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FINAL REPORT TO

ADVANCED RESEARCH PROJECTS AGENCY

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"EEG Concomitants of Exposure to

Oscillating Environmental Electric Fields"

May 1, 1967 through September 30, 1970

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INVESTIGATIONS OF COMPARATIVE EFFECT OF LOW-FREQUENCY AND VHF ELECTRIC FIELDS ON LEARNING AND LEARNED BEHAVIOR IN PRIMATES.

1. Effect of low-level, low-frequency fields on fixed interval responding and EEG in monkeys.

   A series of experiments was completed on the effect of low-level, low-frequency electric fields on EEG and behavior in *Macaca nemestrina*. Three monkeys were implanted with cortical and subcortical EEG electrodes and trained to press a panel on a fixed-interval, limited-hold schedule of reinforcement. In this task, the animal was required to "pace" his own responses; no external cues -- lights, bells, etc. -- signaled availability of the reward. After the animals were well trained, they were tested under low-level (2.8 volts p-p), low-frequency (7 and 10 Hz) fields. Voltage was applied to two large metal plates 40 cm apart, which enclosed the monkeys' heads. Field frequencies were selected to fall within the range of usual EEG recording (0-32 Hz). Four-hour daily tests of fields "on" were randomly interspersed with four-hour tests with fields "off." Behavioral results shows that all three monkeys pressed slightly faster in the presence of the 7 Hz fields. The 10 Hz field did not show a reliable effect. Analyses of the EEG data revealed relative peaks in power at the frequency of the field (either 7 Hz or 10 Hz) for certain brain structures. These peaks appeared most reliably in the hippocampus and less consistently in the amygdala and center median. (A further description of this study is included in the resultant publications. See Appendix, "Effect of low-level, low-frequency electric fields on EEG and behavior in *Macaca nemestrina*," Gavalas, Walter, Hamer and Adey. *Brain Research* 18: 1970, 491-501.)

2. Effects of length of exposure to field on EEG: end of run versus beginning of run-peak quotients.

   In the preceding study, all EEG analysis was done on 80 second epochs selected near the end of the four-hour experiment when the animal was making predominantly incorrect responses. A visual inspection of percent power graphs for the EEG of each brain structure suggested that end of the run segments were the most promising segments in which to observe field effects. In addition, 80 second segments were sampled for predominantly correct responses near the end of the run and also for correct and incorrect responses at the beginning of the run. All four sets of data were evaluated for two of the three monkeys. For "responsive" brain structures -- i.e., those that had shown a 7 Hz peak in power for end of the run samples -- it was found that two of five structures had not shown similar peaks at the beginning of the run. As one would expect, non-responsive structures did not show 7 Hz peaks at the beginning of the run either. These results suggest that the effect of the fields may be linked to length of exposure, and suggest that future experiments should explore this variable. These results also lend indirect support to the notion that the change in brain wave activity observed was not artifactual since it was not immediately coincident with the onset of the fields. (A complete set of auto-spectra graphs for beginning and end of the run are included in the Appendix. P values for peak quotients are included.)

3. EEG changes accompanying "slow" and "fast responses.

In the study described earlier, it had been observed that the most marked EEG changes appeared to occur in samples of predominantly incorrect responses taken from near the end of the four-hour exposure. A review of the incorrect responses sampled revealed that they tended to be responses that were too fast rather than those that were too slow. This was expected since the behavioral tests had shown that the monkeys pushed slightly faster when they were exposed to the low-level, 7 Hz field. If the fields were directly affecting responsive brain structures, which in turn resulted in a modified (faster) behavioral response, one would expect to see significant differences in EEG for these brain structures for samples of "fast" and "slow" responses.

New EEG samples were selected from sets of fast and slow responses near the end of the four-hour run. Fast responses were defined as those falling within 5.0 and 5.5 seconds; slow responses were defined as those falling between 6.0 and 6.5 seconds. This meant that both fast and slow responses were rewarded responses and fell approximately on either side of the mean value for the IRT distributions for the field-on and field-off condition, for two (Z and J) of the three monkeys. Analysis of peak quotients in the fields-"on" condition showed that there was a greater peak in power at the frequency of the field for fast than for slow responses for four of five responsive brain structures for the two monkeys.

The third monkey, A, had a much more variable IRT distribution and the fast-slow criteria could not be applied. It is of special interest to note that these differences were quite reliable with the fields on. When the fields were off, only two of the five structures showed significant fast-slow differences.

Although these results need replication and validation, they do suggest that the behavioral effect that had been observed was, indeed, mediated by a change in the electrical activity of the brain (especially the hippocampus) at the frequency of the imposed field.

Auto-spectra graphs and P values for fast versus slow responses are included in Appendix III.

4. Two-hour exposure tests.

A series of experiments was completed in which three monkeys were tested for fixed-interval responding and EEG under low-level, low-frequency fields of two-hours duration. This experiment was performed so that fields-on versus fields-off data could be directly compared within one day's run. It was hoped that this would allow us to use more sophisticated techniques (discriminant analysis) to look for changes in EEG at non-field frequencies. However, inter-response time distributions revealed that a systematic behavioral effect could not be observed under these conditions. Two possible explanations are: (1) the animals' behavior was much more variable for these short runs than for the four-hour run; and (2) it is possible that longer exposure to the field is needed to produce an effect.

Peak quotients, similarly, were less reliable in this study than in the four-hour study and discriminant analysis of the EEG changes did not reveal any systematic differences that were reliable across animals.

IRT graphs and a table of P values for peak quotients are included in the Appendix.

5. Twenty-four hour exposure to low-level, low-frequency fields.

Preliminary studies have been done on 24-hour exposure to 7 Hz fields. IRT results show great variability in the animals' behavioral performance. It had been expected that our fully trained animals could be quickly re-adapted (1 or 2 days) to the experimental conditions. However, this apparently is not the case, and we hope to pursue these studies using well-practiced (2-3 weeks) monkeys as we had in the original four-hour studies. These data point up the need for having extremely stable conditions for the behavioral testing of the animals.

6. Effect of low-level, low-frequency fields on EEG and sleep.

A set of studies was completed on each of three monkeys during their normal sleeping hours. The 7 Hz field was systematically turned on and off during a two-hour interval from midnight until 2:00 A.M. Autospectra contour maps of these data are presented in the Appendix. Monkeys were not awakened by the presence of fields nor was there any gross distortion in their EEG patterns. It is possible that fields of greater intensity or longer exposure would show an effect.

7. Modulated VHF fields.

Special apparatus and a screened room have been developed for these studies. They are described in the following section.

ENGINEERING AND INSTRUMENTATION DEVELOPMENT.

1. Low-frequency electrical fields system.

The initial experimental configuration apparatus for the studies of low-frequencies electrical field consisted of a low-frequency function generator driving a pair of aluminum plates which were located in an isolation room of dimensions of 1 x 1.5 x 2.1 meters. The isolation room is shown in Figure 1* and the monkey's position relative to the plates is shown in Figure 2. The monkey's EEGs were monitored and recorded on both the Grass Polygraph (see Figure 3) and on Ampex 1300 Tape Recorder (see Figure 4). The tape recorder data was then digitized and processed by computer.

2. Development of VHF fields system.

In order to minimize the changes between low-frequency electric fields studies and low-frequency amplitude modulated VHF studies, the experimental conditions remained the same with one exception: the driving source for the parallel plates was modified. The parallel plates were driven by an amplitude modulated VHF transmitter rather than by the low-frequency function generator.

* See Appendix 111 for all Figures referred to in this section

The power source for the VHF field consisted of a low-frequency function generator and a 150 MHz transmitter powered by a 300 VDC power supply and a modulated power supply. Figure 5 shows the block diagram for the apparatus configuration and Figure 6 is a photograph of a console containing the apparatus.

The amplitude modulated VHF field was transmitted by a 50 ohm coaxial cable to the same pair of aluminum plates that were used in the low-frequency electric field studies. The configuration of the plates was such that they were impedance matched to the coaxial cable.

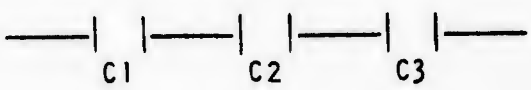
3. <u>Instrumentation problems encountered in VHF fields</u>.

During the VHF field studies, monitoring of the monkey's EEGs became virtually impossible. At frequency of 150 MHz, the displacement current is comparable to the conduction current; consequently, stray VHF fields were coupled to the EEG recording apparatus by means of parasitic capacitances between various conductors in the experimental chamber. Once the stray VHF field was coupled to the EEG recorder, numerous artifacts appeared in the EEG channels. The artifacts corresponded to the modulation frequency of the VHF field. The mechanism by which the artifacts appeared was the rectification of the modulated signal by the EEG amplifier.

Since the only possible way of obtaining non-artifact EEG recording was to completely eliminate stray VHF fields from the EEG recording apparatus, a decision was made to construct an RF screen room.

4. <u>Development of an RF screen room</u>.

At the present time, a double bronze screened enclosure of dimensions 8 ft. wide, 8 ft. long, and 6 ft. high has been constructed. The dimensions of the screen room were carefully selected in order to minimize the coupling capacitance between the parallel plates and the screen room walls. The walls had to be sufficiently far away from the plates in order to avoid standing electric wave patterns caused by a mismatched load at the termination of the transmission lines. The load, as seen by the transmission line, is represented below:



where

C1 is the capacitance between one plate and the adjacent screen room wall.

C2 is the capacitance between the parallel plates.

C3 is the capacitance between the second plate and its adjacent screen room wall.

If the walls are too close to the plates, C1 and C3 are nearly equal to C2 and it is evident that the distribution of the VHF field is no longer confined between the parallel plates. This type of configuration would only lead to enormous tasks in defining the field to which the monkey is exposed.

The only remaining task that has to be completed before we can progress with the VHF field studies in the screen room is the routing of the camera cables, 120 VAC cables and EEG monitoring cables through filtered connection into the screen room.

Preliminary measurements were made to demonstrate the effectiveness of the screen room. A battery powered 25 watt transmitter was placed in the screen room with a whip antenna connected to it. The measured field attenuation outside the shield room was 80 db.

5. <u>Difficulties in measuring RF power that the monkey is exposed to between the plates.</u>

Since the primary interest lies in the field effects on the animal, it is important to relate the average power transmitted between the plates without the monkey and to obtain a reasonably good measurement of the amount of RF power to which the monkey is exposed. The difficulties in obtaining a reliable value are discussed below:

The variation in voltage along the plates is a function of time and linear distance from the field source (transmitter) and is expressed by

$$V=V_o e^{jwt+jw\sqrt{\mu\epsilon}\ x}$$

$j = \sqrt{-1}$

$w = 2\pi f$

μ = permeability

ϵ = permittivity

x = linear distance

V_o = peak voltage supplied by transmitter

The electric field across the plates is perpendicular to the plate's surface and given by

$$\vec{E}=\frac{V}{d} \text{ volts/meter}$$

d = distance between the plates.

The electric field $\vec{E}$ between the plates induces equal and apposite charge densities on the two plates; the currents flowing in the plates produce a uniform magnetic field $\vec{H}$. The unit current density $\vec{J}$ in this instance is numerically equal to $\vec{H}$. Thus the total current flowing in the plates is:

$$I=\vec{H}A=\frac{A\vec{E}_o e^{jwt+jw\sqrt{\mu\epsilon}\ x}}{\eta}$$

A = cross-sectional area of the plates

η = intrinsic impedance $\sqrt{\mu/\epsilon}$

The average power can be computed by the use of transmission line equations:

$$V=V_o e^{\pm jBx}$$

$$I=\left(\frac{V_o}{Z_o}\right) e^{\pm jBx}$$

$$Z_o=\sqrt{L/C}$$

$$B=\sqrt{LC}$$

For parallel plates, the capacitance and inductance are given by:

$$C=\frac{\varepsilon A}{d}$$

$$L=\frac{\mu d}{A}$$

$$Z_o=\sqrt{\left(\frac{\mu d}{A}\right)\left(\frac{d}{\epsilon A}\right)} = \frac{\eta d}{A}$$

$$B=\sqrt{\left(\frac{\mu d}{A}\right)\left(\frac{d}{\epsilon A}\right)} = k$$

From the voltage current relationship, the average power transmitted by a single positive traveling is:

$$W_T= 1/2\ Re(VI^*)=\frac{V_o^2}{2Z_o}=\frac{E_o^2 Ad}{2\eta}$$

However, W_T is for an ideal situation where there are no losses in the plates and no losses between the plates.

By placing a monkey between the plates, numerous complications arise in determining W_T. In the dielectric region between the plates, the permittivity ϵ has to be replaced by a complex term $(\epsilon'-je'')$ and the wave impedance may be written in the form

$$Z_t= \sqrt{j w\mu/\sigma +jw\ (\epsilon'-je'')}$$

Because of this complexity, special research[1] is now being conducted in determining the possible values for the complex permittivity. Even with

[1] J. Bigu del Bianco, "An Introduction to the Effects of Electromagnetic Radiation on Living Matter with Special Reference to Microwaves," September, 1969.

these known values, the problem of solving W_T is complex because of the inability to define the proper $\vec{E}$.

The other alternative is to measure the RF power. The measurement is probably just as complex as the calculation since it would be difficult to establish the electric field pattern incident to the monkey. The electric field can be absorbed and reflected, and the power measurement has no means of separating the absorbed and reflected power.

EFFECTS OF LOW-FREQUENCY, LOW-LEVEL ELECTROMAGNETIC FIELDS ON THE VISUAL EVOKED RESPONSE IN THE CAT.

Past experimentation has shown that it is possible to manipulate timing behavior by the presence of low-frequency, low-level electromagnetic fields. Studies have measured reaction time (1,2) as well as subjective time estimates of humans (3) and of monkeys (4) in the presence and absence of these fields. The experiment reported below was designed to measure the effects that electromagnetic fields have on the latencies and wave form of various components of the visually evoked response. This response is quite stereotyped, and its measurement at various points along the visual pathway could provide a sensitive measure for determining the effect of an imposed external field on various cellular components of the nervous system.

Three cats were acutely prepared, one under nembutal anesthesia and the remaining two under flaxidel and a local anesthetic. The flaxidelized animals were artificially respirated. After craniotomy, coaxial electrodes were placed at various points in the visual system (optic chiasma, optic tract, lateral geniculate nucleus, and/or visual cortex). The visually evoked response was amplified and fed into a Computer of Averaged Transients (TMC). In all cases, 50 evoked responses constituted one averaged response that was put on an X-Y plotter. The stimulus was a flash of light presented by a Grass Photo Stimulator at rates varying from 1 sec to 1/3 sec. Each flash was triggered randomly by the experimenter and was, therefore, presented asynchronously with respect to any field imposed on the animal. The room lights were extinguished, and the only ambient light was that emanating from the equipment.

The electromagnetic fields were presented via a Hewlett Packard Low-Frequency Function Generator (#202A) and an isolation transformer. The fields were applied via 4 stainless steel screws that were attached directly to the skull of the animal. Two of the screws, placed in an anterior and posterior position over one hemisphere and shorted together, were connected to one side of the transformer's secondary winding. The second set of screws were placed in a similar configuration over the opposite hemisphere and connected to the other side of the winding. Fields of various frequencies (4, 6, 8, 12 and 24 Hz) and various intensities (10 μv, 1 to 100 mv pp.) were used. Periods of field presentation varied from several minutes to one hour and were intermingled with periods when no field was present. During these times, flashes of light were delivered to the animal and the evoked responses were averaged.

Measurement of the EEG from various electrodes in the animal manifested normal patterns. When the fields were applied to the screws in the skull, there were no gross indications from viewing the records that a change had occurred. This is the case for fields of less than 5 mv (pp.). Upon increasing the strength of the fields up to 100 mv (pp.), the frequency of the field became apparent and the EEG and evoked response were superimposed upon it (Figure 1).* In some instances, the presence of the field in the record completely obliterated the brain waves (Figure 2). As can be seen from Figure 2, the EEG from electrode in the right visual cortex is completely obscured, whereas that of the left visual cortex shows only small, if any, frequency components of the field. In spite of the obscuring effect of the field on the right visual cortex, an average evoked response can still be obtained for the stimuli are presented randomly with respect to the phase angle of the field (Figure 2).

In all three animals, there was no change in either the wave form or the latencies of the various components of the evoked response that could be attributed to the presence of any of the fields. Figures 3 and 4 present the entire data for one experiment. Evoked responses were obtained from both right and left visual corticies. Each tracing represents the average of 50 evoked responses. Responses obtained from a bright flash are represented in Figure 3 and from a dim flash in Figure 4. Besides the change in waveform due to the intensity of the flash, there is little, if any, change in the waveform of the responses. Alterations are seen to occur when the effect of the flaxedil is wearing off and supplementary injection is required (Figure 3 time 7:50; Figure 4 time 10:06). A second instance of change in the evoked waveform but not the latencies is seen in Figure 3 (right visual cortex) when a 12 Hz/20mv field was presented. Presence of these changes could be due to modifications of the tissue by the field, but they were not confirmed in subsequent observations.

Long-term changes in latencies (several milliseconds), and in some instances amplitudes, were observed over an experimental session but they could not be attributed to the presence or absence of the field and are probably due to levels of anesthesia, temperature and other physiological conditions of the preparation.

In summary, no changes in waveform or latency of a visually evoked response has been seen to occur when an external electromagnetic field of low intensity and low frequency is applied. It is to be noted that the stimuli were presented asynchronously with respect to the imposed fields.

Bibliography:

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3. Hamer, J. Effects of low-level, low-frequency electric fields on human time judgment. In preparation.

4. Gavalas, R., Walter, D.O., Hamer, J. and Adey, W.R. Effect of low-level, low-frequency electrical fields on EEG and behavior in macaca nemestrina. Brain Res. 18 (1970) 491-501.

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* Figures referred to in this section are on Pages 9, 10, 11, and 12.

