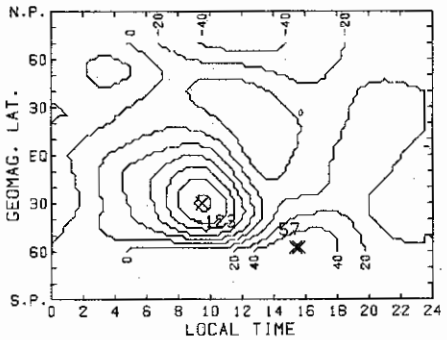

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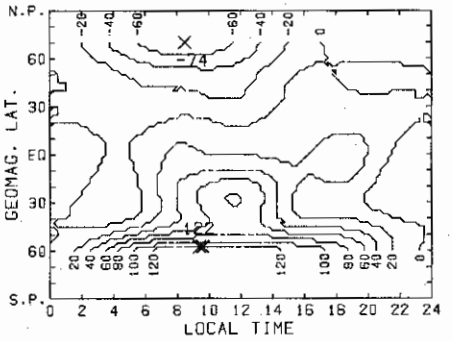

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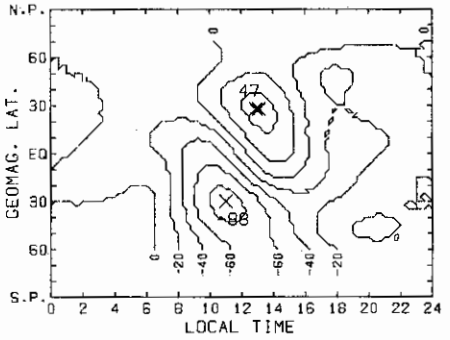

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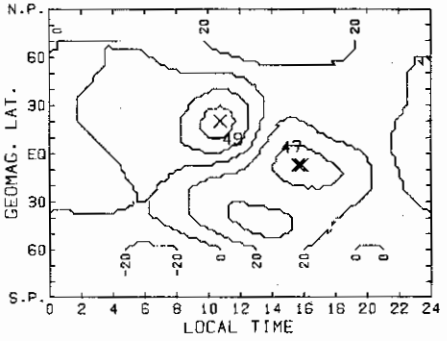

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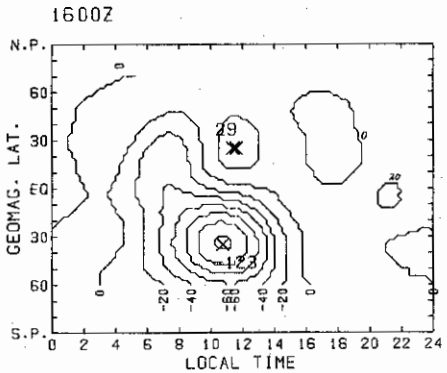

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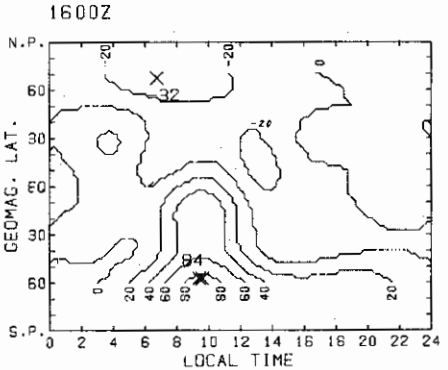

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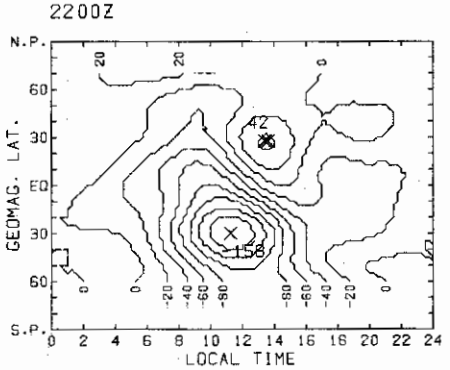

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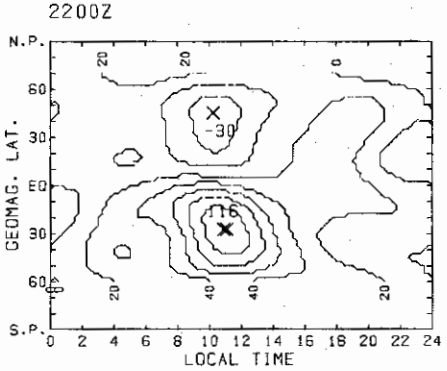

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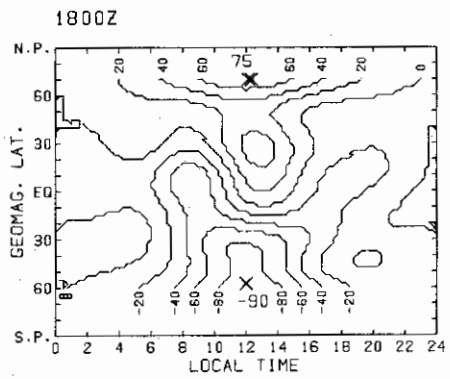

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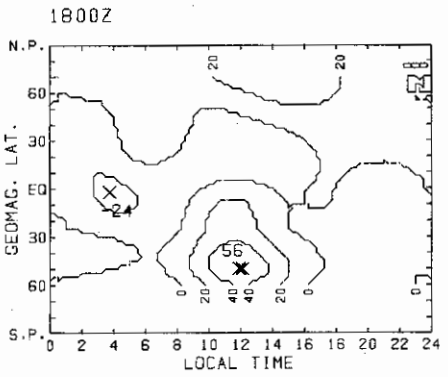

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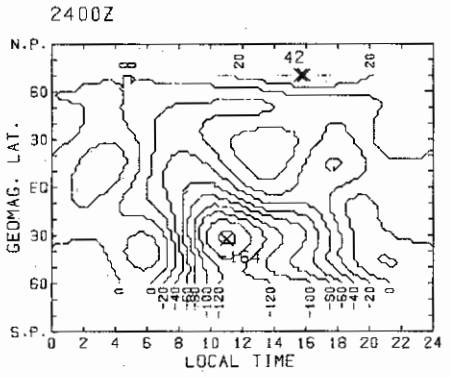

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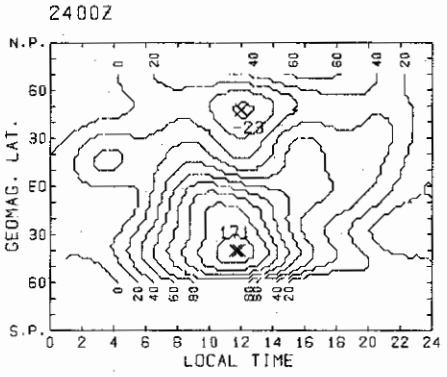

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EXTERNAL

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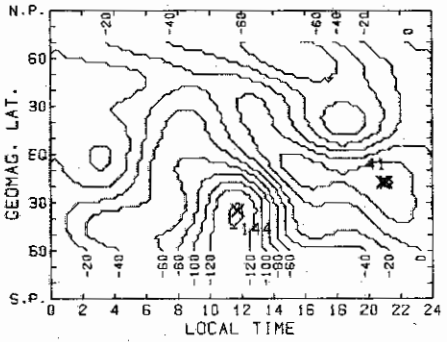
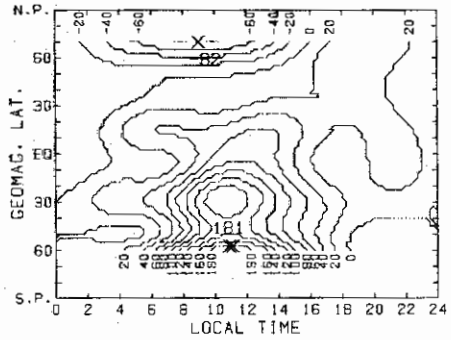


INTERNAL

0200Z



EXTERNAL

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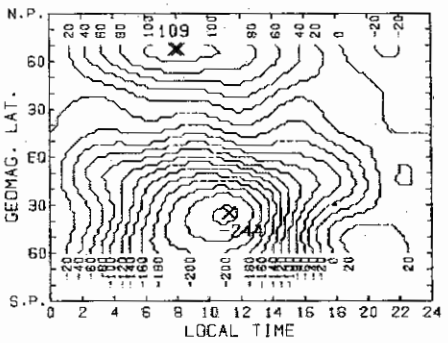

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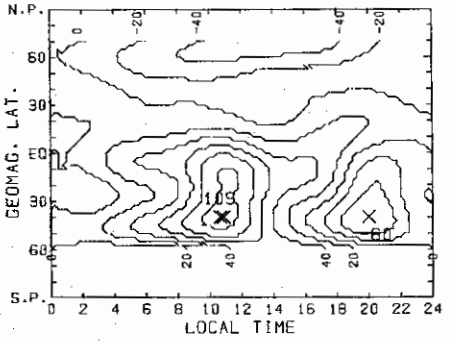

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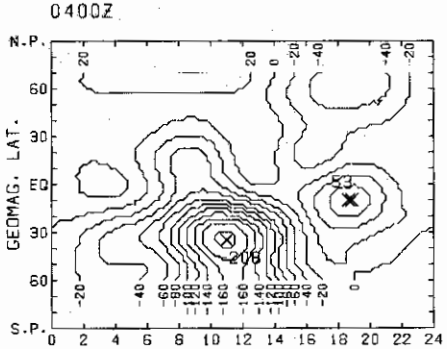

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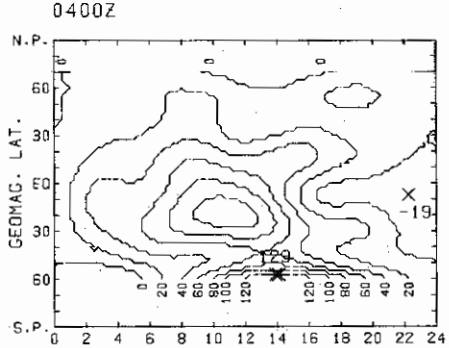

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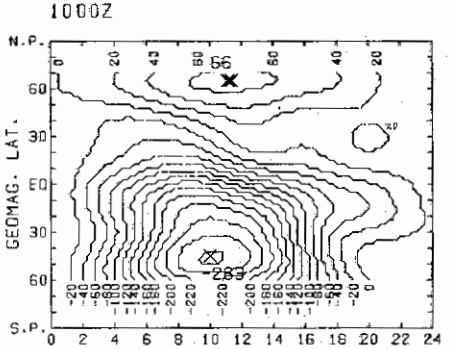

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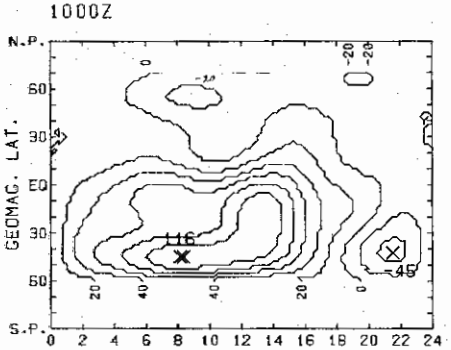

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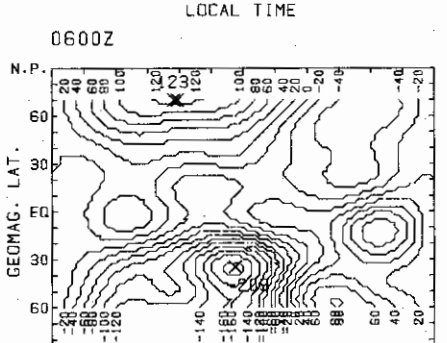

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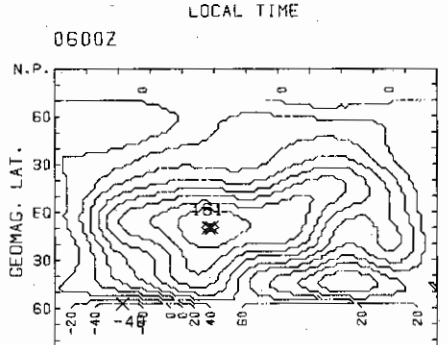

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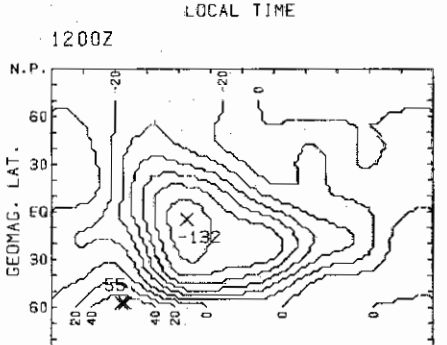

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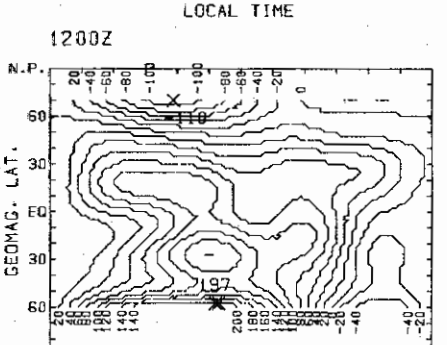

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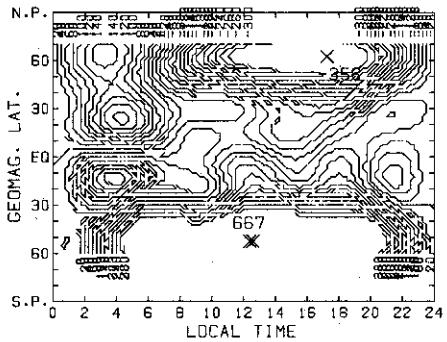

INTERNAL

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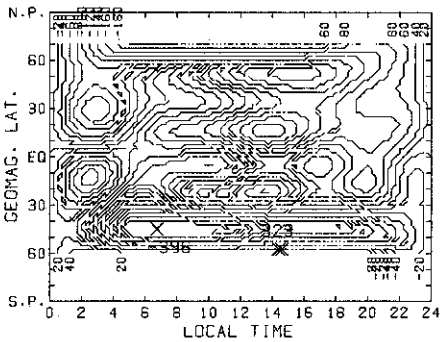

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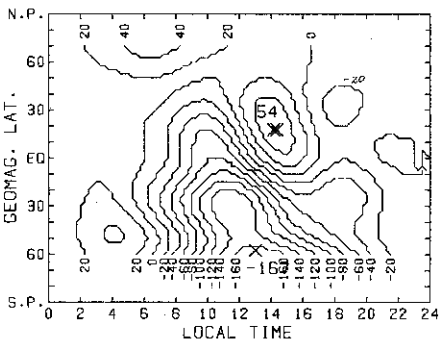

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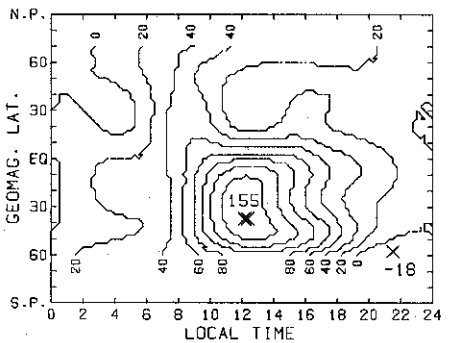

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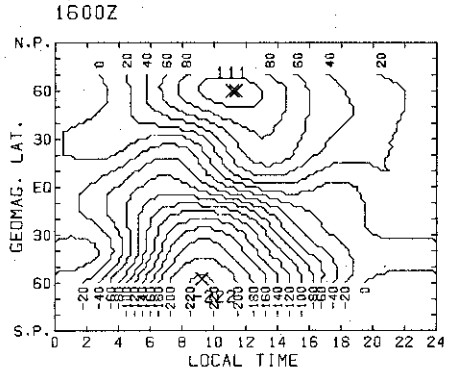

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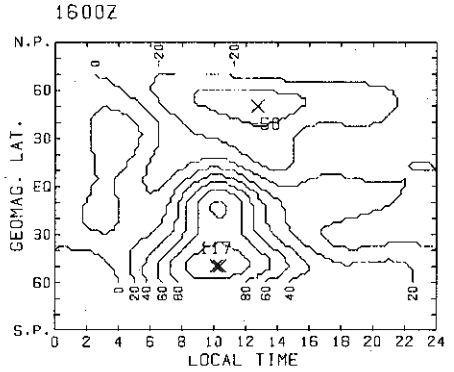

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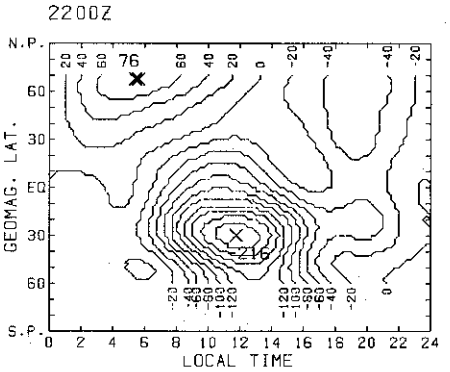

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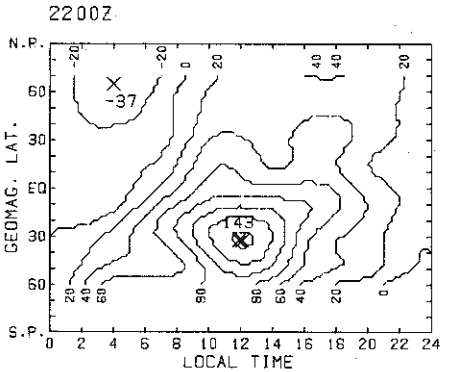

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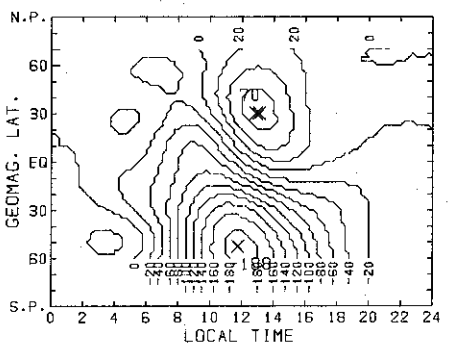

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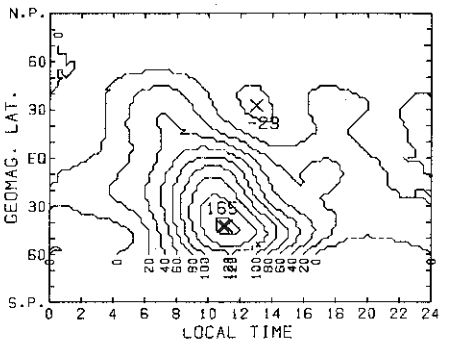

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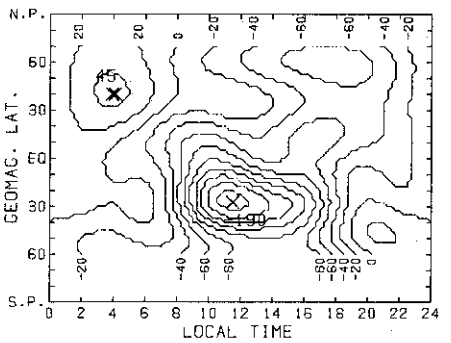

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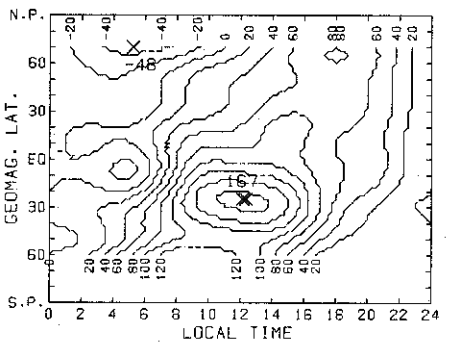

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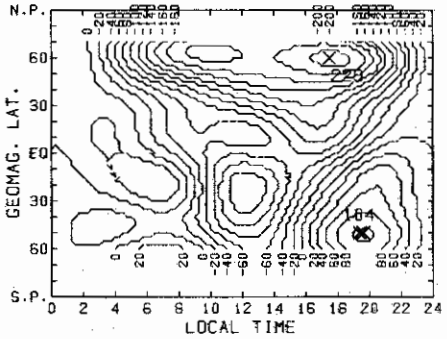
EXTERNAL

0200Z



INTERNAL

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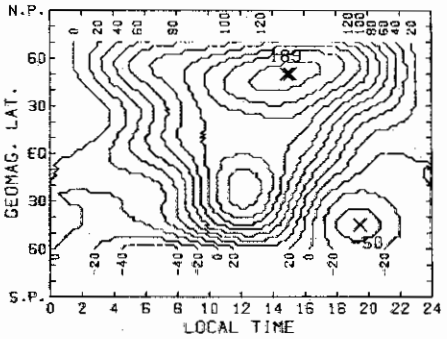

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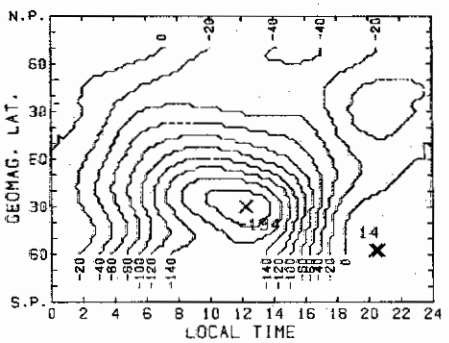

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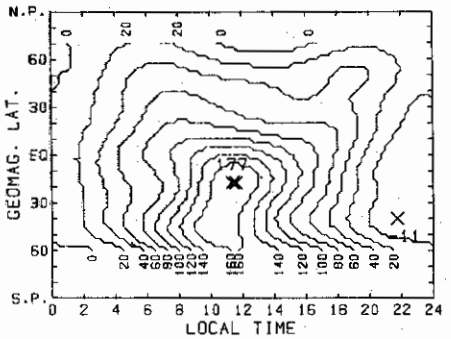

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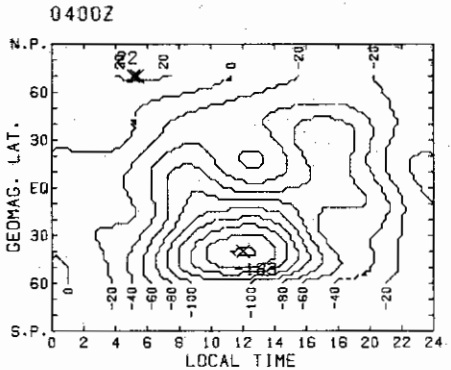

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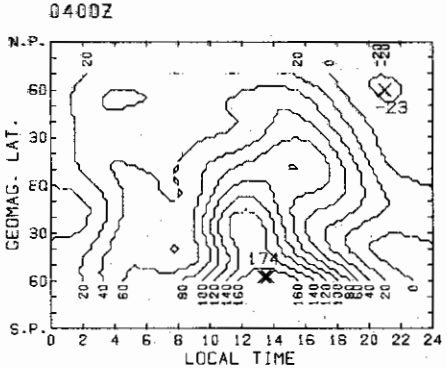

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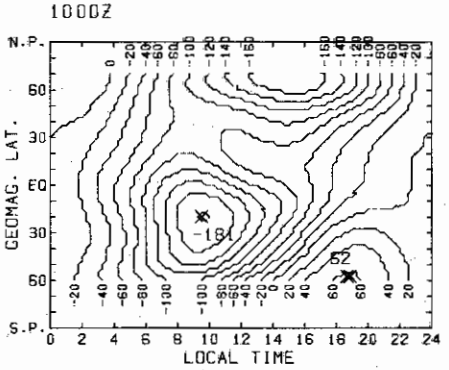

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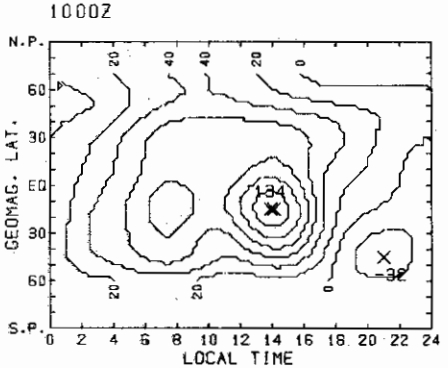

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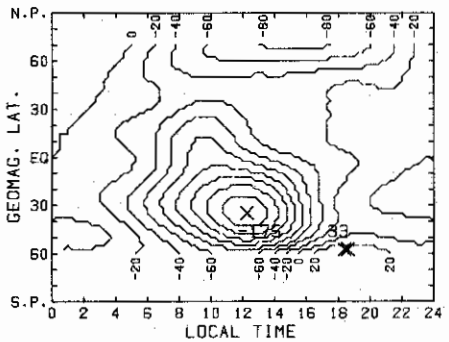

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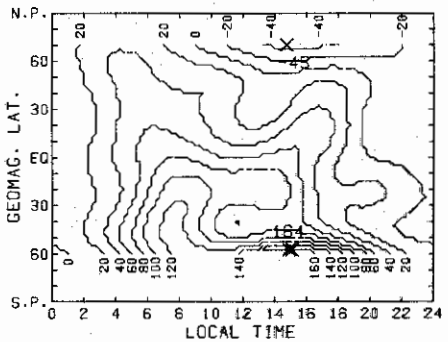

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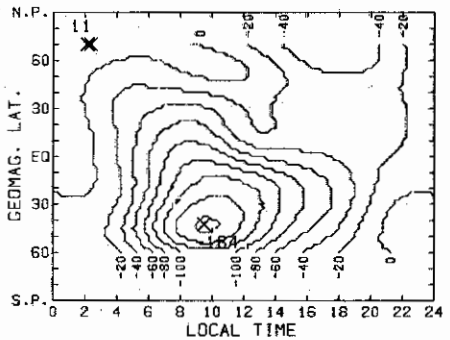

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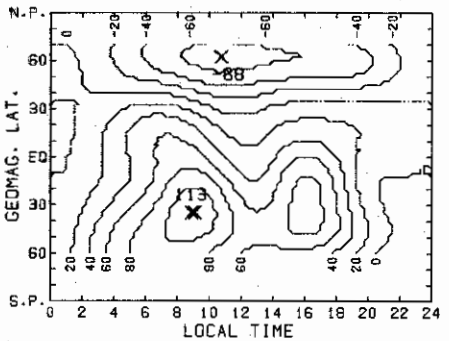

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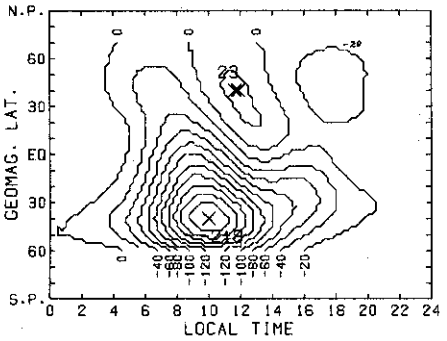

INTERNAL

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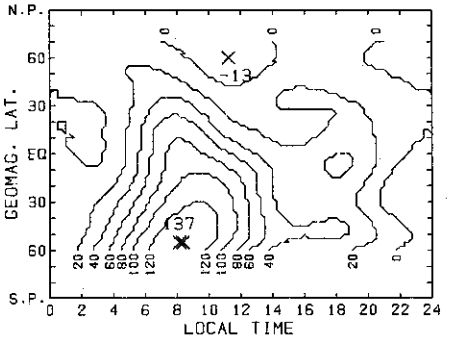

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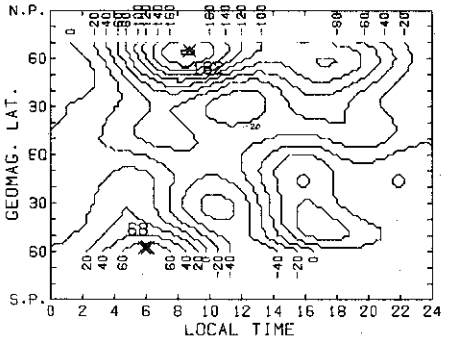

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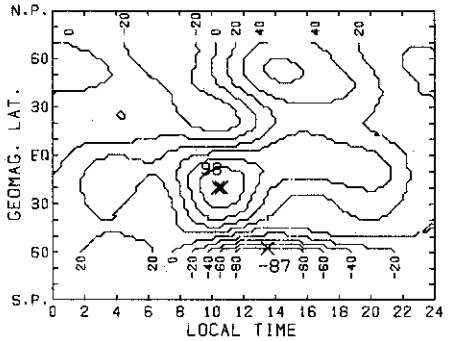

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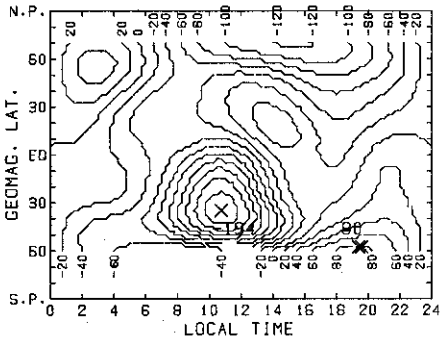

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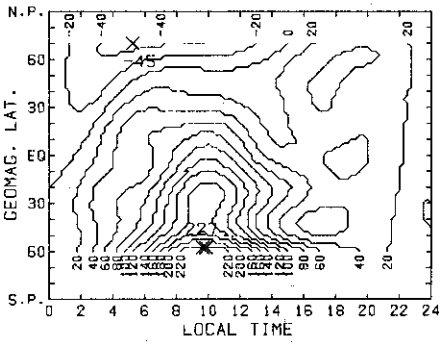

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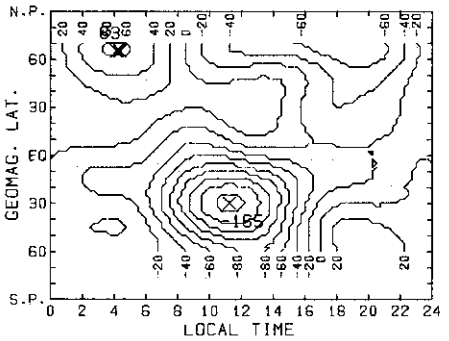

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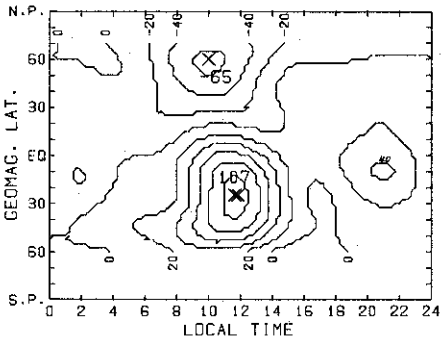

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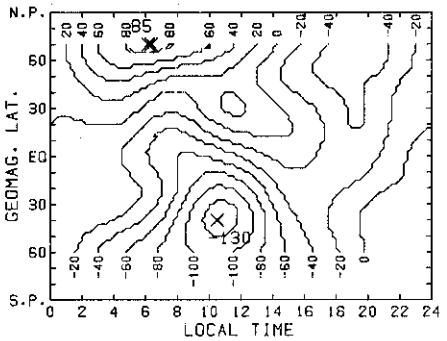

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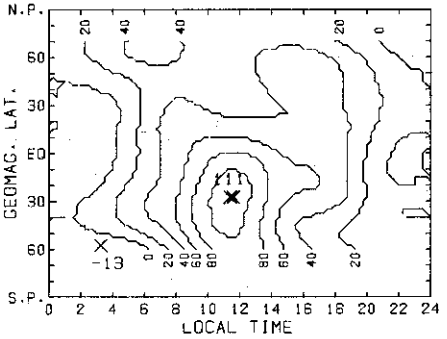

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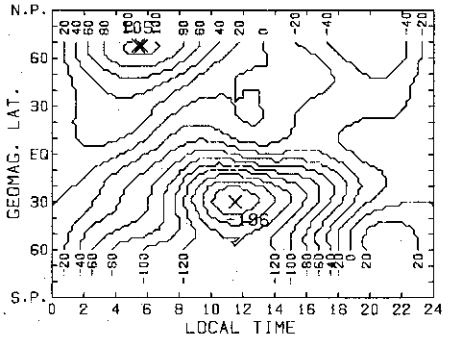

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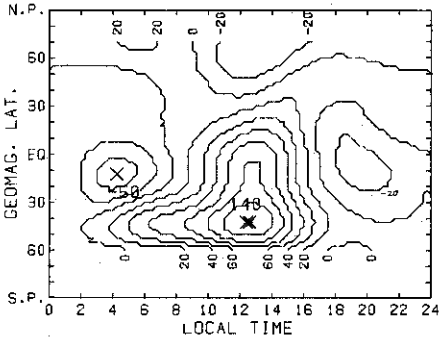

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EXTERNAL

INTERNAL

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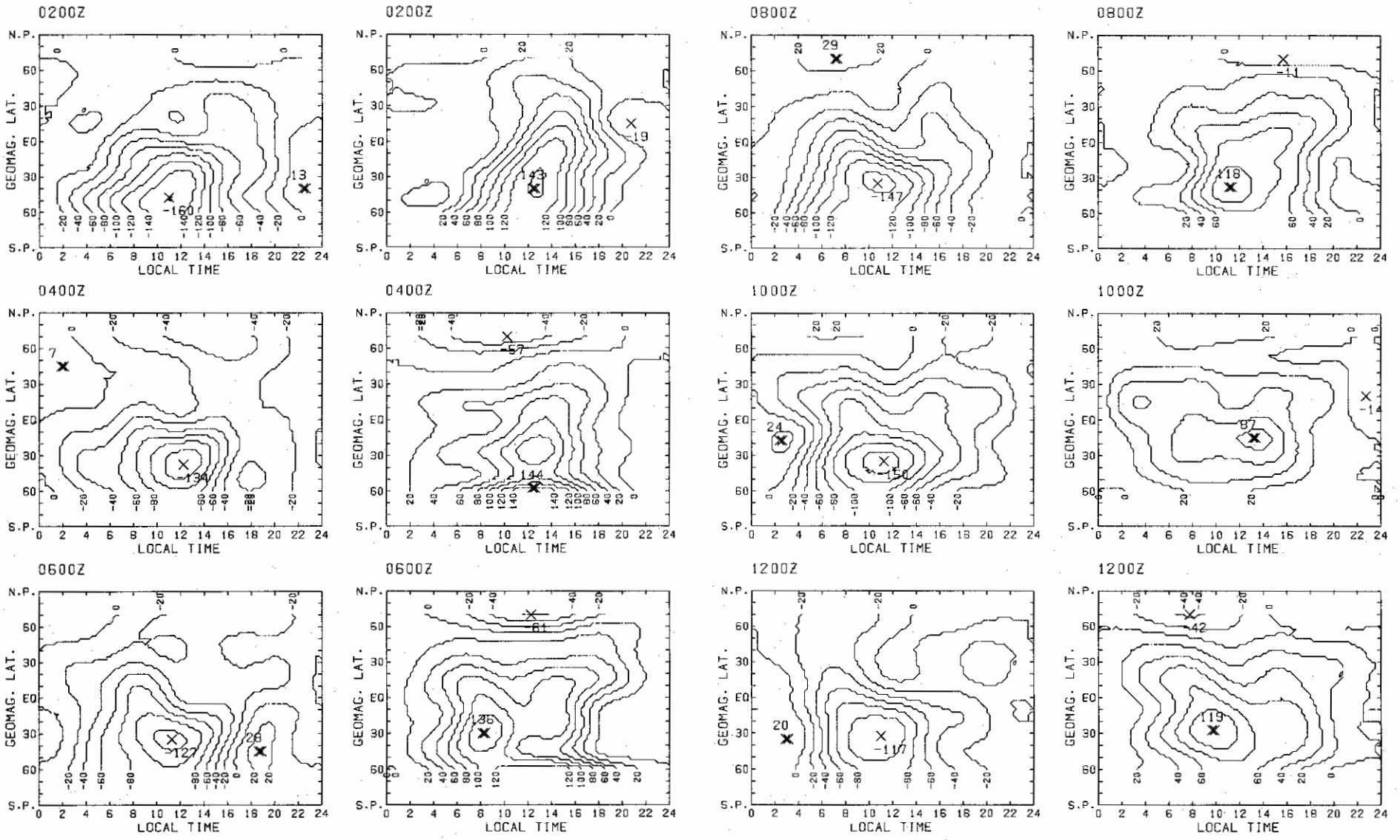