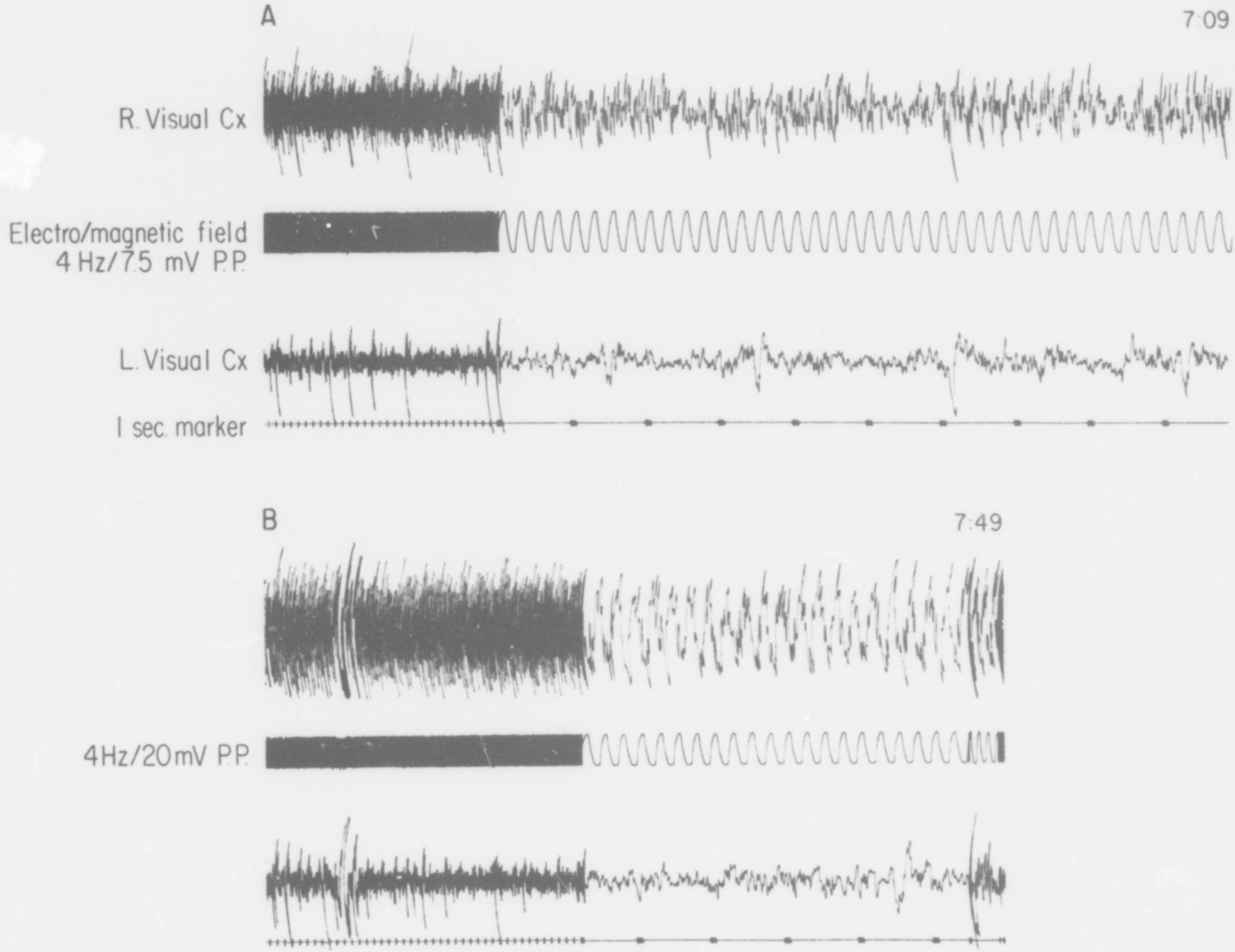
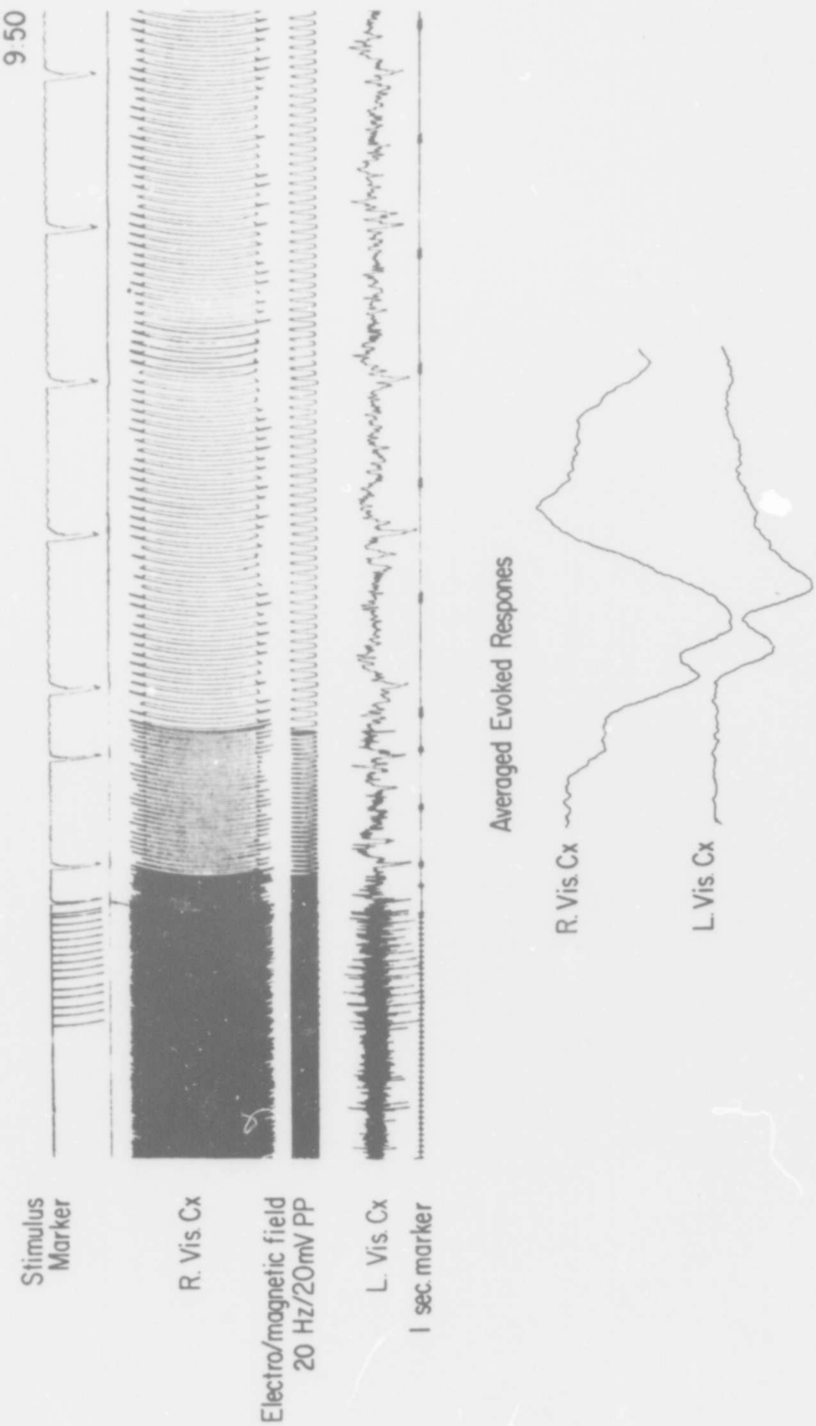

A
7:09
R. Visual Cx
Electro/magnetic field
4 Hz/7.5 mV P.P.
L. Visual Cx
I sec. marker
B
7:49
4Hz/20mV P.P.

FIGURE 1



9:50
Stimulus Marker
R. Vis. Cx
Electro/magnetic field 20 Hz/20mV PP
L. Vis. Cx
1 sec. marker
Averaged Evoked Respones
R. Vis. Cx
L. Vis. Cx

FIGURE 2

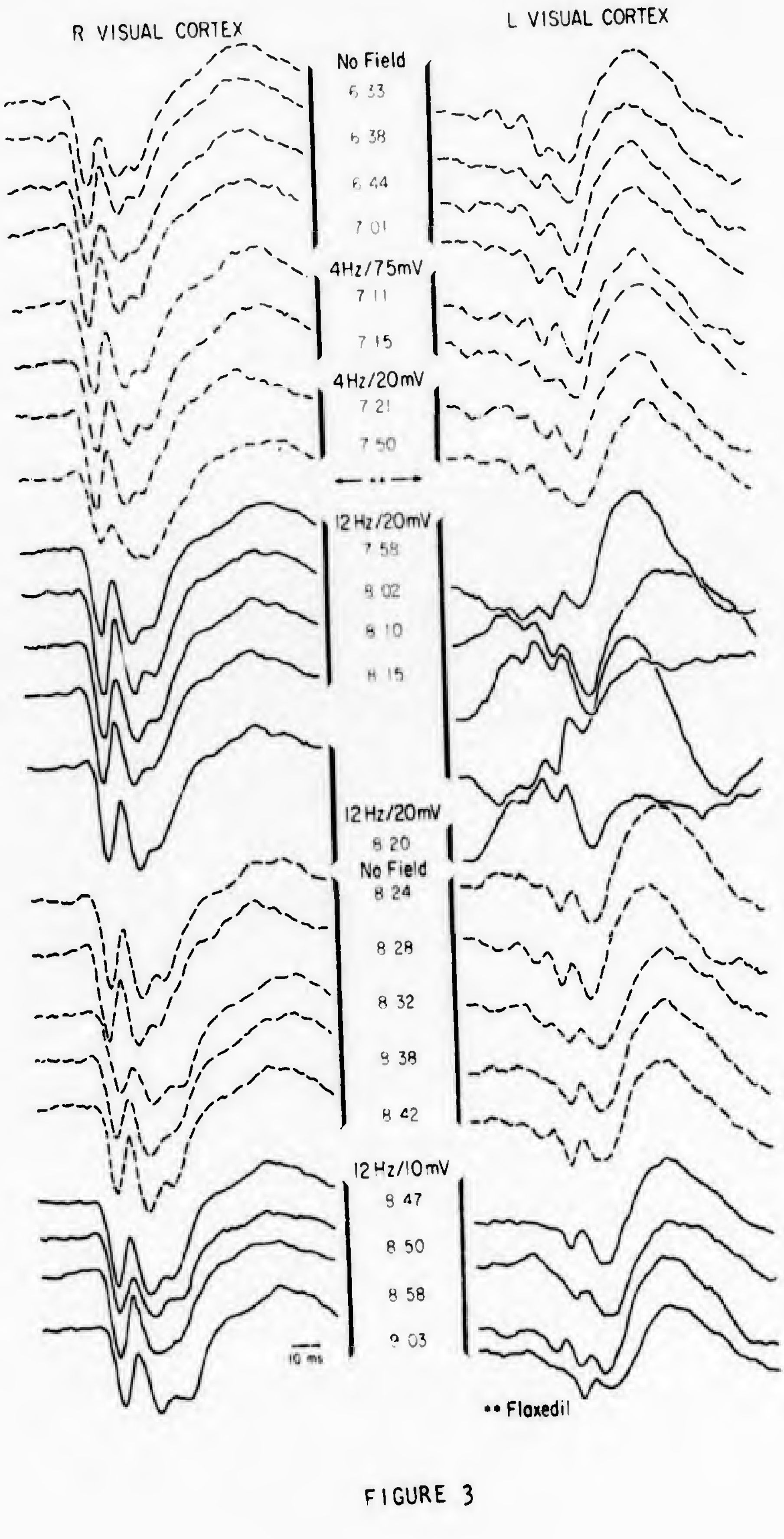

R VISUAL CORTEX
L VISUAL CORTEX
No Field
6 33
6 38
6 44
7 01
4Hz/75mV
7 11
7 15
4Hz/20mV
7 21
7 50
12Hz/20mV
7 58
8 02
8 10
8 15
12Hz/20mV
8 20
No Field
8 24
8 28
8 32
8 38
8 42
12Hz/10mV
8 47
8 50
8 58
9 03
10 ms
•• Flaxedil

FIGURE 3

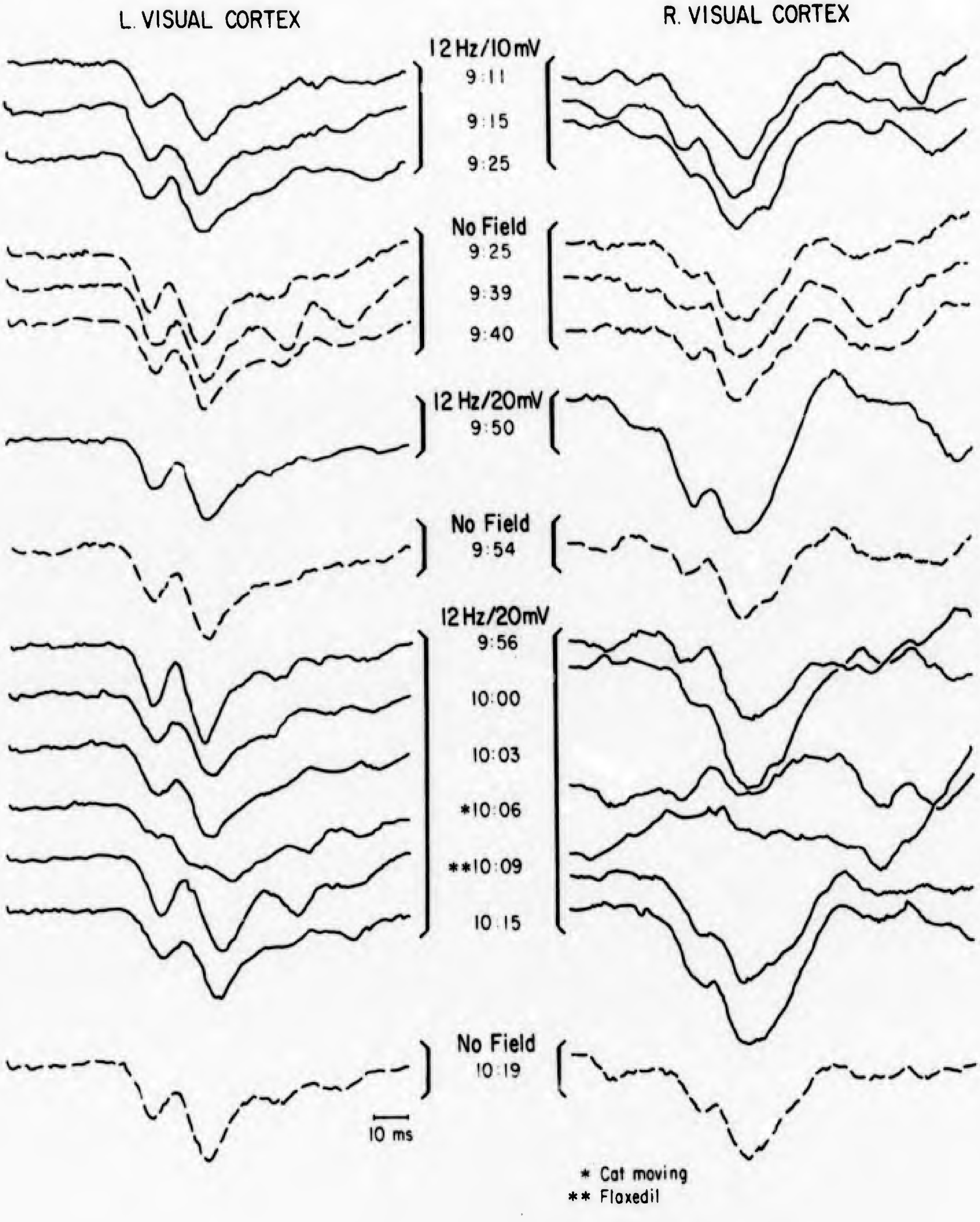

L. VISUAL CORTEX
R. VISUAL CORTEX
12 Hz/10 mV
9:11
9:15
9:25
No Field
9:25
9:39
9:40
12 Hz/20mV
9:50
No Field
9:54
12 Hz/20mV
9:56
10:00
10:03
*10:06
**10:09
10:15
No Field
10:19
10 ms
* Cat moving
** Floxedil

FIGURE 4

PROGRAMS FOR COMPUTATION OF INTER-RESPONSE INTERVALS (IRTs).

Programs for computation of inter-response intervals (IRTs) were written, tested and run in the SDS 930 computer of the Space Biology Laboratory and in the SDS 9300 computer of the Data Processing Laboratory.

Work has progressed in data reduction techniques. As in the previous year, most of the work was done in clustering techniques. The theory of fuzzy or probabilistic clustering was further developed and results were obtained for fuzzy partitions in several sets. Applications of this theory to pattern recognition were studied. At present, work is going on regarding the relation between the distance mapping function and the obtained clusters and in the difficult problem of inverse clustering. By inverse clustering, we mean the determination of an appropriate distance function, taken from a set of possible distances, that will provide clusters similar to conventionally preclassified sets.

Numerical methods for the solution of boundary value problems of potential theory were developed and programmed. These methods may have application to models of electromagnetic fields in the human body. The basic concept underlying these methods is the transformation of the boundary value problem into a system of ordinary differential equations with initial conditions. Work included mathematical and biological consultation with the biological investigators of this project.

Application of data reduction techniques is being made to studies of sleep staging in primates, and it is intended to apply clustering techniques to spectral analyses of the cerebral activity during the fields study.

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Ruspini, E. On the role of the mapping function in fuzzy clustering. (In preparation)

Yahush, A., Kalaba, R., Buell, J. and Ruspini, E. A program for system identification in drug kinetics problems. (In preparation)

Hafemann, D. and Ruspini, E. Determination of the concentration of Na sites in the nerve membrane using computer methods. (In preparation)

Meetings Attended:

Spring Joint Computer Conference
Boston, Massachusetts
May 14-16, 1969.

Symposium on the Applications of Mathematical Methods to Biological Problems
La Jolla, California
June 19-20, 1969.

San Diego Biomedical Symposium
San Diego, California
April 6-7, 1970.

Summer Computer Simulation Conference
Denver, Colorado
June 10-12, 1970.

APPENDIX I

COMPUTER ANALYSIS OF EEG DATA COLLECTED AT WRAIR DURING MICROWAVE FIELD EXPOSURE

In the course of this contract, the laboratory analyzed much data collected from monkeys at the Walter Reed Army Institute for Research. This work was under the direction of Mr. R. T. Kado. A series of four monkeys were implanted by Mr. Kado at Walter Reed with deep and brain surface EEG electrodes. Deep sites were chosen in regions likely to be associated with altered states of alertness and focused attention if they were to interact directly with the microwave field.

Microwave fields were either unmodulated or amplitude modulated at brain wave frequencies between 5 and 15 Hz. As a measure of interactions, cross-spectral analysis was performed on EEG records with cross-calculation between simultaneous records from different brain sites, and between one EEG channel and the low-frequency modulating signal.

These data acquisitions and subsequent calculations required painstaking preparation by our Space Biology Laboratory staff and equally careful attention to possible artifactual correlates arising from these calculations. Initial editing, A-D conversion, and some spectral calculations were made on the TD-100 computer. Most calculations of cross-spectra were made on the IBM 360-75 computer of the UCLA Health Sciences Computing Facility. No charge was made by the Facility against the contract, despite major requirements in processing time.

This appendix includes sample plots from these calculations. Coherence plots were made as contour maps, with each map compiled from data from repeated calculations on successive 10 or 20 sec epochs of data. High coherences appear as dark areas, and low coherences as unshaded or lightly shaded zones.

Conclusions from this phase of the contract were suggestive but not conclusive that interactions did occur with certain brain regions at the modulating frequencies. They have left unanswered two main questions: (1) To what extent interaction with the fields may have evoked altered EEG rhythms at frequencies other than the modulating frequencies. (This was also suggestive, since altered total EEG power was a frequent and lasting effect of fields-on states in some brain leads, particularly in centrum medianum of the thalamus and from the hippocampal formation.) (2) To what extent appearance of power in the EEG spectrum at the modulating frequency was due to demodulation of the microwave signal in a simple rectifying action at the liquid-metal interface of the electrode-tissue junction. As in other studies with sinusoidal whole body vibration (Adey, Kado and Walter, 1965), the evidence is against such a simple artifactual basis for the spectral contamination, since very high powers are present at 3rd and 4th harmonics of the modulating frequency, far higher than in the modulating signal. Unless the rectifying characteristics of the electrode-tissue interface were to exhibit extreme nonlinearity (for which there is no biophysical evidence), the high powers in these harmonics strongly suggest an active tissue response to the modulated microwave field. These high harmonic powers can be clearly seen in some of the contour maps.

Abbreviations Used on Contour Maps:

RVA - Right nucleus ventralis anterior thalami.

RHIP - Right hippocampal formation.

RCM - Right nucleus centrum medianum thalami.

LMCX - Left centroparietal cortex.

RMRF - Right midbrain reticular formation.

LVCX - Left visual cortex.

LACX - Left frontocentral cortex.

MODL - Modulating frequency.

Abscissae: Epoch numbers in accordance with attached experiment protocol.

Ordinates: Spectral frequencies in Hz.

PLEASE NOTE:

WE REGRET THAT WE ARE UNABLE TO SUBMIT THE ORIGINAL PHOTOGRAPHS ON THE FOLLOWING ILLUSTRATIVE MATERIAL. THEY WERE SUBMITTED TO WALTER REED ARMY INSTITUTE OF RESEARCH UPON COMPLETION OF THIS PARTICULAR SEGMENT OF THE PROJECT.

INDEX FOR WRAIR E-782

Preliminary Analysis Group

Coherences and Auto-Spectra Maps

1. Coherence levels (identified by channel 1/channel 2).
   0-0.3 white
   0.3-0.5 light dots
   0.5-0.7 heavy dots
   0.7-1.0 black

2. Auto-spectra levels (identified by channel only).
   0-300 white
   300-1000 vertical lines
   1000-3000 light dots
   3000-10,000 heavy dots
   10,000-30,000 black

3. The ordinate gives frequencies of analysis, absicca gives codes. Note, code interval is 5 seconds between successive code numbers. Maps may not have successive codes.

4. Analysis is performed on 10 second segments of the data; therefore, each number on the abscissa represents a 10 second period.

WRAIR E-782

Analysis Results

Coherence and Auto Spectra Maps

Number	Code	Event	
WR-1	1	10 cps AM	
	10	10-5 cps shift	
	to	191 5 cps	
WR-2	195	15 cps AM	frequency peaks at 14.5 cps
	to 360	15 cps AM	
WR-3	203	15 cps AM	
	389	15-7 cps AM shift	
	to 430	7 cps AM	
WR-4	389	15-7 cps	
	391	7 cps	
	430	7 cps slow wave EEG	
	432	7 cps slow wave EEG	
	460	7 cps activated EEG	
	to 550	7 cps	
WR-5	566	7-13 cps AM	frequency peaks at 12.5 cps
	to 775	13 cps AM	modulation channel lost in digitizing at code 670.
WR-6	430	7 cps slow wave EEG	
	432	7 cps slow wave EEG	
	460	7 cps activated EEG	
	464	7 cps activated EEG	
	469	7 cps activated EEG	
	566	7-13 cps	
	568	13 cps activated EEG	
	to 572	13 cps activated EEG	
	602	13 cps slow wave EEG	
	to 606	13 cps slow wave EEG	
	670	13 cps modulation channel lost in digitizing. Does not affect inter EEG coherences only EEG/mod and modulation channel.	
	777	power off	
	to 950	power off	

WRAIR E-782

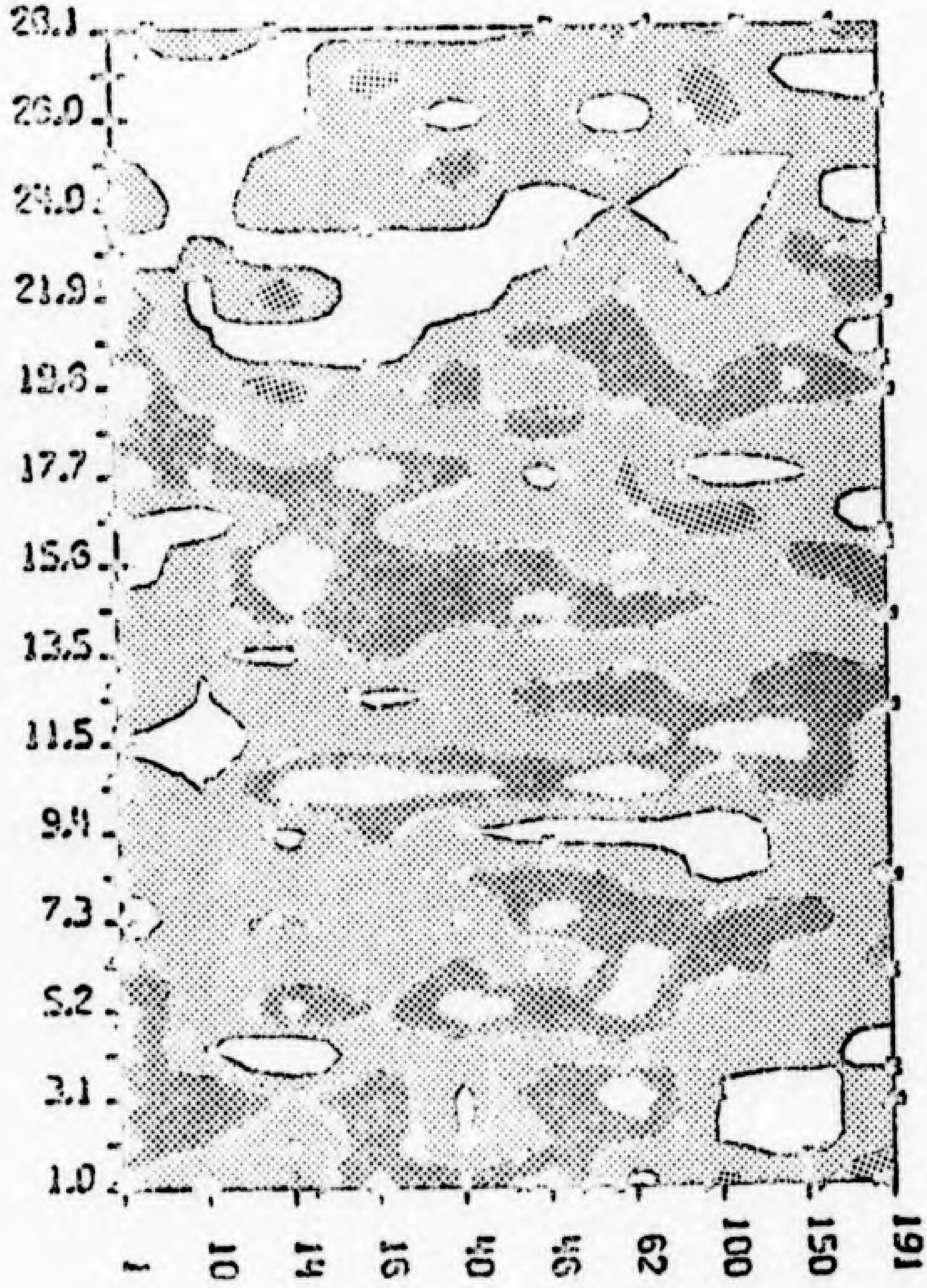
Analysis Results

Coherence and Auto Spectra Maps

Number	Code	Event	
WR-FM	562 to 567	power off	
	567-679	5 cps FM	
	520-690	10 cps FM	
	614-840	power off	modulation channel only still on

WR-1

RHIP/RVA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24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
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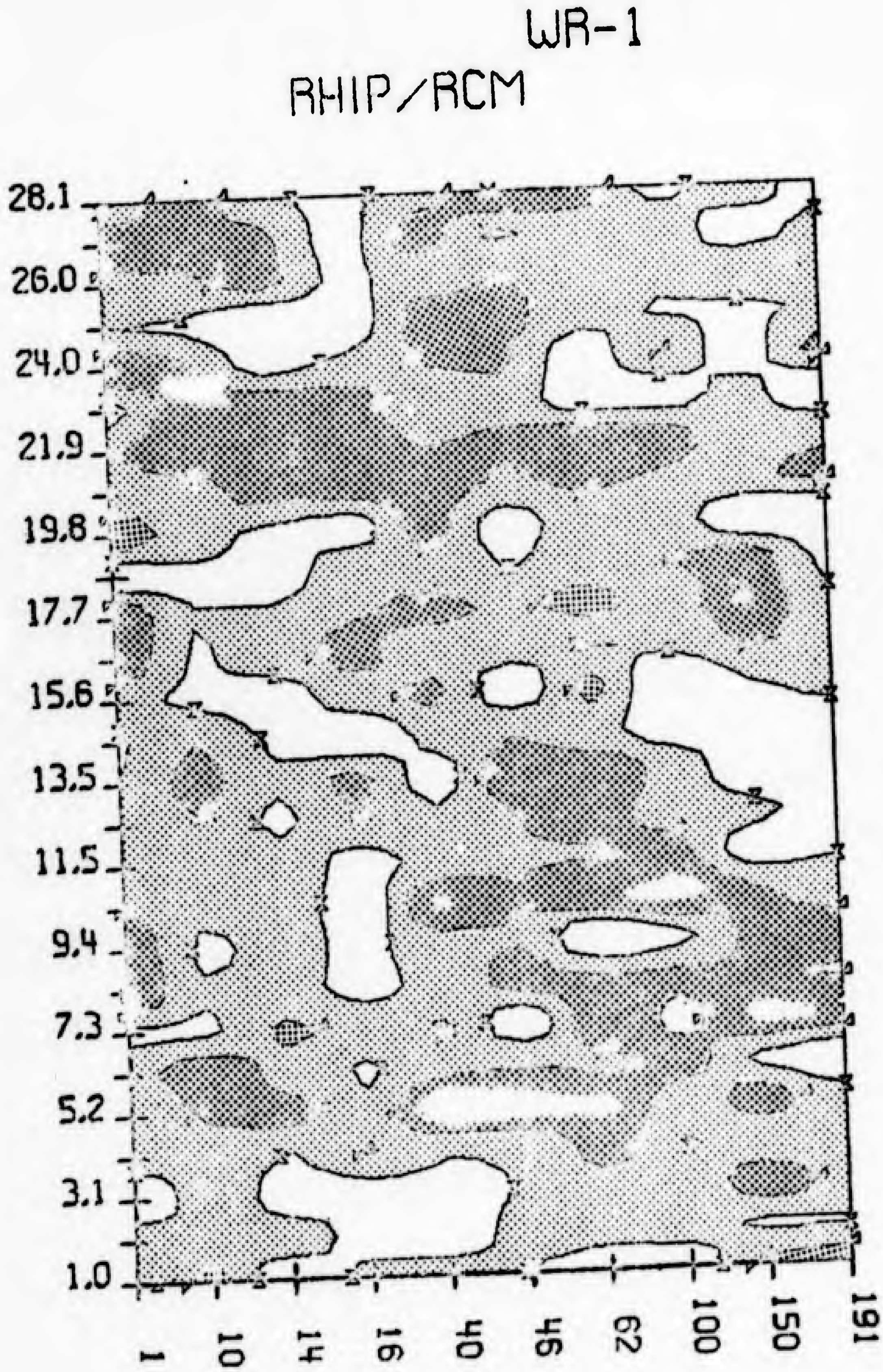
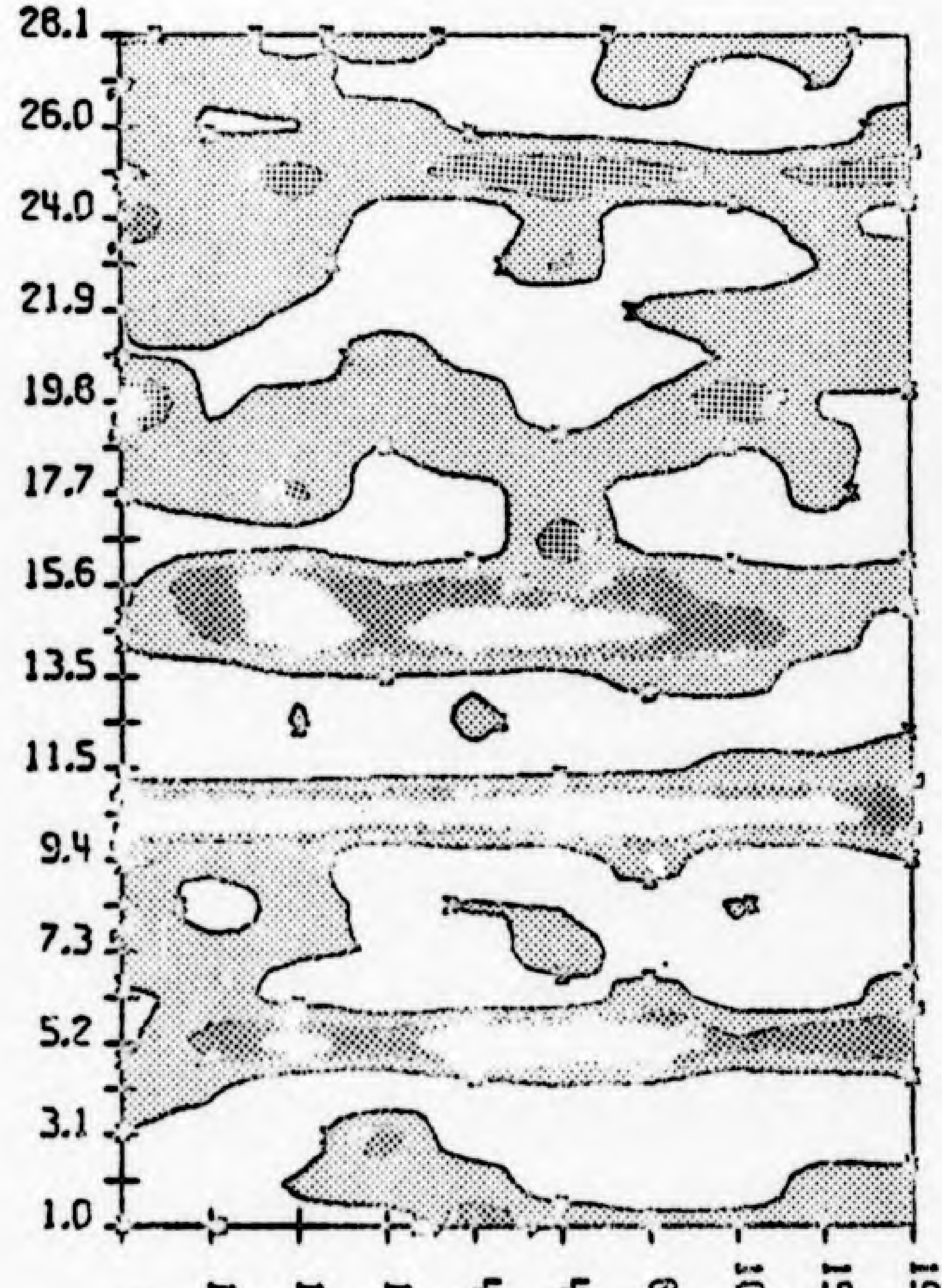
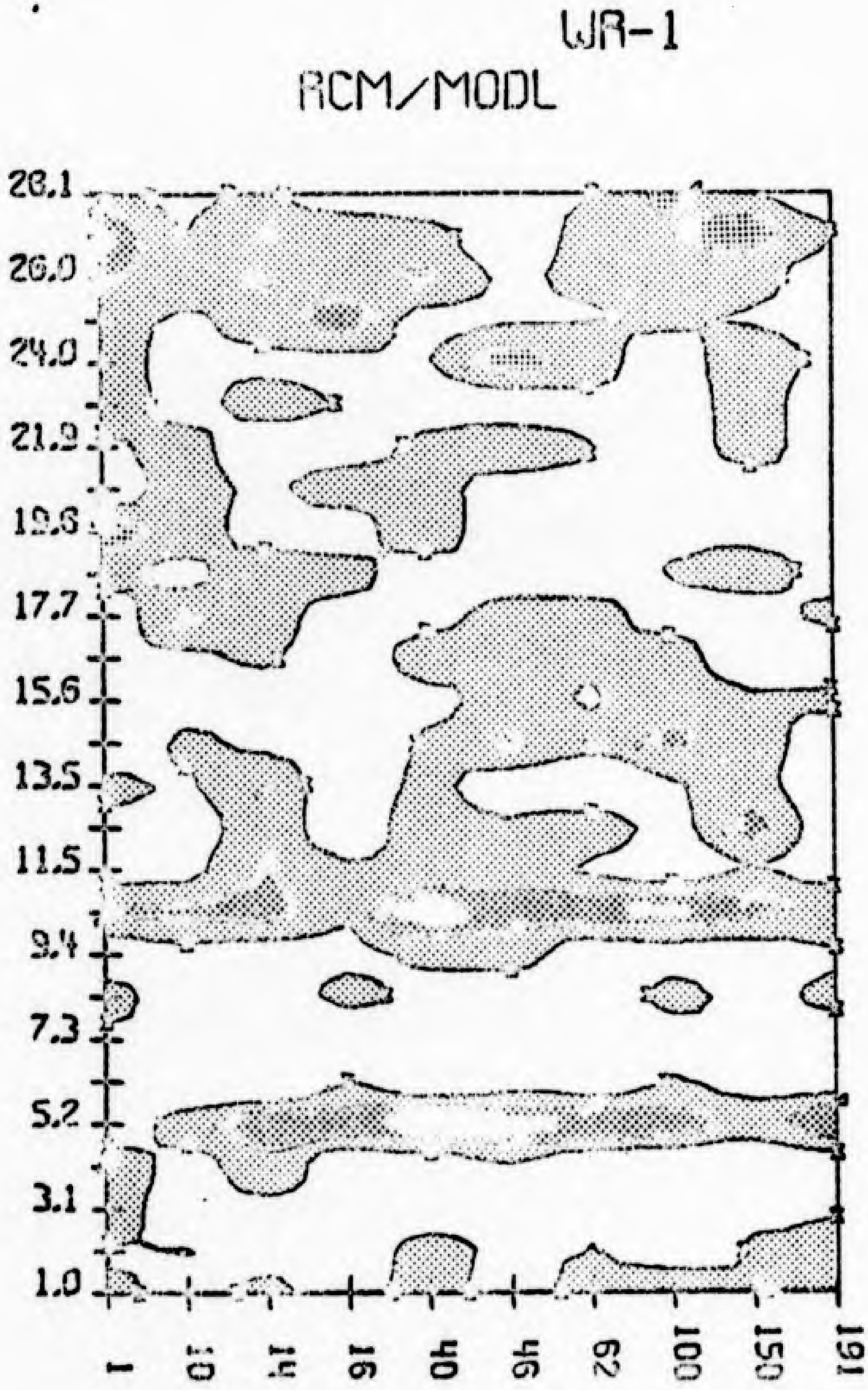
14
15
40
46
62
100
150
191


WR-1
RHIP/RCM
28.1
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
1
10
14
16
40
46
62
100
150
191