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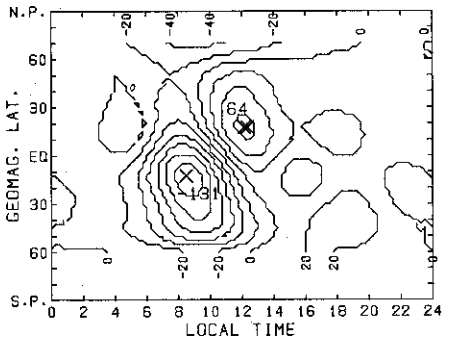

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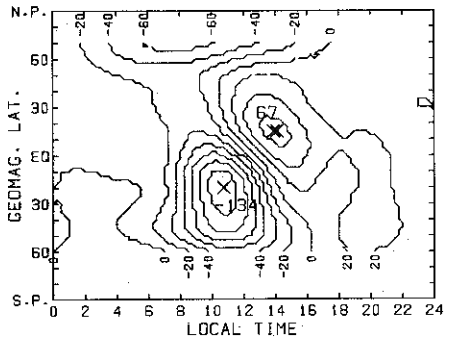

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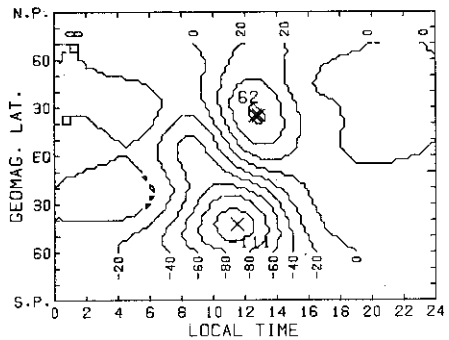

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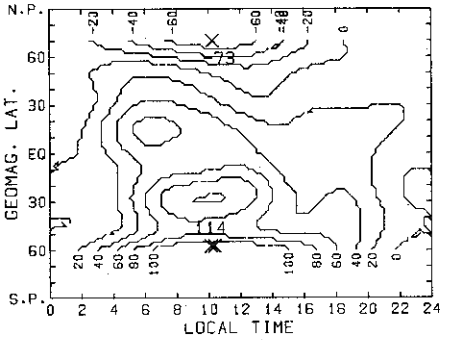

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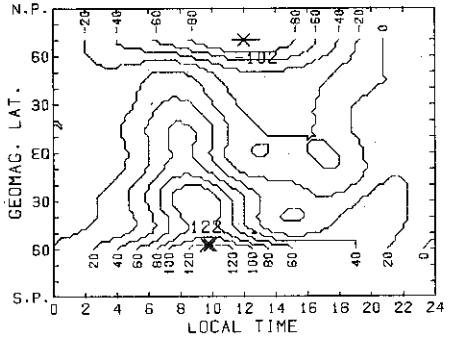

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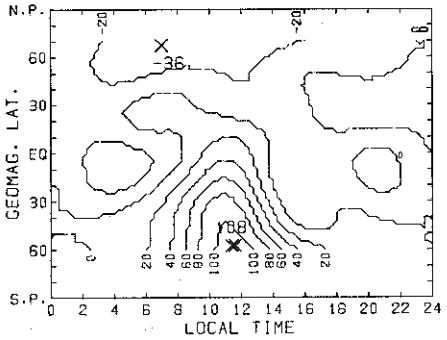

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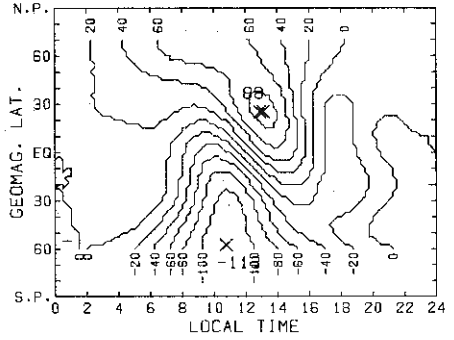

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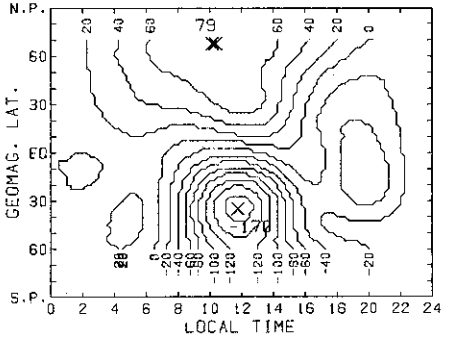

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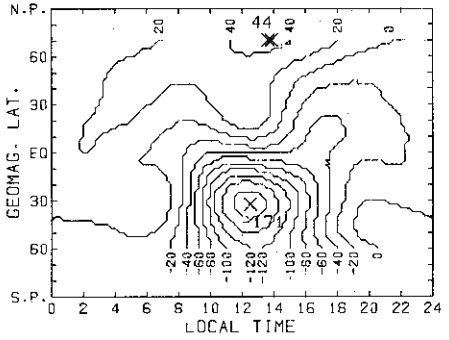

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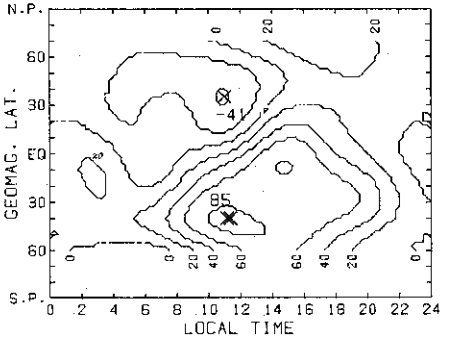

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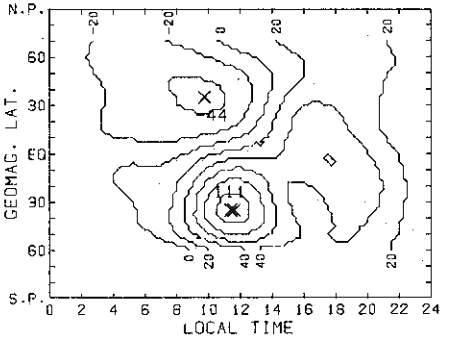

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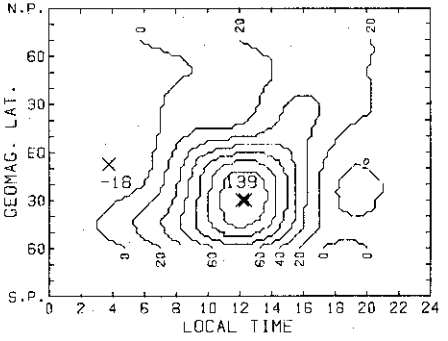

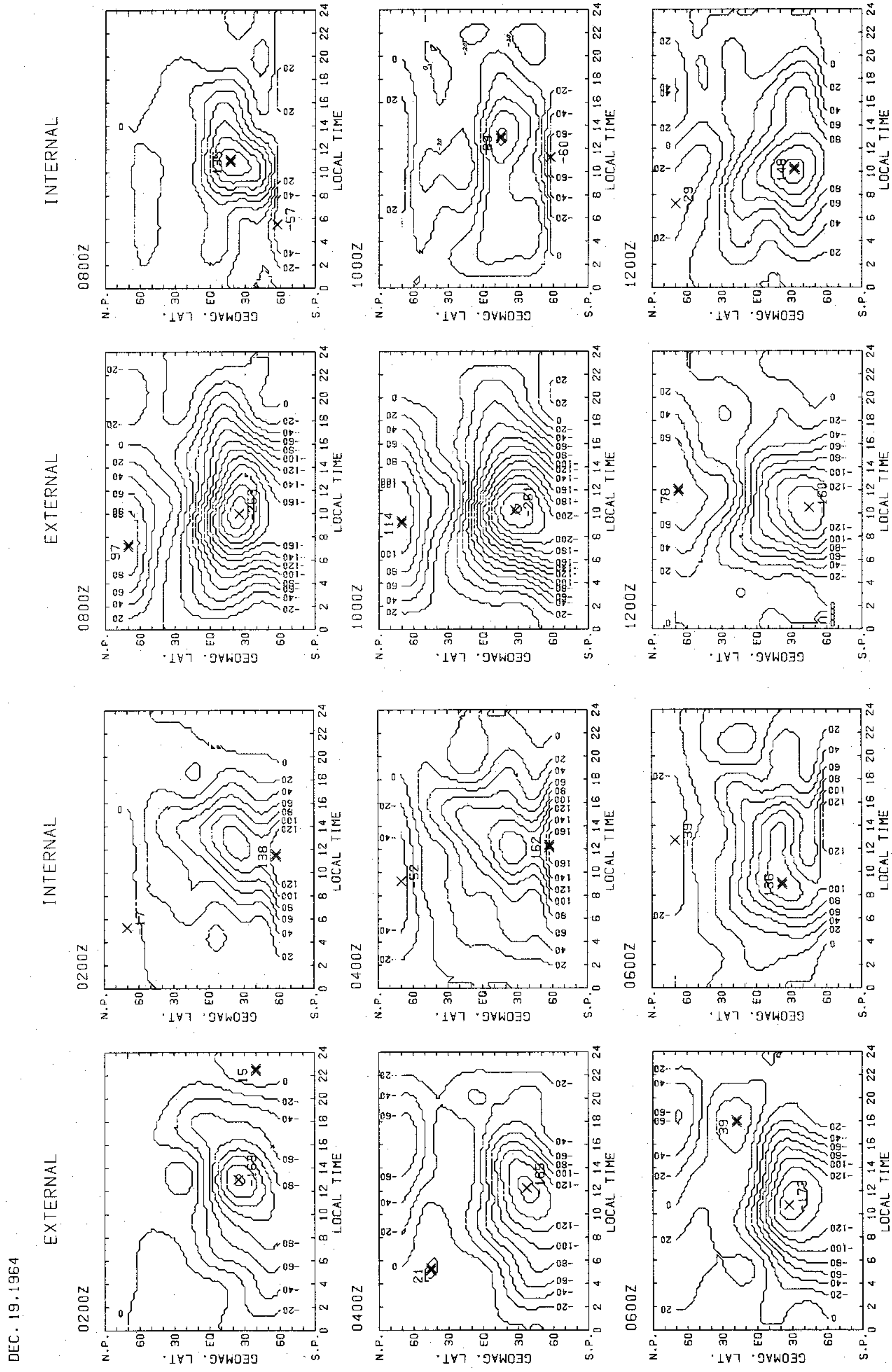

DEC. 19.1964
EXTERNAL
INTERNAL
EXTERNAL
INTERNAL
0200Z
0400Z
0600Z
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1200Z
GEOMAG. LAT.
LOCAL TIME
N.P.
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EQ

DEC. 19.1964

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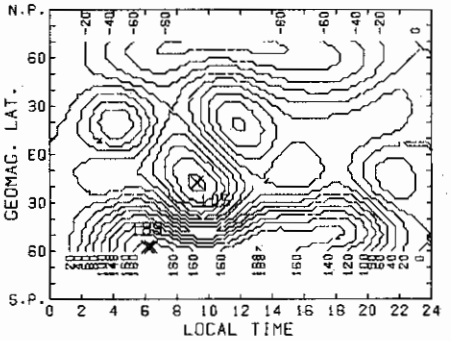

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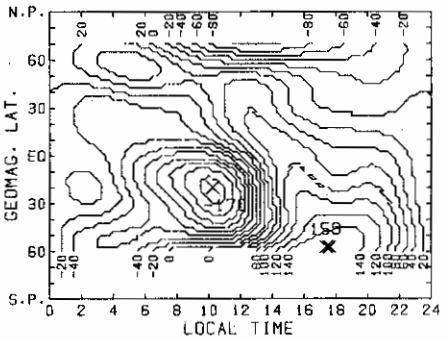

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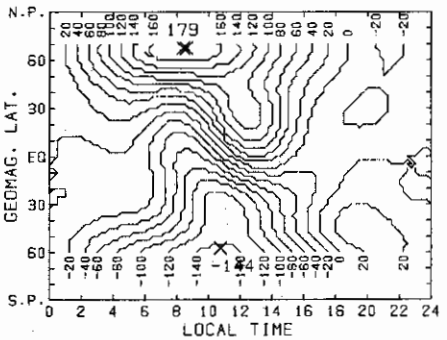

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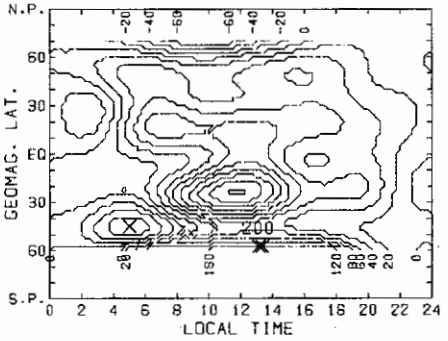

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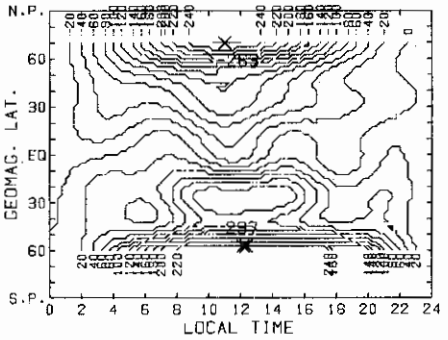

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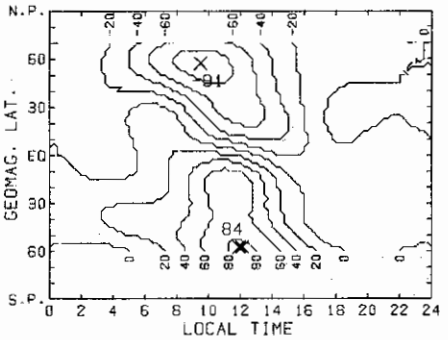

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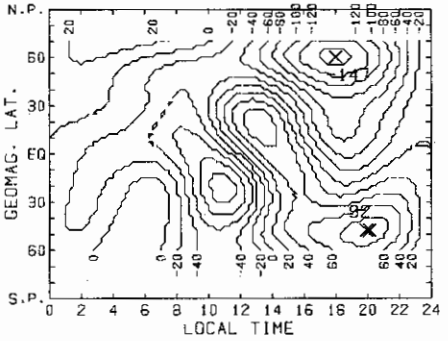

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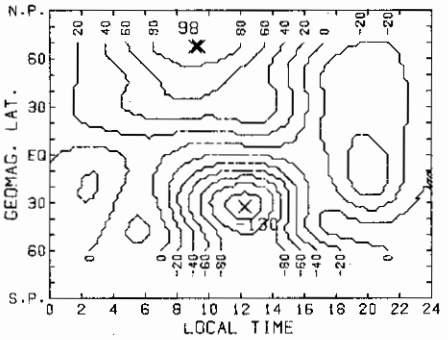

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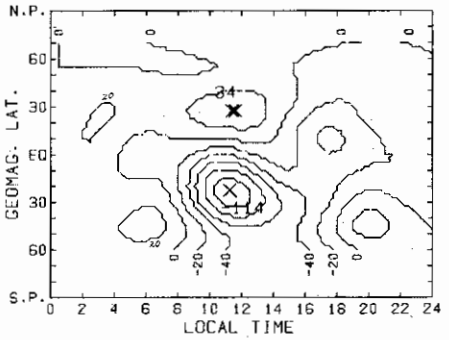

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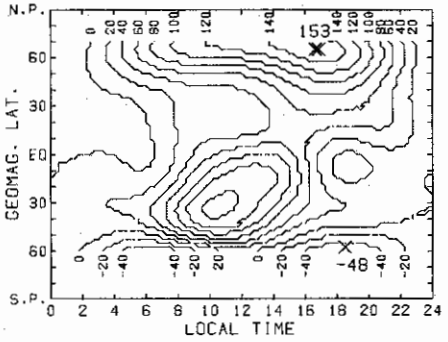

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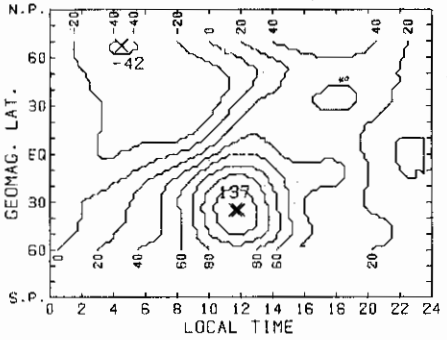

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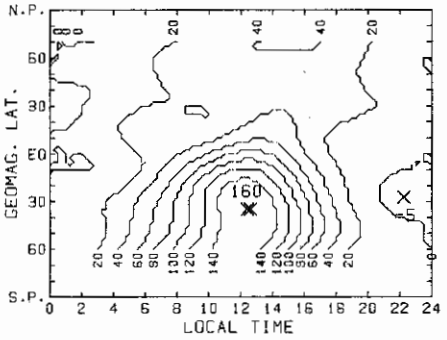

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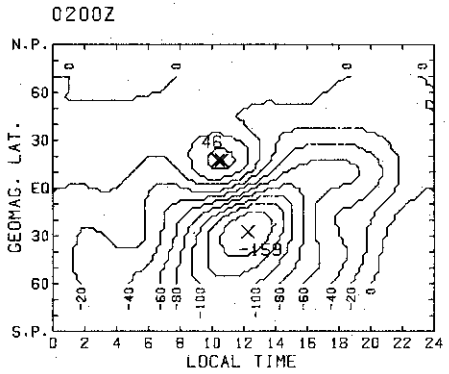

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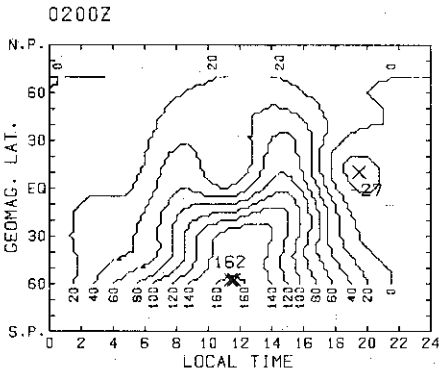

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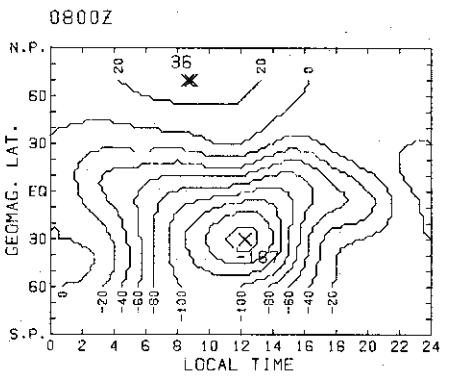

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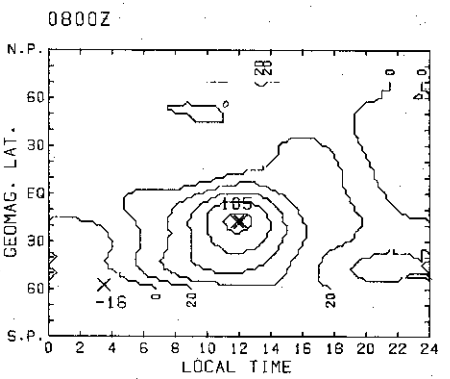

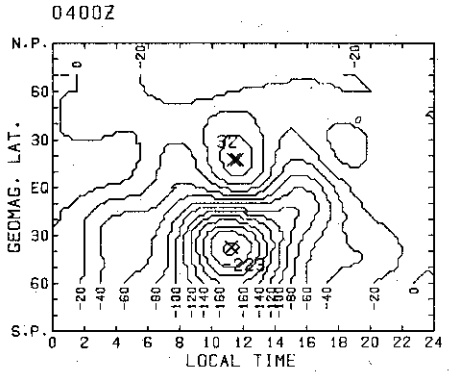

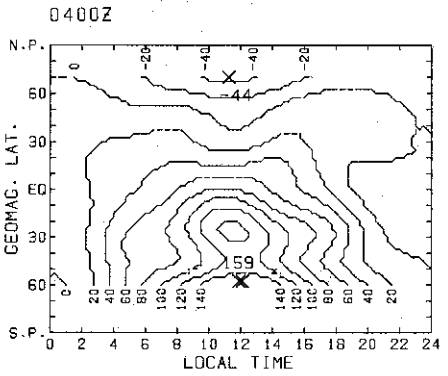

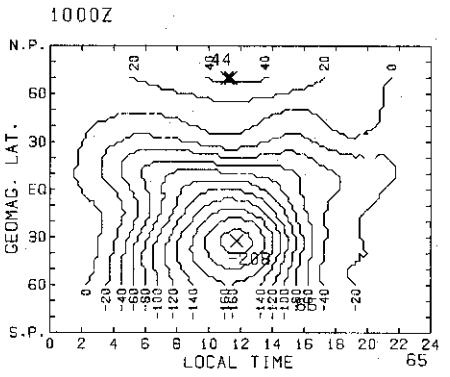

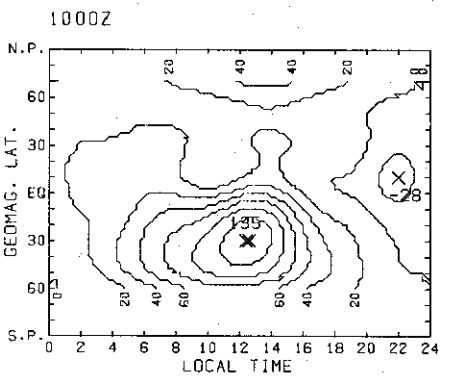

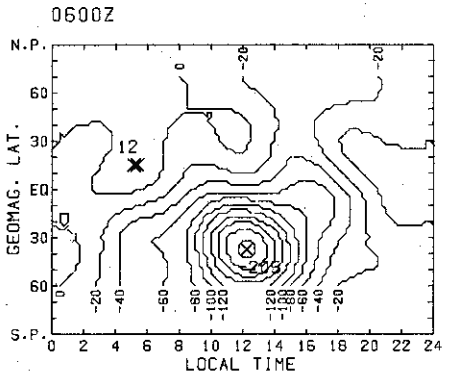

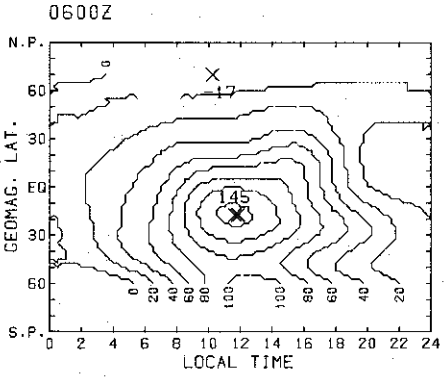

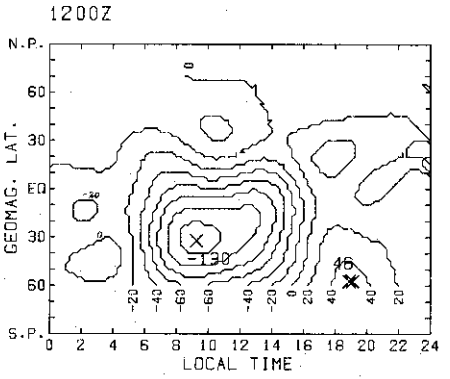

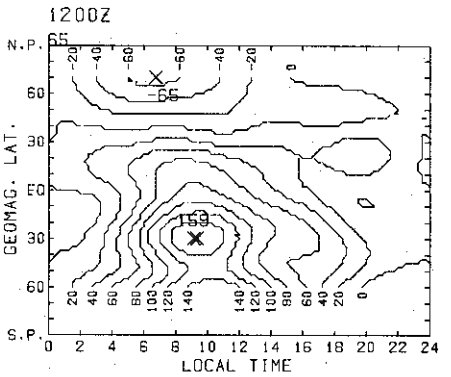

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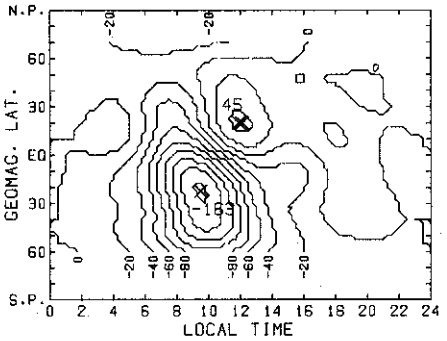

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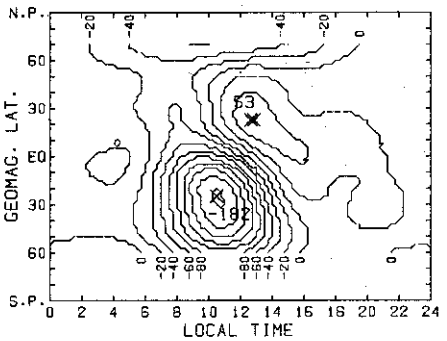

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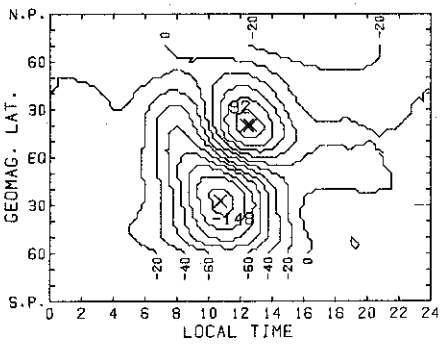

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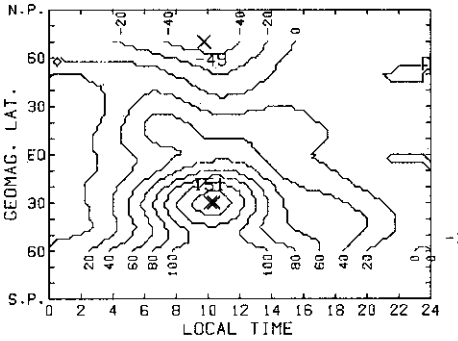

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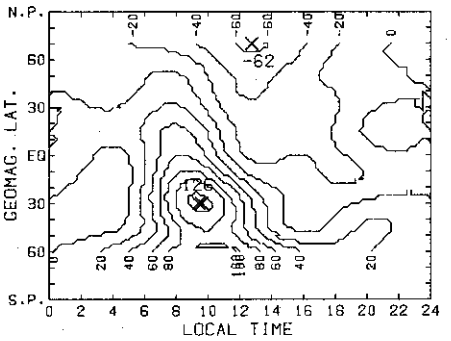

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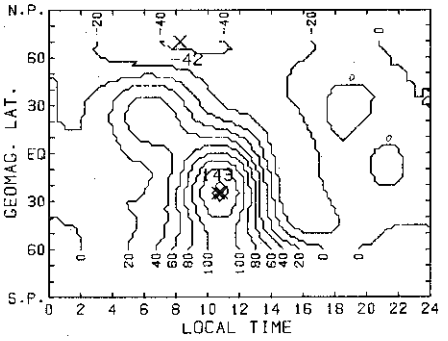

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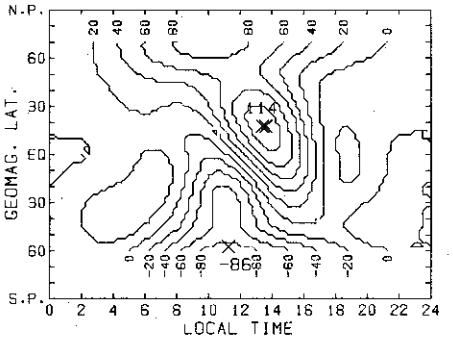

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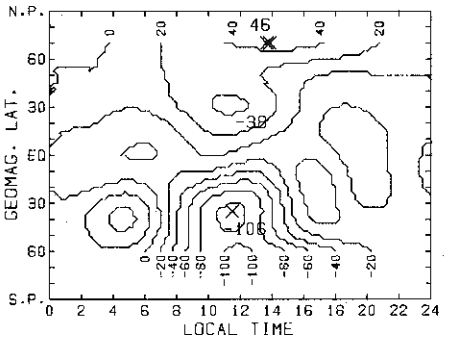

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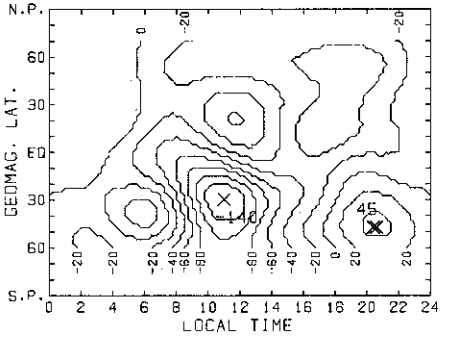

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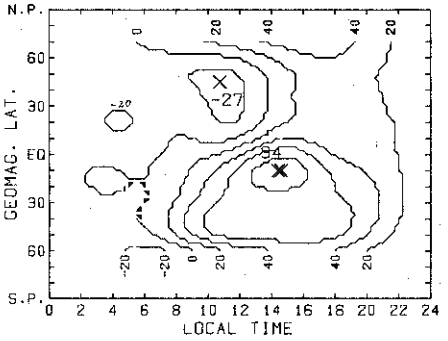

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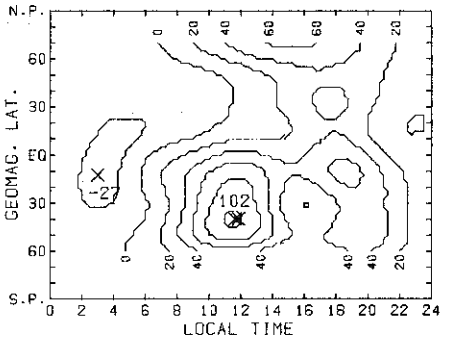

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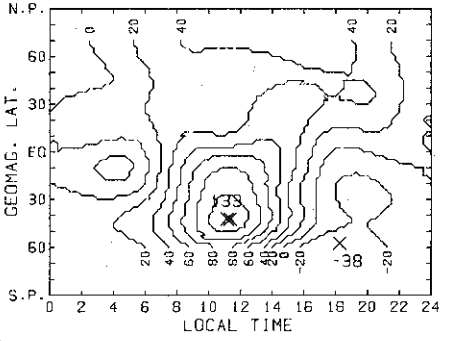

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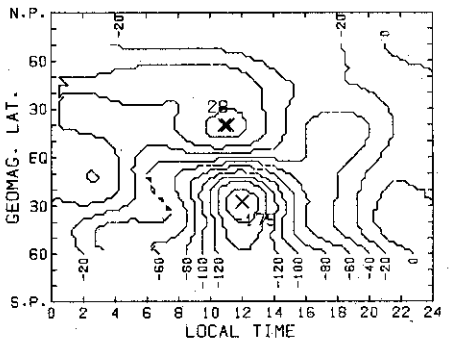

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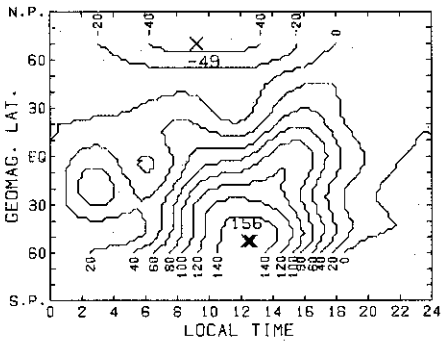

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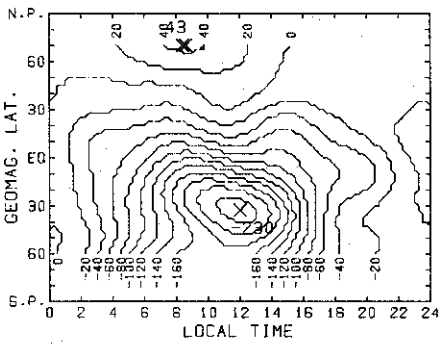

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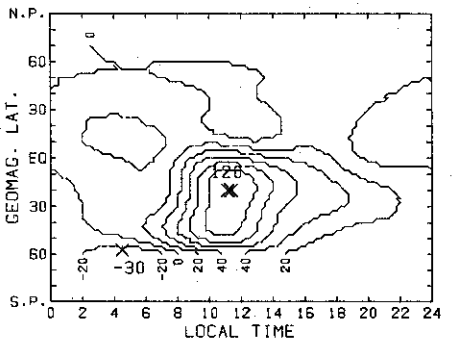

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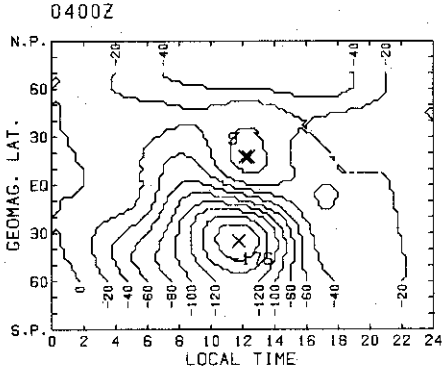

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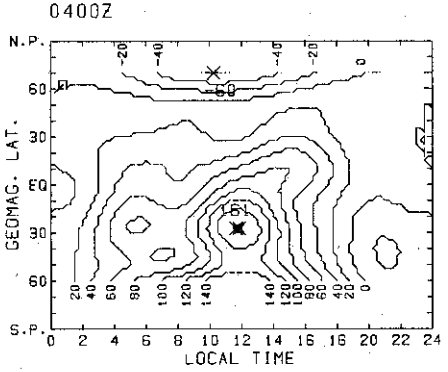

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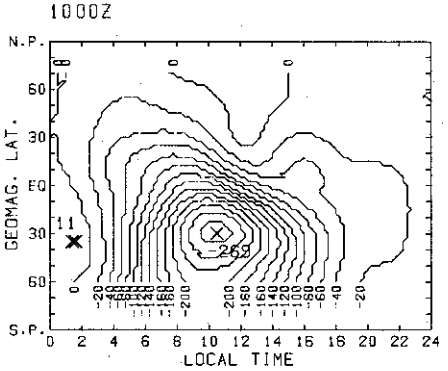

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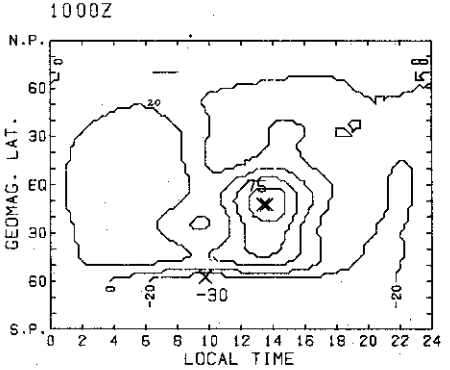

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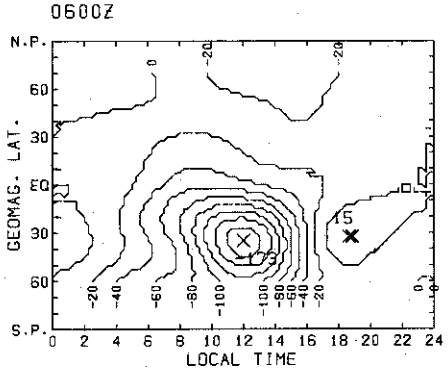

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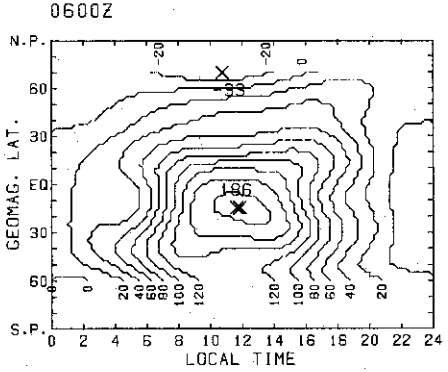

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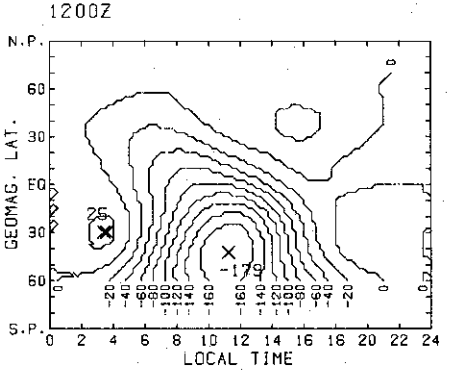

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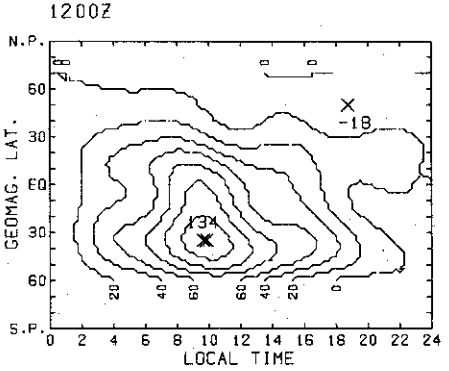

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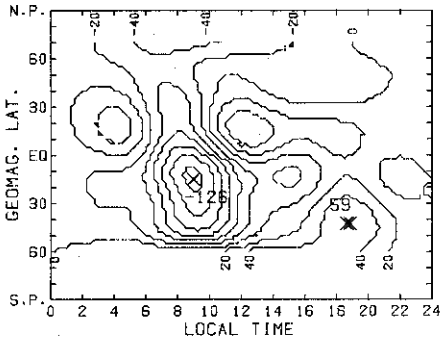

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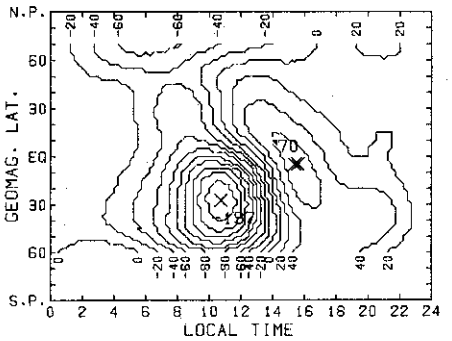

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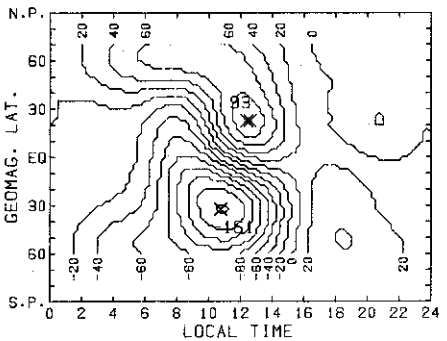

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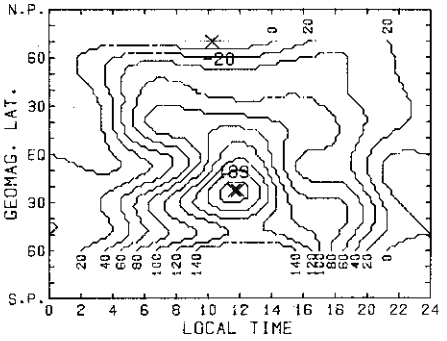

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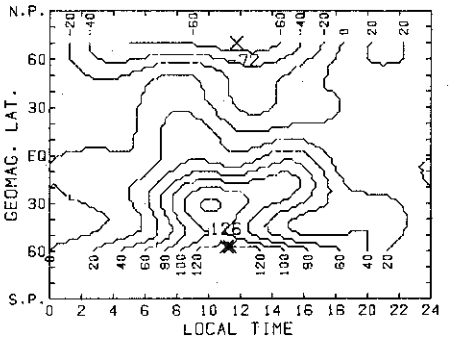

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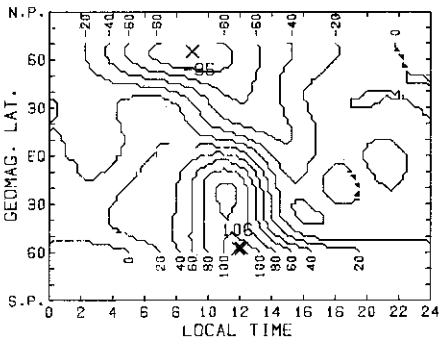

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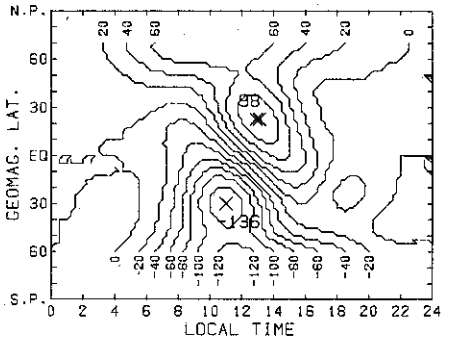

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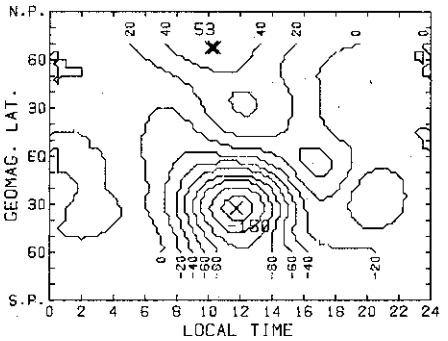

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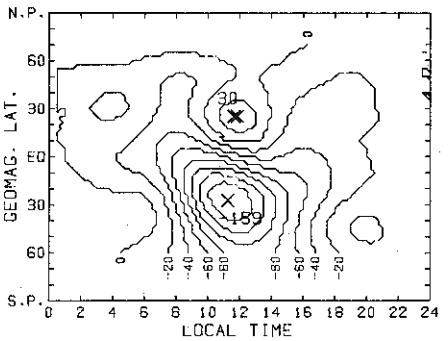

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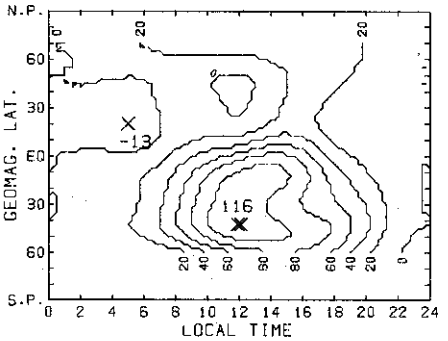

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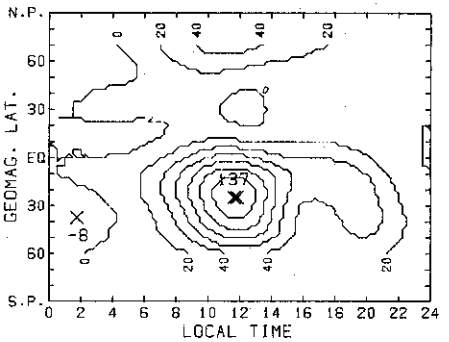

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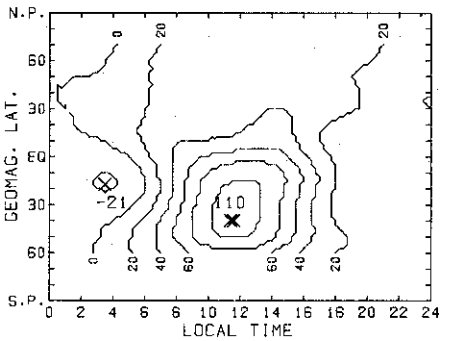

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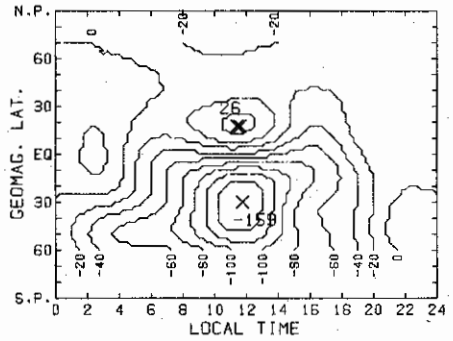

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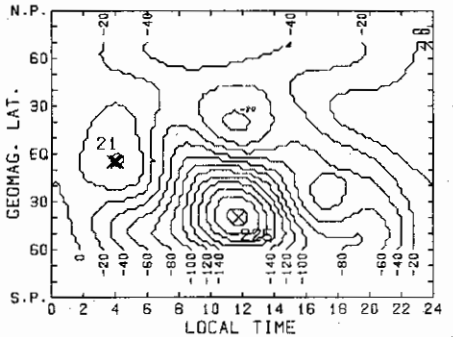

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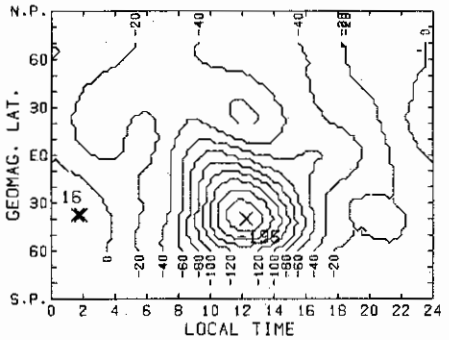

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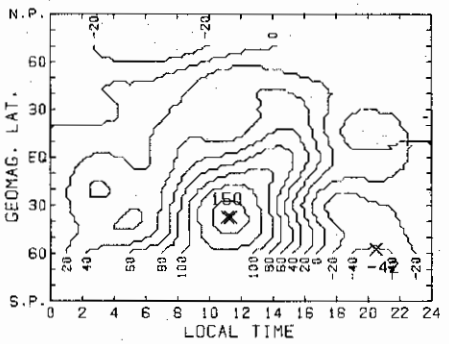

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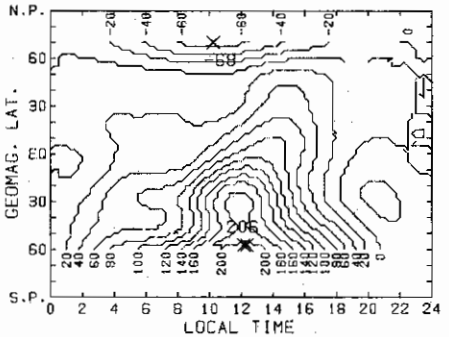

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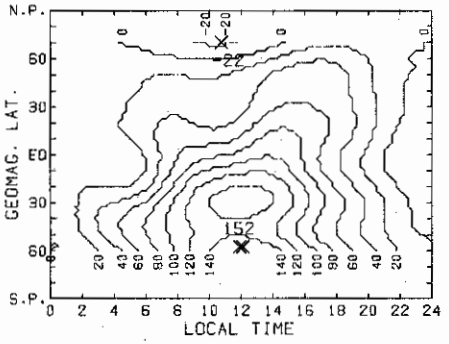

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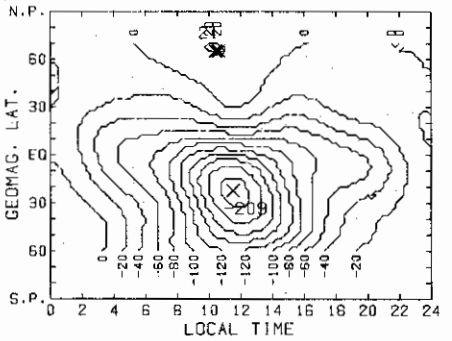

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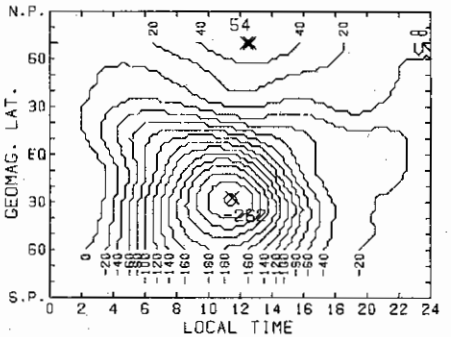

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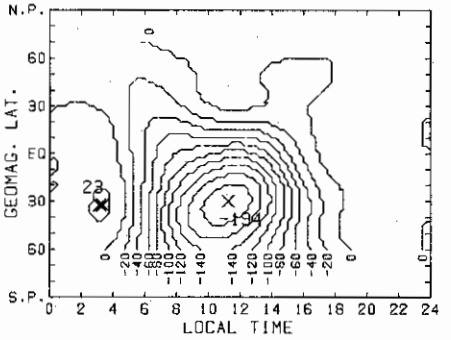

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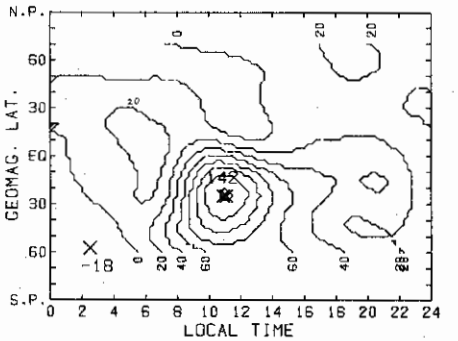

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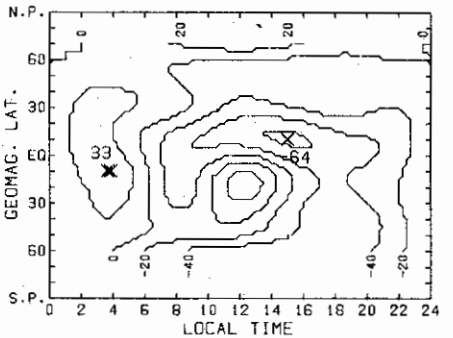

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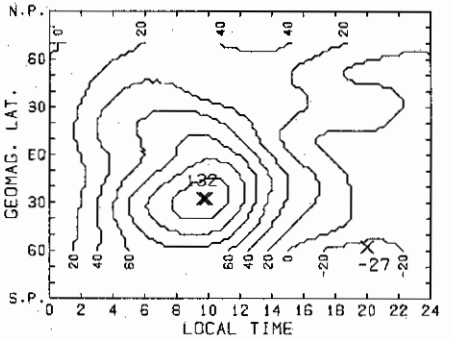

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EXTERNAL

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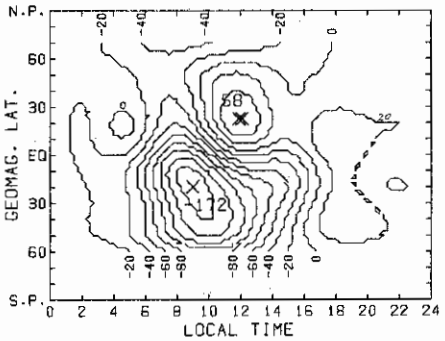
INTERNAL

1400Z



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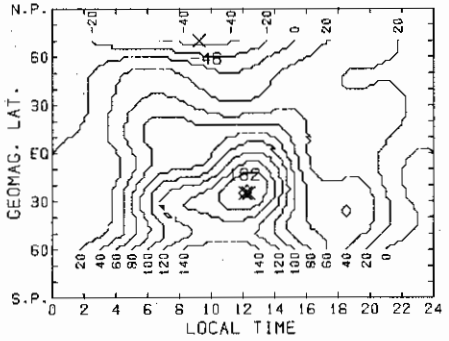

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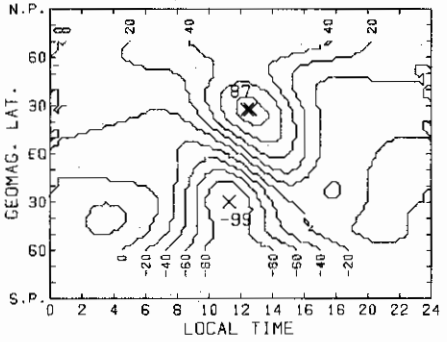

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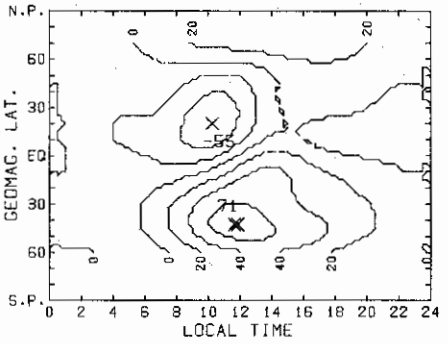

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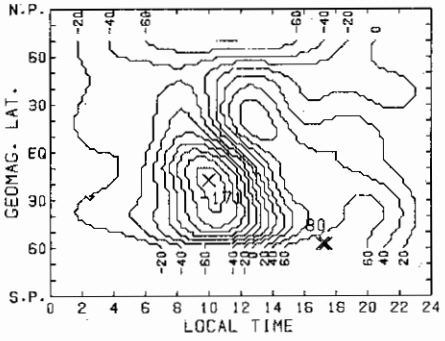

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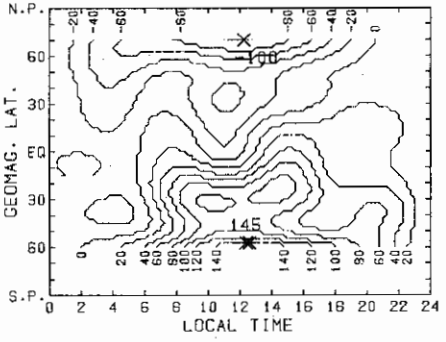

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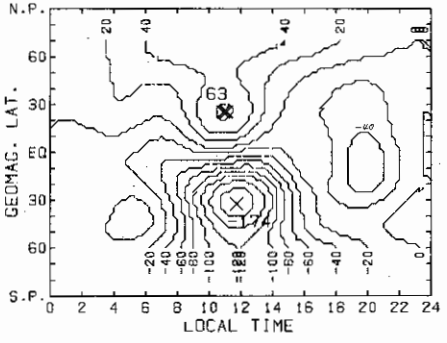

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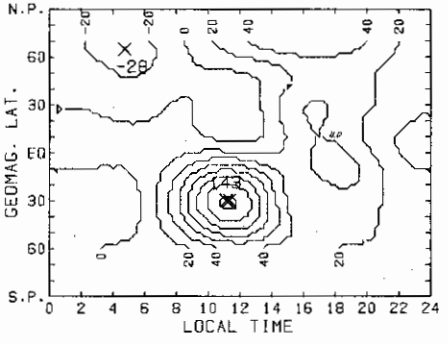

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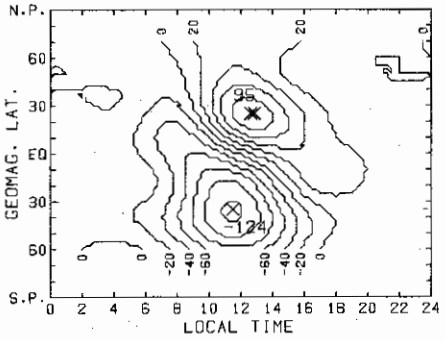

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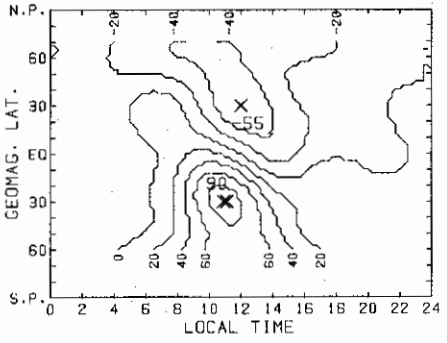

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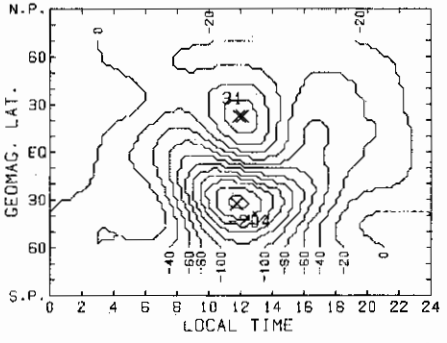

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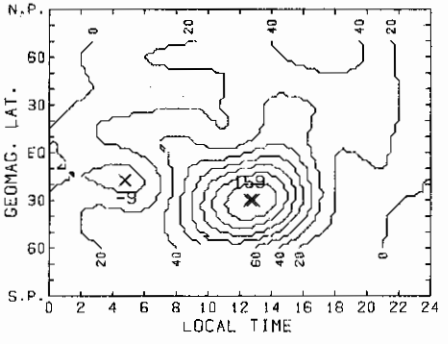

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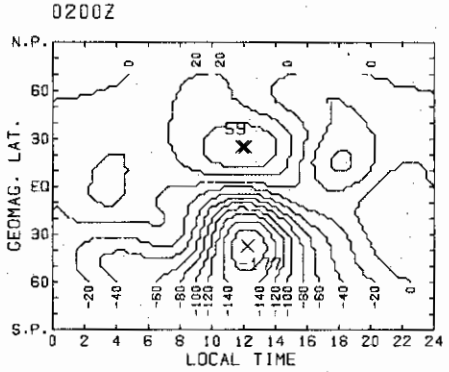

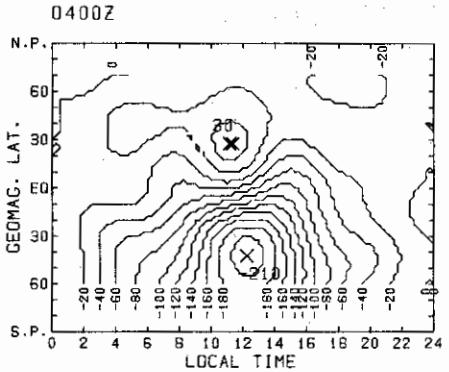

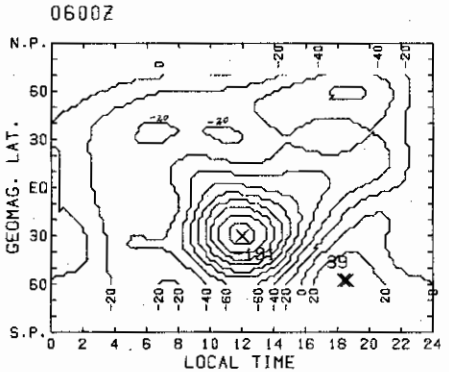

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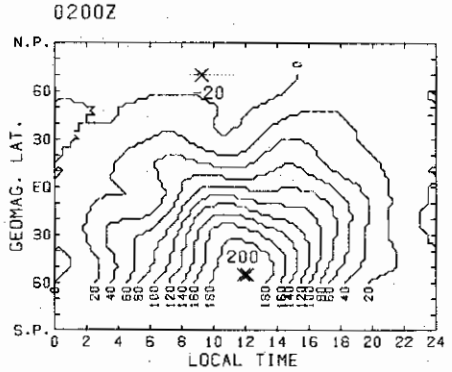

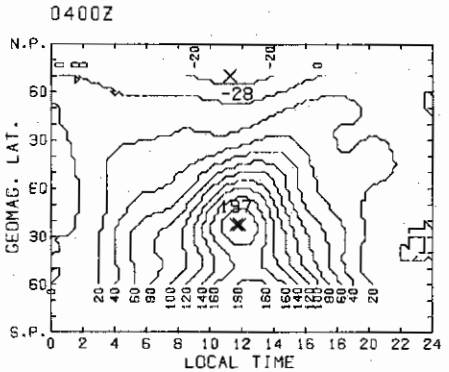

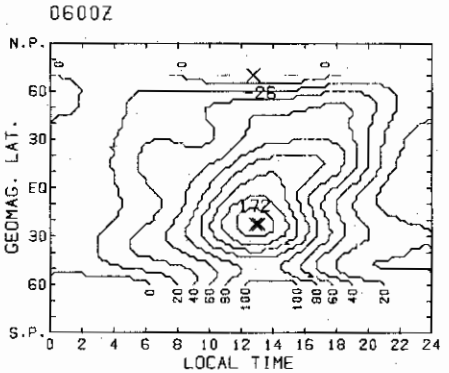

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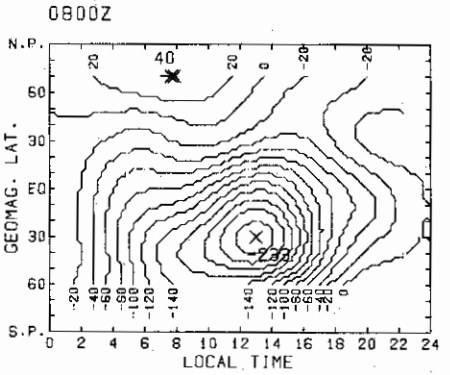

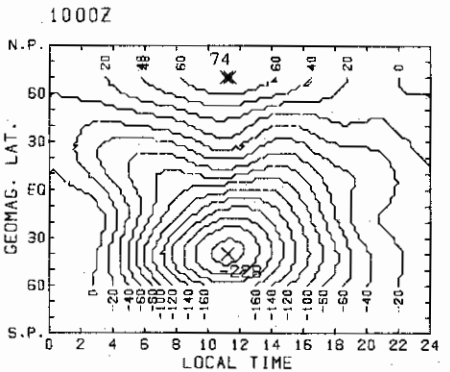

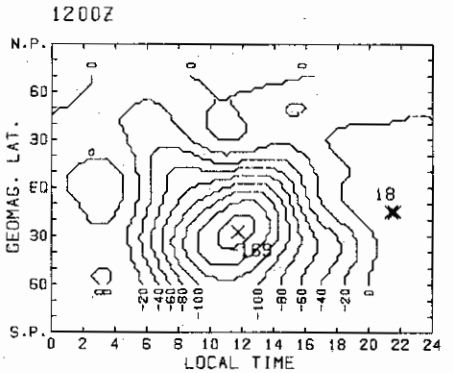

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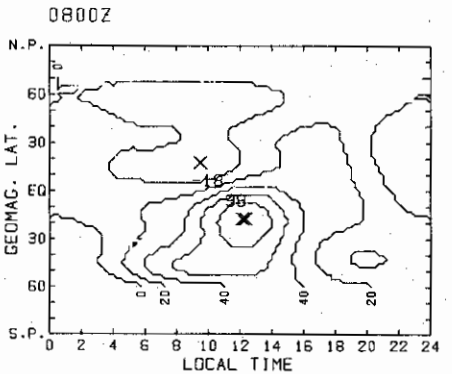

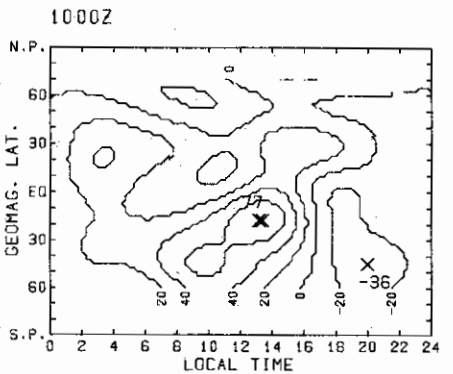

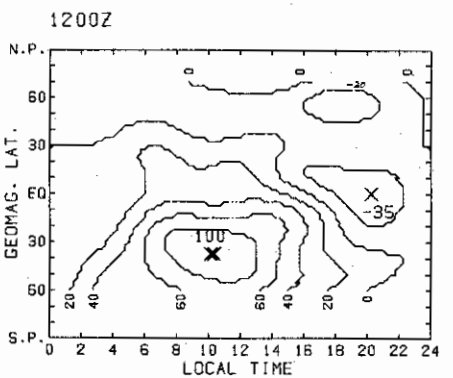

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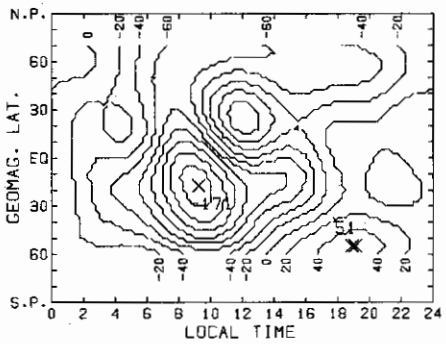

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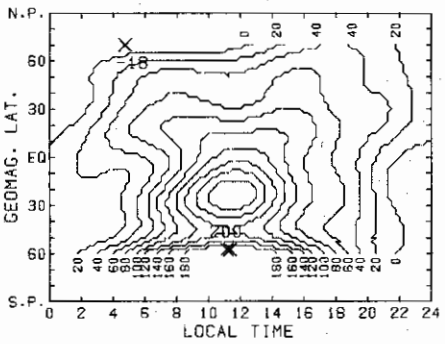

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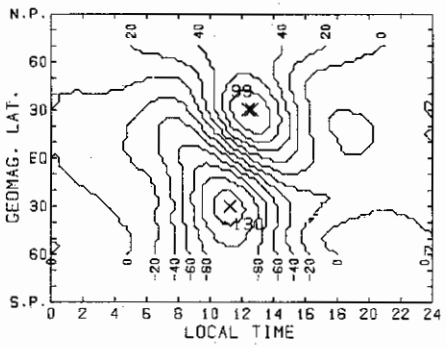

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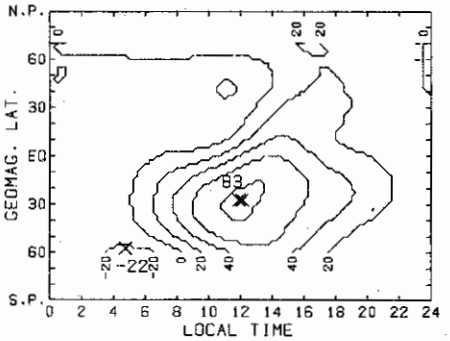

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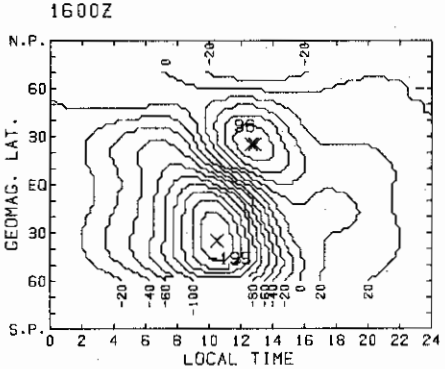

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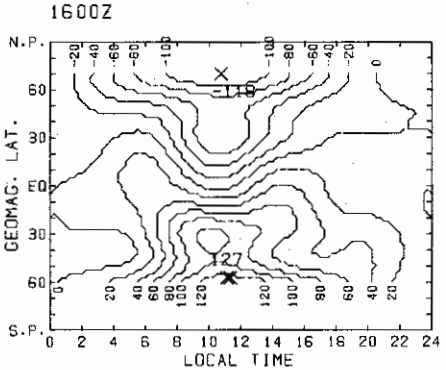

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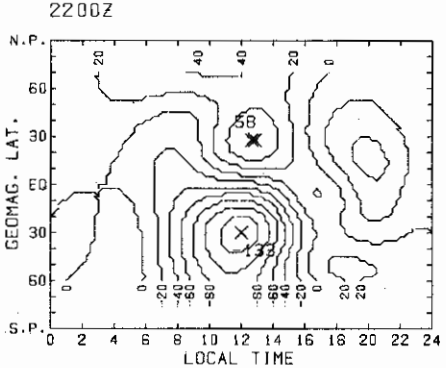

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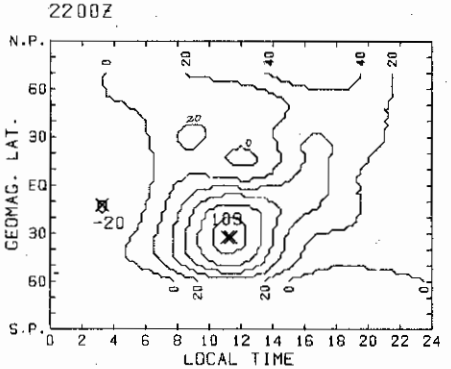

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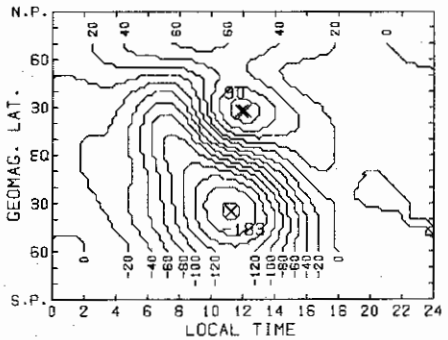

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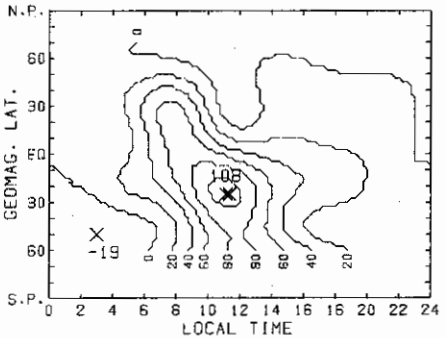

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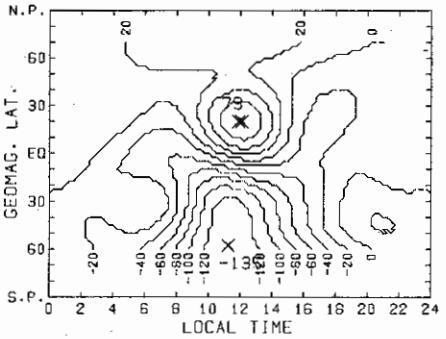

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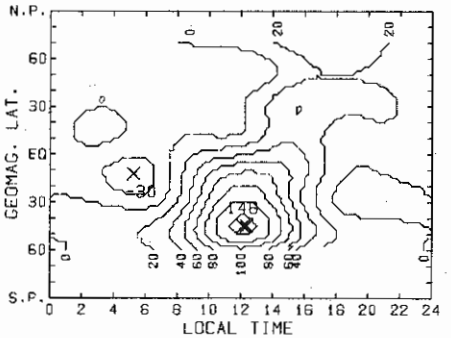

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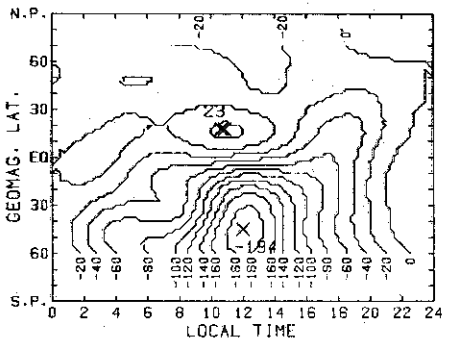

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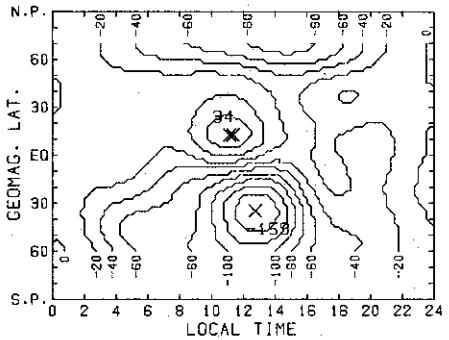

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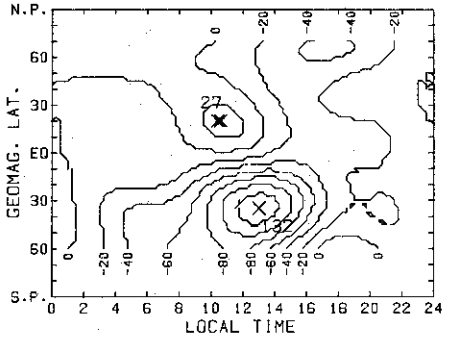

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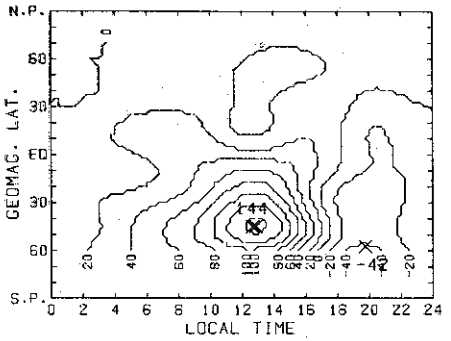