WR-1
RHIP/MODL

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RCM/MODL
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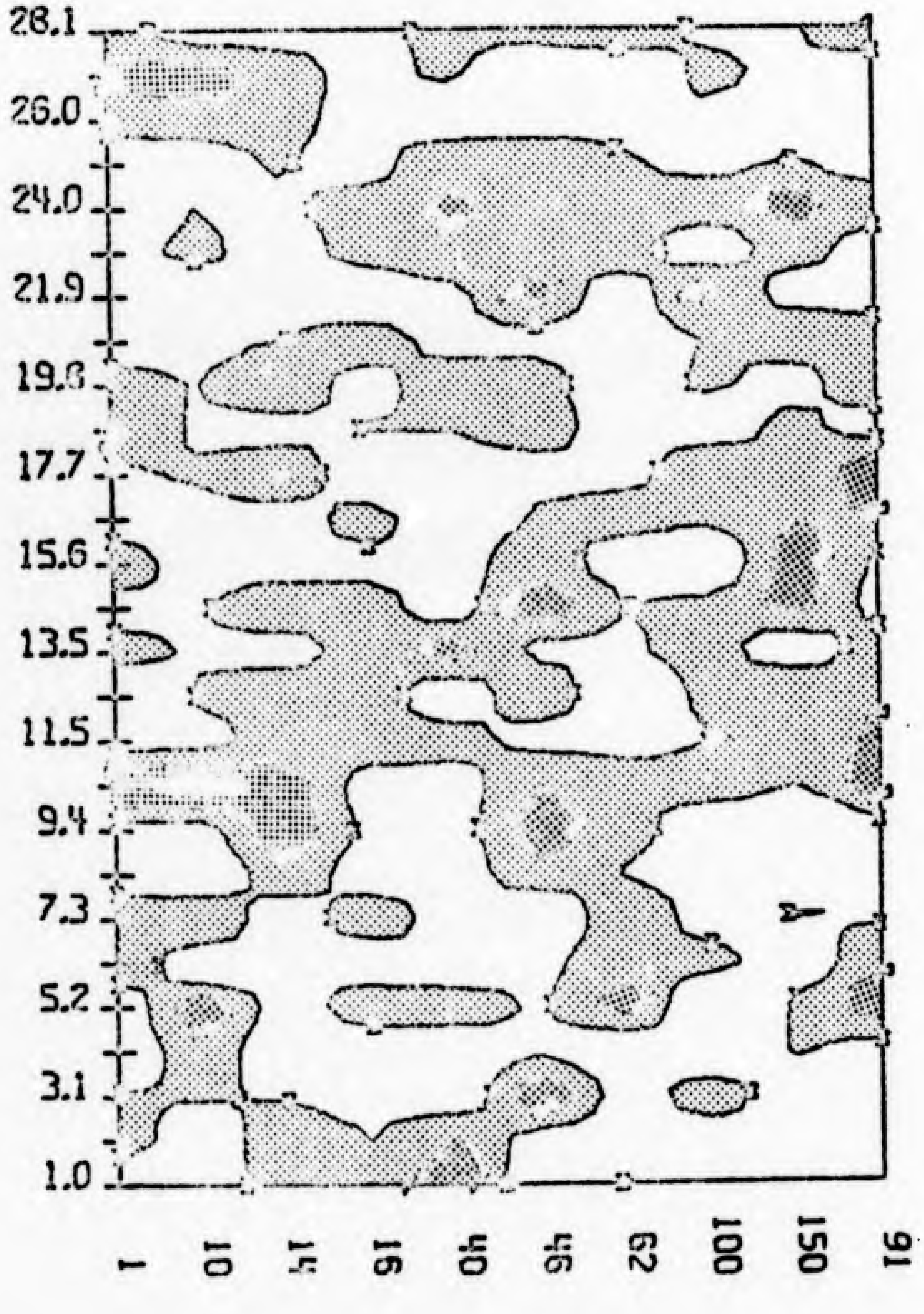
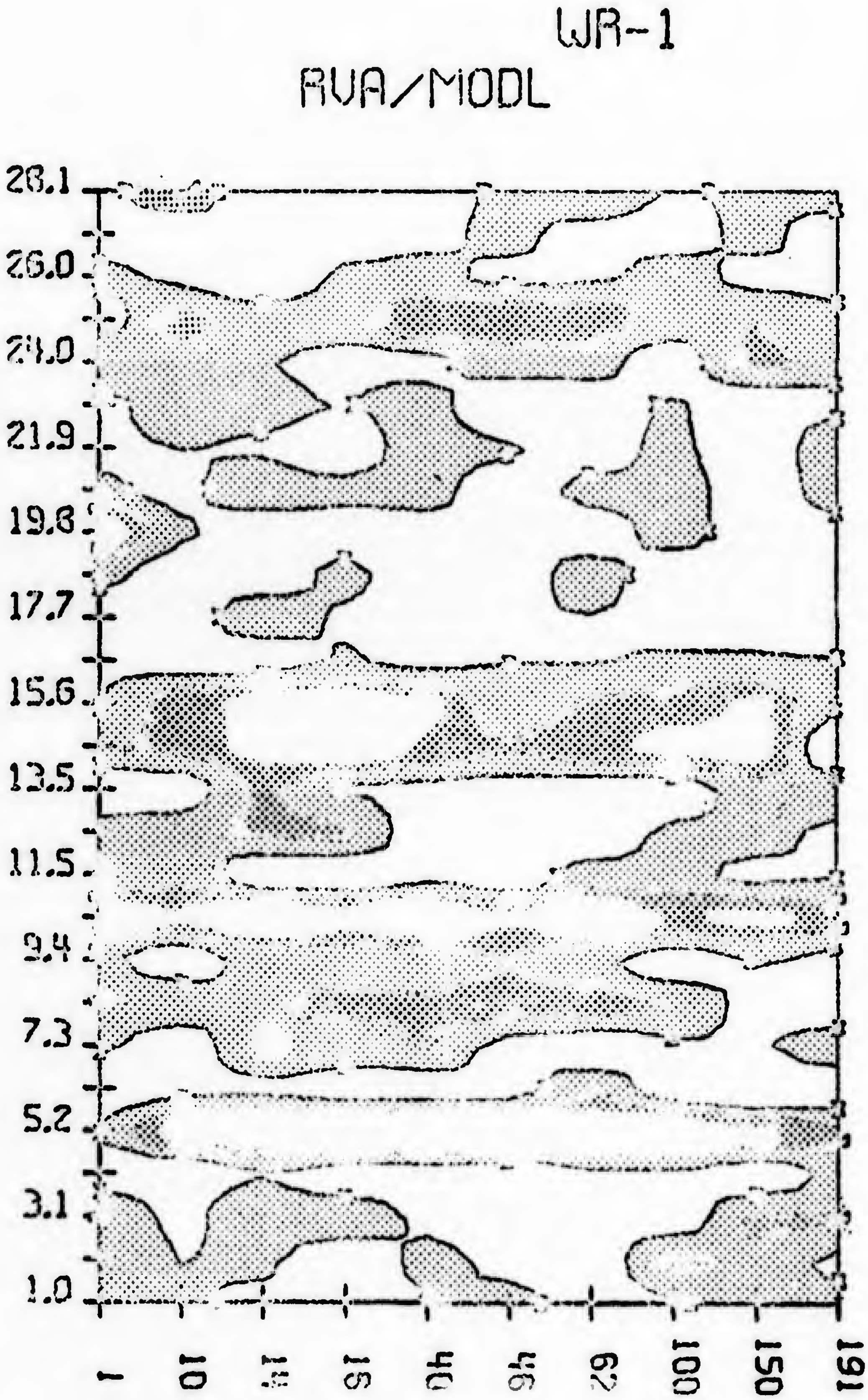
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
1
10
14
16
40
46
62
100
150
191

WR-1
LMCX/MODL




WR-1
RVA/MODL
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24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
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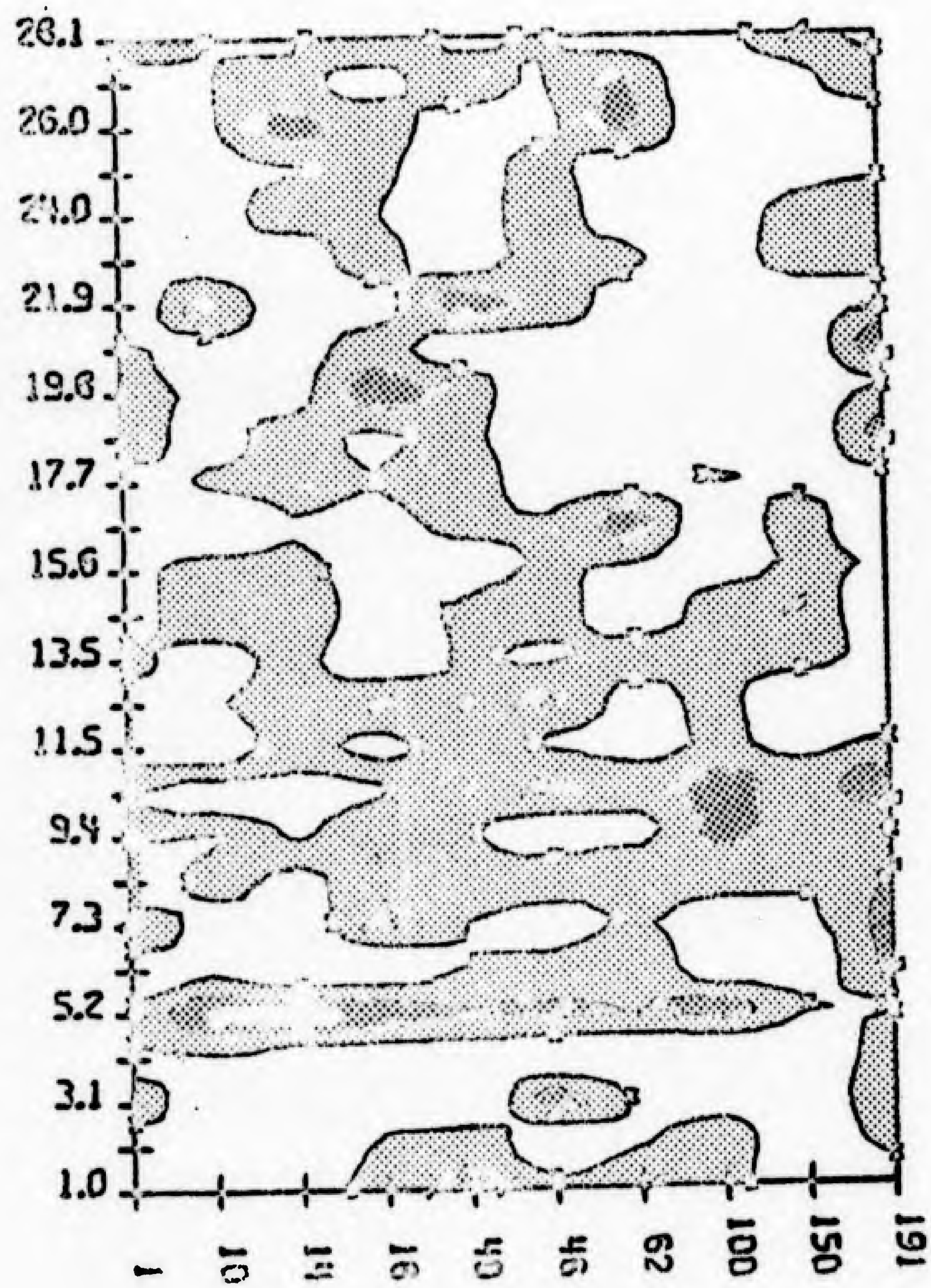
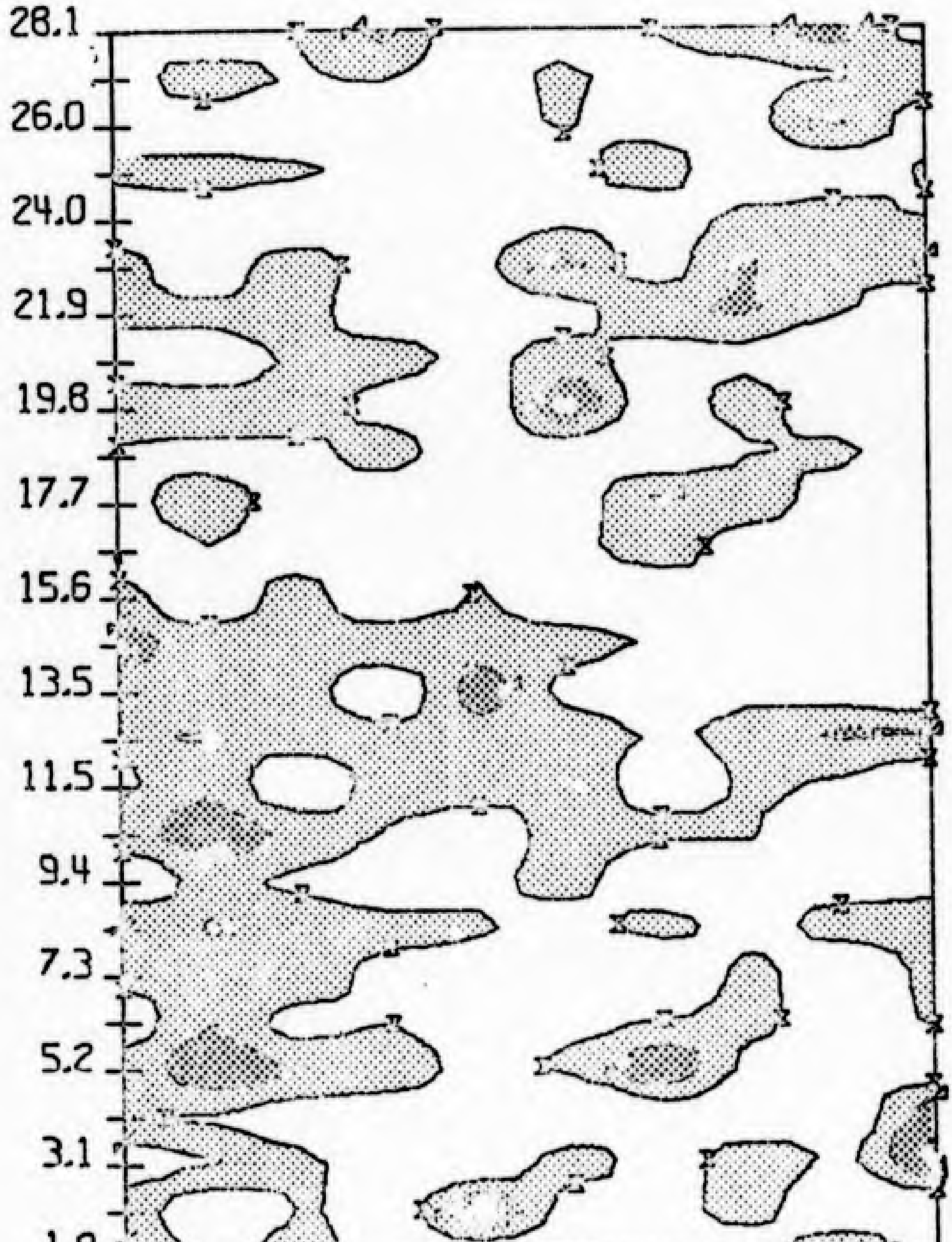
1
10
14
19
40
46
62
100
150
191

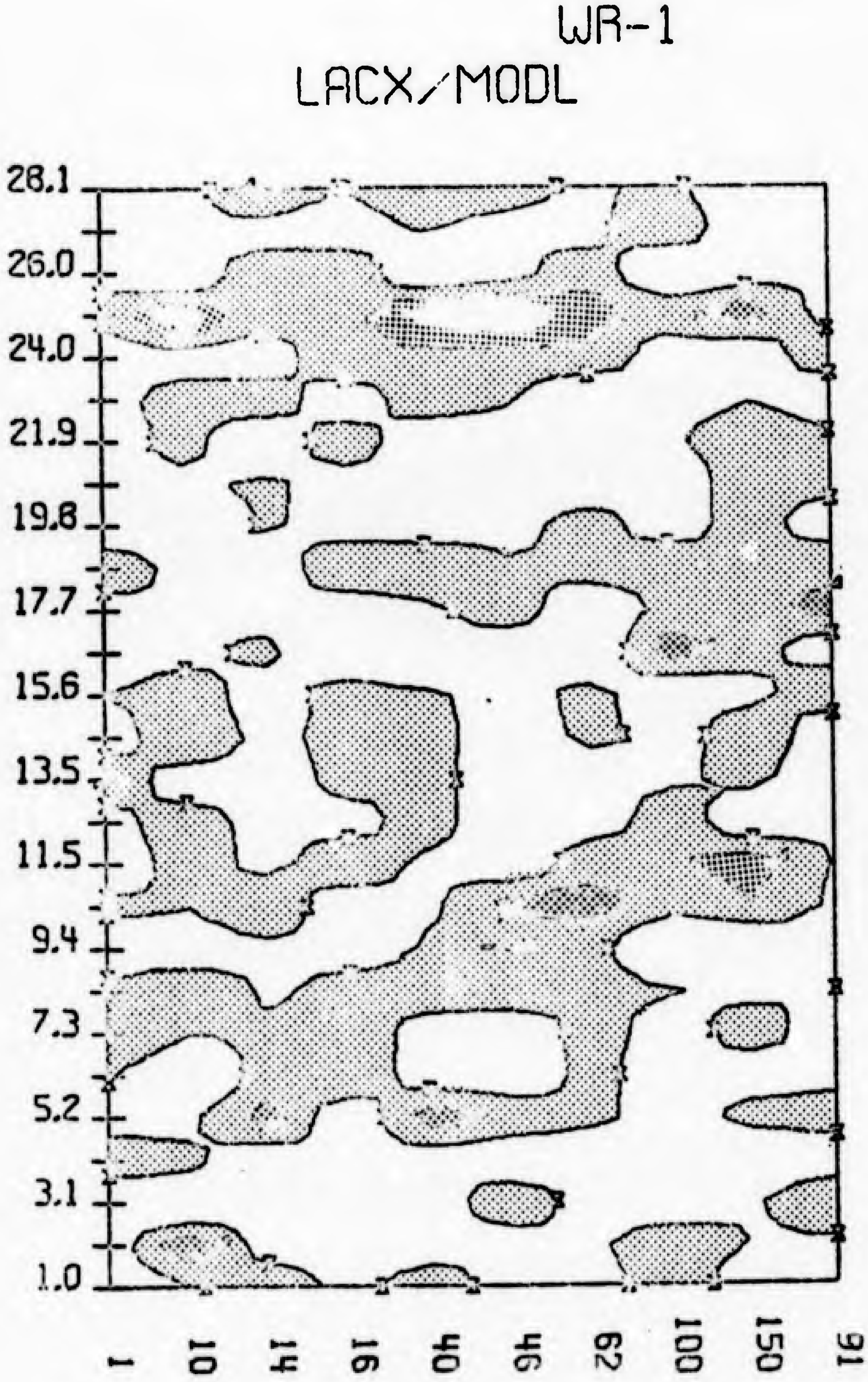
WR-1

RMAF/MODL



WR-1
LVCX/MODL

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LACX/MODL
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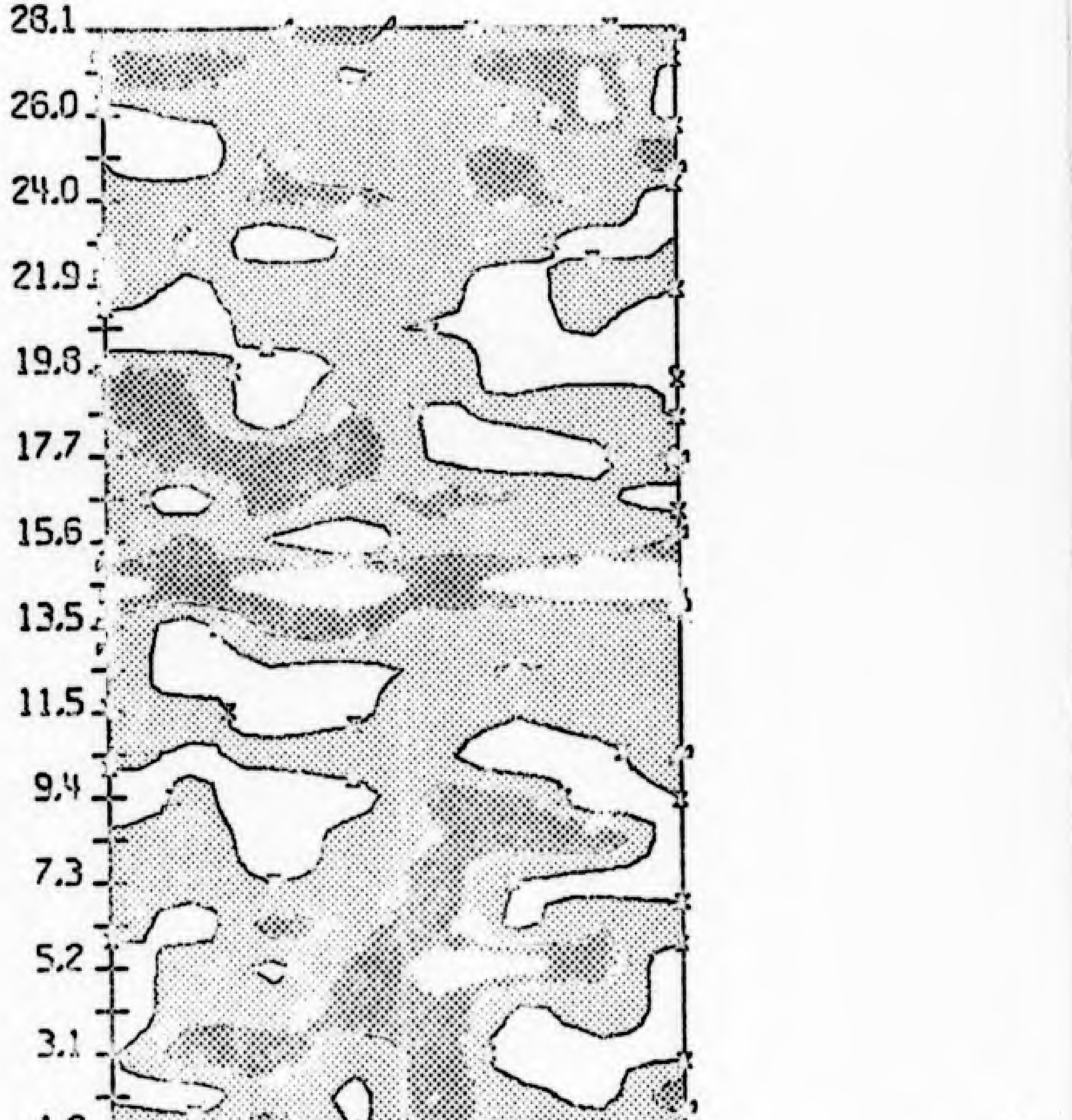
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
1
10
14
16
40
46
62
100
150
91

WR-2

RHIP/RVA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21.9
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17.7
15.6
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11.5
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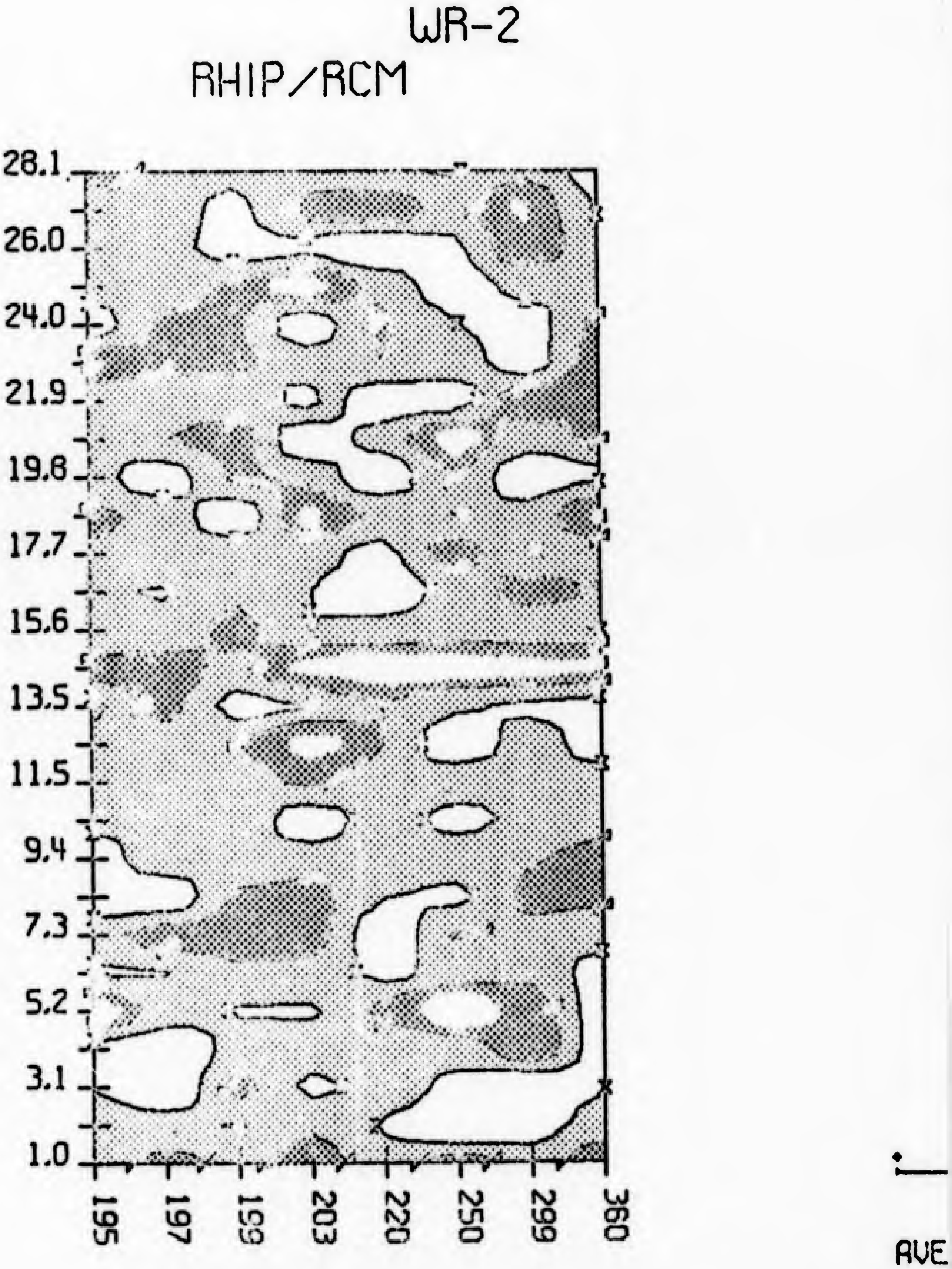
7.3
5.2
3.1
1.0
195
197
199
203
220
250
299
360
AVE


WR-2
RHIP/RCM
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26.0
24.0
21.9
19.8
17.7
15.6
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7.3
5.2
3.1
1.0
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197
199
203
220
250
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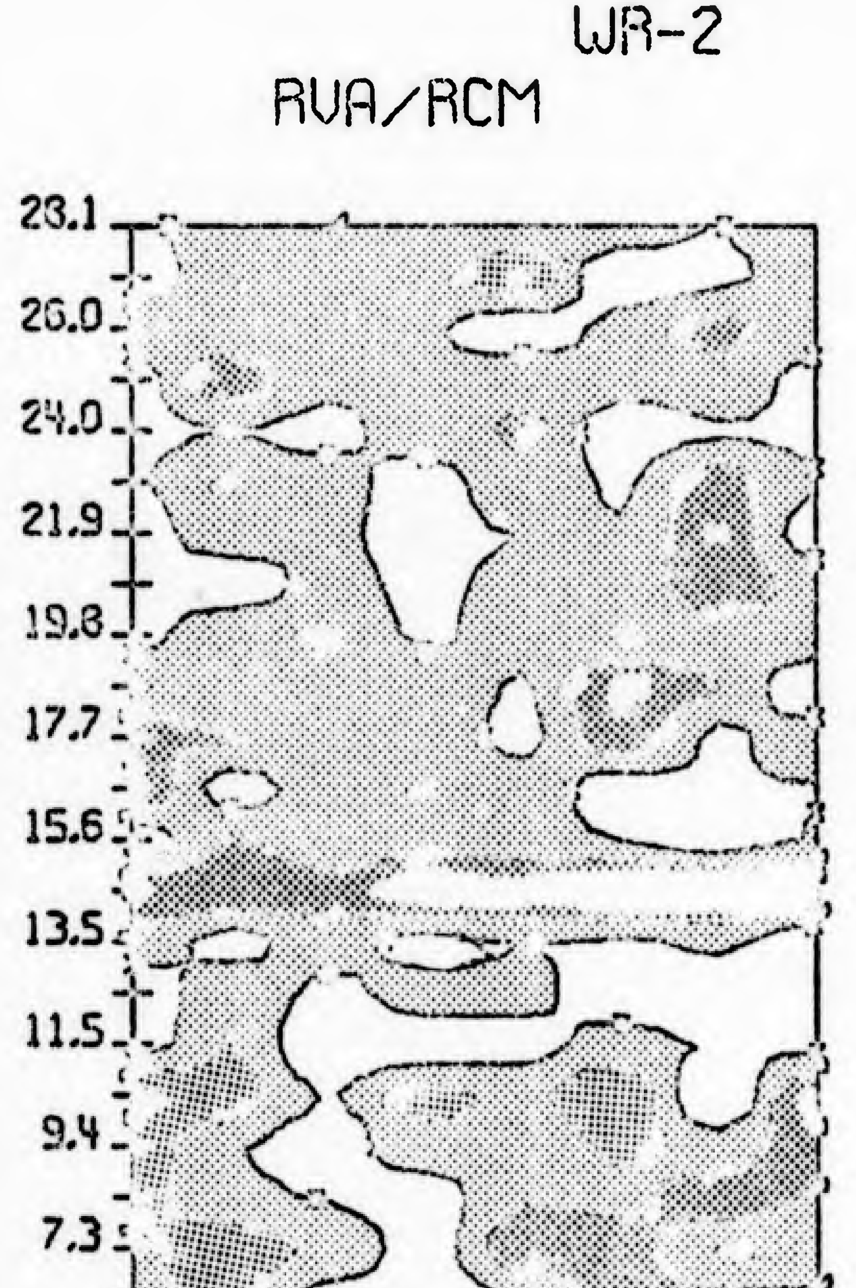
360
AVE


WR-2
RVA/RCM
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26.0
24.0
21.9
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17.7
15.6
13.5
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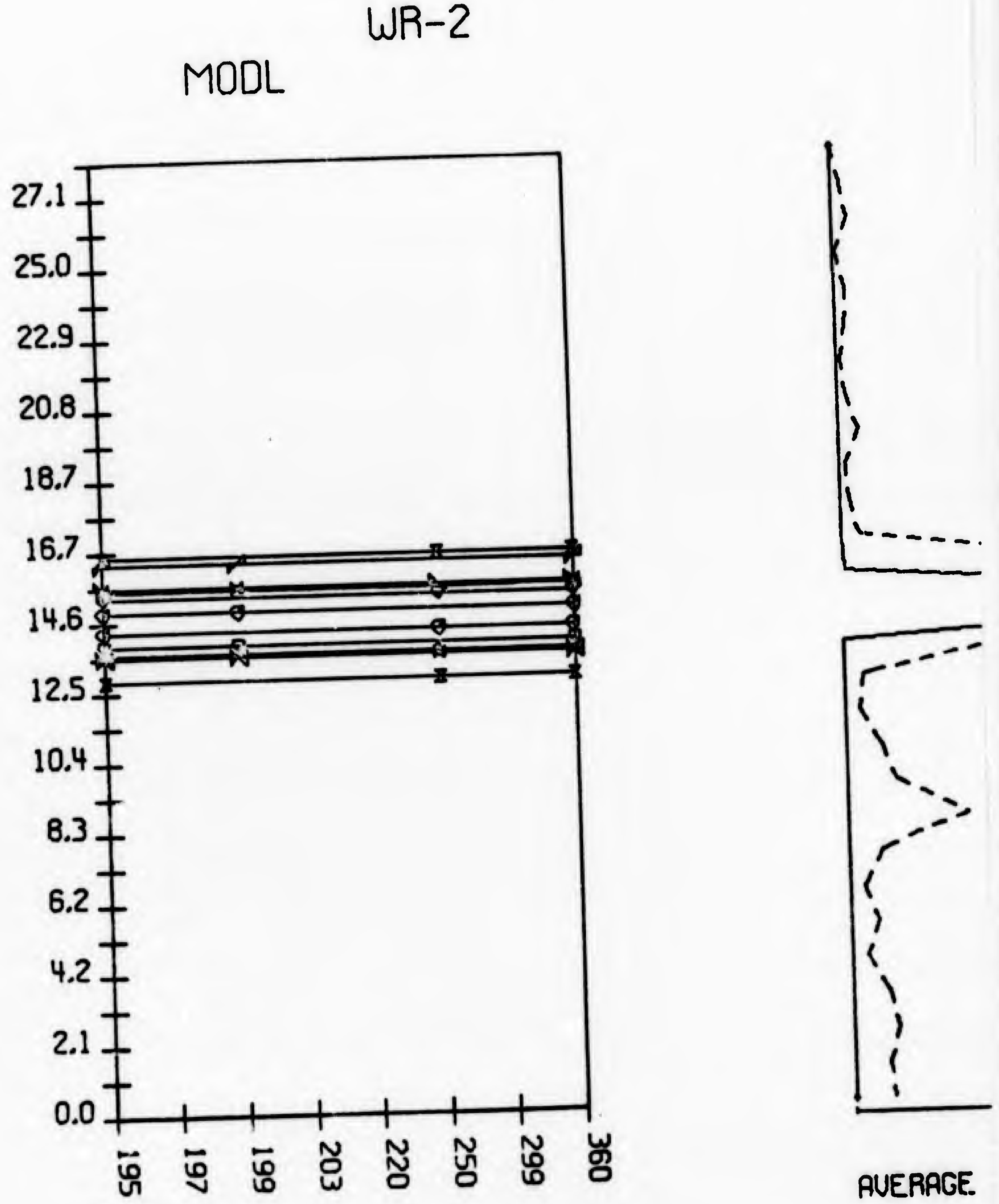
7.3
5.2
3.1
1.0
195
197
199
203
220
250
299
360

AVERA


WR-2
MODL
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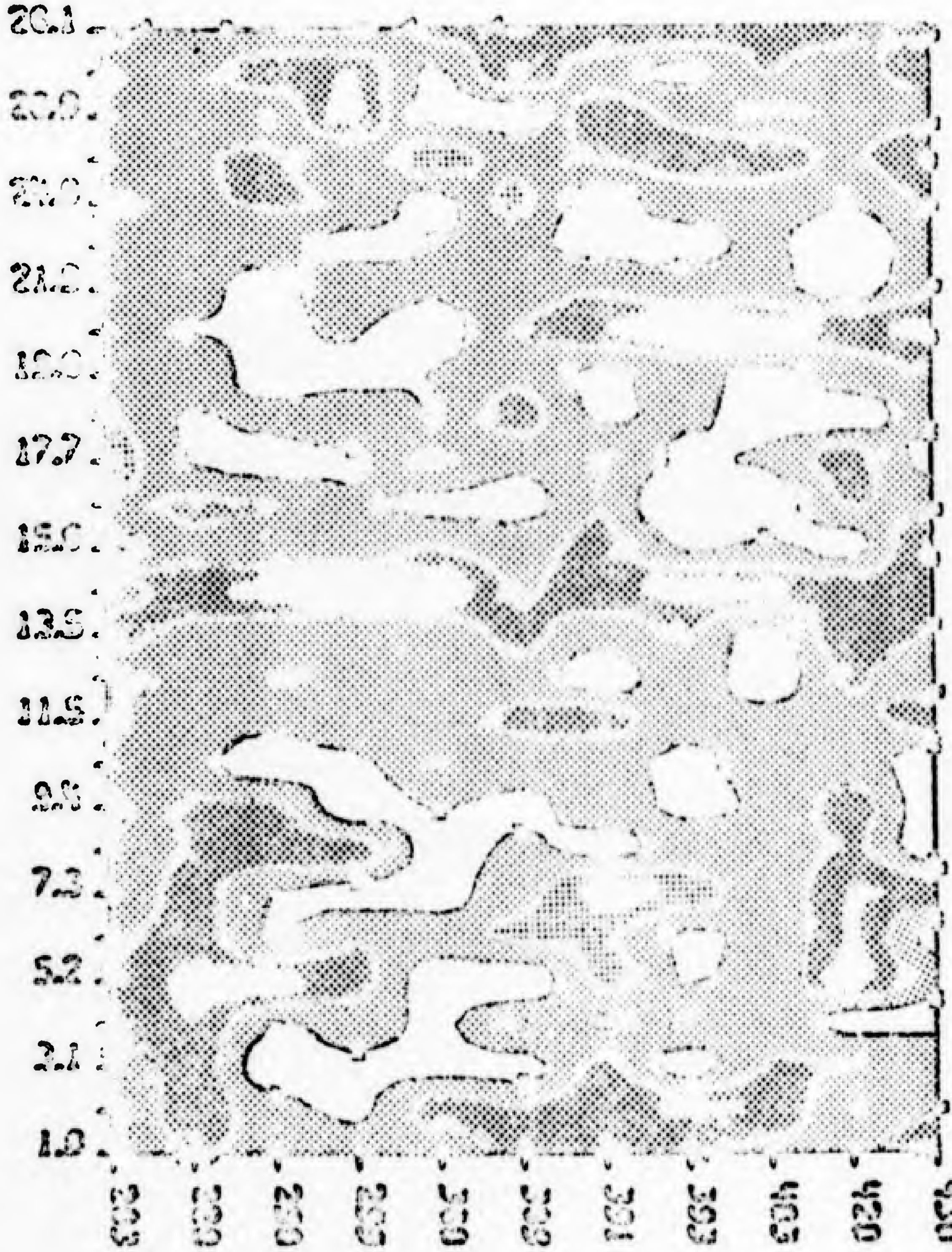
22.9
20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
0.0
195
197
199
203
220
250
299
360
AVERAGE.