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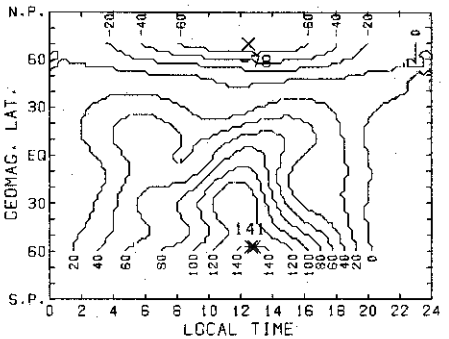

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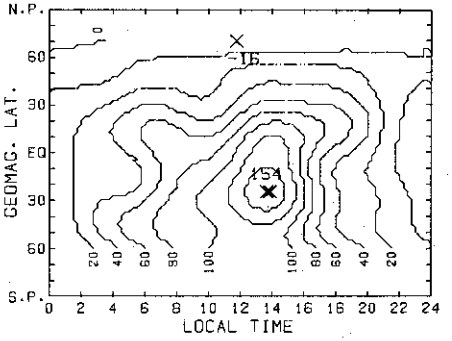

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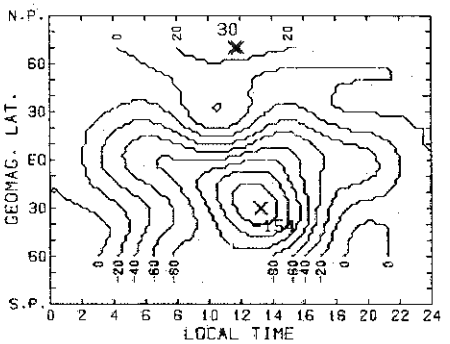

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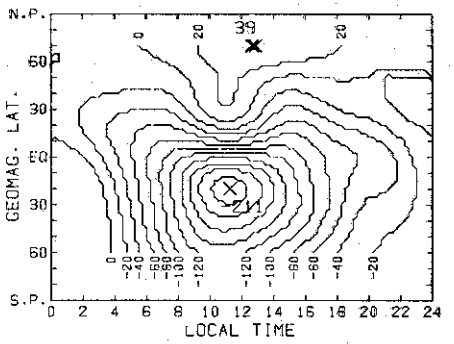

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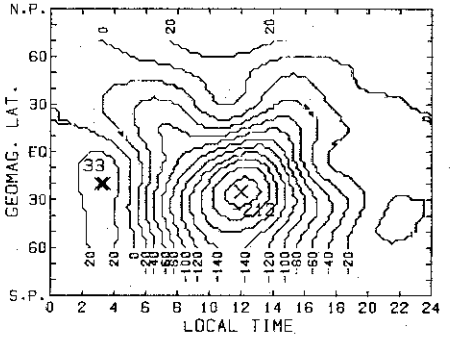

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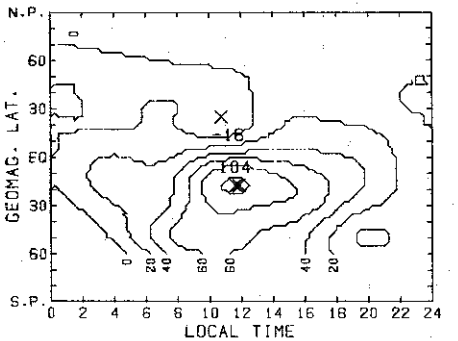

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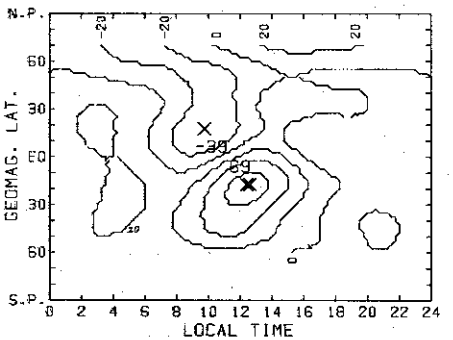

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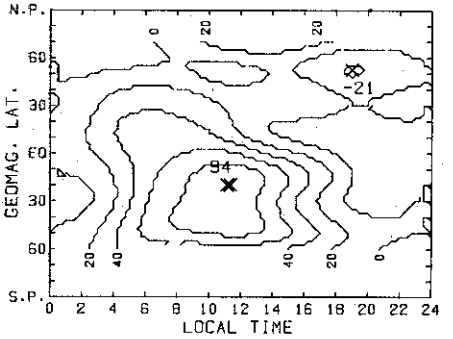

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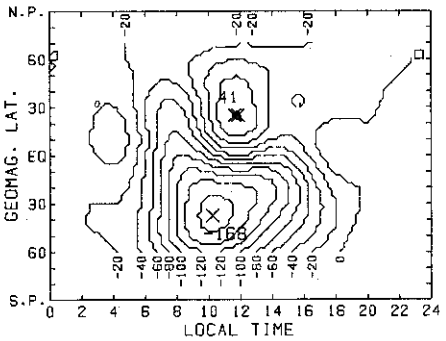

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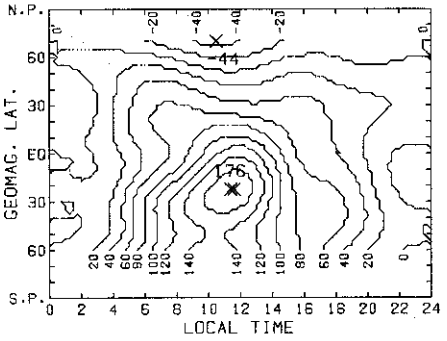

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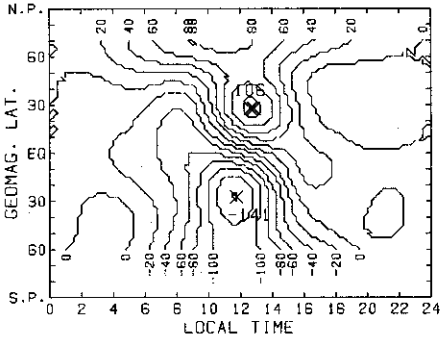

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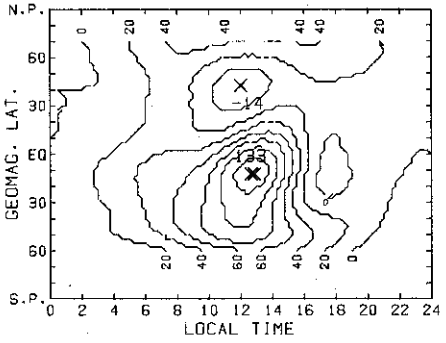

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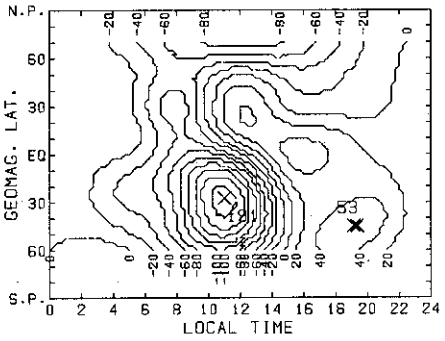

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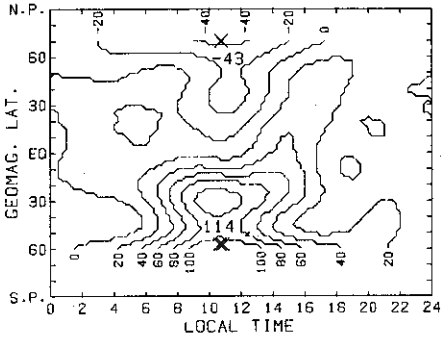

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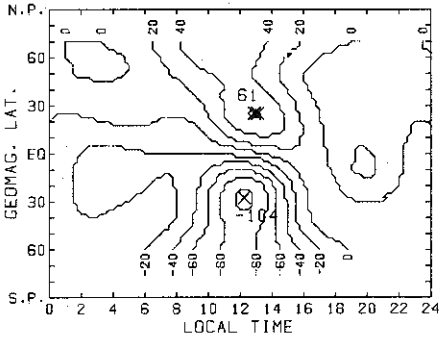

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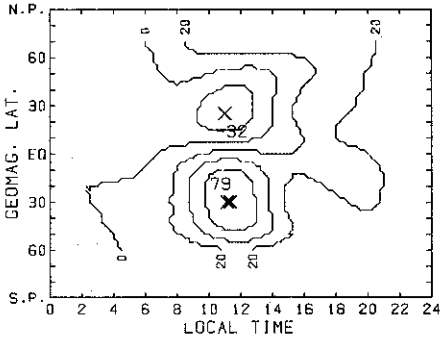

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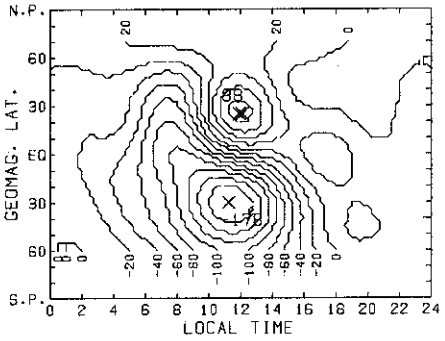

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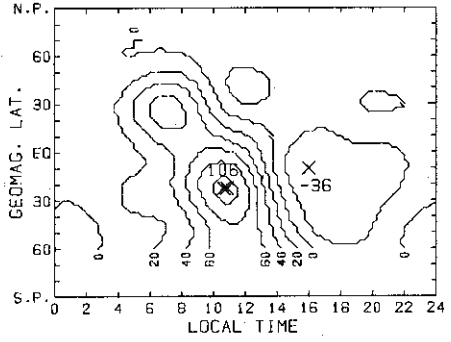

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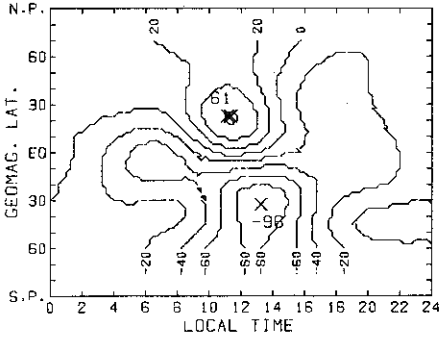

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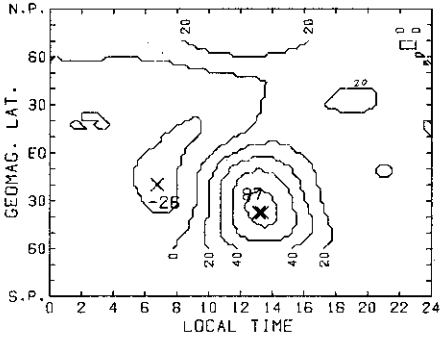

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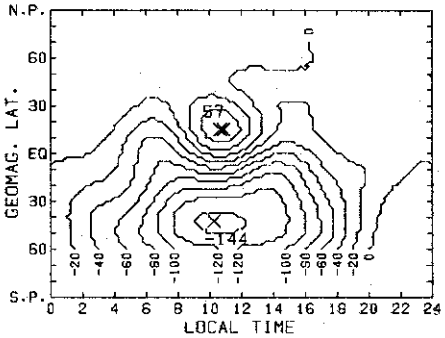

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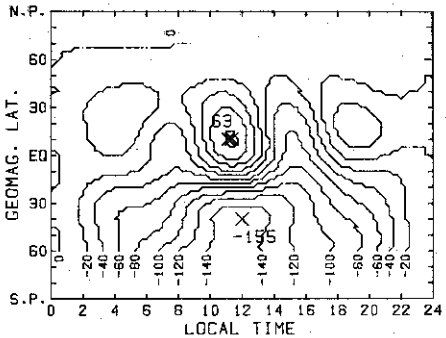

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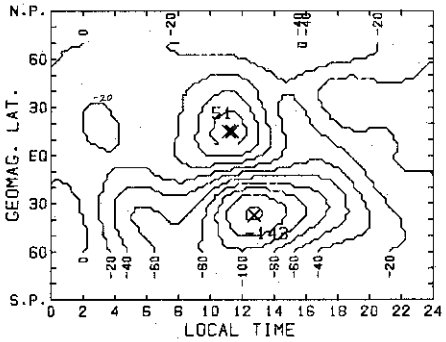
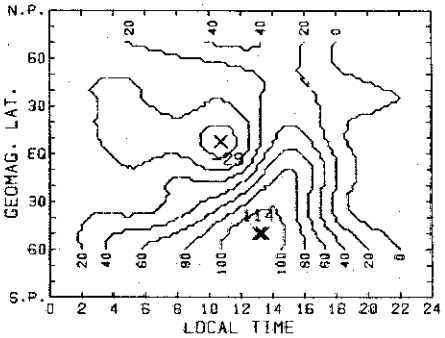


INTERNAL

0200Z



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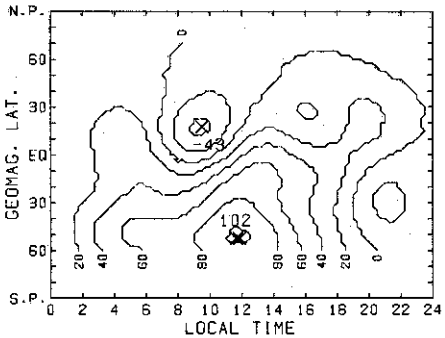

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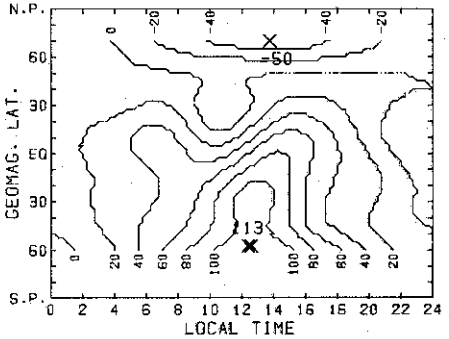
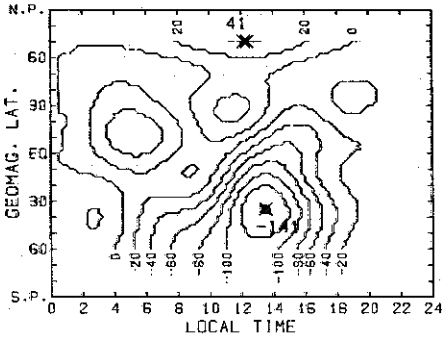


EXTERNAL

0800Z



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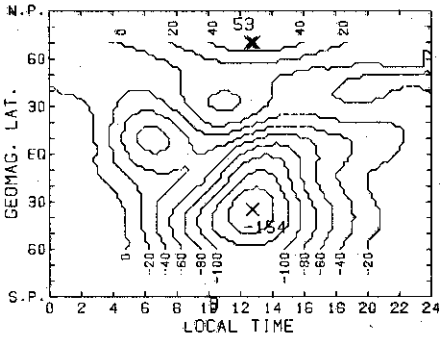

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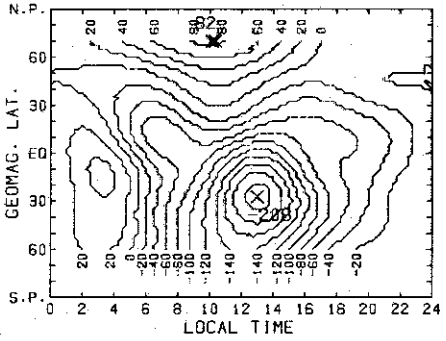

INTERNAL

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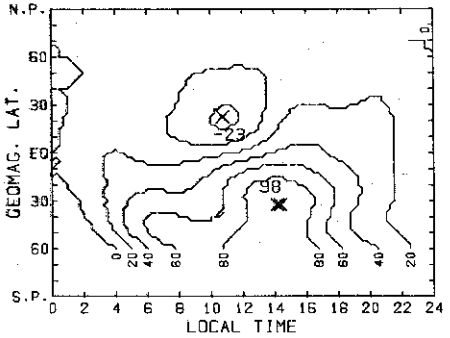

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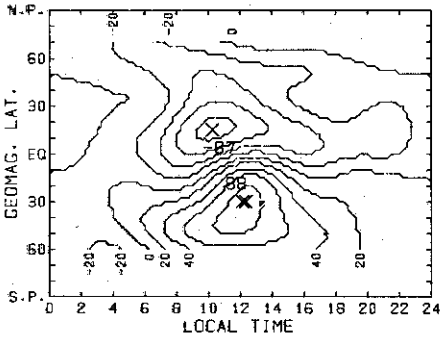

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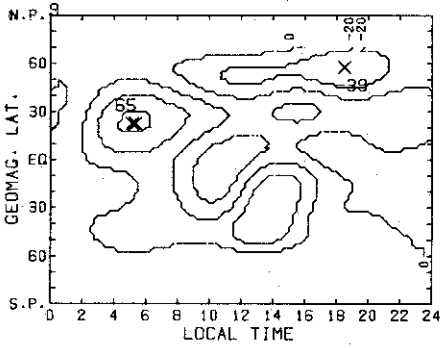

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EXTERNAL

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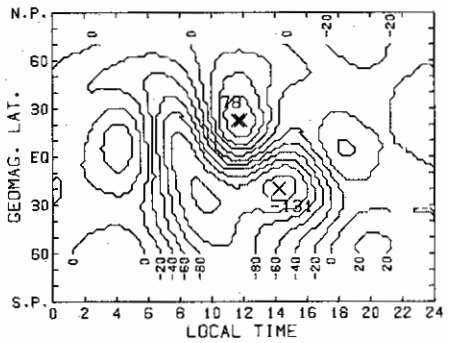

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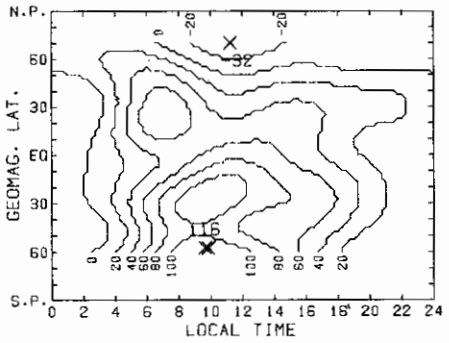

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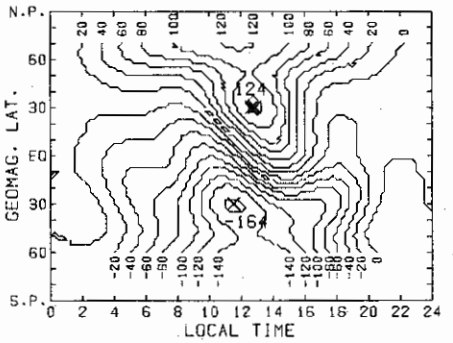

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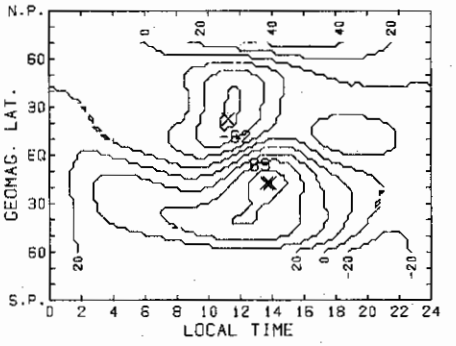

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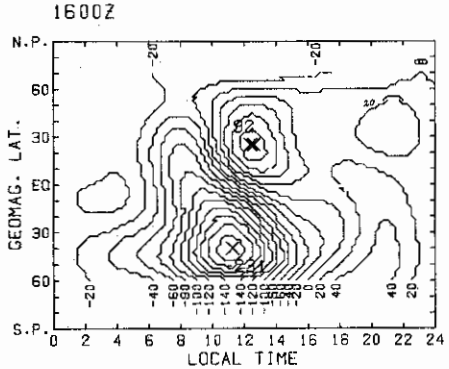

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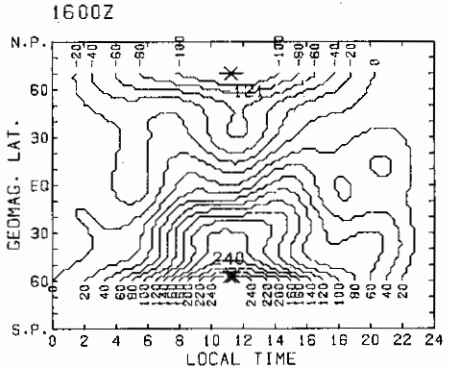

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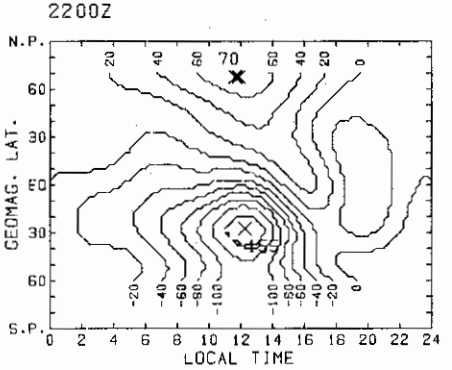

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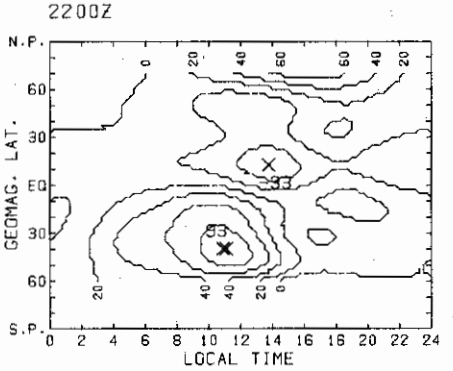

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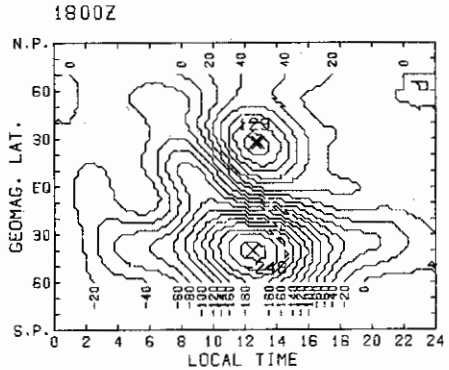

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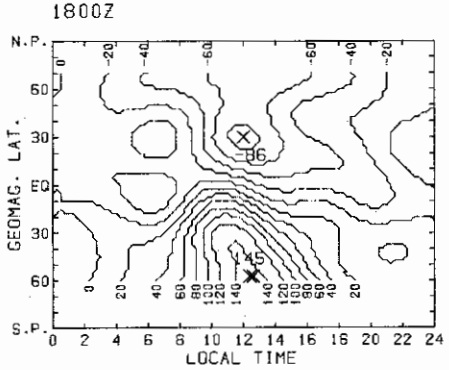

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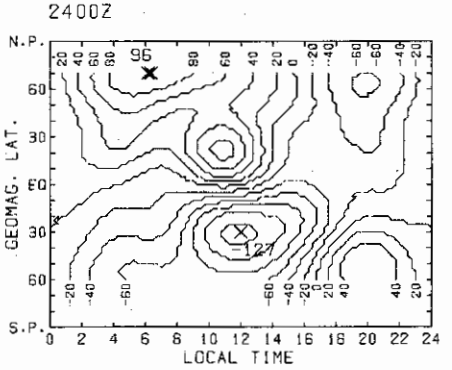

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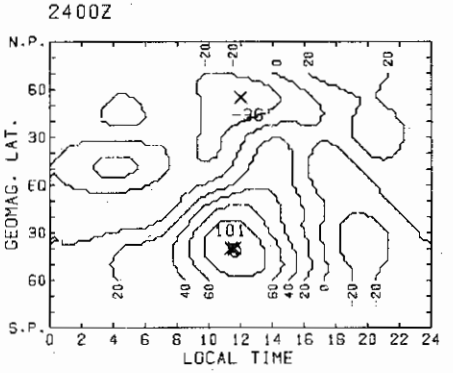

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EXTERNAL

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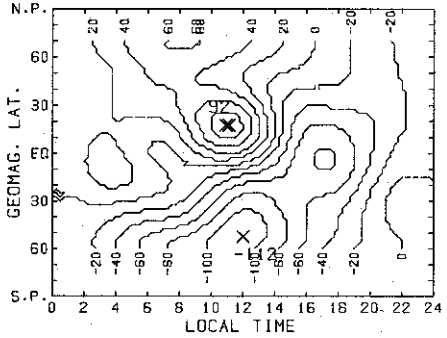

INTERNAL

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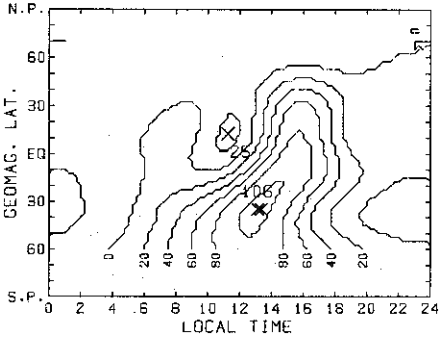

EXTERNAL

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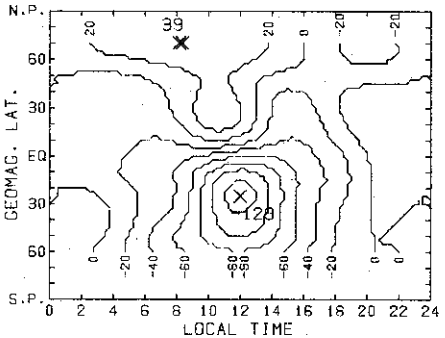

INTERNAL

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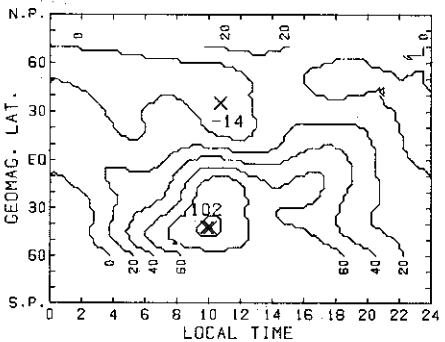

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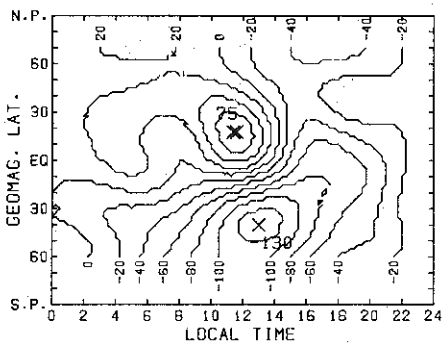

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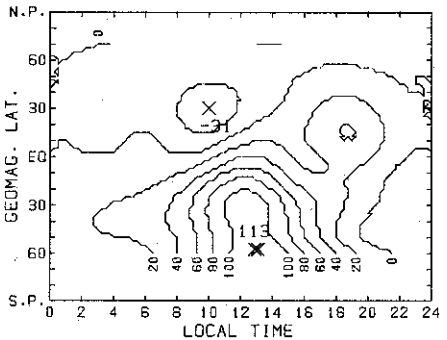

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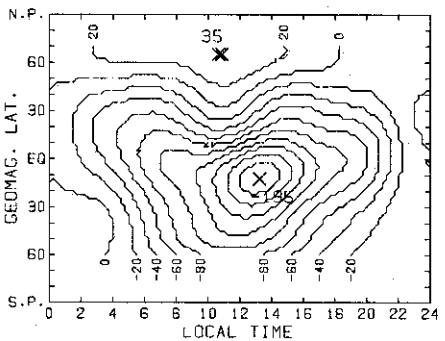

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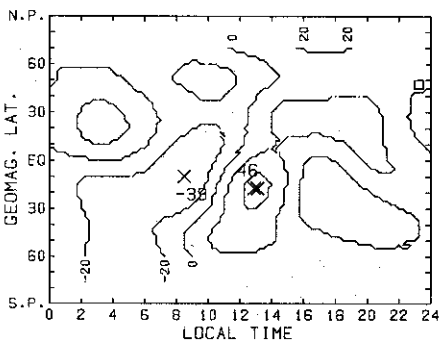

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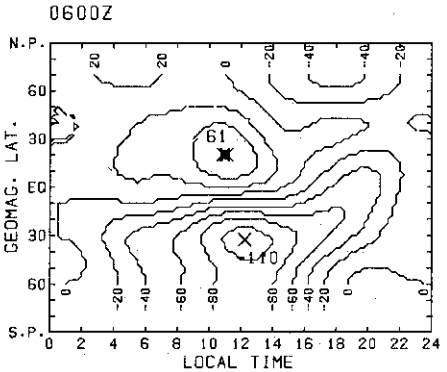

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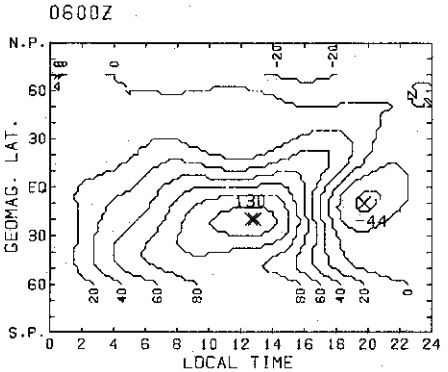

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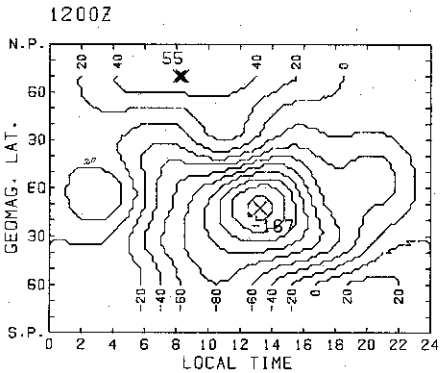

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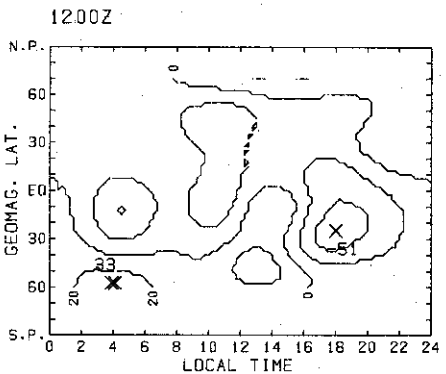

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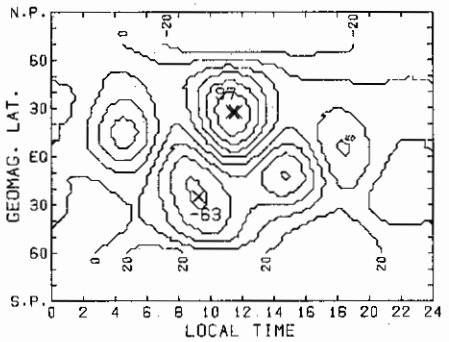
EXTERNAL

1400Z



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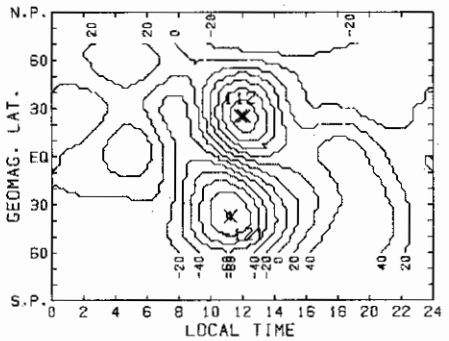

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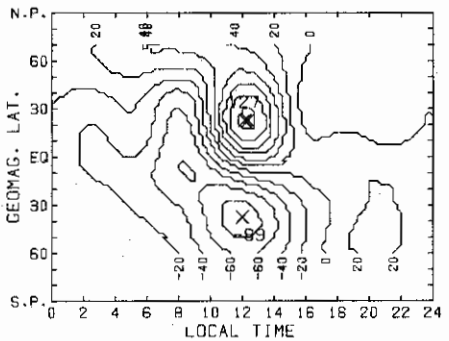

INTERNAL

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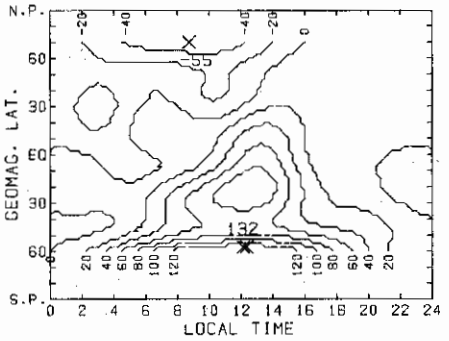

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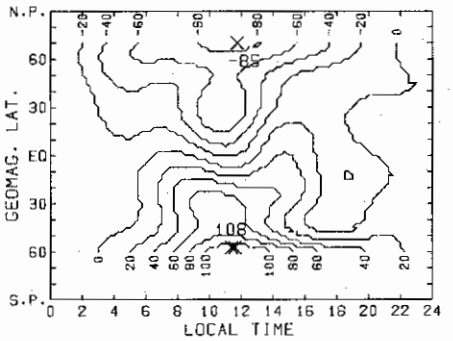

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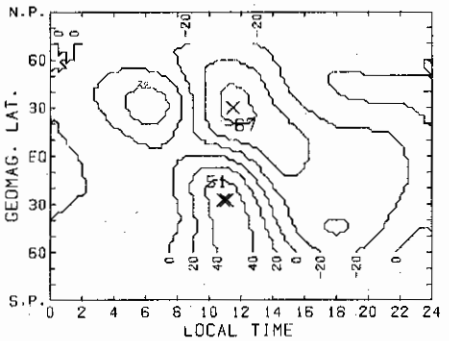

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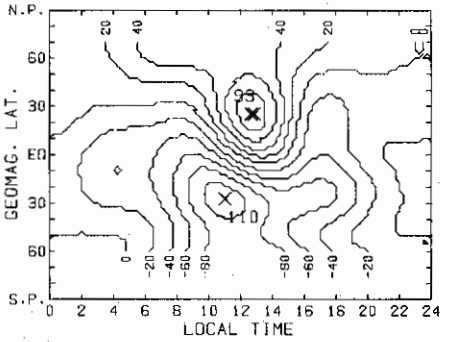

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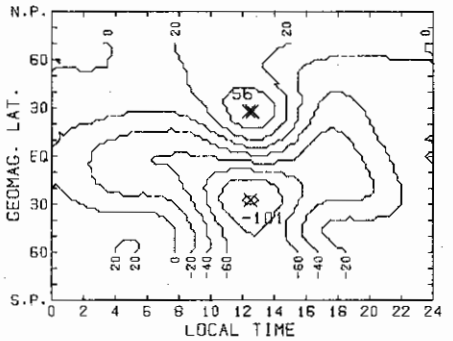

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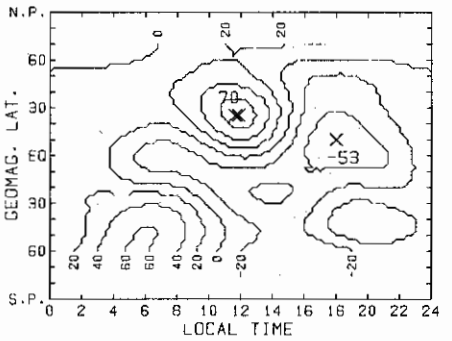

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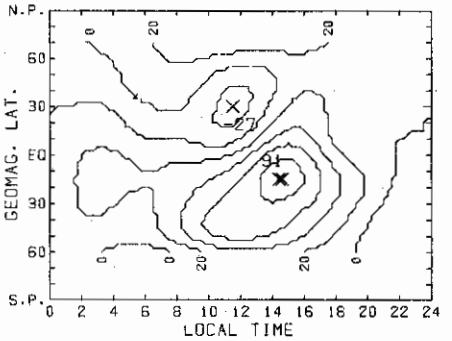

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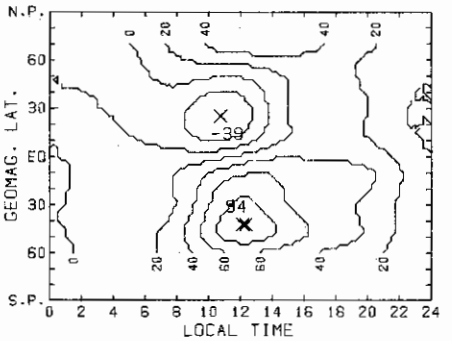