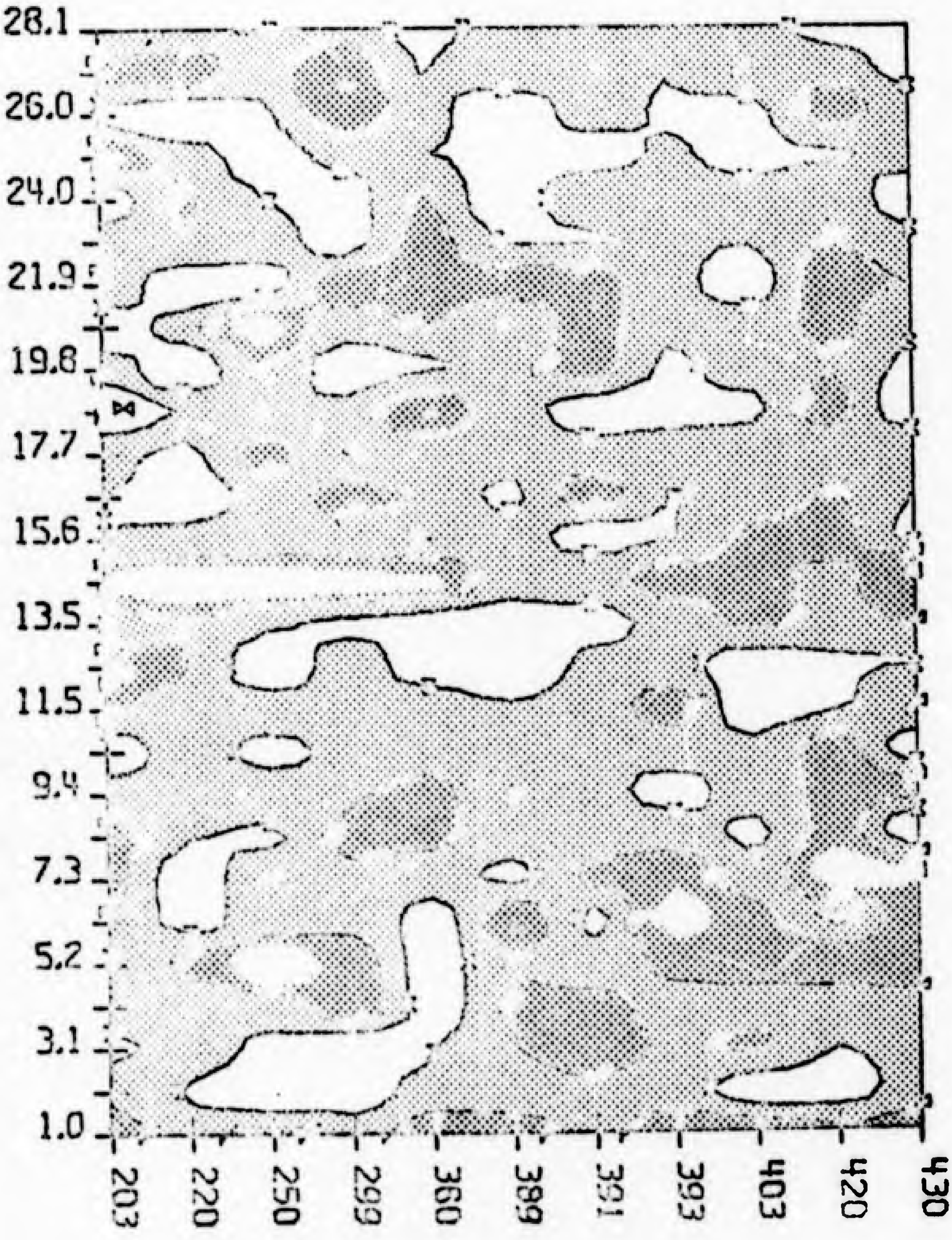
WR-3

RHIP/RVA



WR-3

RHIP/RCM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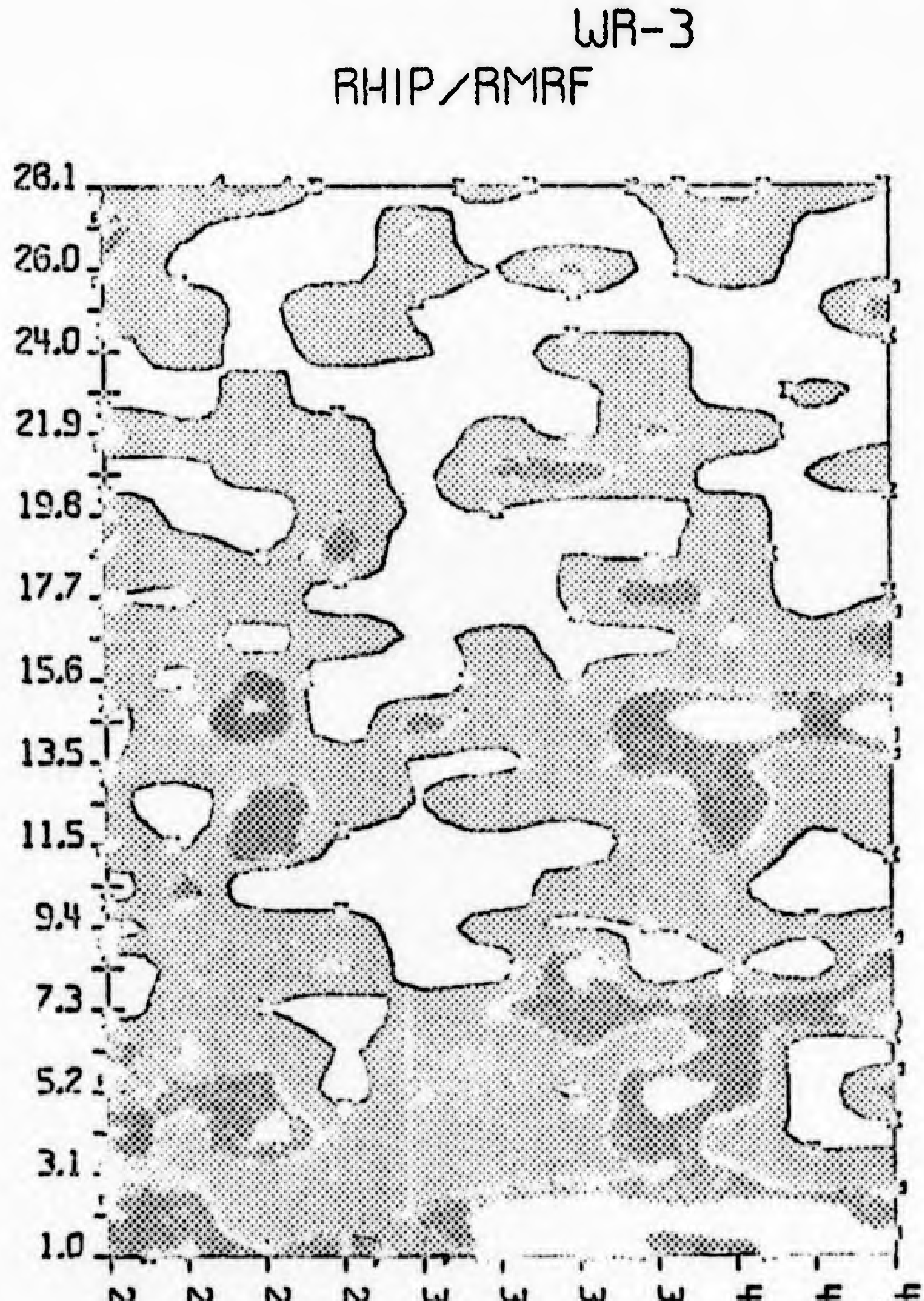
3.1
1.0
203
220
250
299
360
389
391
393
403
420
430


WR-3
RHIP/RMRF
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26.0
24.0
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11.5
9.4
7.3
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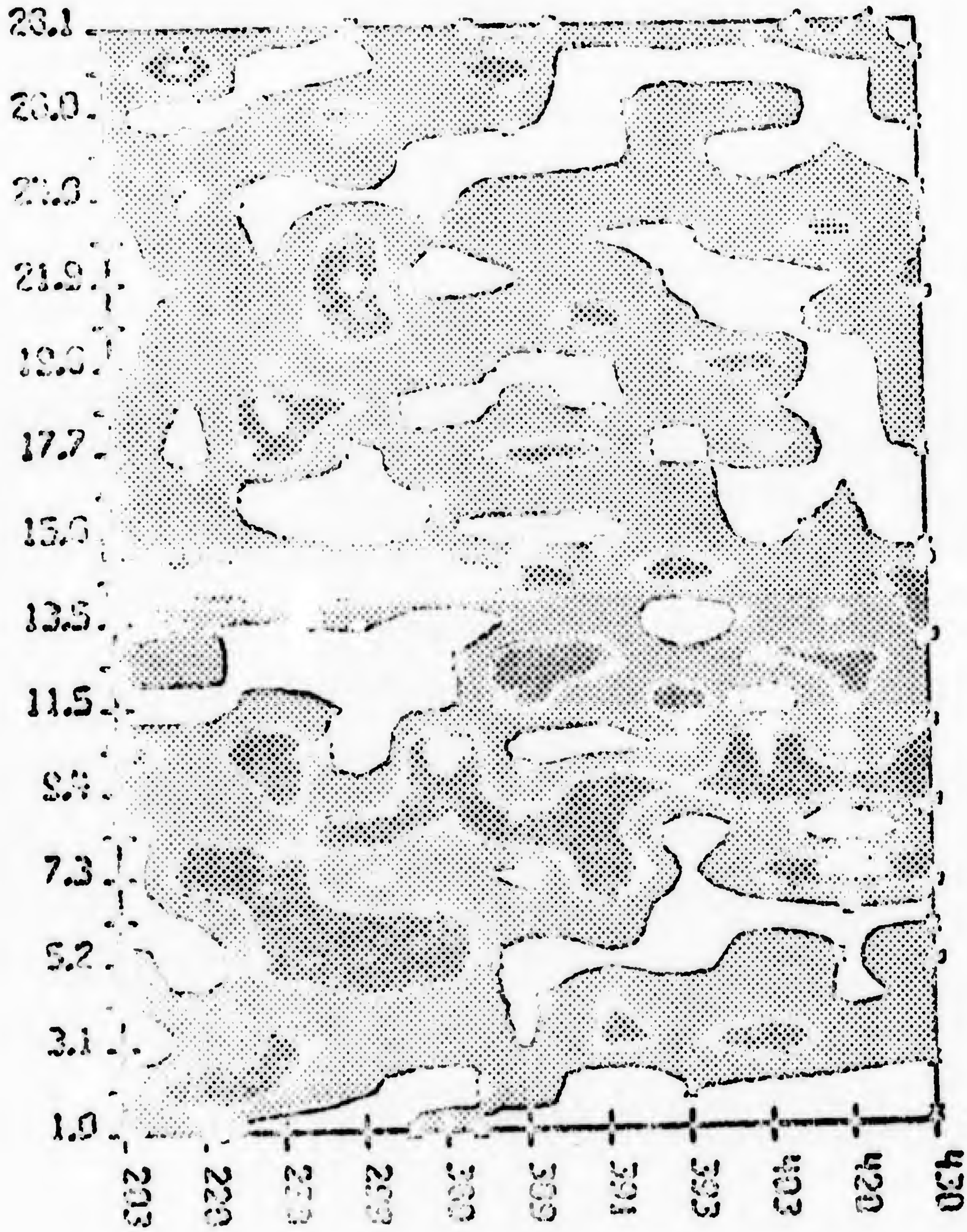
250
299
360
389
391
393
403
420
430