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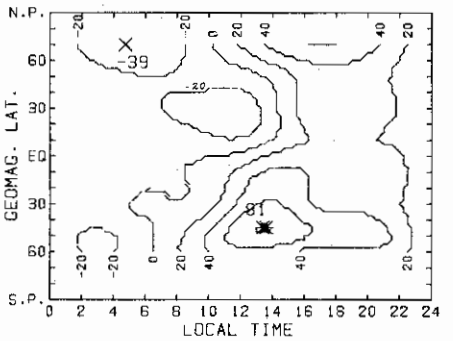

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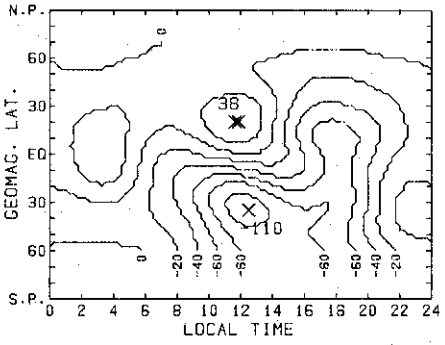

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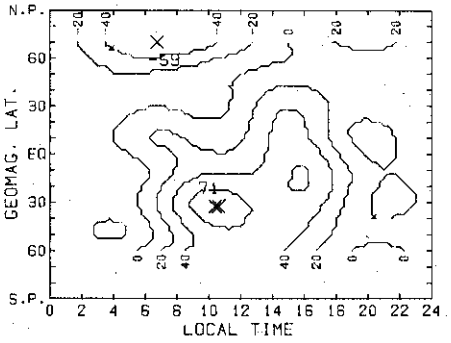

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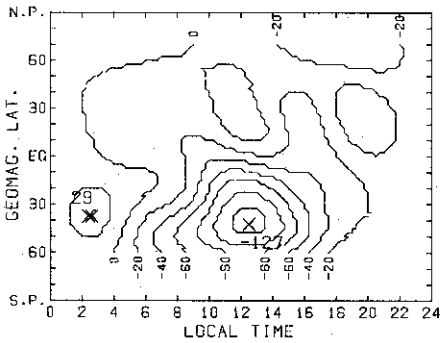

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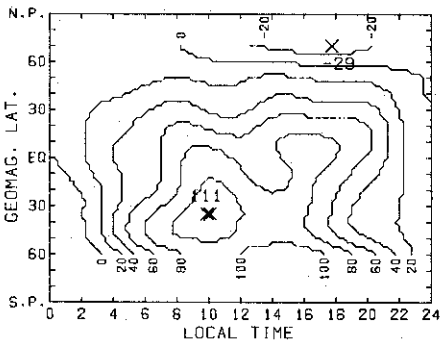

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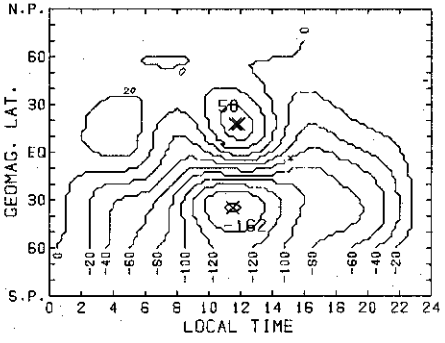

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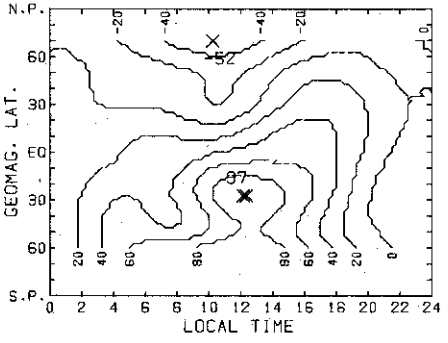

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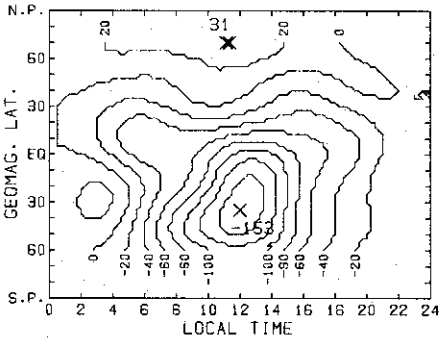

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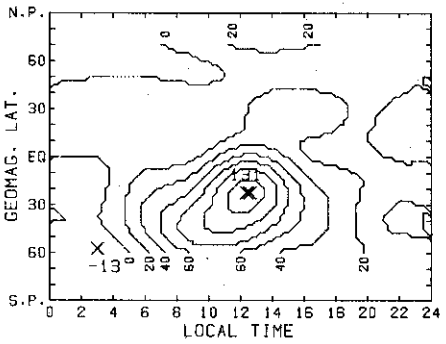

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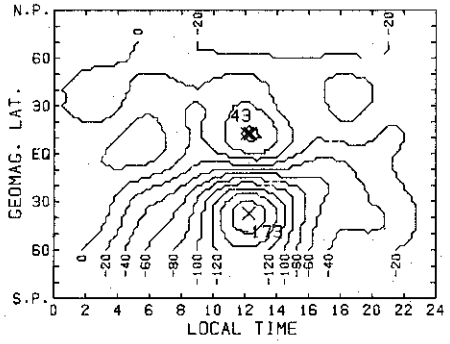

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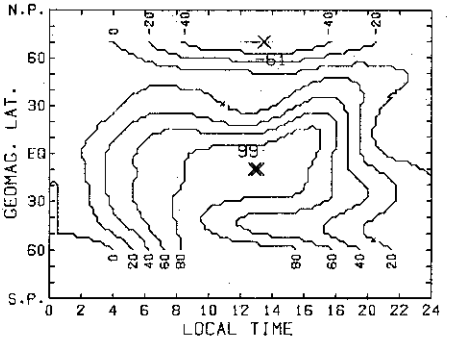

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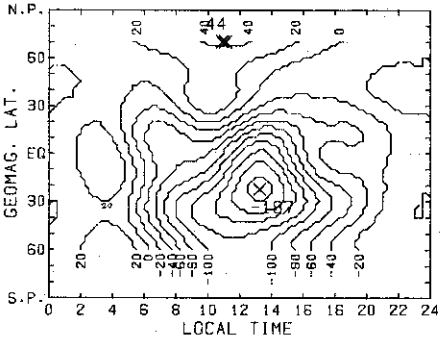

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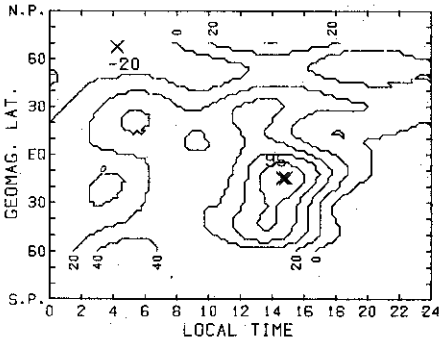

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EXTERNAL

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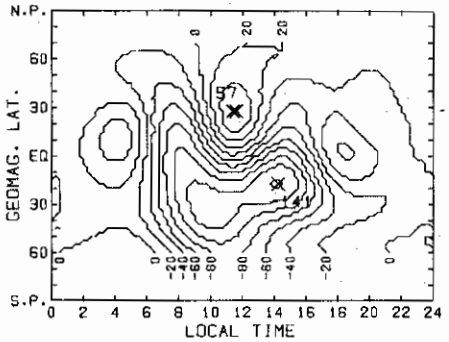

INTERNAL

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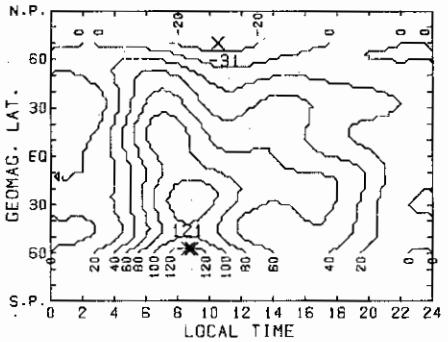

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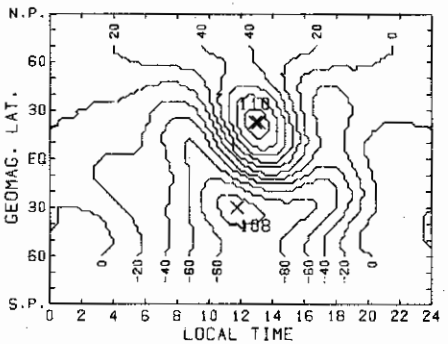

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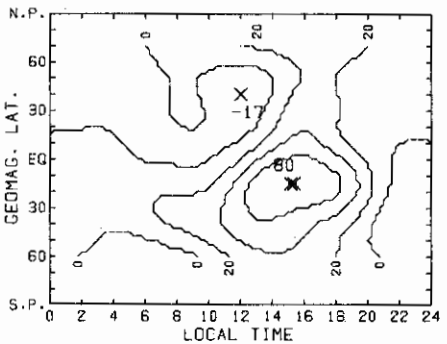

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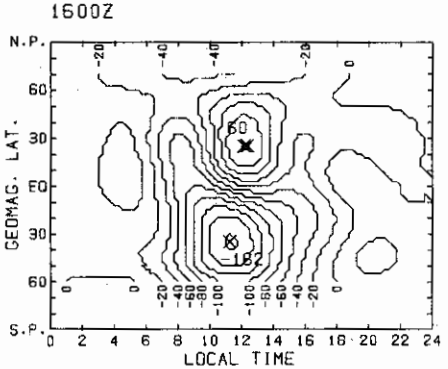

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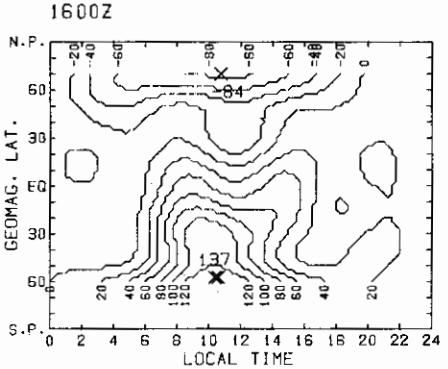

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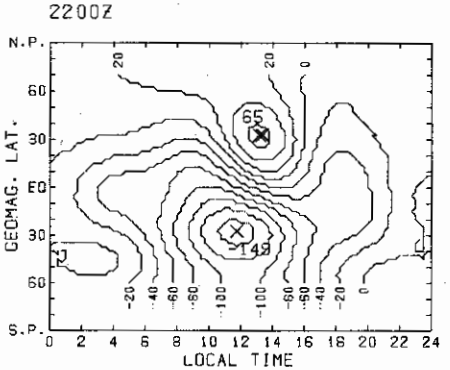

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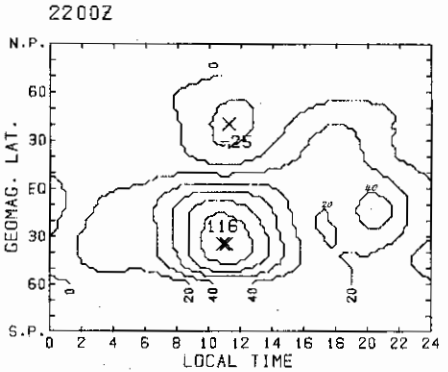

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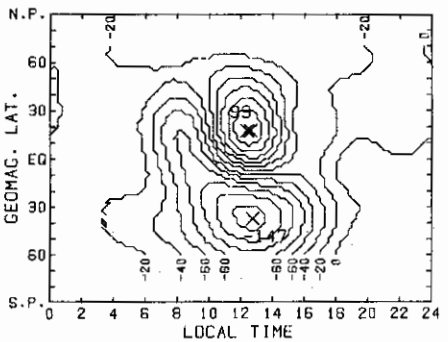

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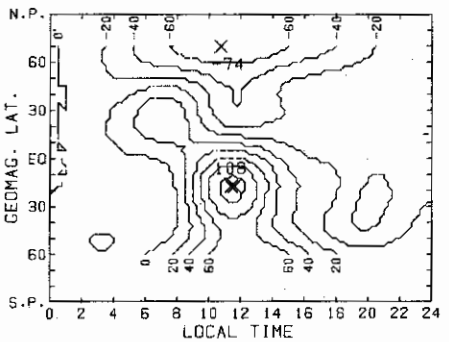

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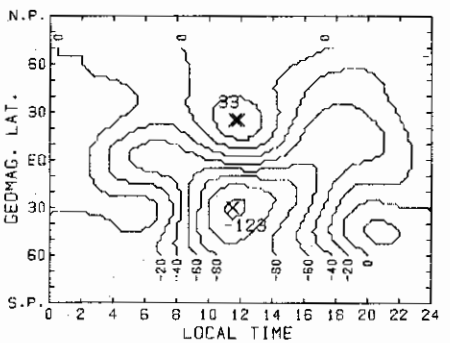

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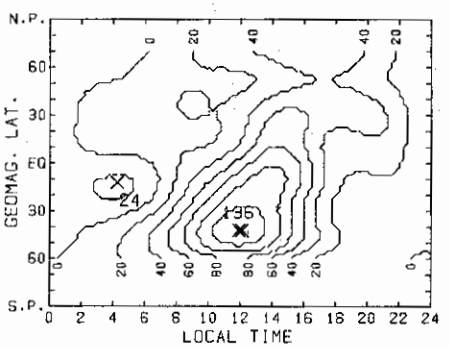

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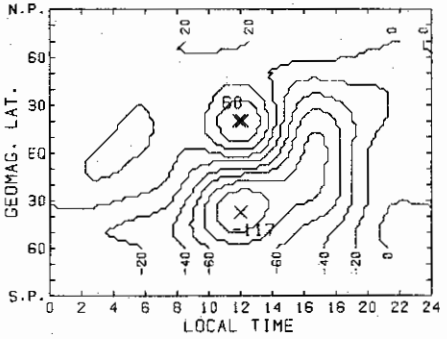

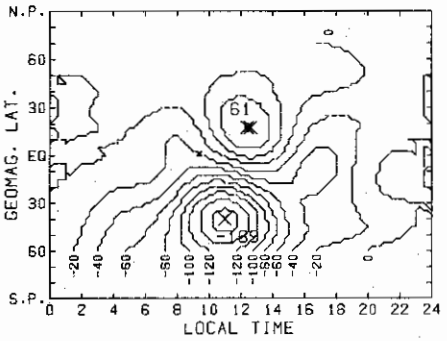

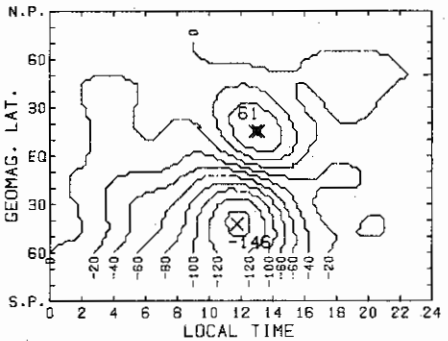

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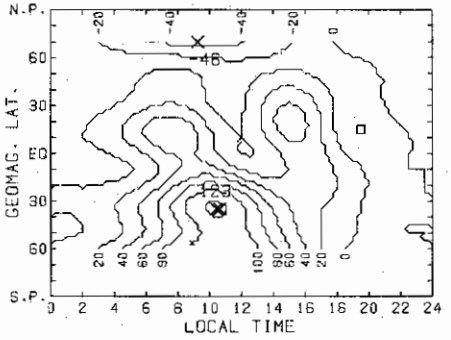

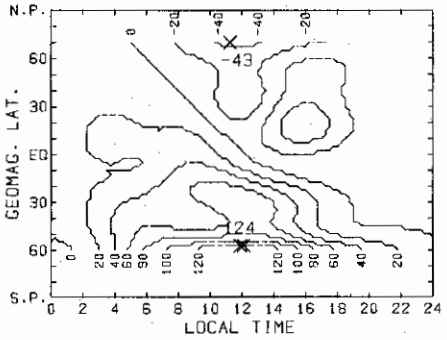

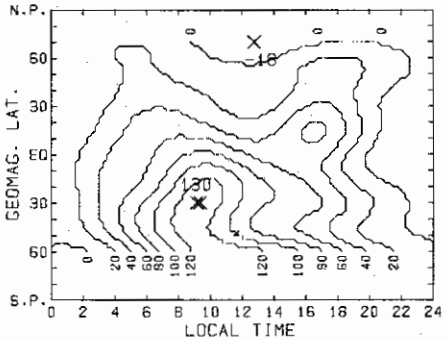

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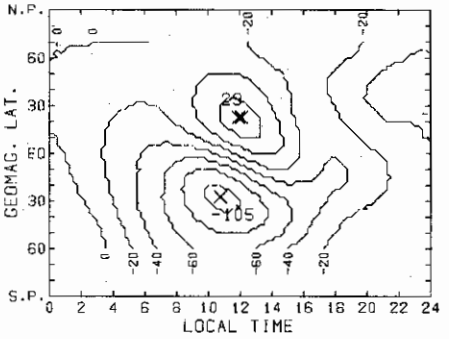

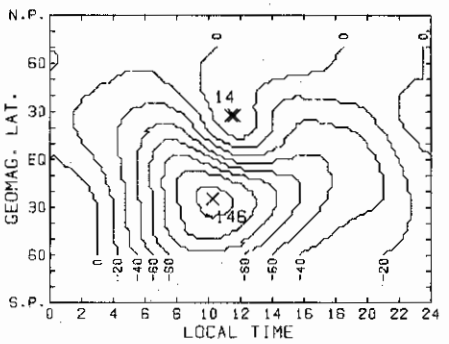

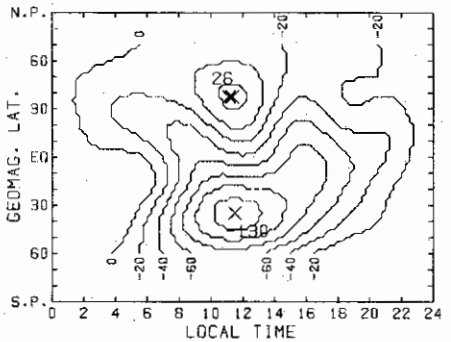

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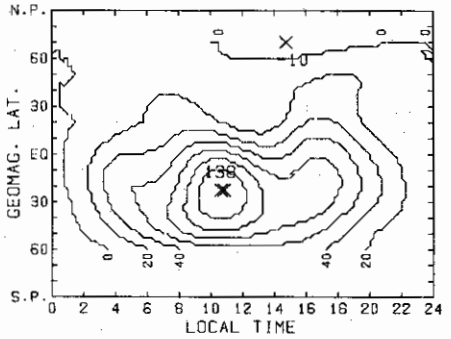

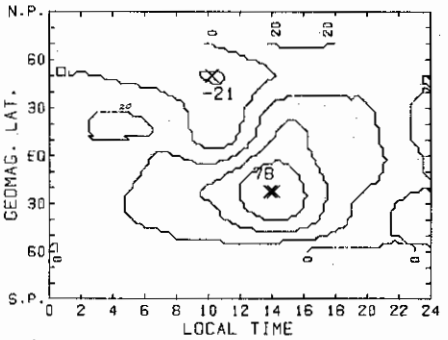

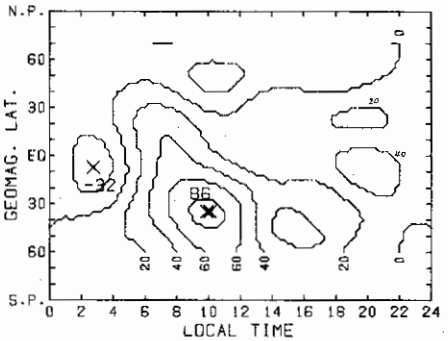

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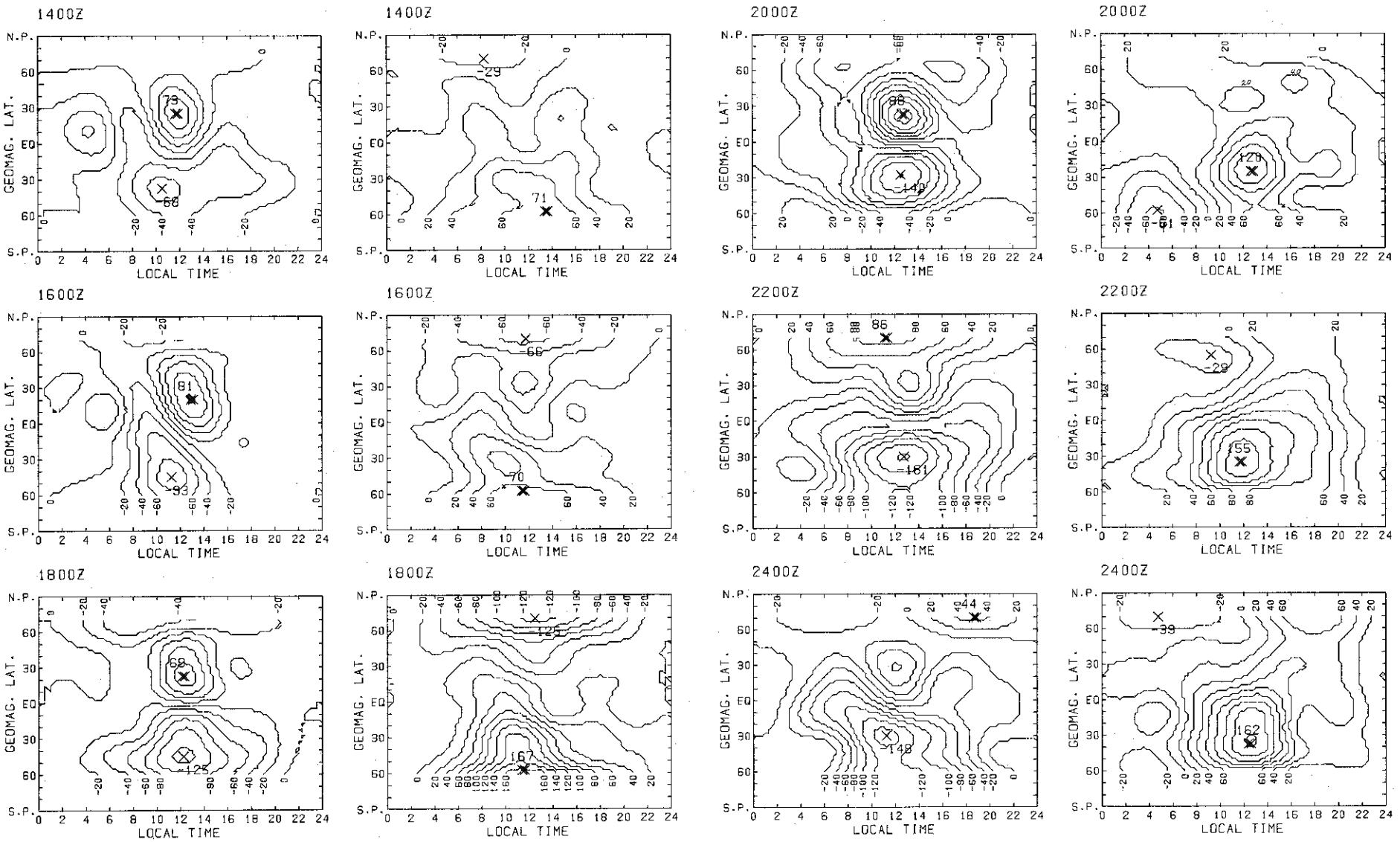

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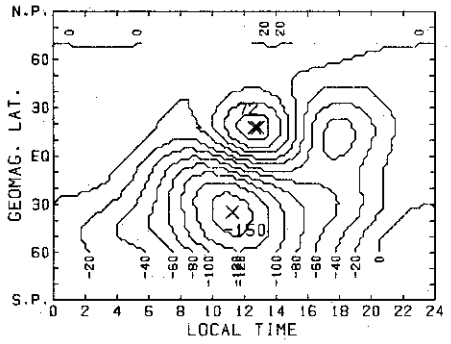

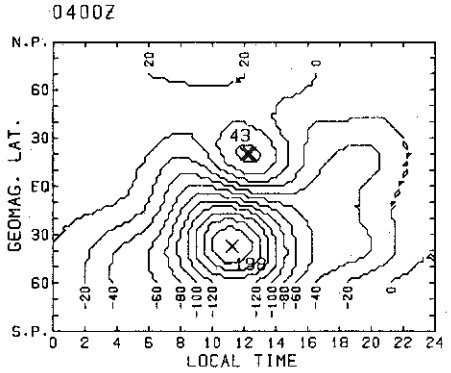

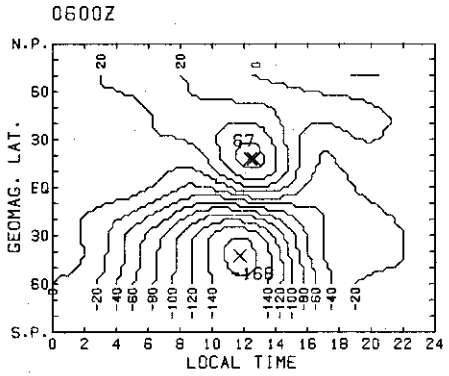

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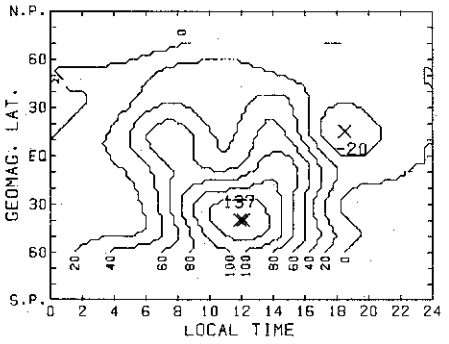

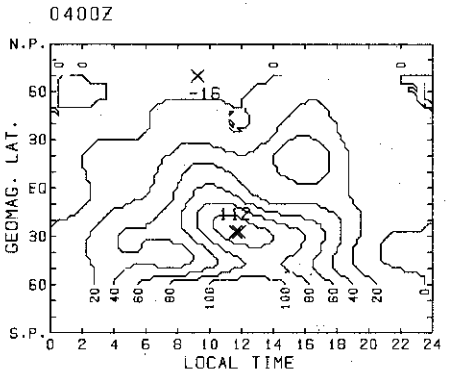

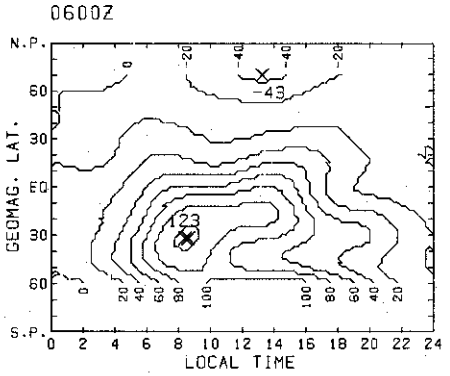

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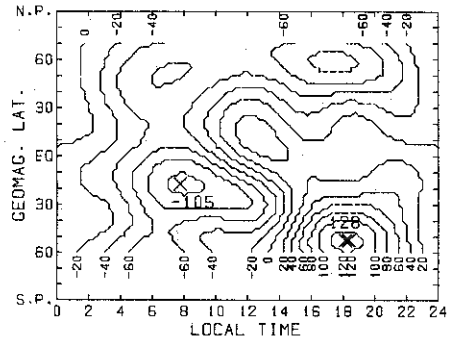

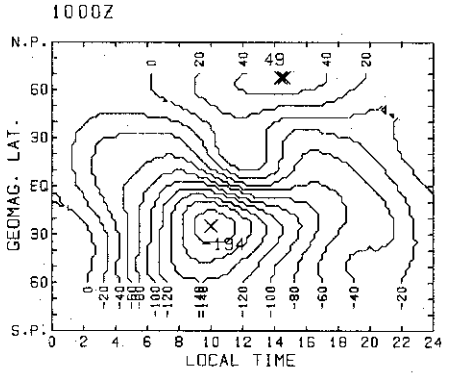

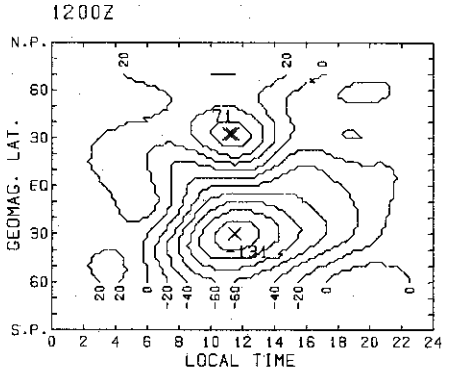

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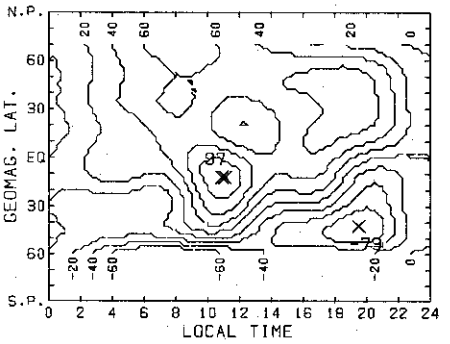

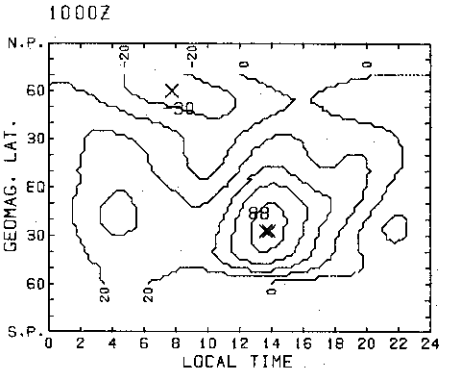

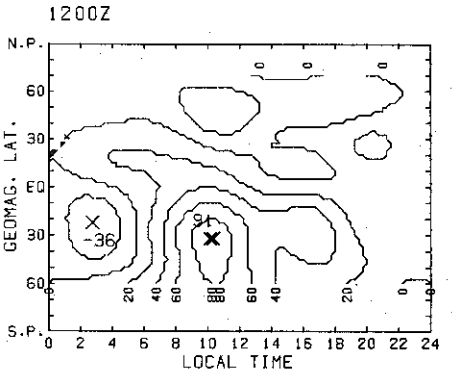

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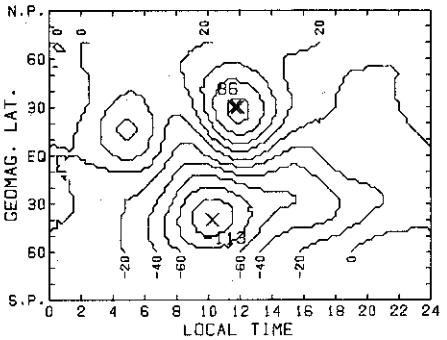

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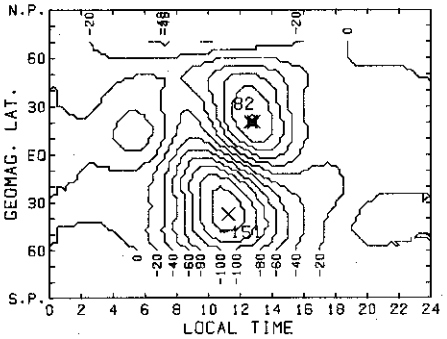

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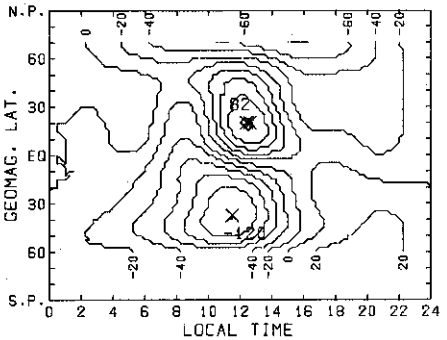

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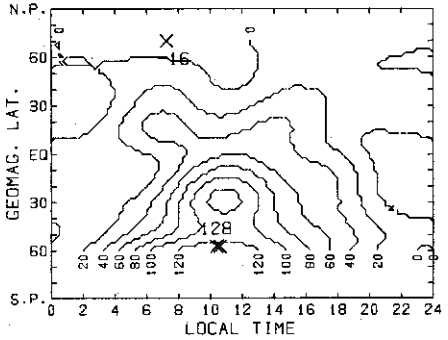

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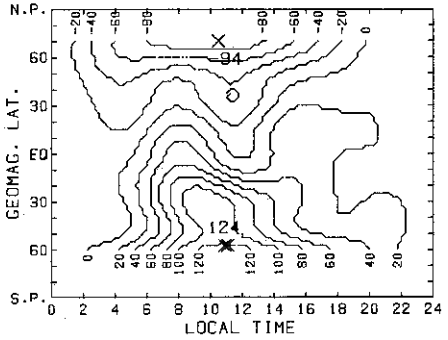

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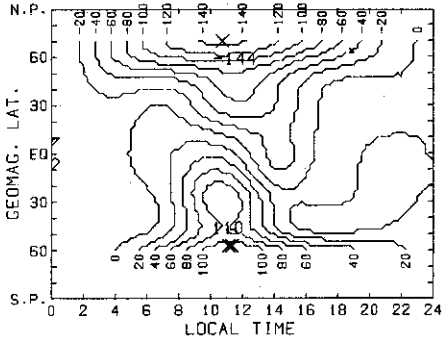

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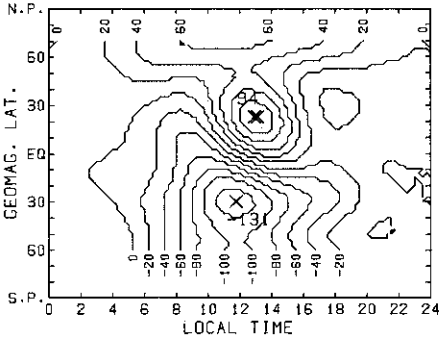

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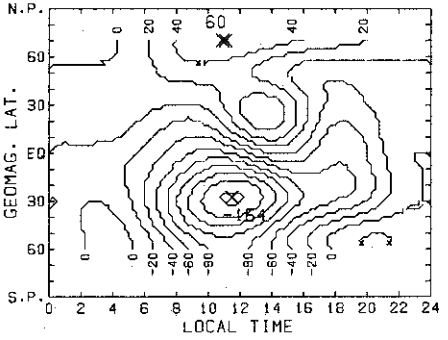

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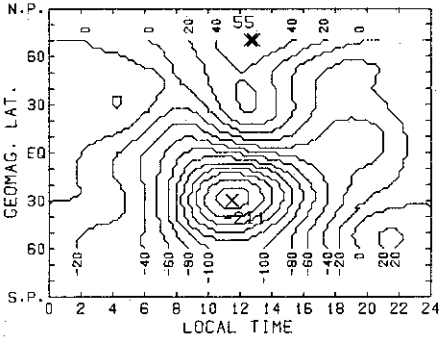

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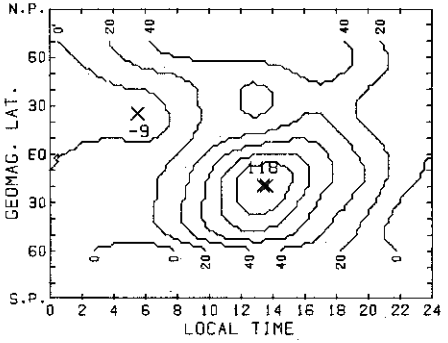

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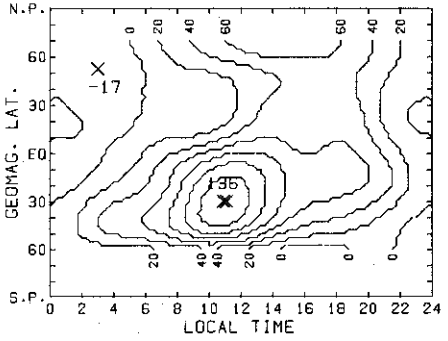

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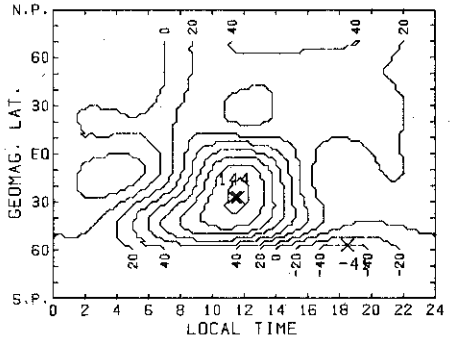

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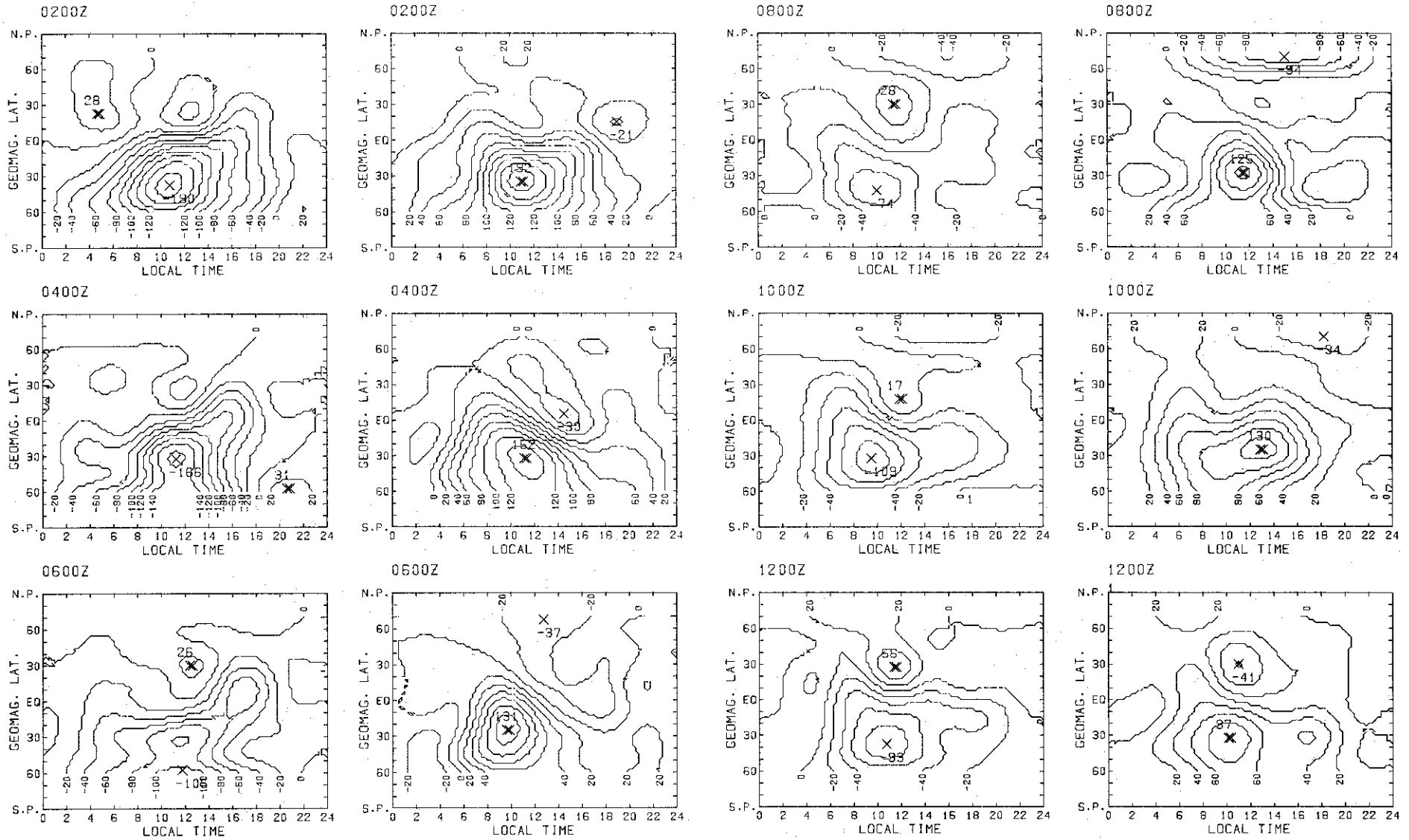

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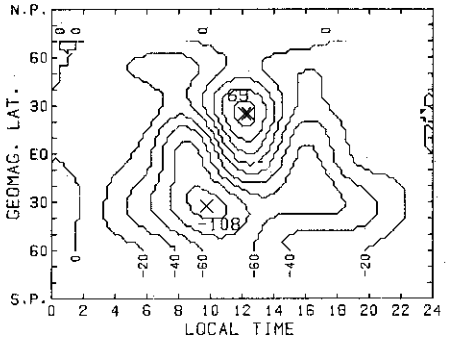

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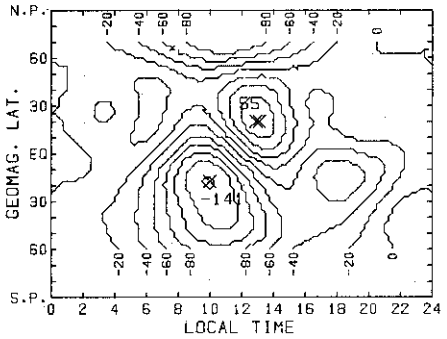

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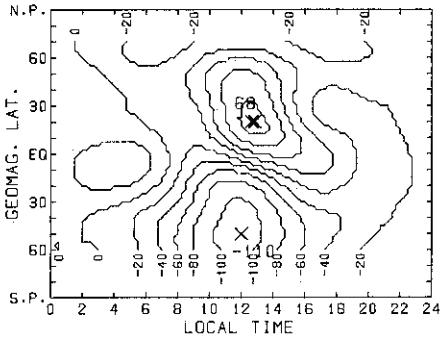

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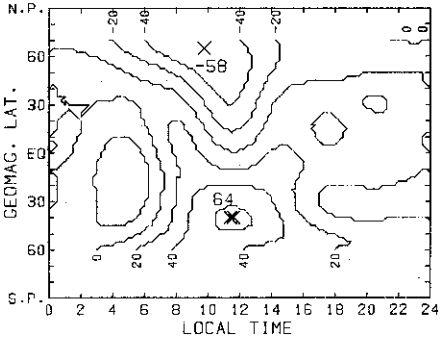

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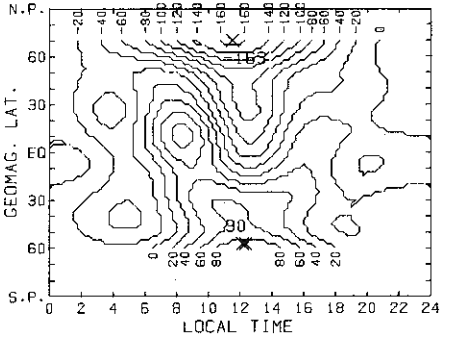

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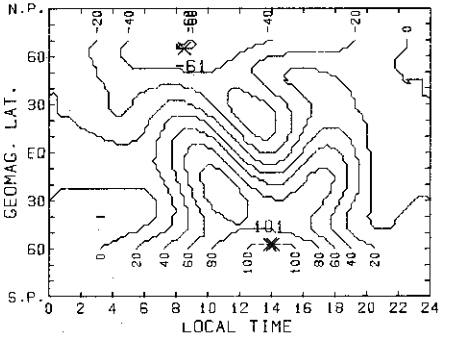

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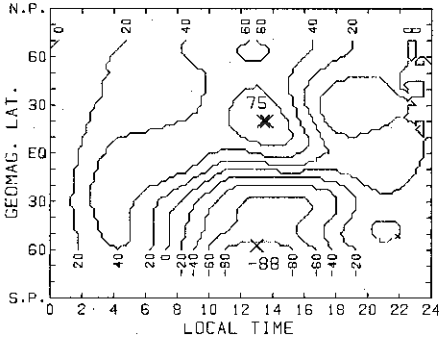

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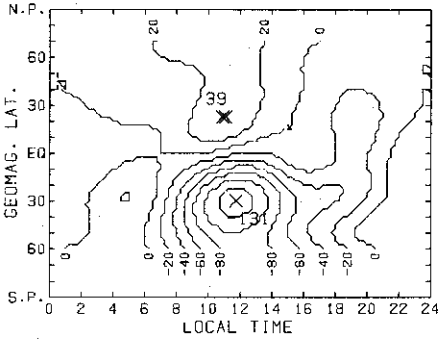

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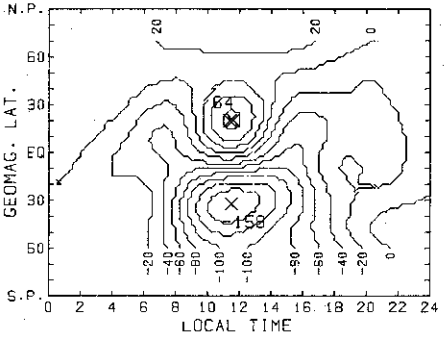

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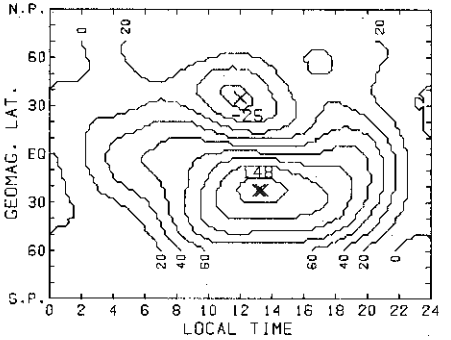

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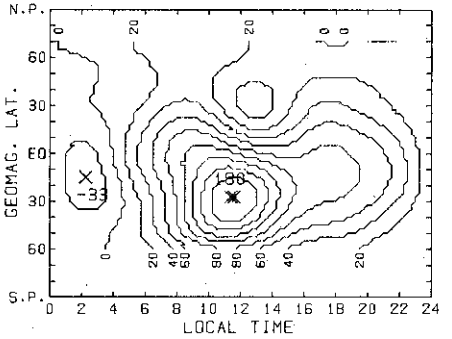

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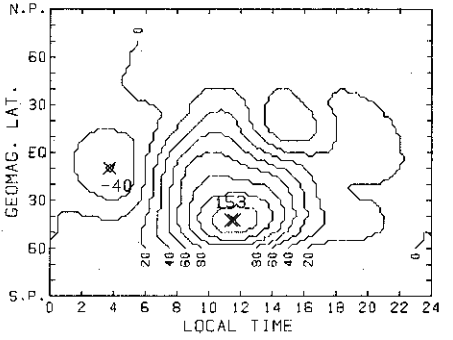

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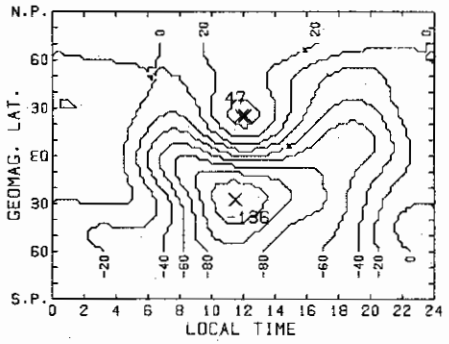

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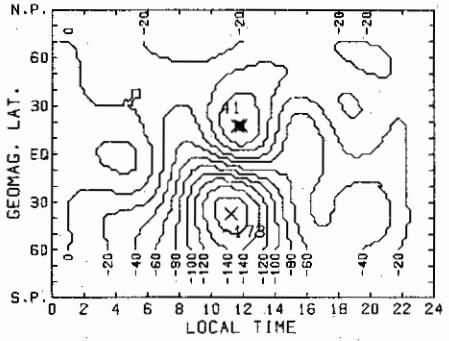

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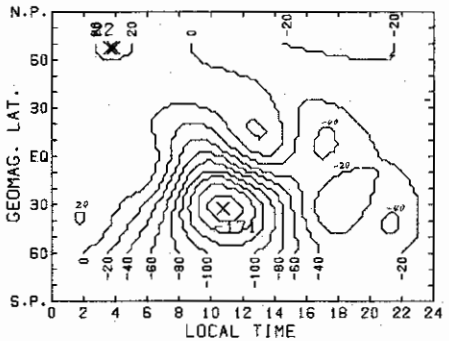

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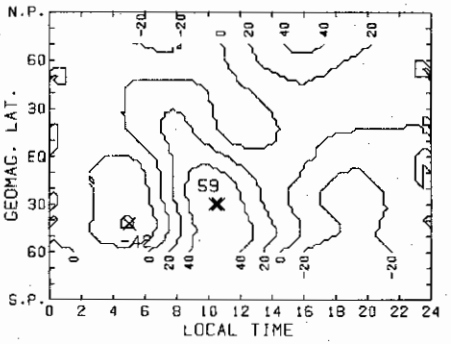

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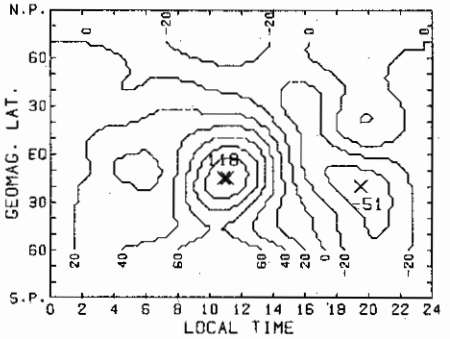

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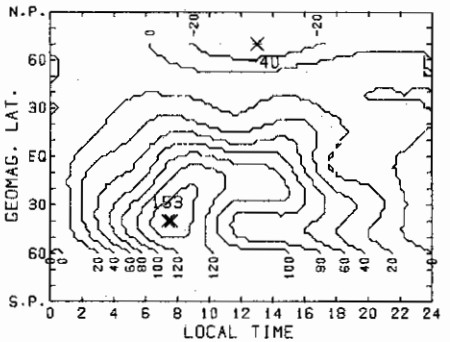

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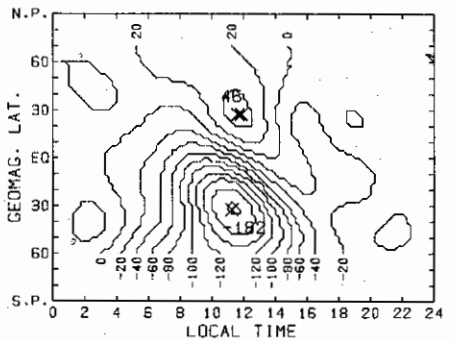

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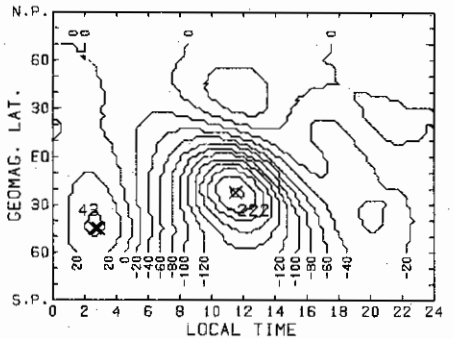

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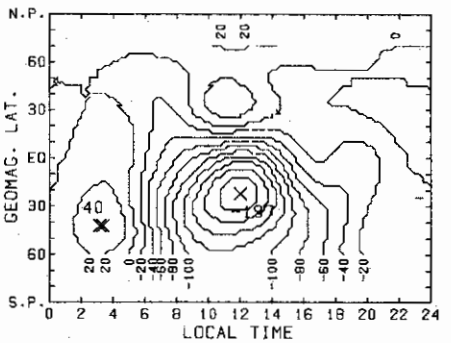

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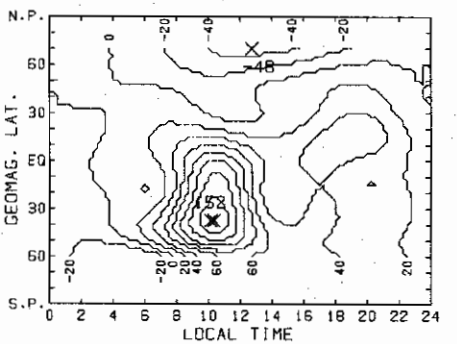

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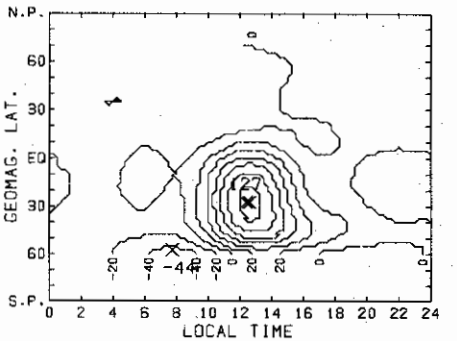

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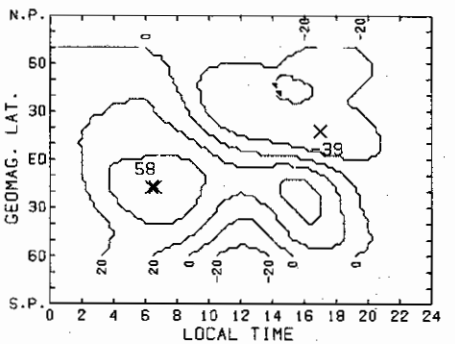

DEC. 31, 1964

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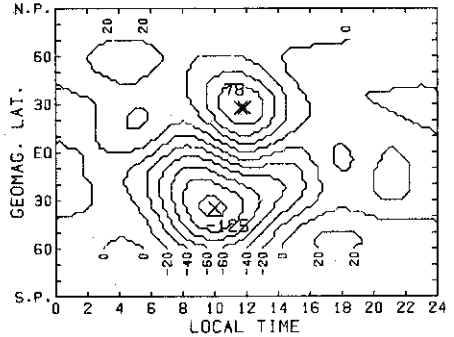

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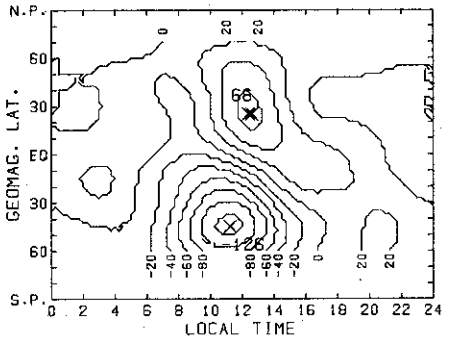

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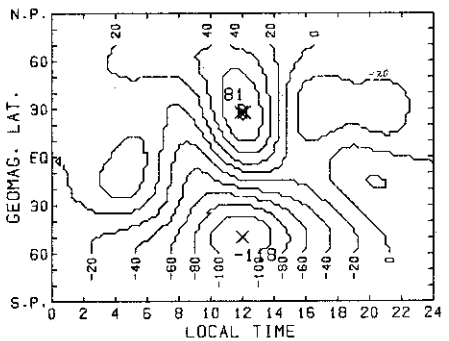

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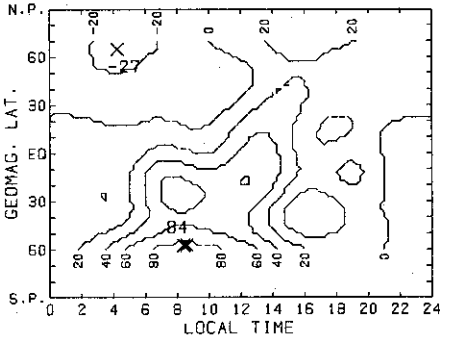

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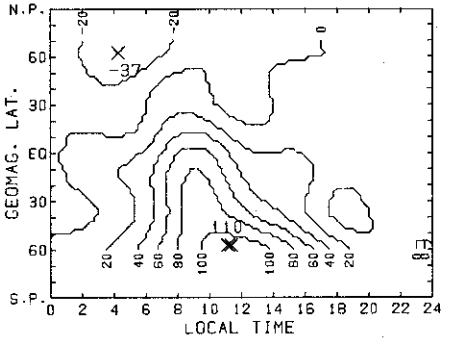

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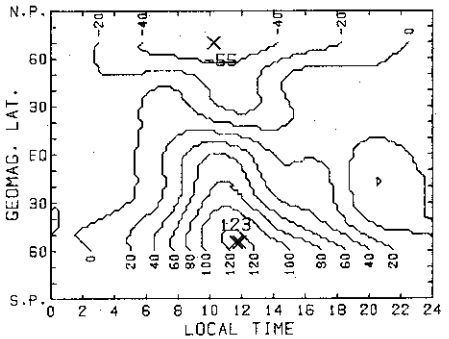

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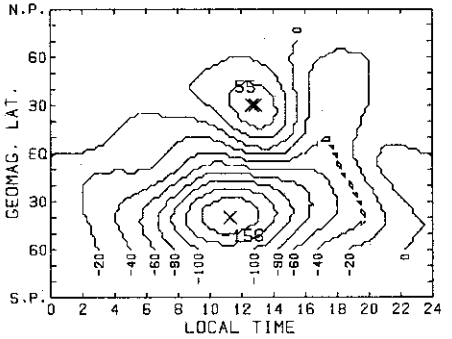

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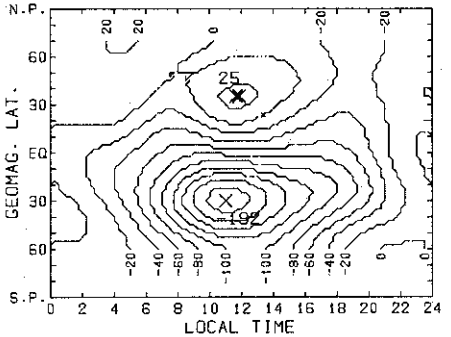

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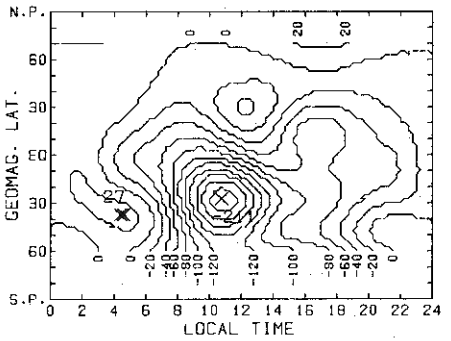

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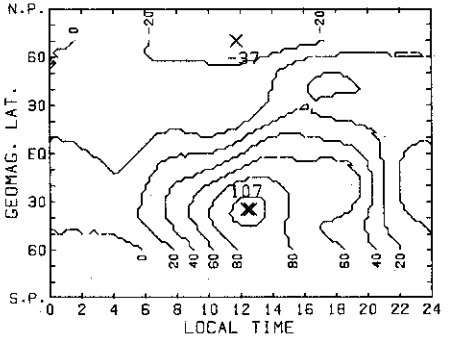

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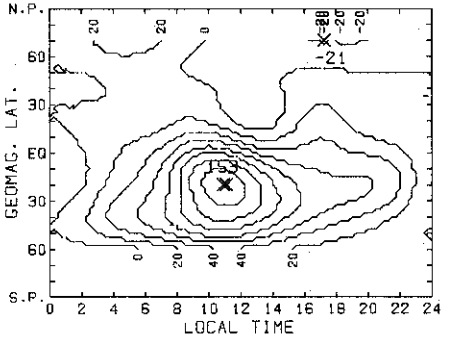

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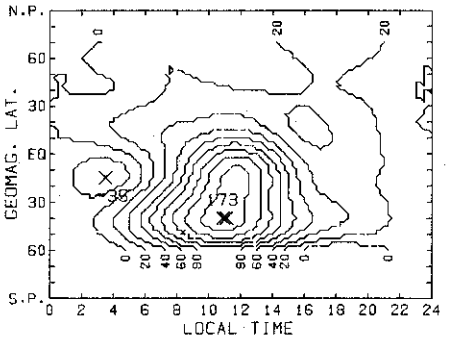
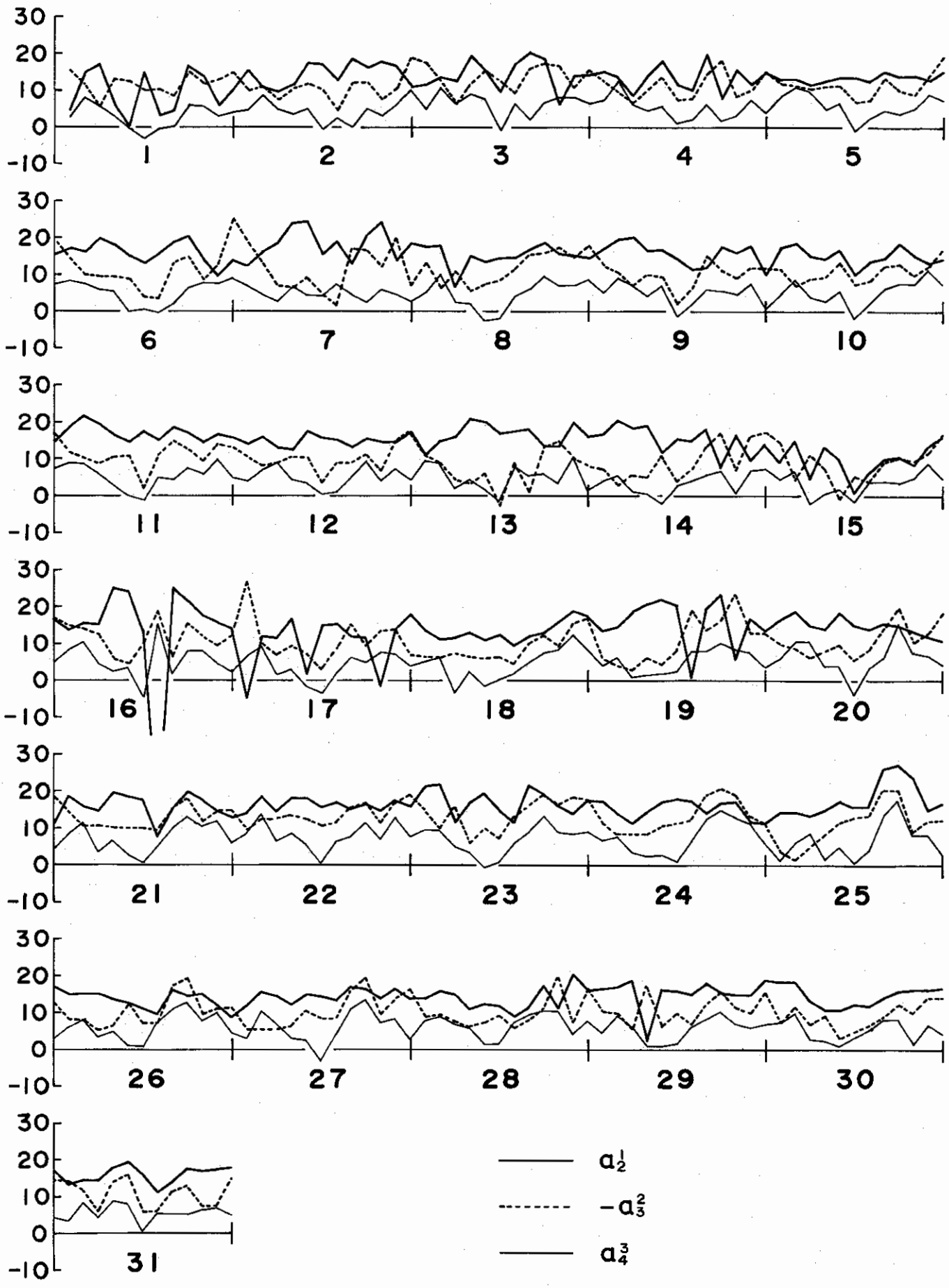


FIGURE 3

Harmonic coefficients of the horizontal (*a*'s and *b*'s) and vertical (**a**'s and **b**'s) field components at every two UT hours in December 1964.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a_2^1
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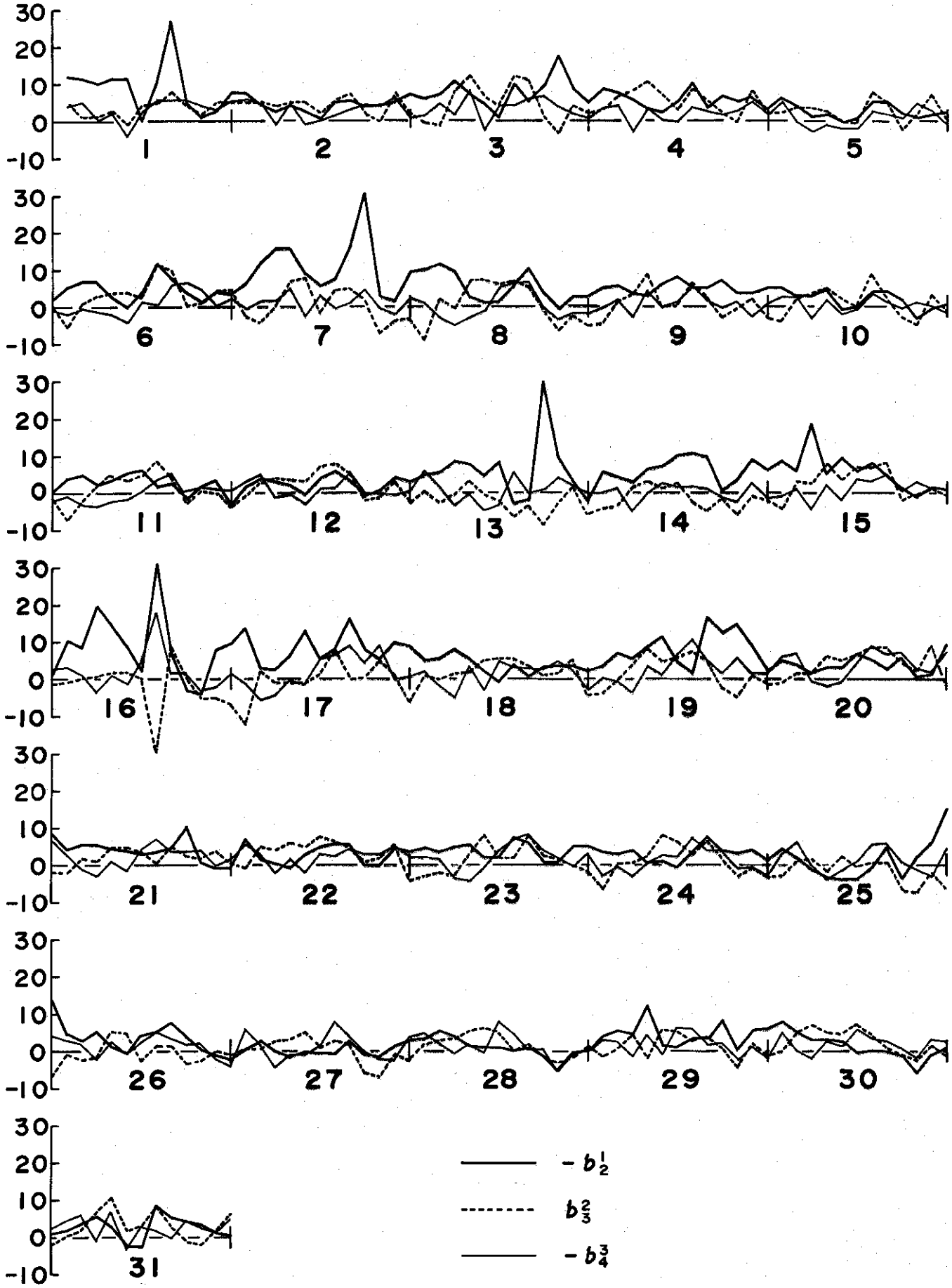
a_4^3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$-b_2^1$
b_3^2
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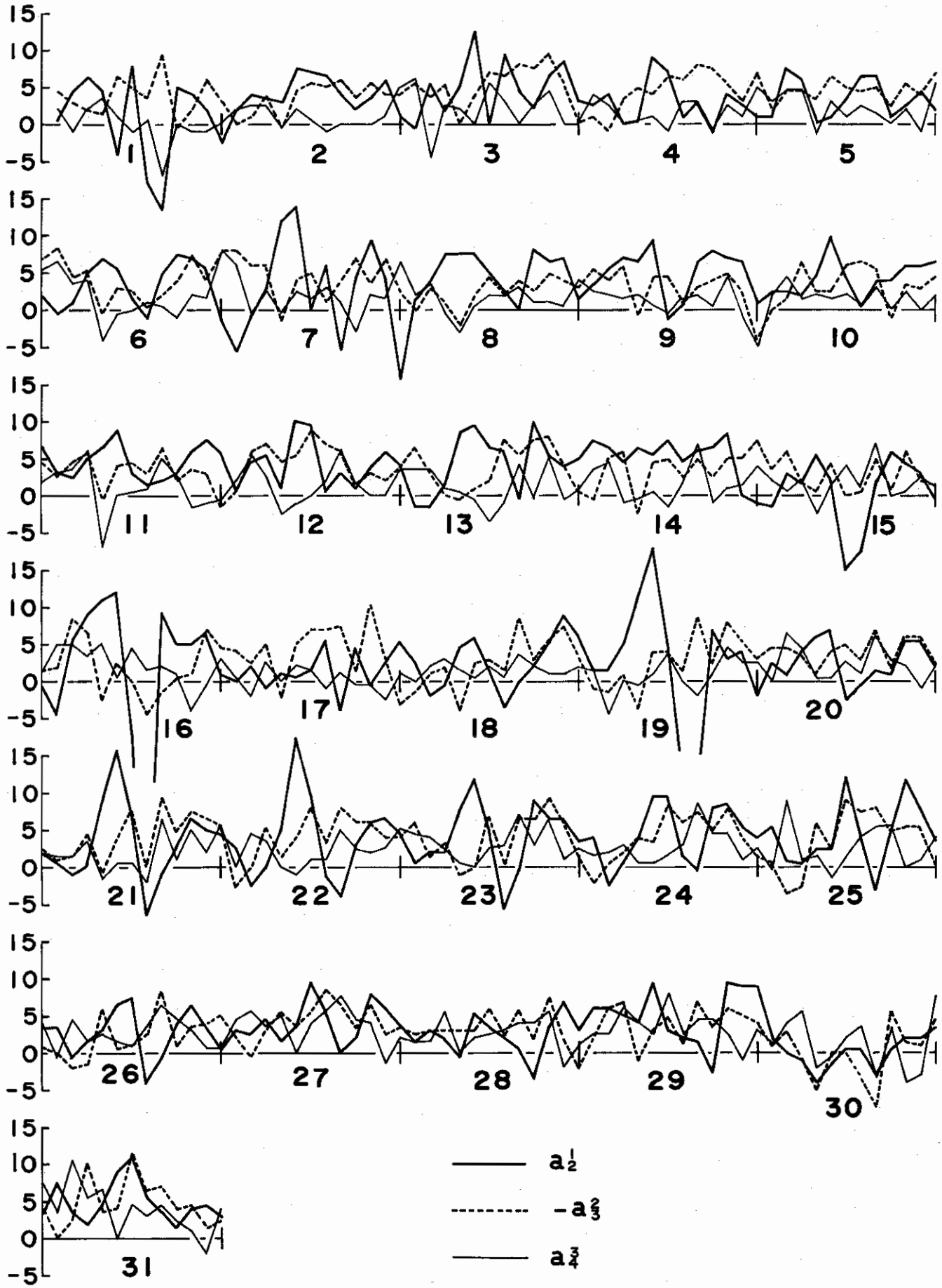
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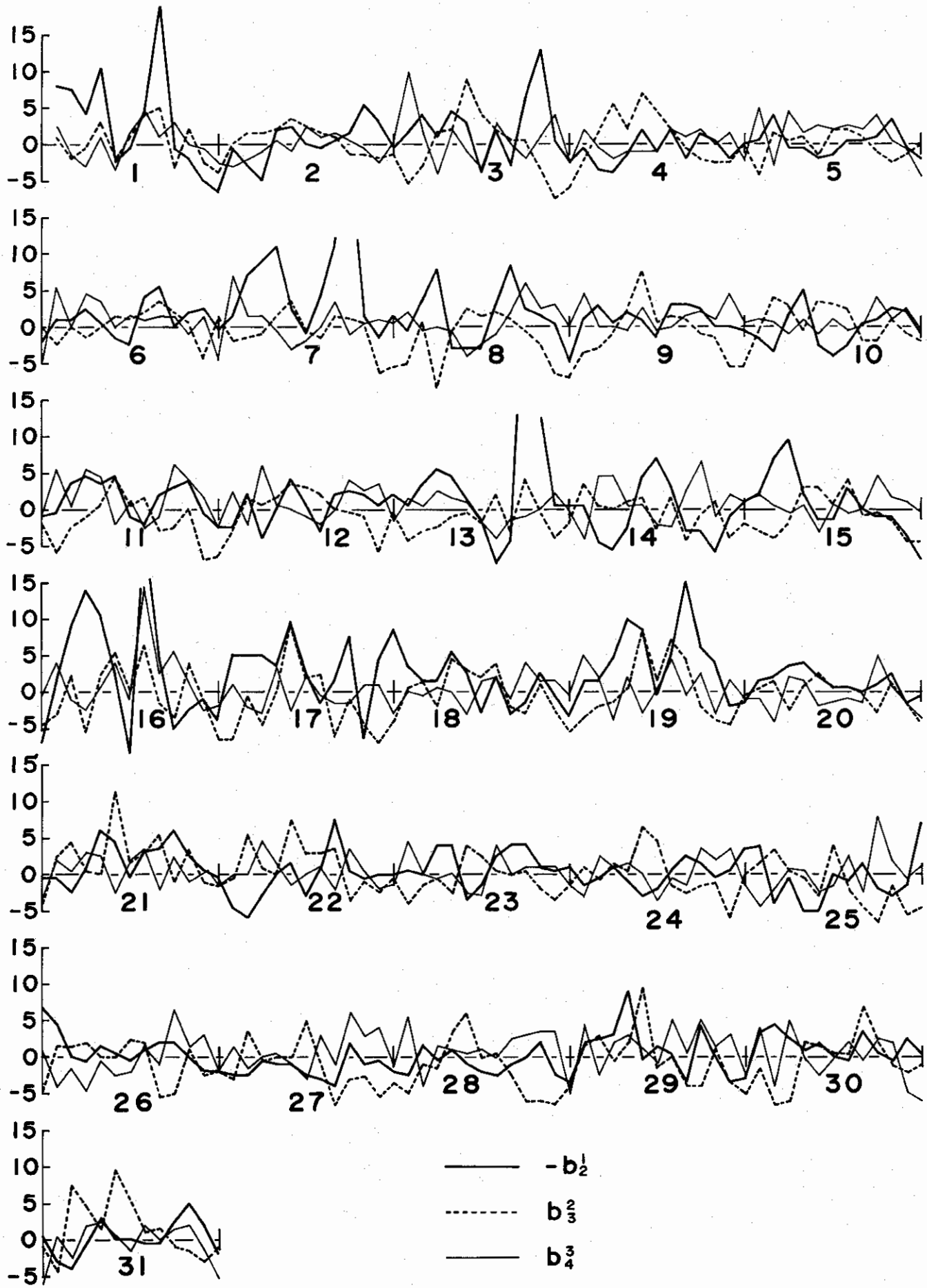
a_4^3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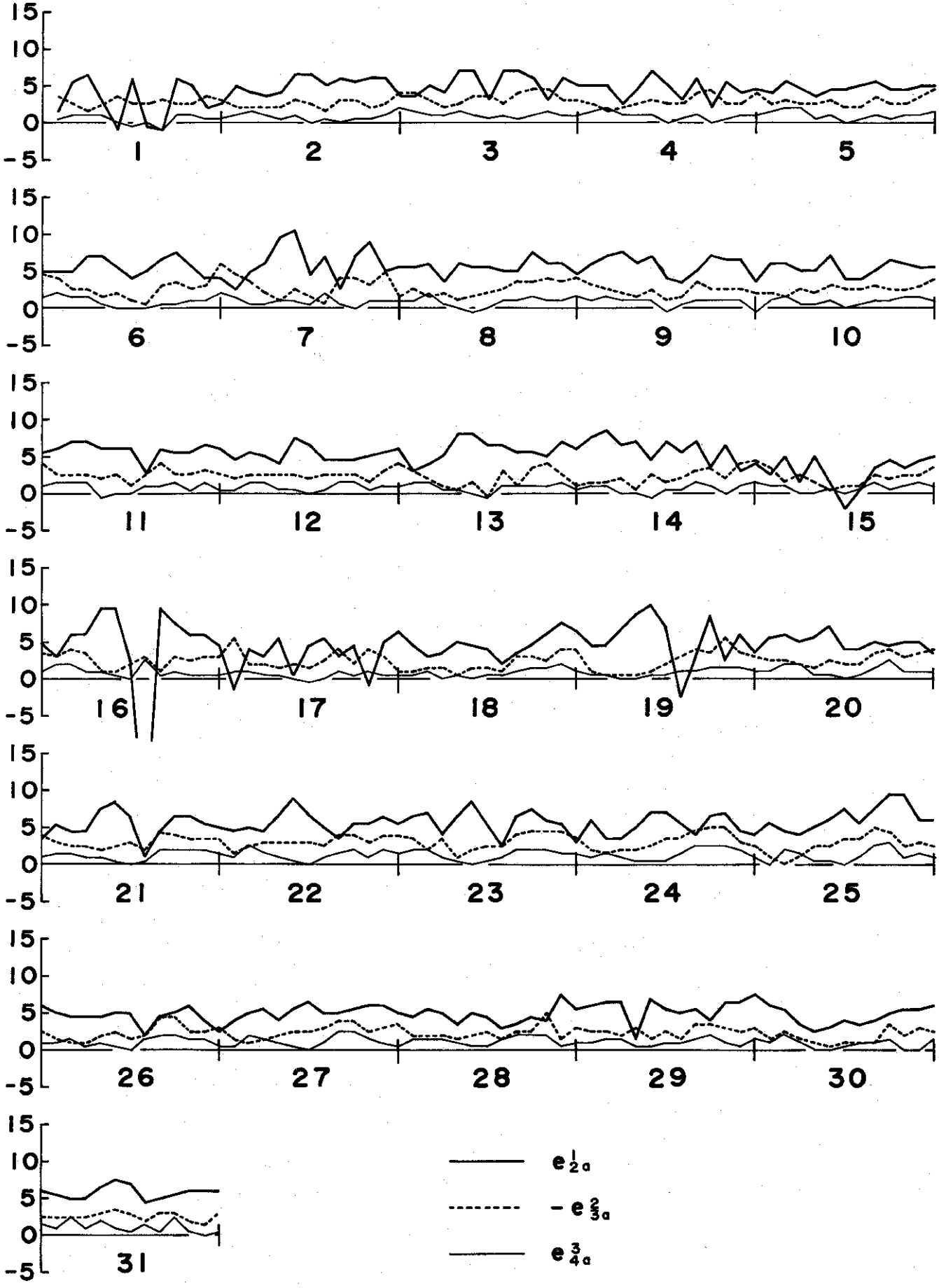
$-b_2^1$
b_3^2
b_4^3