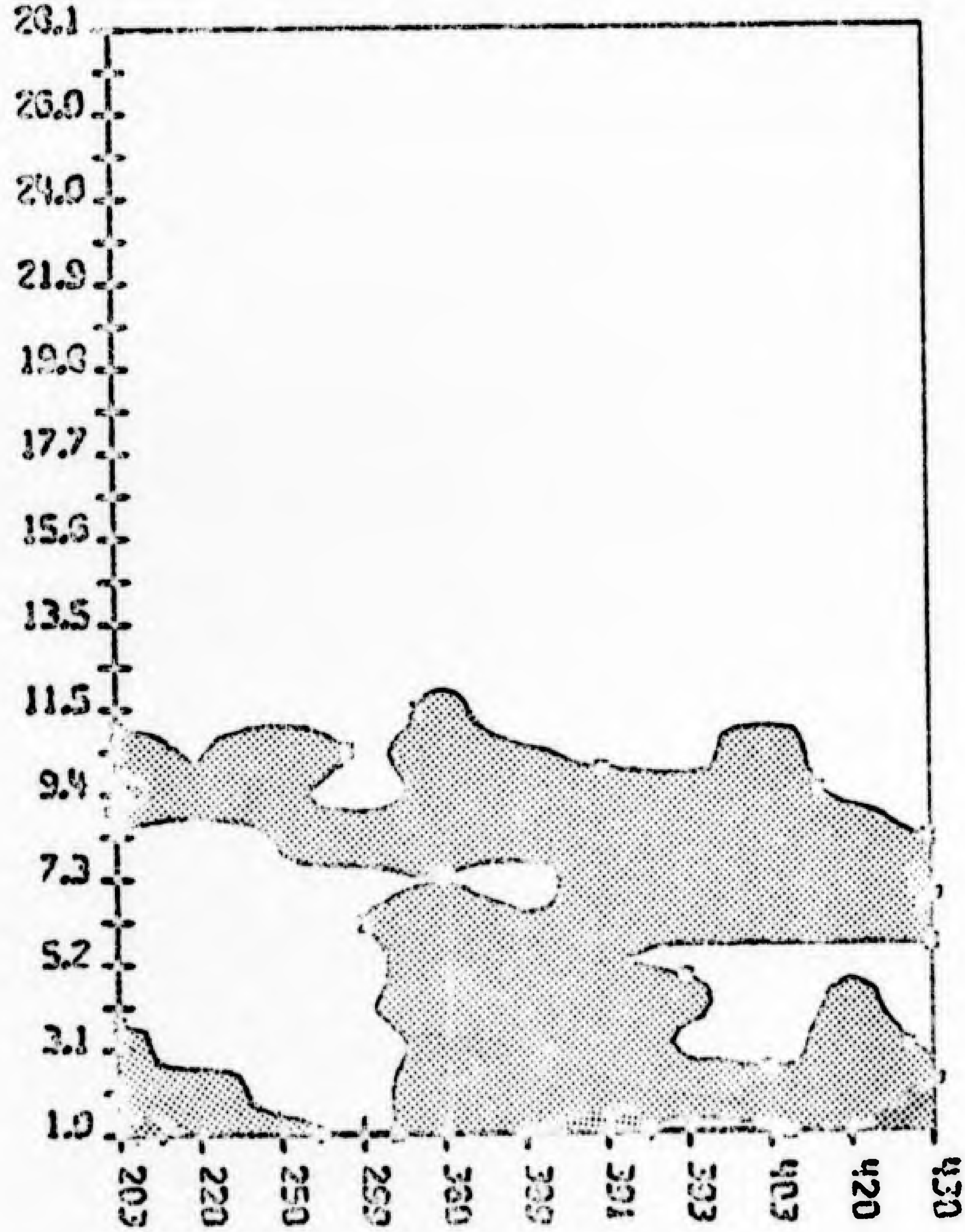
WR-3

AVA/RCM



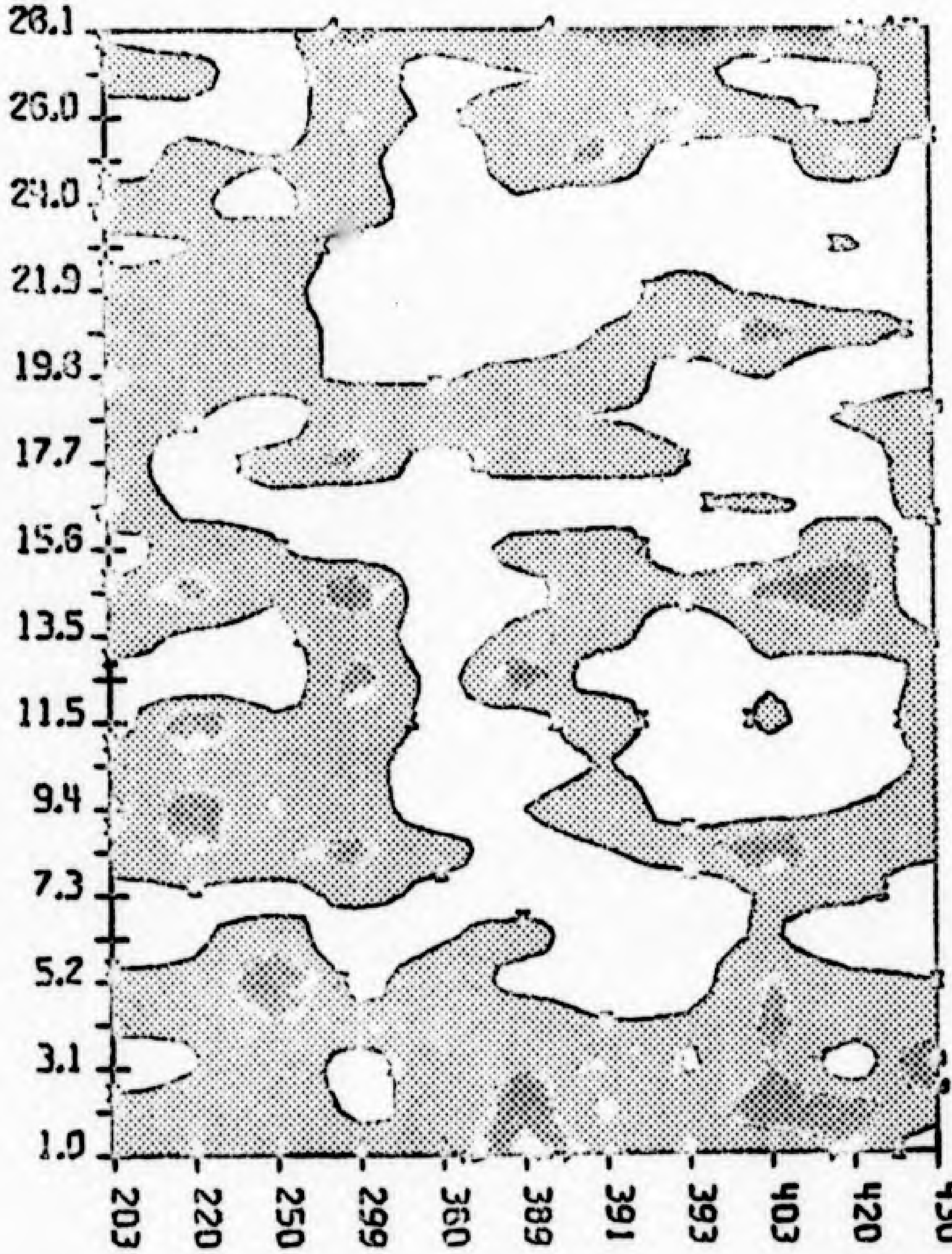
WR-3

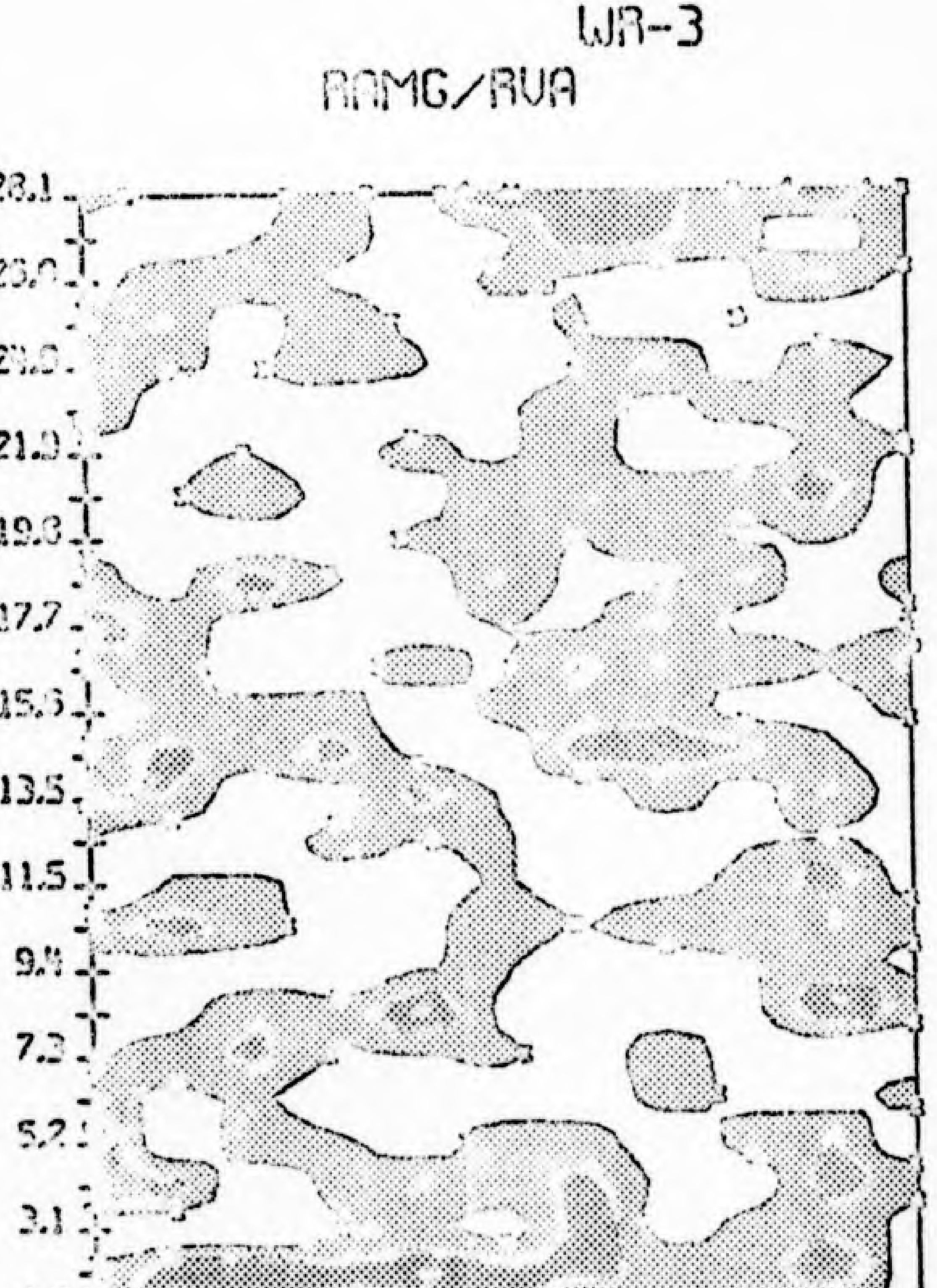
RVA/RMRF

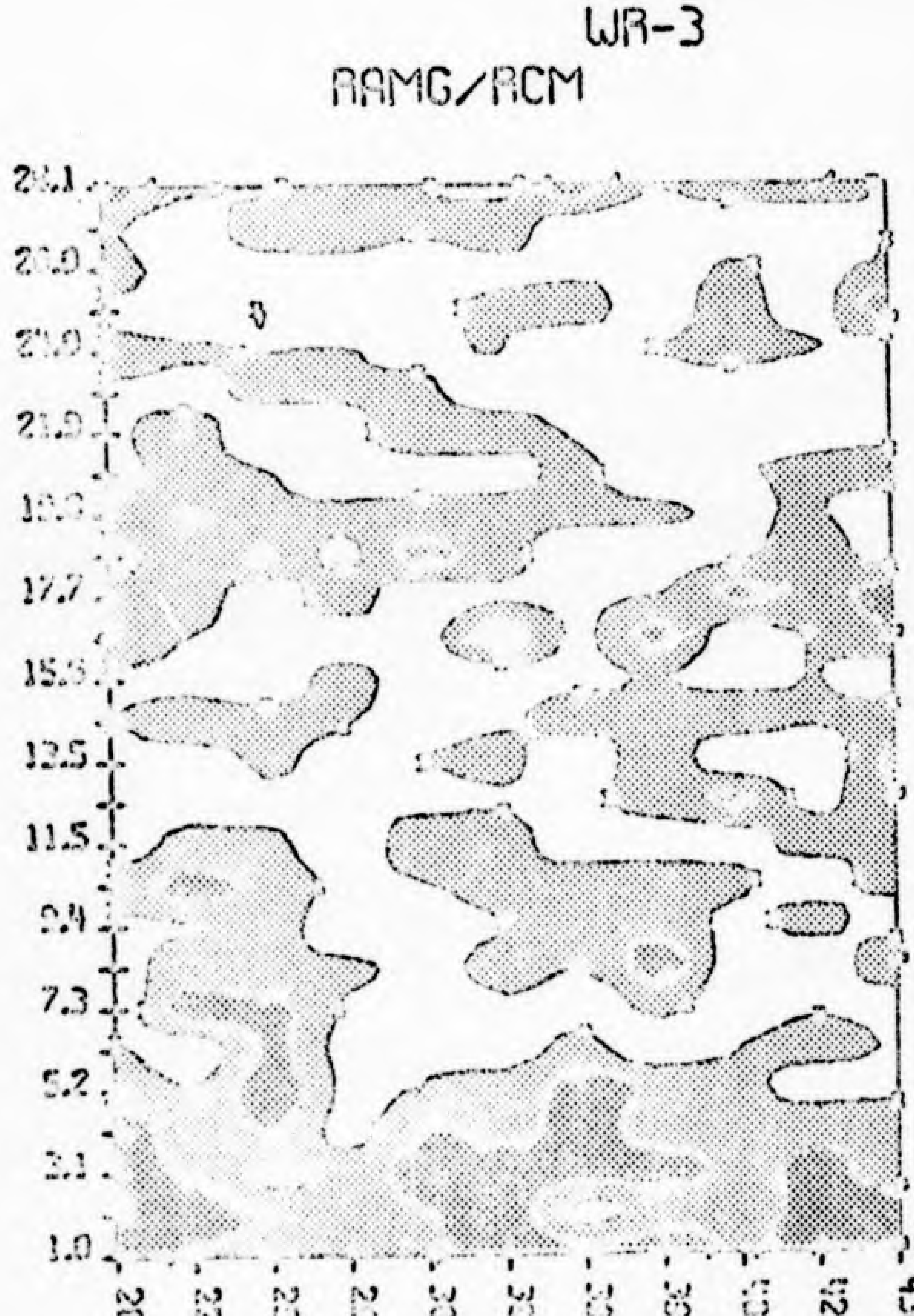


WR-3

RAMG/RHIP

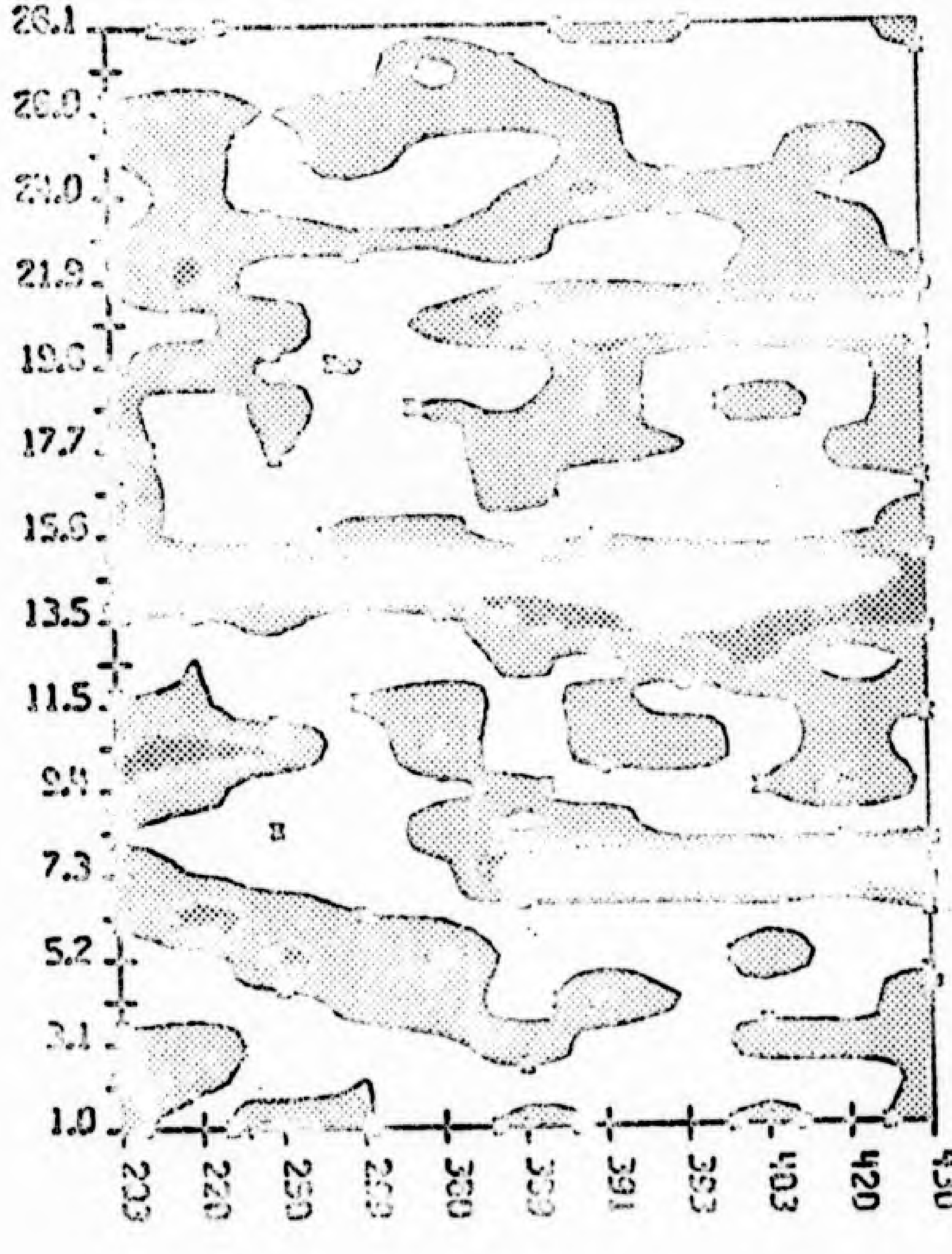


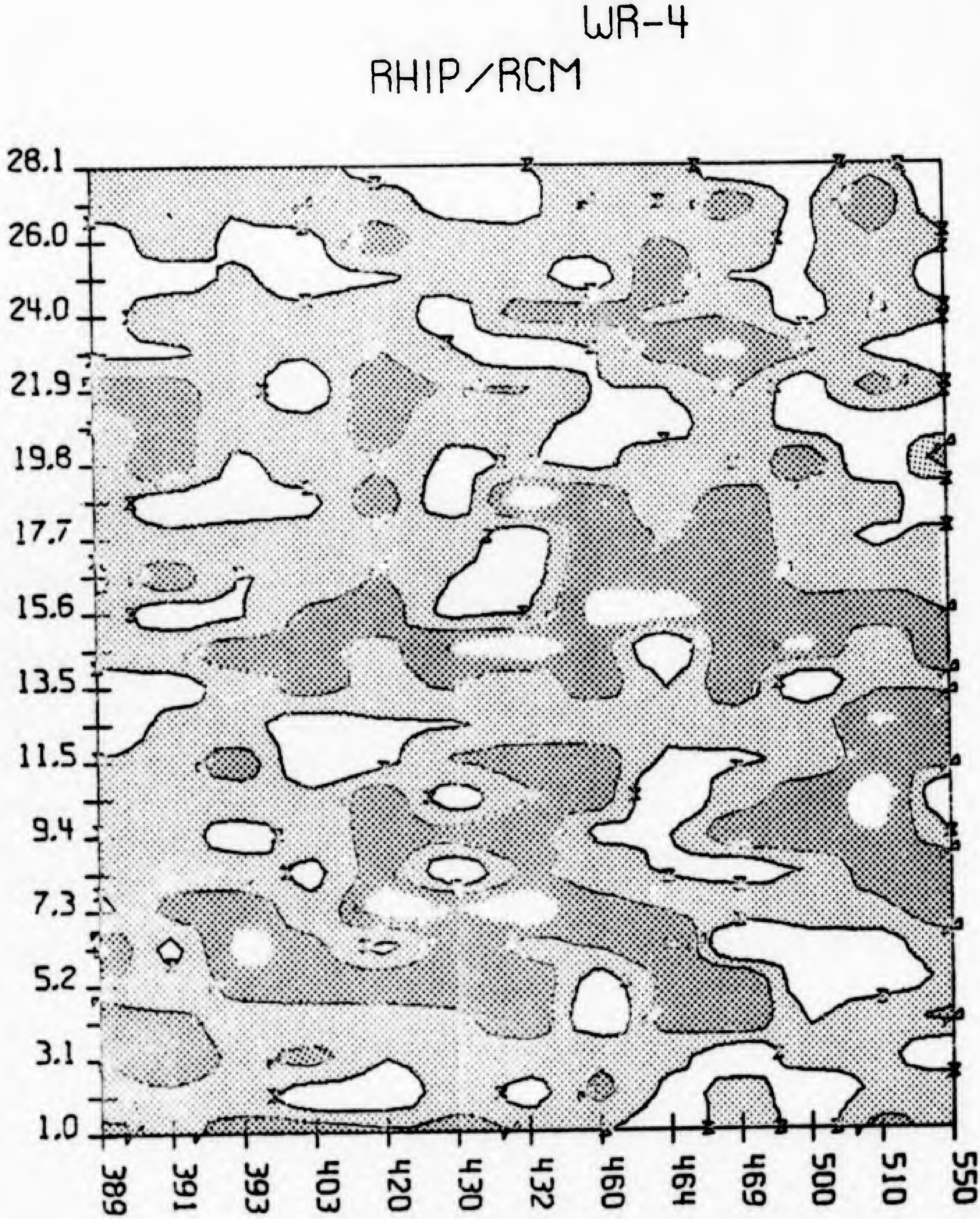

WR-3
RAMG/RVA


WR-3
RAMG/RCM

WR-3

RHIP/MODL

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RHIP/RCM
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21.9
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13.5
11.5
9.4
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3.1
1.0
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391
393
403
420
430
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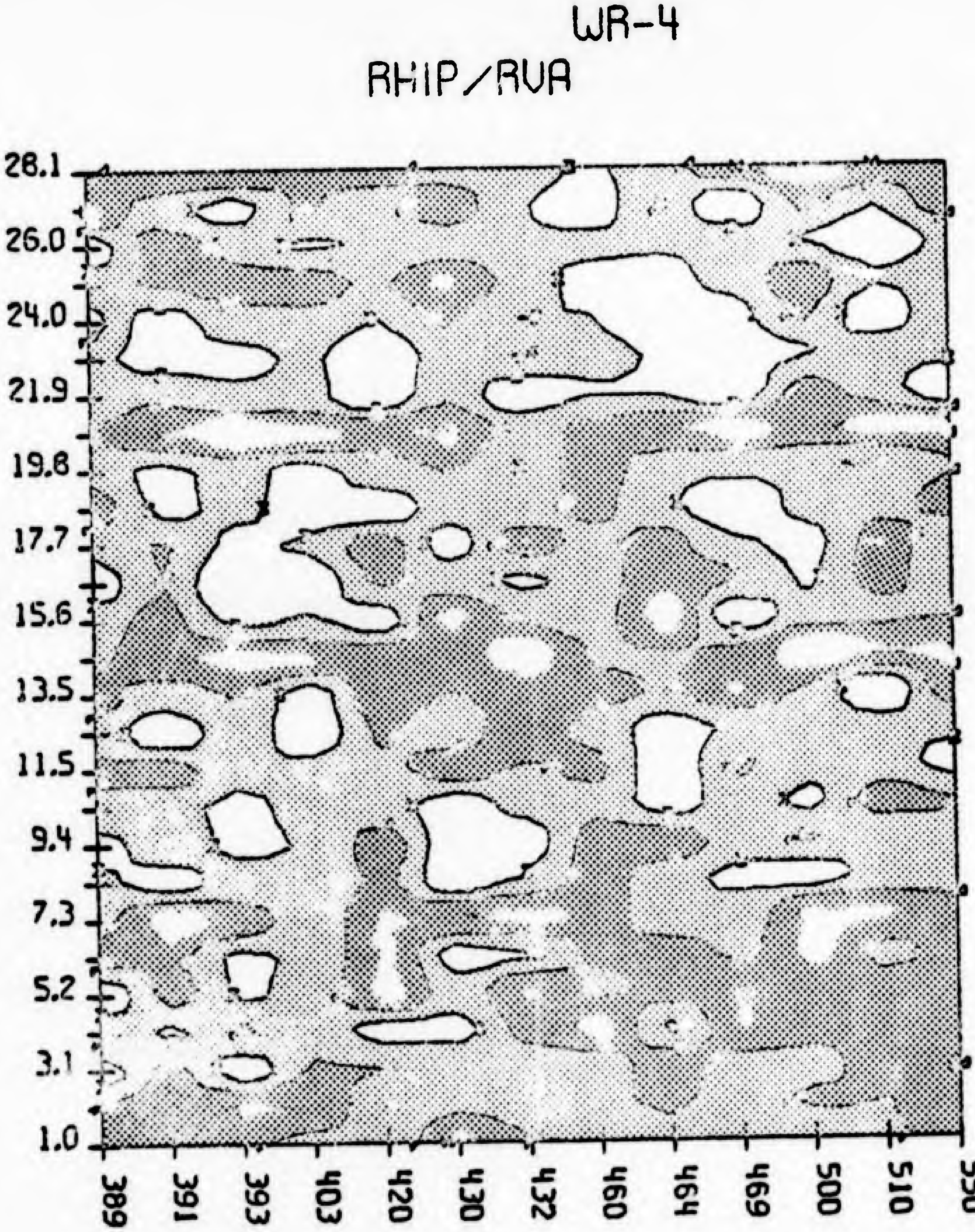
469
500
510
550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RHIP/RVA
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26.0
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9.4
7.3
5.2
3.1
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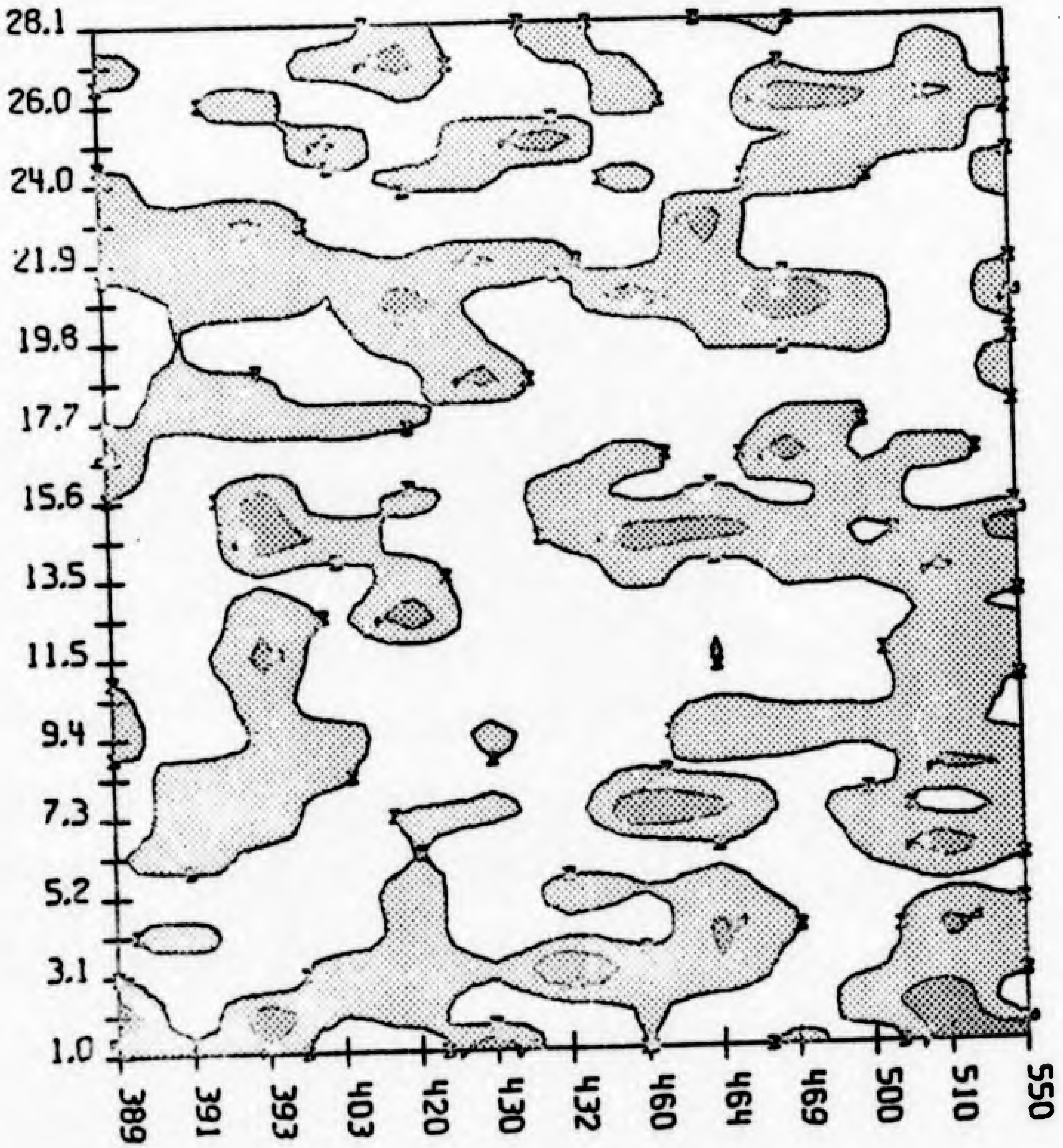
391
393
403
420
430
432
460
464
469
500
510
550