FIGURE 4

Harmonic coefficients of the external (e_a's and e_b's) and internal (i_a's and i_b's) potential components at every two UT hours in December 1964.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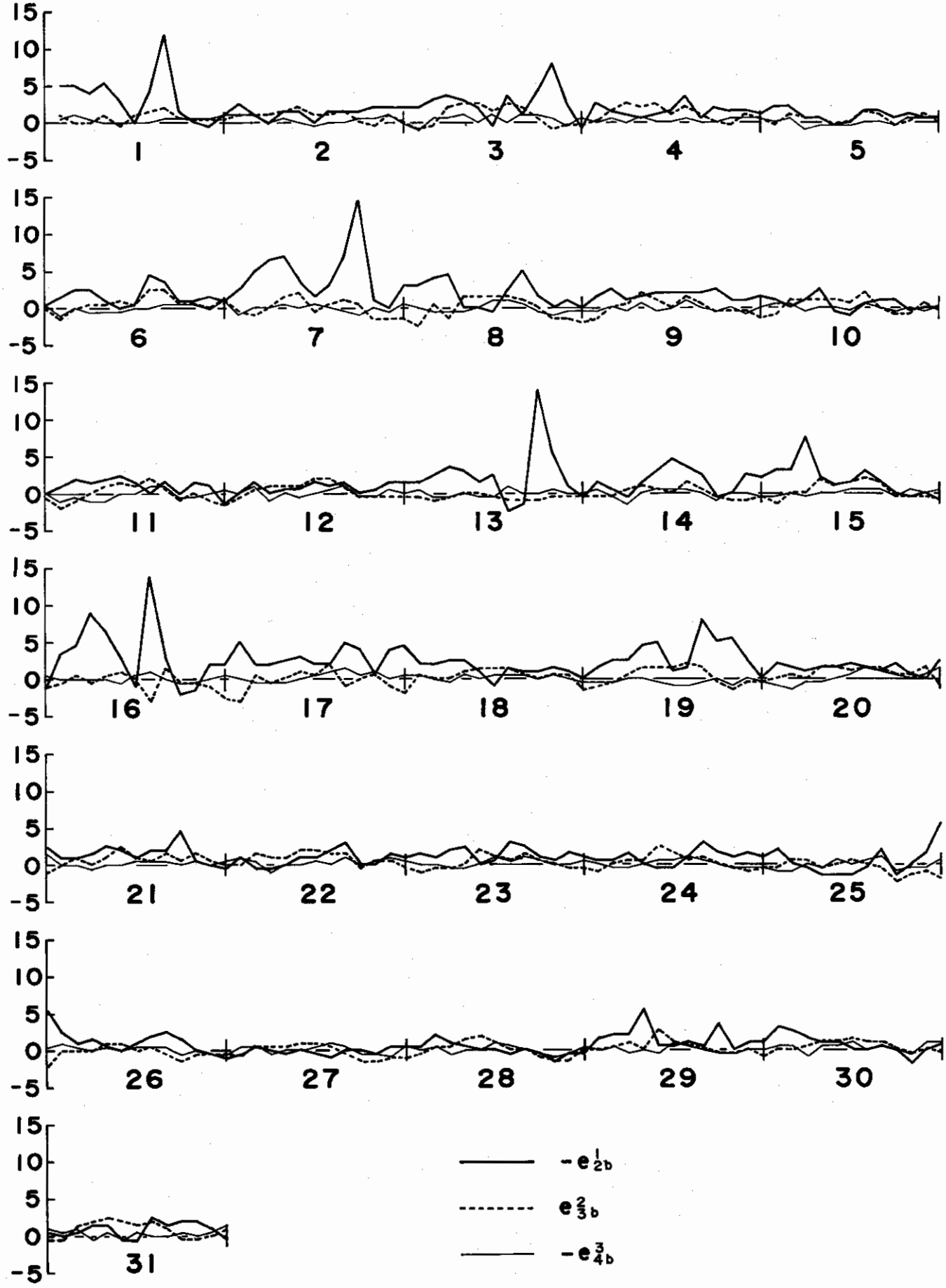
e^{1}_{2a}
$-e^{2}_{3a}$
e^{3}_{4a}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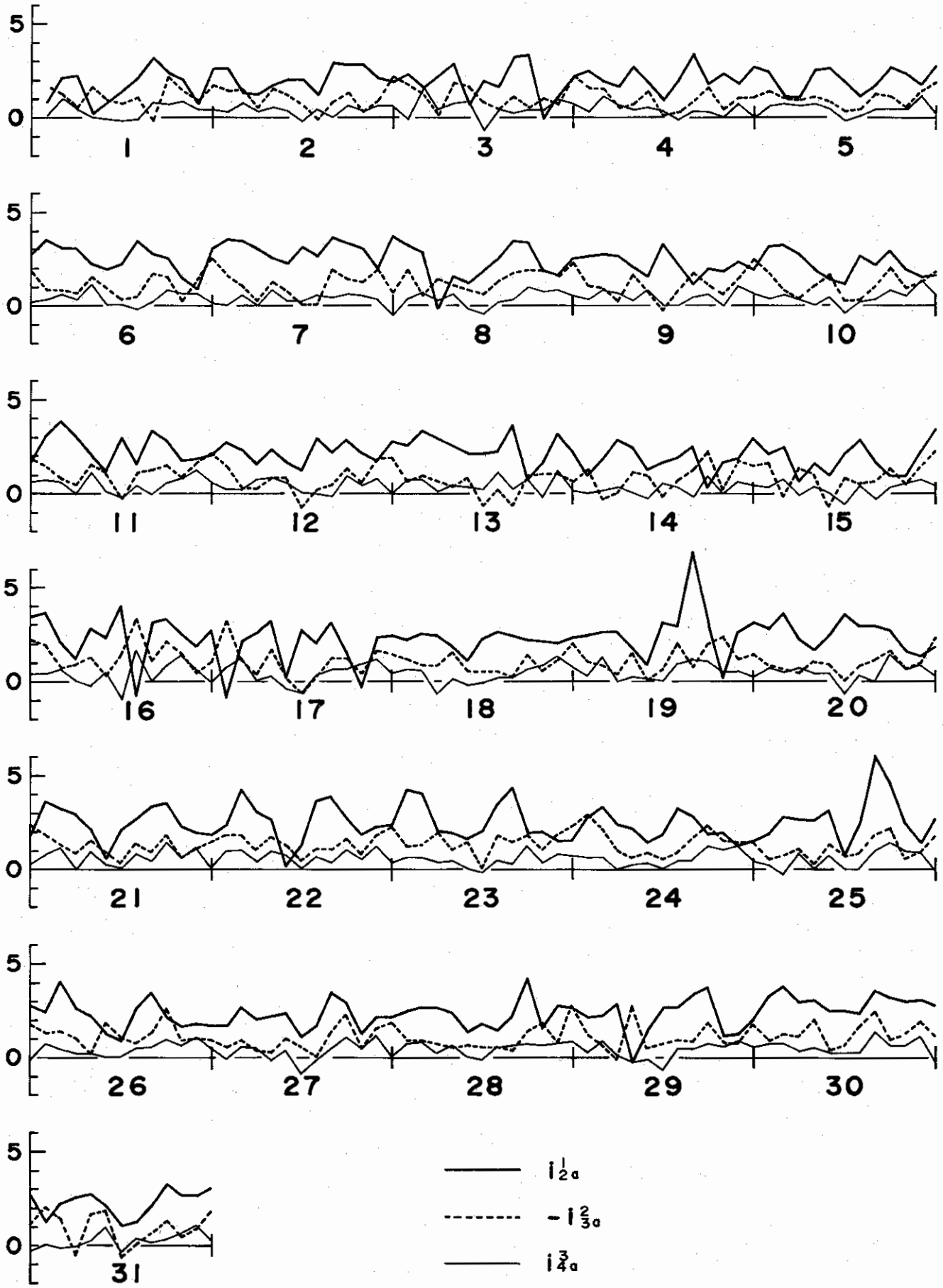
e^{2}_{3b}
$-e^{3}_{4b}$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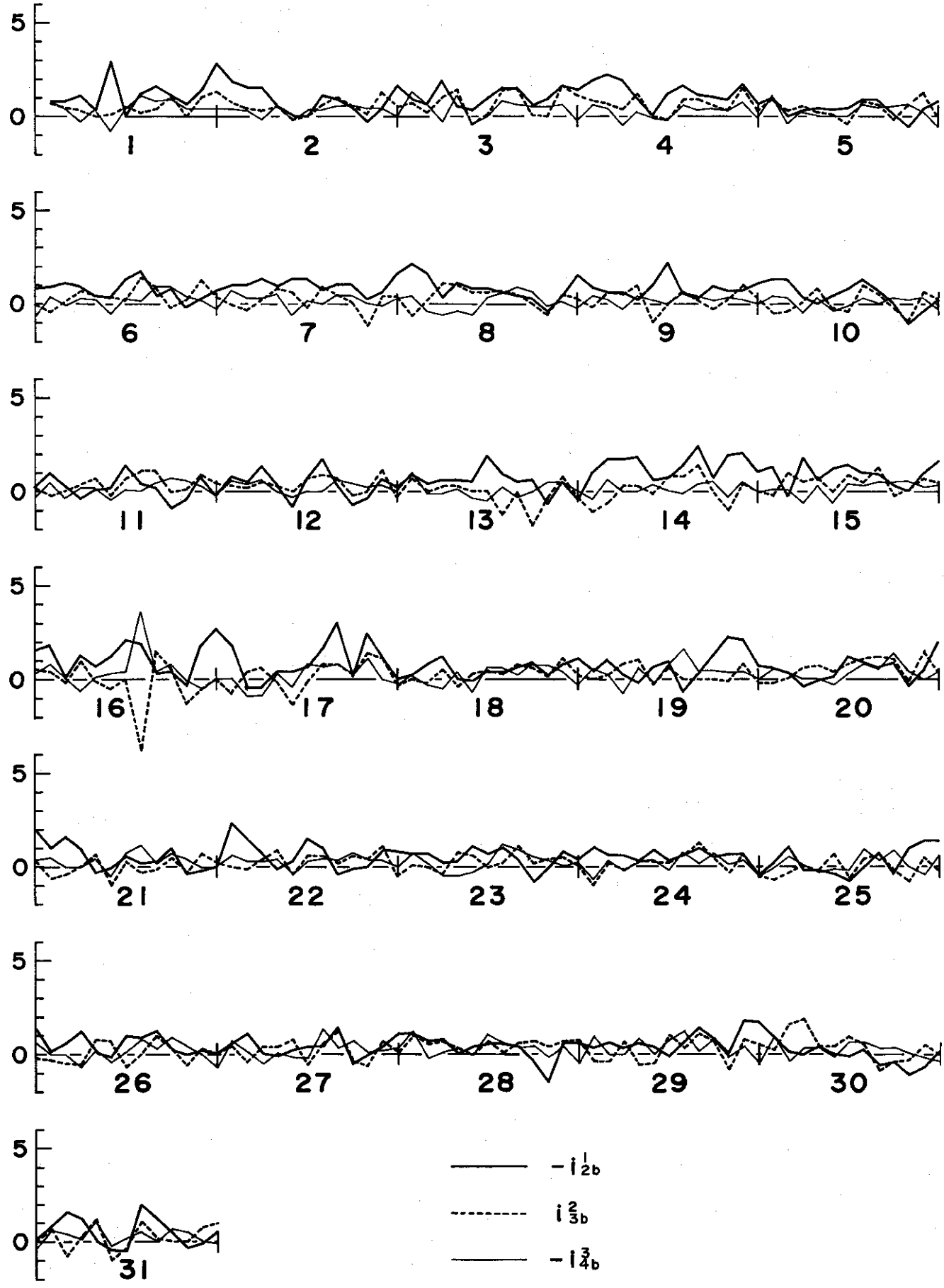
i^{1}_{2a}
$-i^{2}_{3a}$
i^{3}_{4a}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$-i^{1}_{2b}$
i^{2}_{3b}
$-i^{3}_{4b}$

APPENDIX

Successive Mapping of Sq Current Systems

ABSTRACT A new method for analysing the geomagnetic variation fields at a fixed instant is presented and applied to the data in September, 1964. Results are shown by the equivalent current systems obtained at successive two hours on six quiet days. It is found that two basic parts co-exist in the UT variations of the external current systems, regular variations and occasional variations.

1. Introduction

The equivalent current system is often used for studying the global distribution of the geomagnetic variation fields. It is, however, very difficult to draw a current system at a fixed instant with proper separation of the external and internal origin parts, mainly because of non-uniform distribution of magnetic observatories.

We revised the Gaussian method for Sq analysis and developed a new method for the fixed instant analysis, or what is often called instantaneous analysis. In this paper, we describe the outline of the method of analysis and present the results obtained at successive two hours on four and two consecutive days. Details for the method of analysis and the discussions of the results will be given in a separate paper (Suzuki, 1978[*1]).

2. Method of Analysis

Our method is essentially based on the Gaussian method of the spherical harmonic analysis[*2], but the following revisions are made:

(1) The equatorial observatories are excluded from the analysis.

(2) Three magnetic components H, D and Z are used simultaneously.

(3) A weighting factor is applied to each observatory, according to its importance in the spatial relation to other observatories and to the reliability of the data.

(4) Some ghost stations are employed in sparse regions of observatories, the data at which are interpolated from those at other observatories.

Sixty stations used in the present analysis are plotted in Fig. 1 by dots and eight ghost stations by square marks. Curves of the dip equator and $\pm 60^\circ$ dip latitudes are also shown. These stations are chosen between two dip latitudes $\pm 60^\circ$ as they distribute as evenly as possible.

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*1 Suzuki, A., J. atmos. terr. Phys., 1978 (in press).

*2 Gauss, C.F., Allgemeine Theorie des Erdmagnetismus, 1–57, 1839.

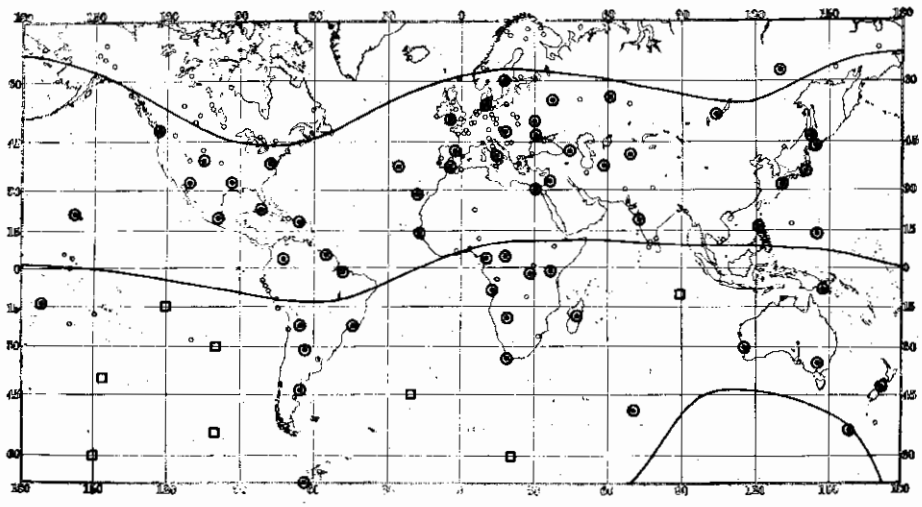

Fig. 1 The distribution of magnetic observatories. The location of the sixty observatories used are shown by dots and the eight ghost stations by square marks. The dip equator and ±60° latitude curves are also shown.

3. Results

The analysis was made for Sep. 12th to 15th and 19th and 20th, 1964, which are the Five Quiet Days and a day included in the Ten Quiet Days of this month. Calculated current systems mapped by computer are given in Figs. 2 to 7. In th figures, the left columns show the external current systems and the right columns the internal ones. Current contours are drawn at every 25×10^3 amps. The plus peak, i.e. the center of the counter-clockwise current vortex, is marked by ⊠ and the minus peak by ⊡. The ordinate and the abscissa are the geomagnetic latitude and the local time, respectively. Thus, the subsolar point always exists near the center of the frame and the earth's surface rounds from the right to the left between the external and the internal current systems.

4. Discussion

The UT variations of the external current systems seem to consist of two parts, regular and occasional variations. The regular variations appear regularly at fixed hours and repeat every day. On the other hand, the occasional variations are occasional phenomena and appear irregularly. When the latter is absent, the current pattern resemble the usual Sq current system, but sometimes the latter is strong enough to overcome the former.

The regular variations are tentatively supposed to be associated with the solid earth. The geomagnetic or topographic configulations may have a significant effect on the distribution of ionospheric parameters such as the conductivity, wind and electric fields, and cause a regular change of current systems. On the contrary, the occasional variations are supposed to be originated from the solar-terrestrial conditions.

The internal currents seem to flow more freely than ever considered, perhaps because of no local enhancement of electrical conductivity in the earth's interior, such as the equatorial and auroral zones in the ionosphere.

Acknowledgements: The author wishes to thank Prof. H. Maeda of Kyoto University and Prof. K. Nagashima of Nagoya University for their instructive guidances and helpful discussions. Calculations were made at the Data Processing Centers of Kyoto University and the Hokkaido University Computing Center. Data were supplied from the World Data Center C2 for Geomagnetism in Kyoto.

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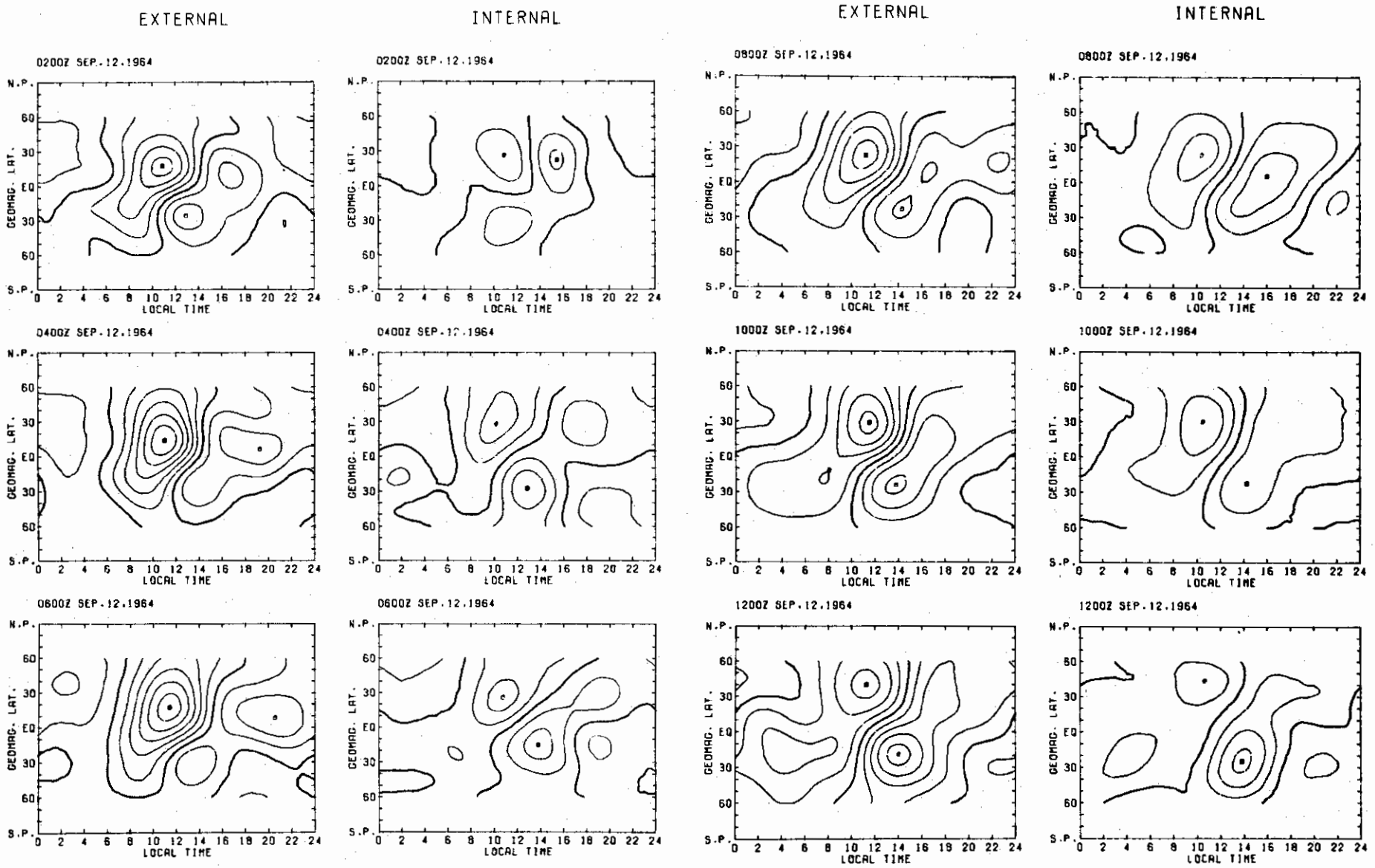
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1200Z SEP.12,1964
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S.P.
EQ
GEOMAG. LAT.
LOCAL TIME
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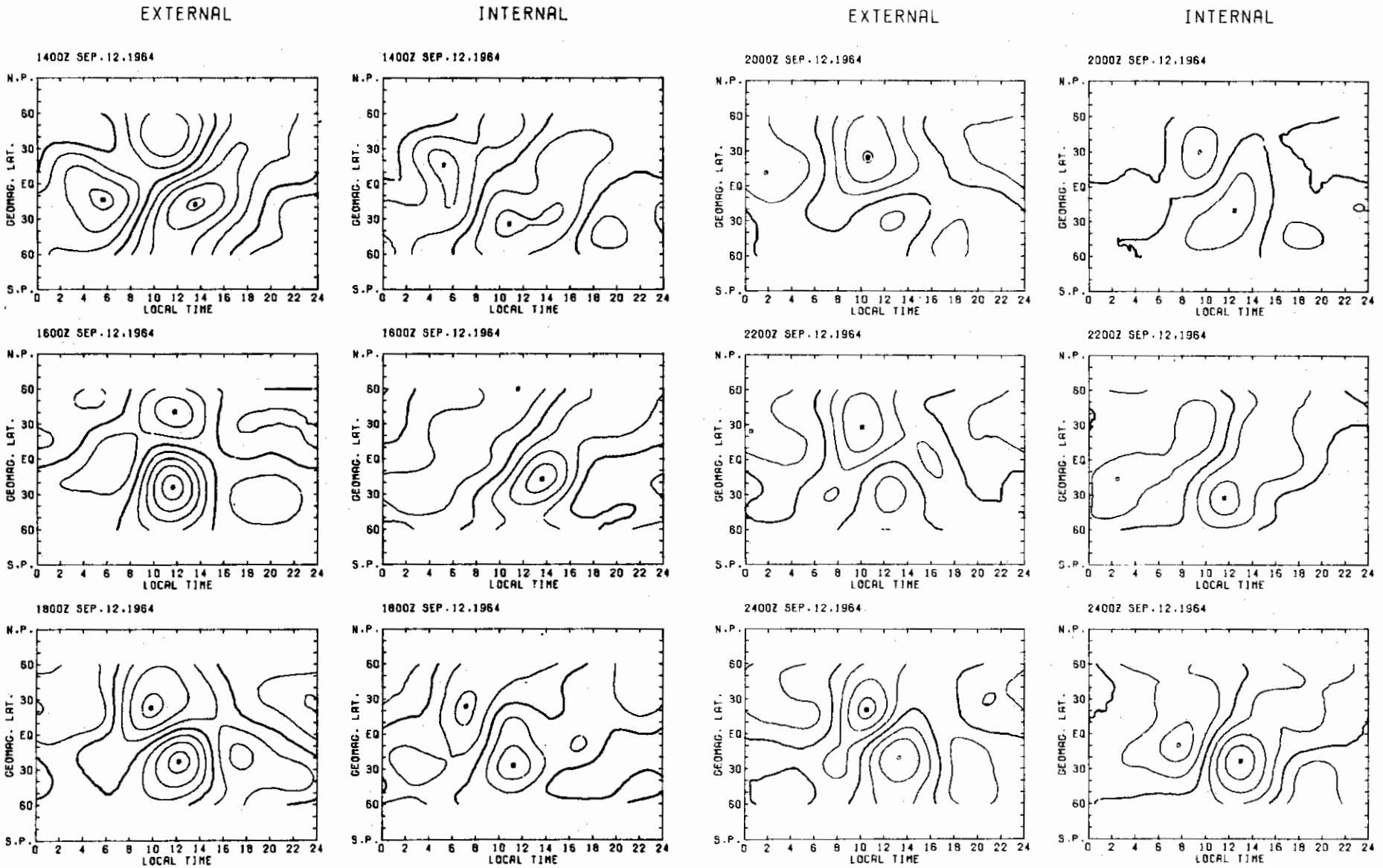
Fig.2(a)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GEOMAG. LAT.
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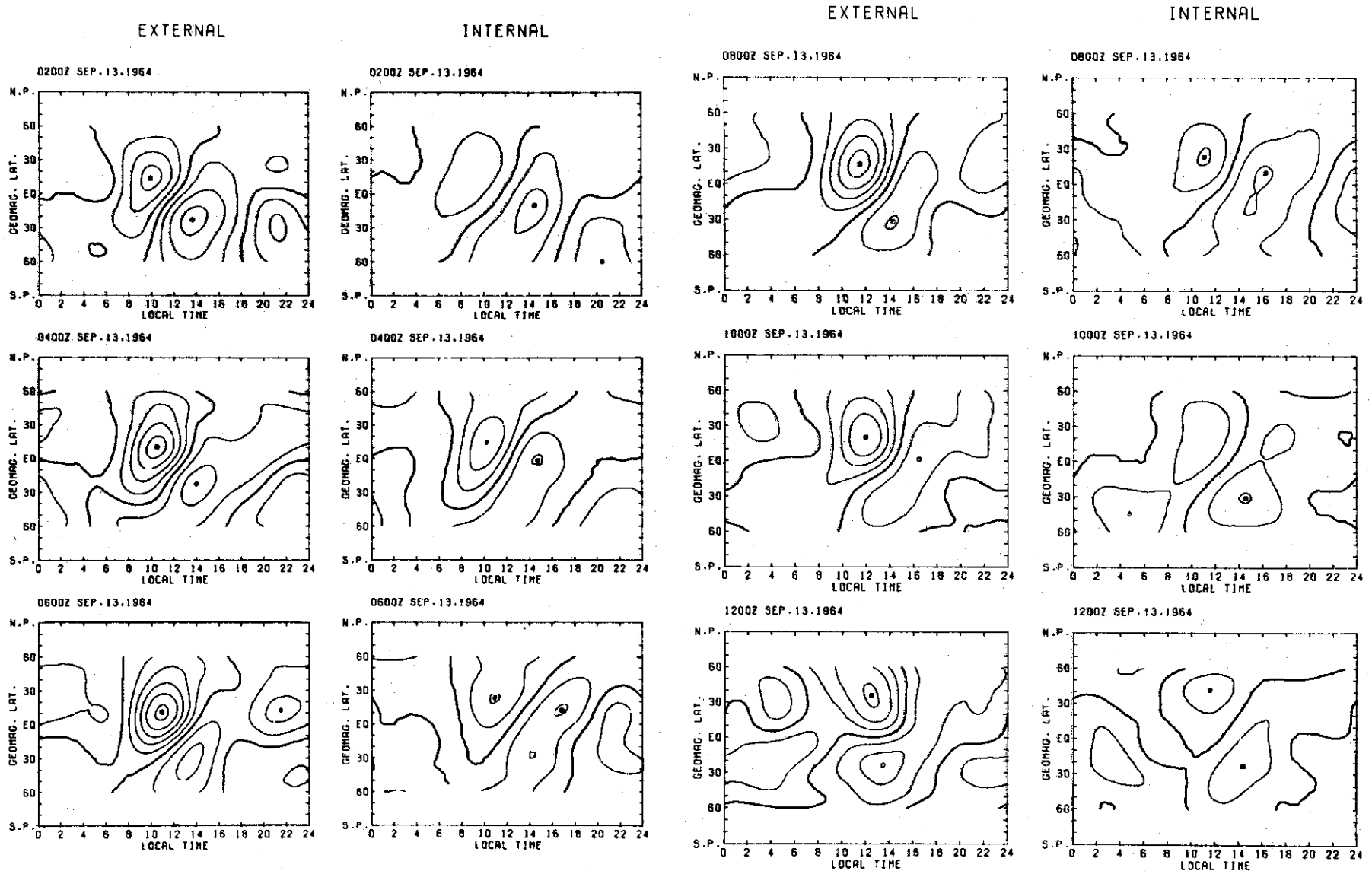
LOCAL TIME

Fig.2(b)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GEOMAG. LAT.
LOCAL TIME
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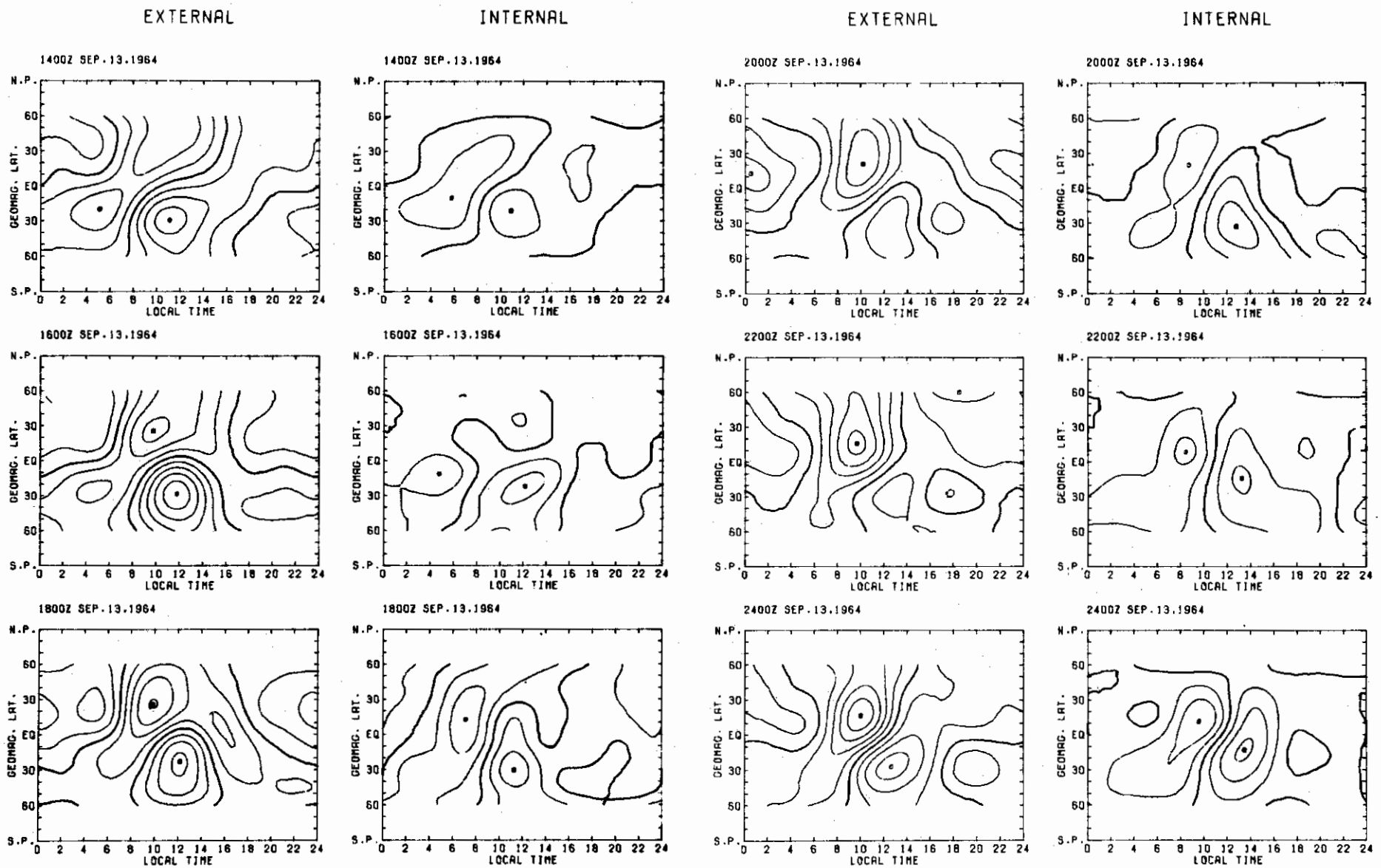
60 30 EQ 30 60

Fig.3(a)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2400Z SEP.13.1964
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EQ
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S.P.
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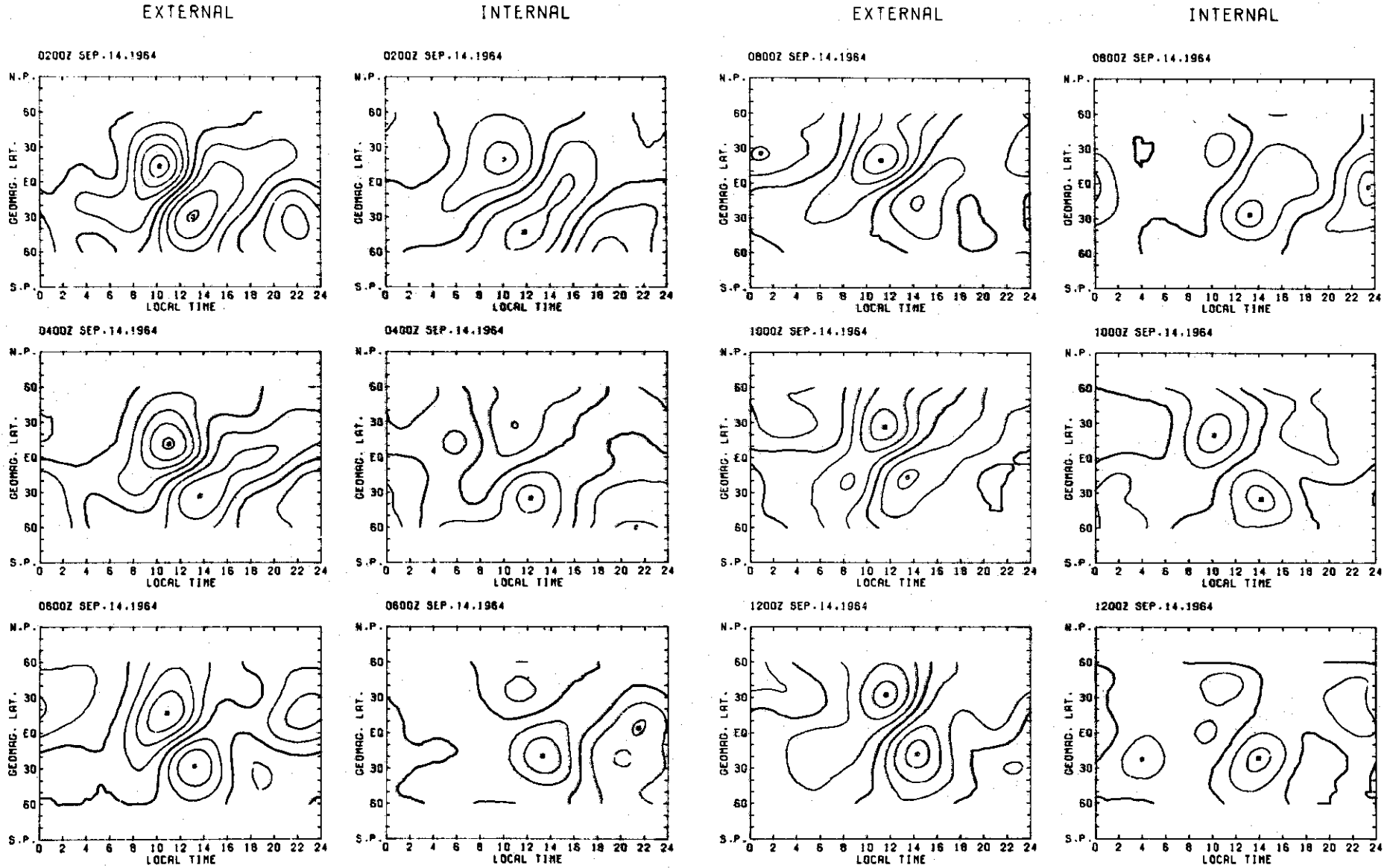
LOCAL TIME

Fig.3(b)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1200Z SEP.14.1964
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S.P.
EQ
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30
GEOMAG. LAT.
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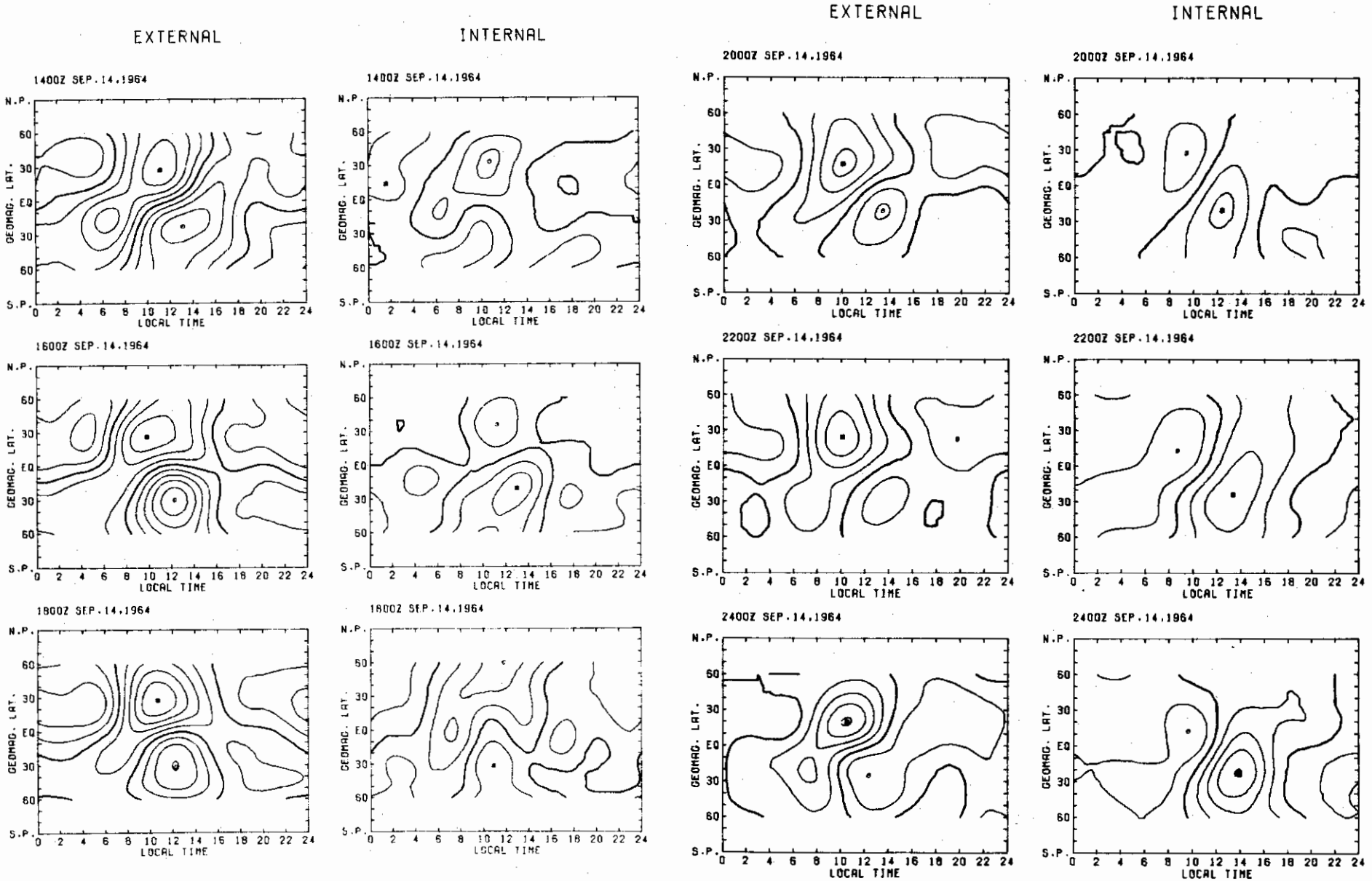
LOCAL TIME

Fig.4(a)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2400Z SEP.14,1964
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S.P.
EQ
GEOMAG. LAT.
LOCAL TIME
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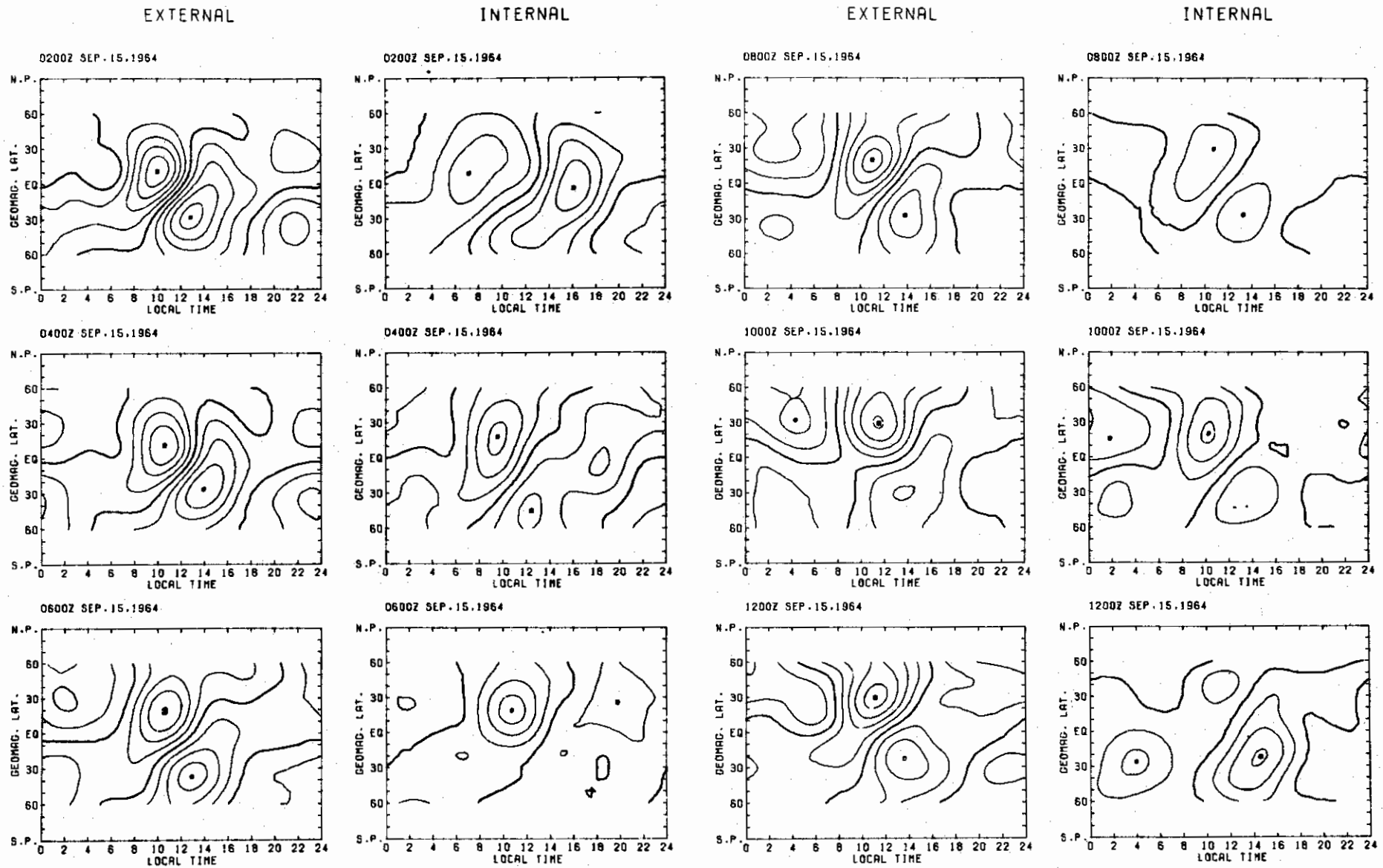
60 30 EQ 30 60

Fig.4(b)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1200Z SEP.15.1964
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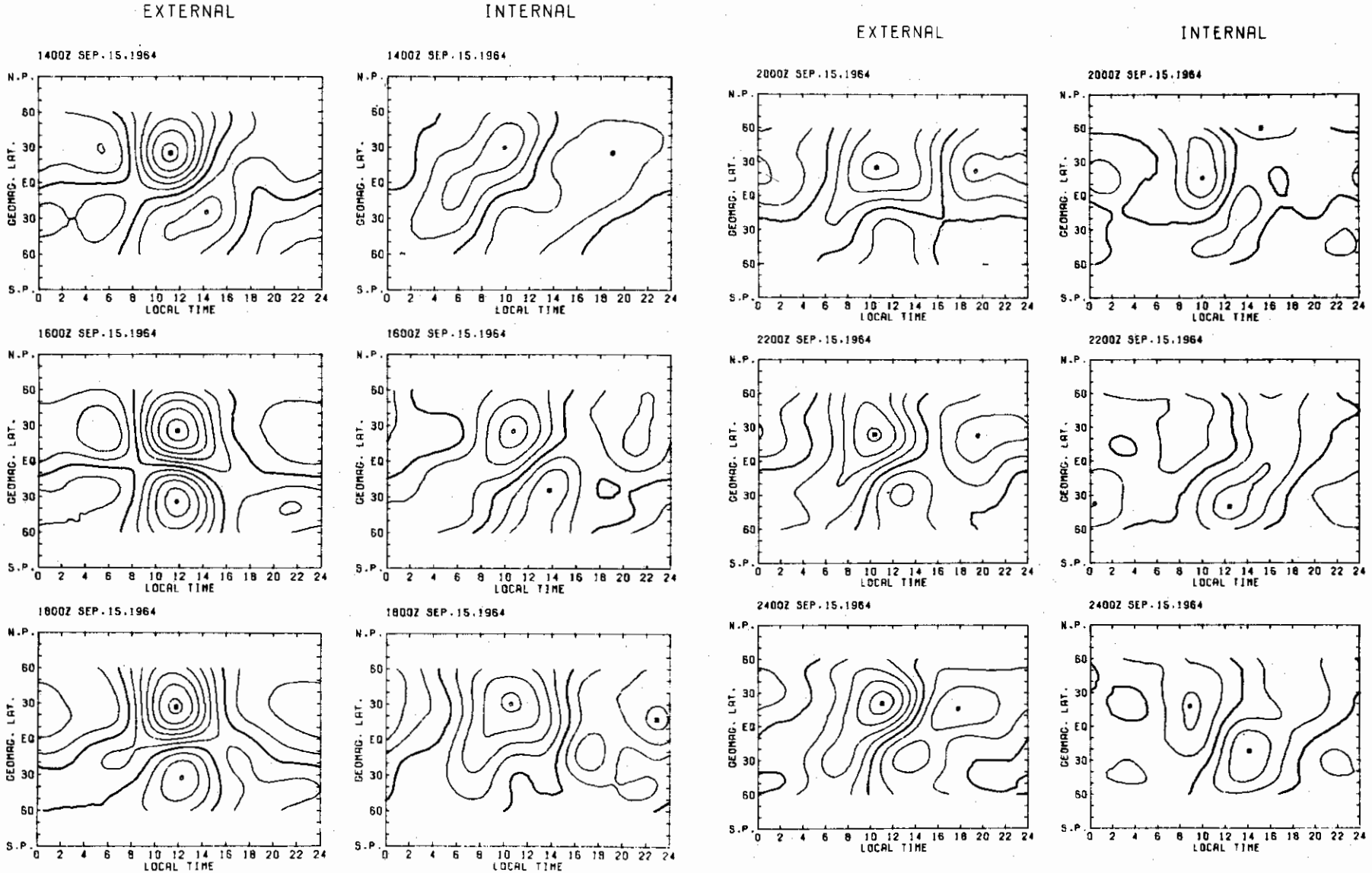
S.P.
EQ
GEOMAG. LAT.
LOCAL TIME
60
30
0 2 4 6 8 10 12 14 16 18 20 22 24

Fig.5(a)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GEOMAG. LAT.
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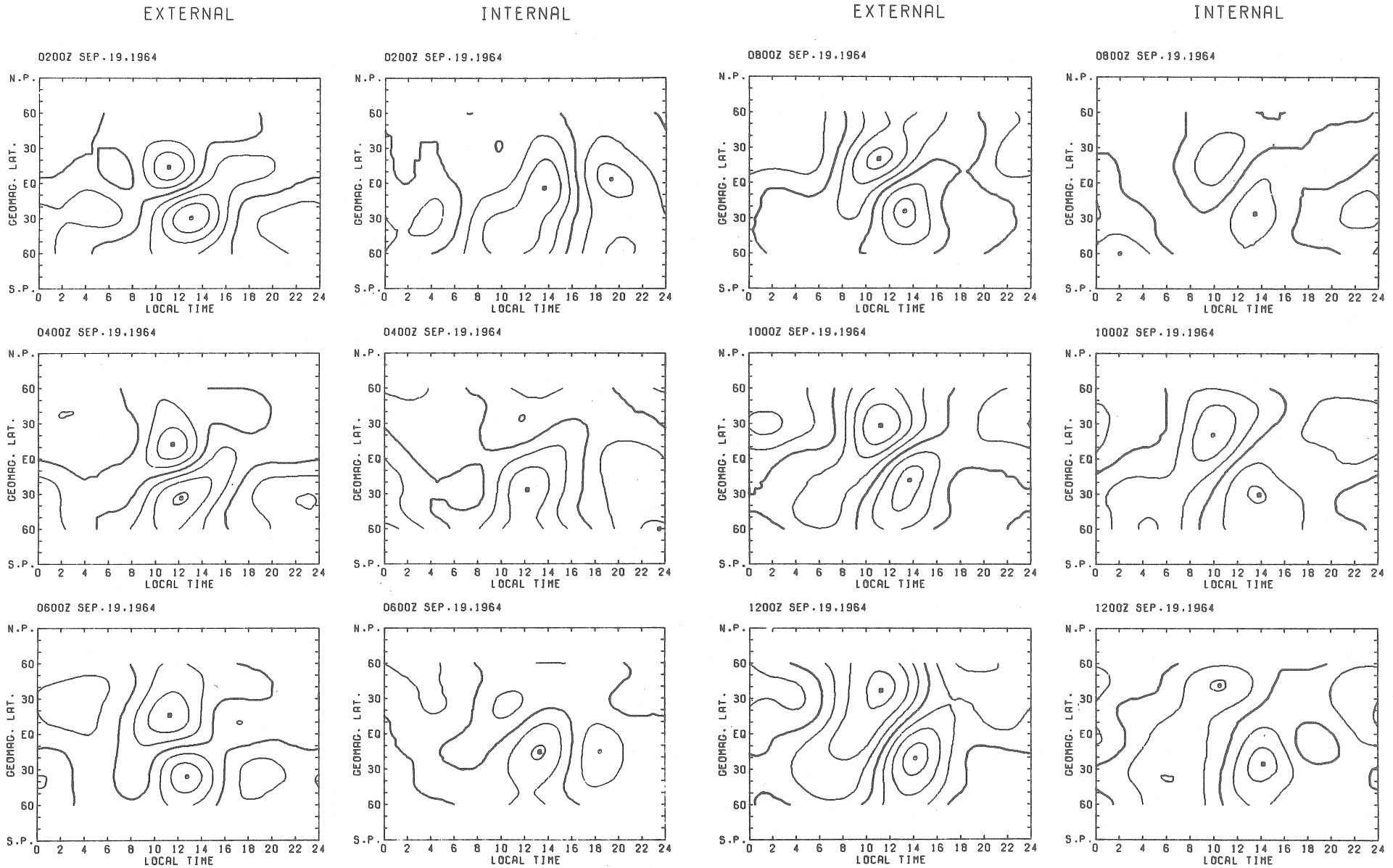
LOCAL TIME

Fig.5(b)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EQ
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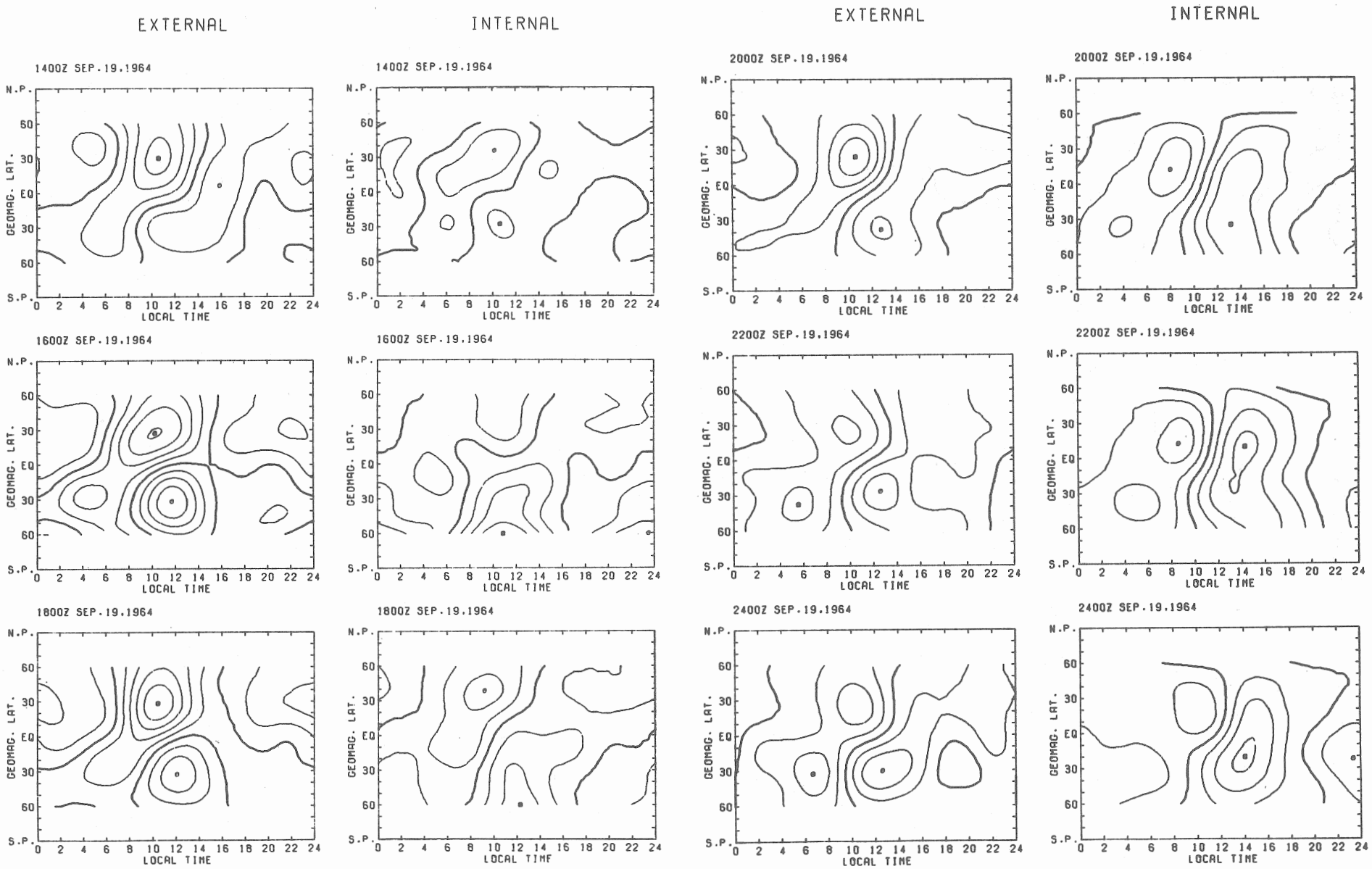
S.P.
GEOMAG. LAT.
0 2 4 6 8 10 12 14 16 18 20 22 24
LOCAL TIME

Fig.6(a)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2400Z SEP.19.1964
N.P.
S.P.
EQ
GEOMAG. LAT.
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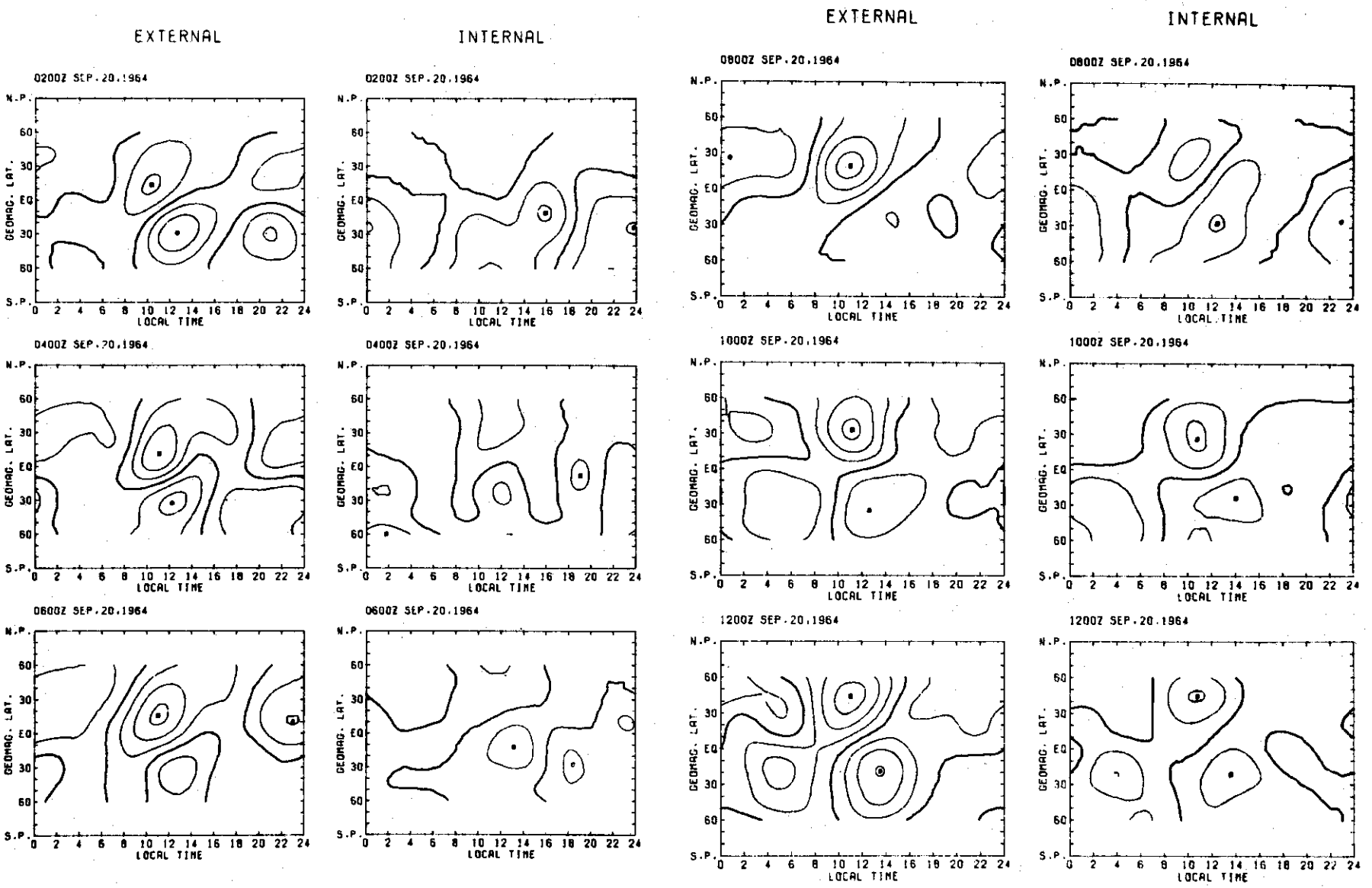
30
0 2 4 6 8 10 12 14 16 18 20 22 24
LOCAL TIME

Fig.6(b)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0600Z SEP.20.1964
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1200Z SEP.20.1964
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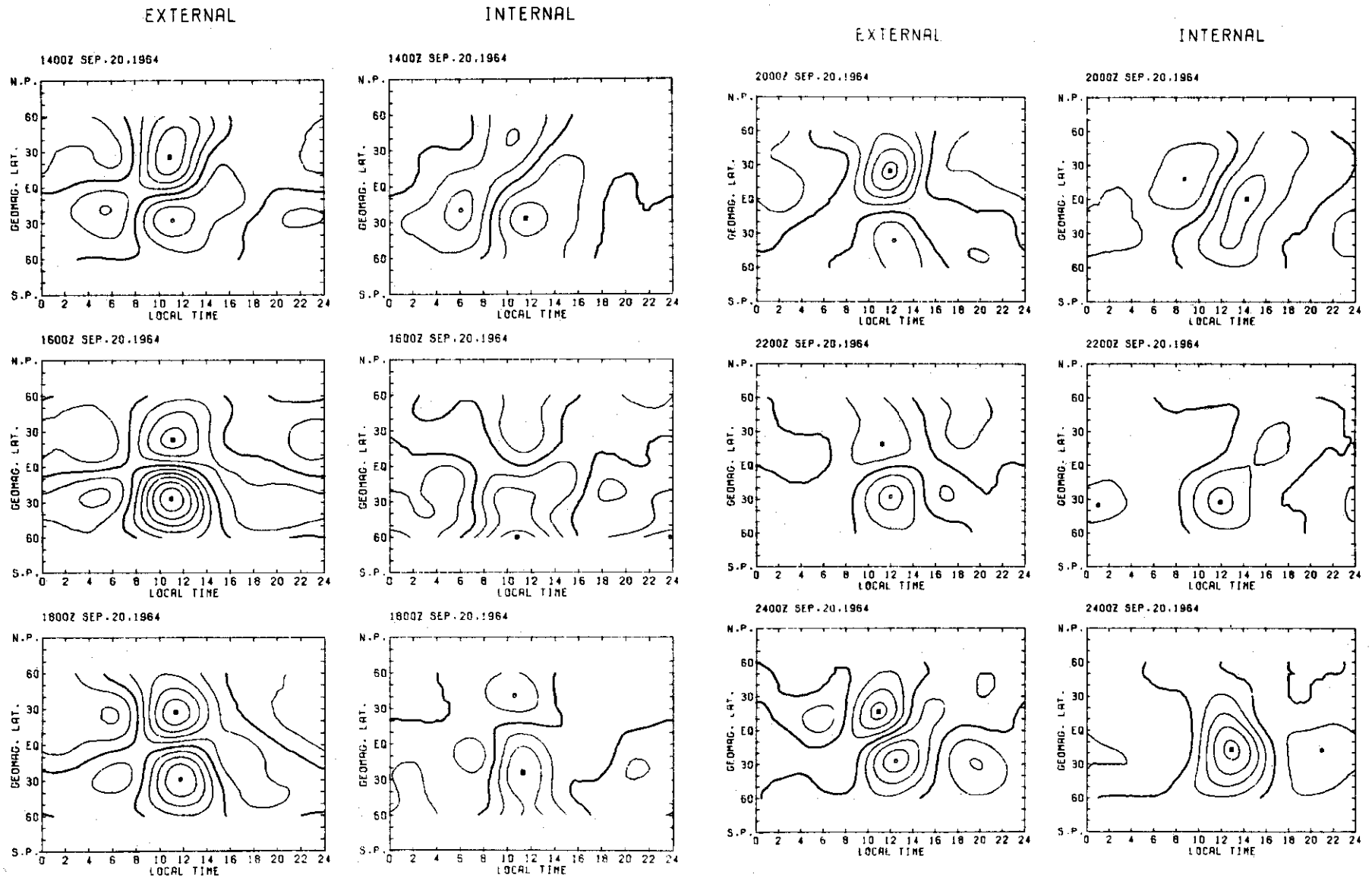
S.P.
EQ
GEOMAG. LAT.
LOCAL TIME
0 2 4 6 8 10 12 14 16 18 20 22 24
60 30 EQ 30 60

Fig.7(a)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1600Z SEP.20,1964
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2200Z SEP.20,1964
1800Z SEP.20,1964
1800Z SEP.20,1964
2400Z SEP.20,1964
2400Z SEP.20,1964
N.P.
S.P.
EQ
GEOMAG. LAT.
LOCAL TIME
0 2 4 6 8 10 12 14 16 18 20 22 24
60 30 EQ 30 60

Fig.7(b)