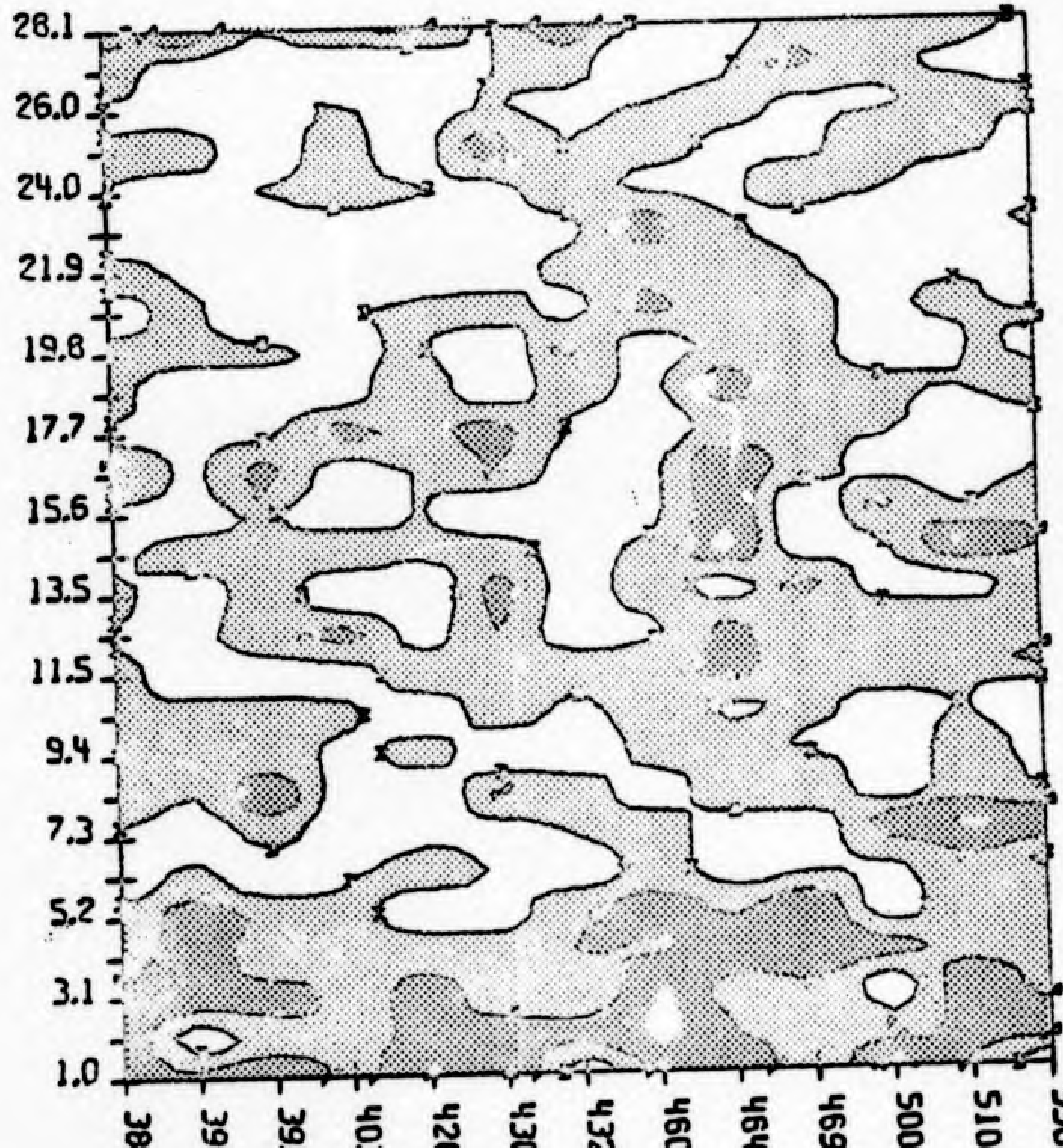
WR-4

RHIP/LUCX



WR-4

RAMG/RCM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5.2
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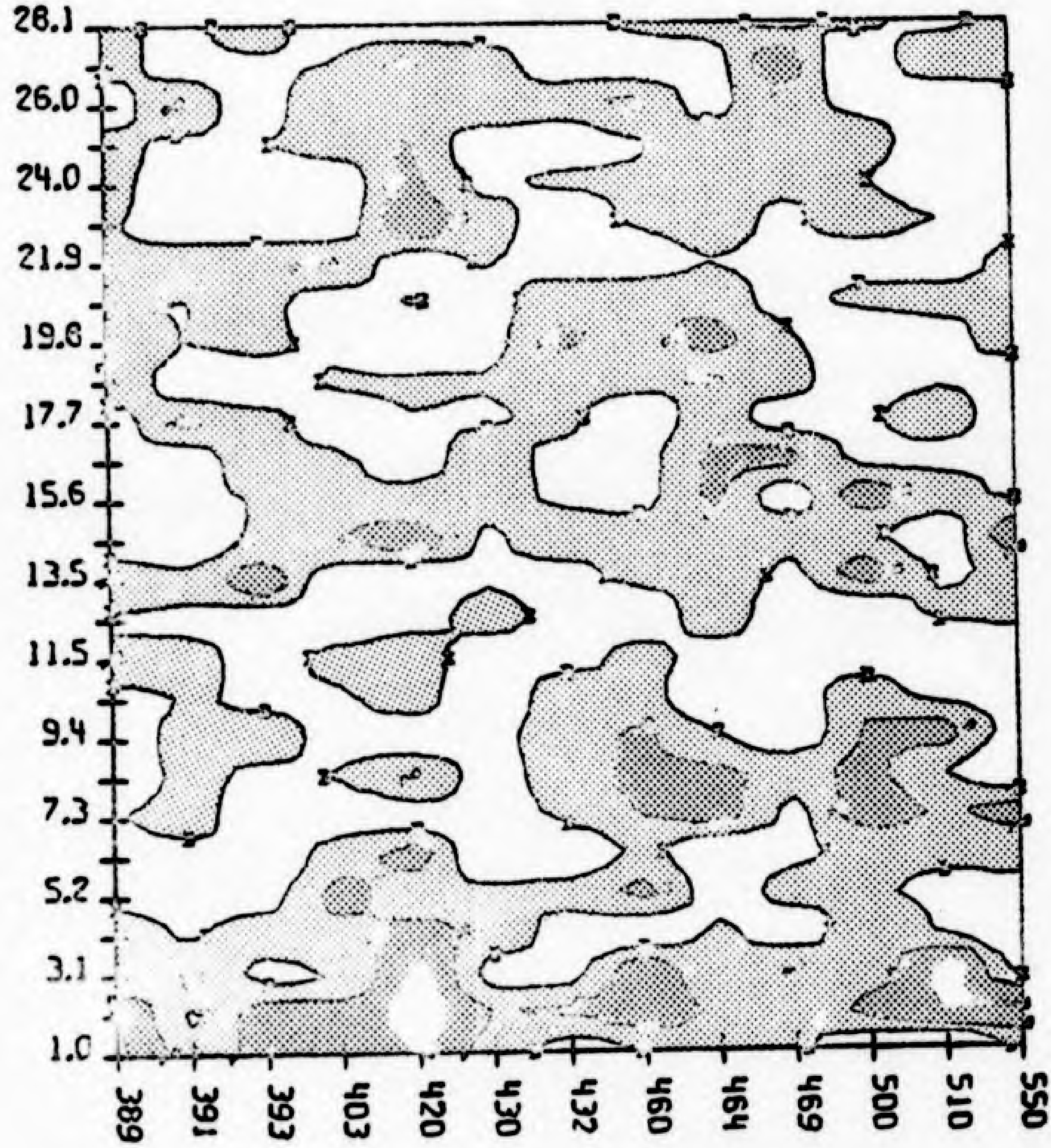
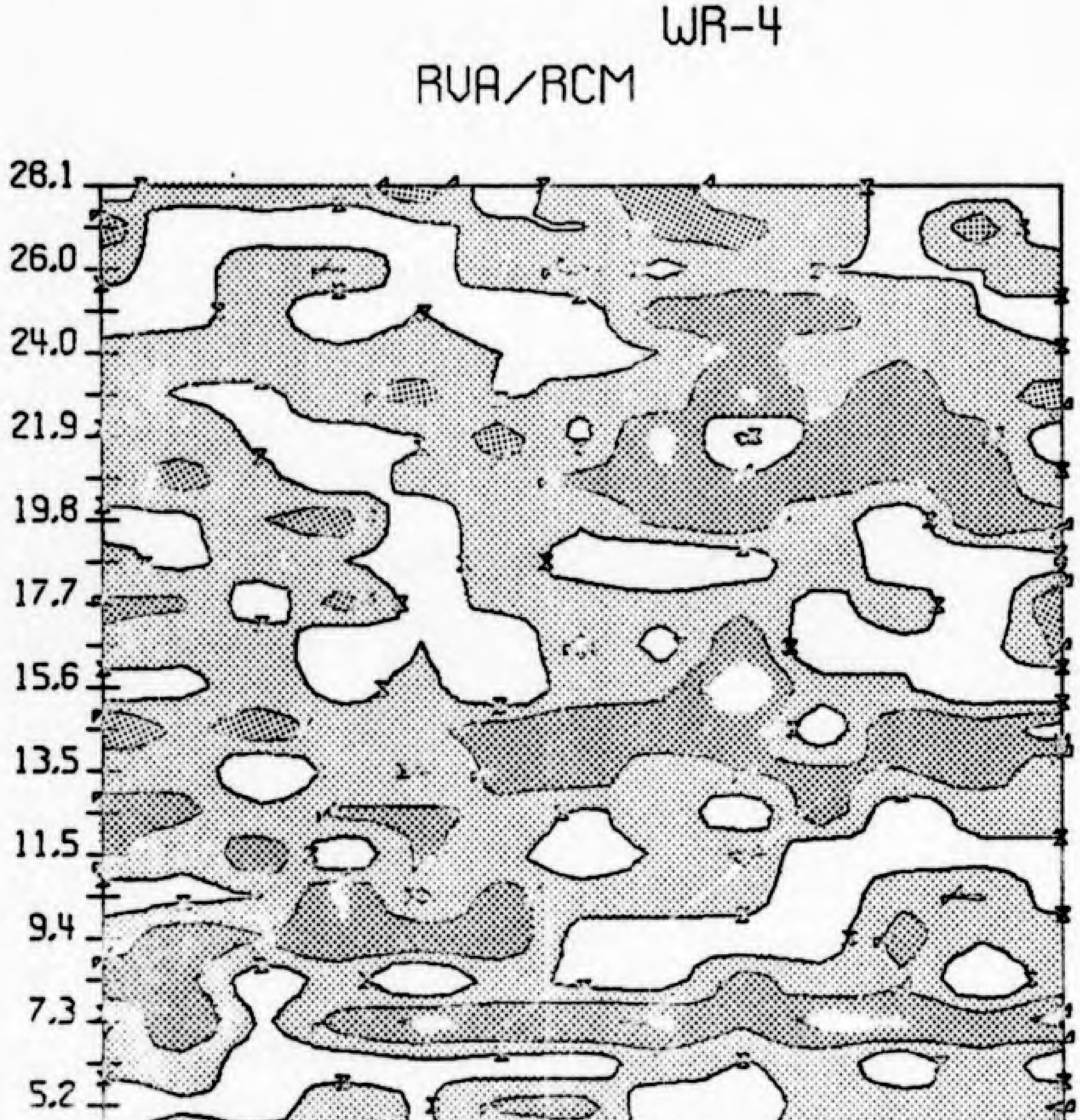
391
393
403
420
430
432
460
464
469
500
510
550

WR-4

RAMG/RMRF




WR-4
RVA/RCM
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26.0
24.0
21.9
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17.7
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13.5
11.5
9.4
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1.0
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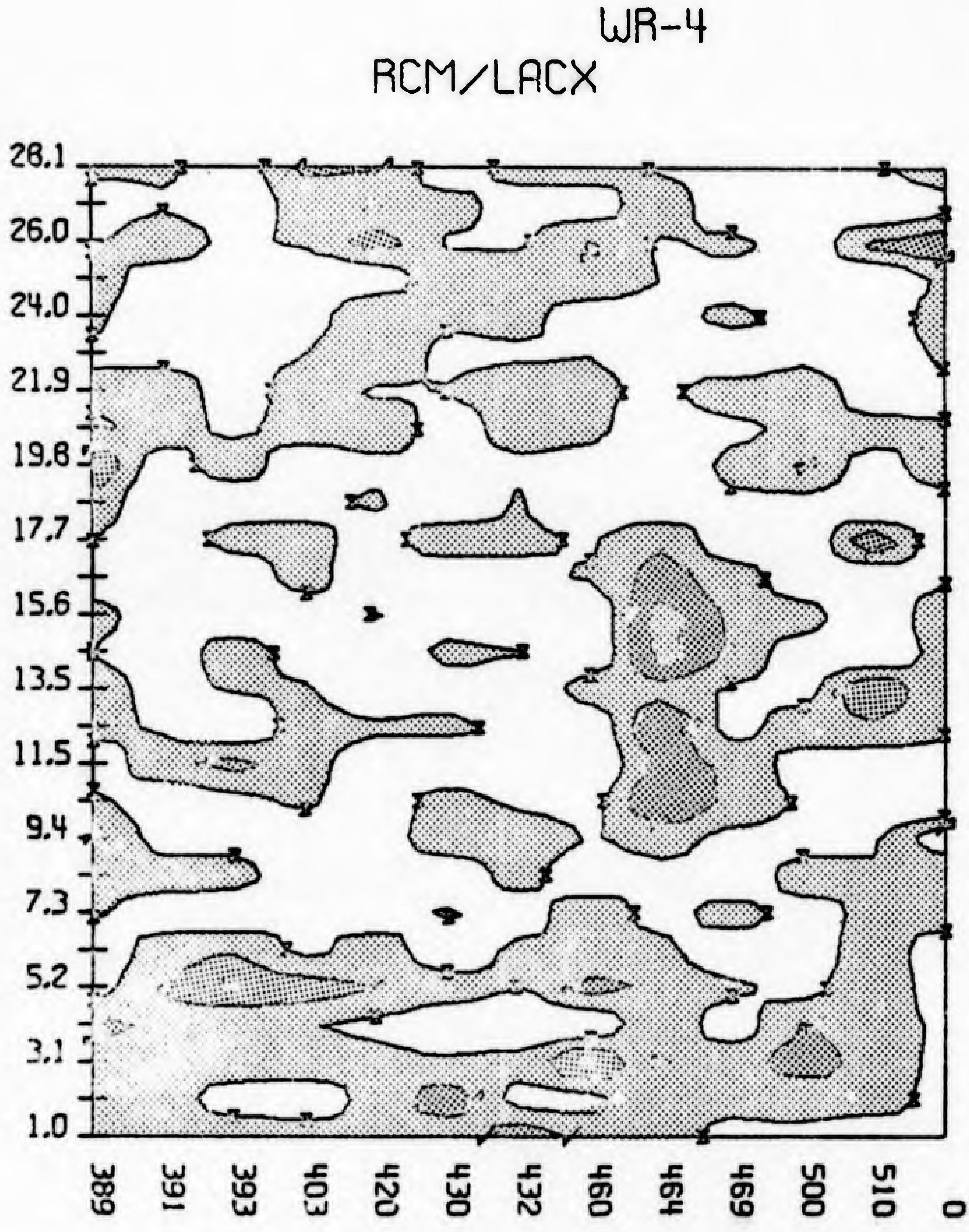
WR-4
RCM/LACX
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24.0
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13.5
11.5
9.4
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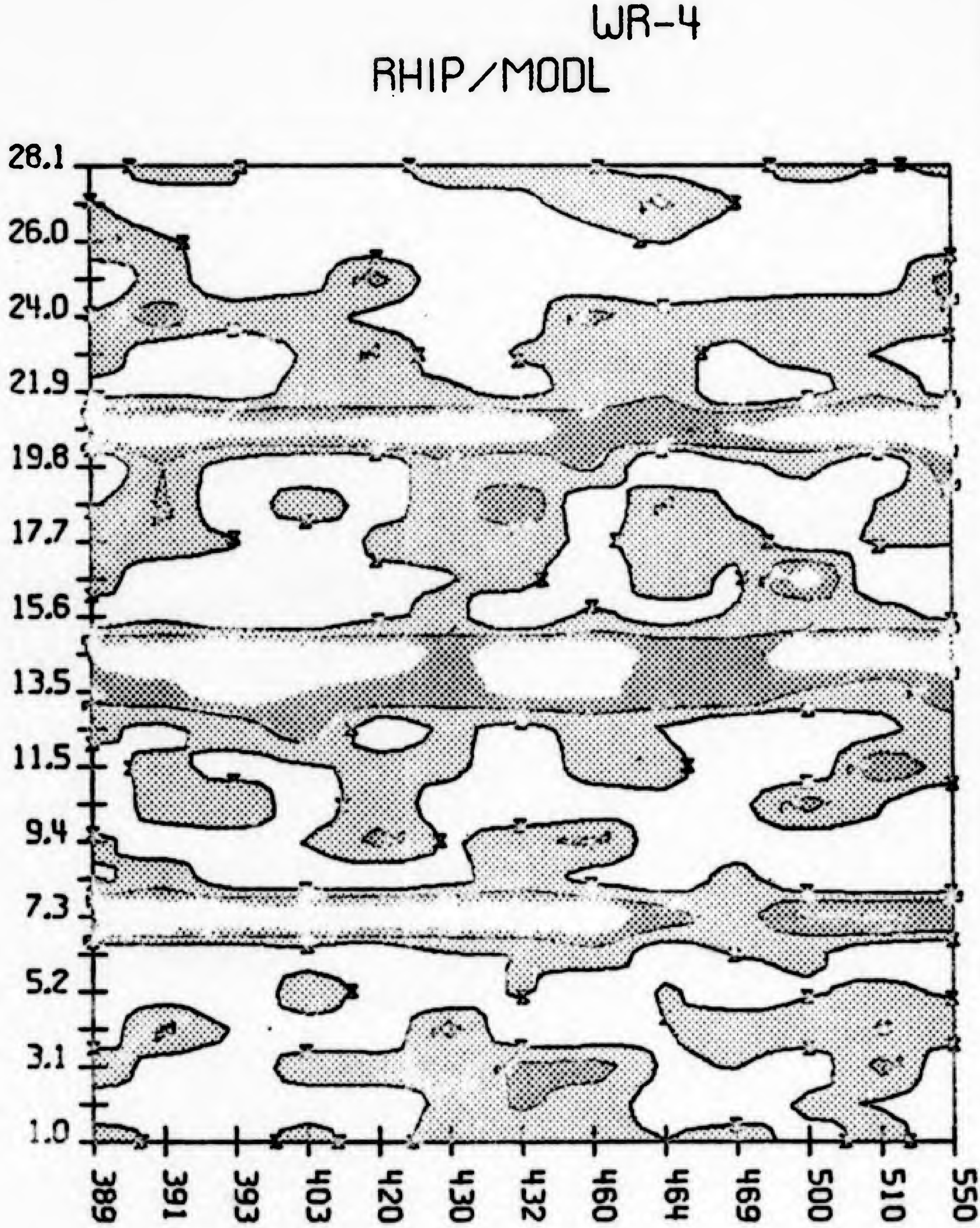
WR-4
RHIP/MODL
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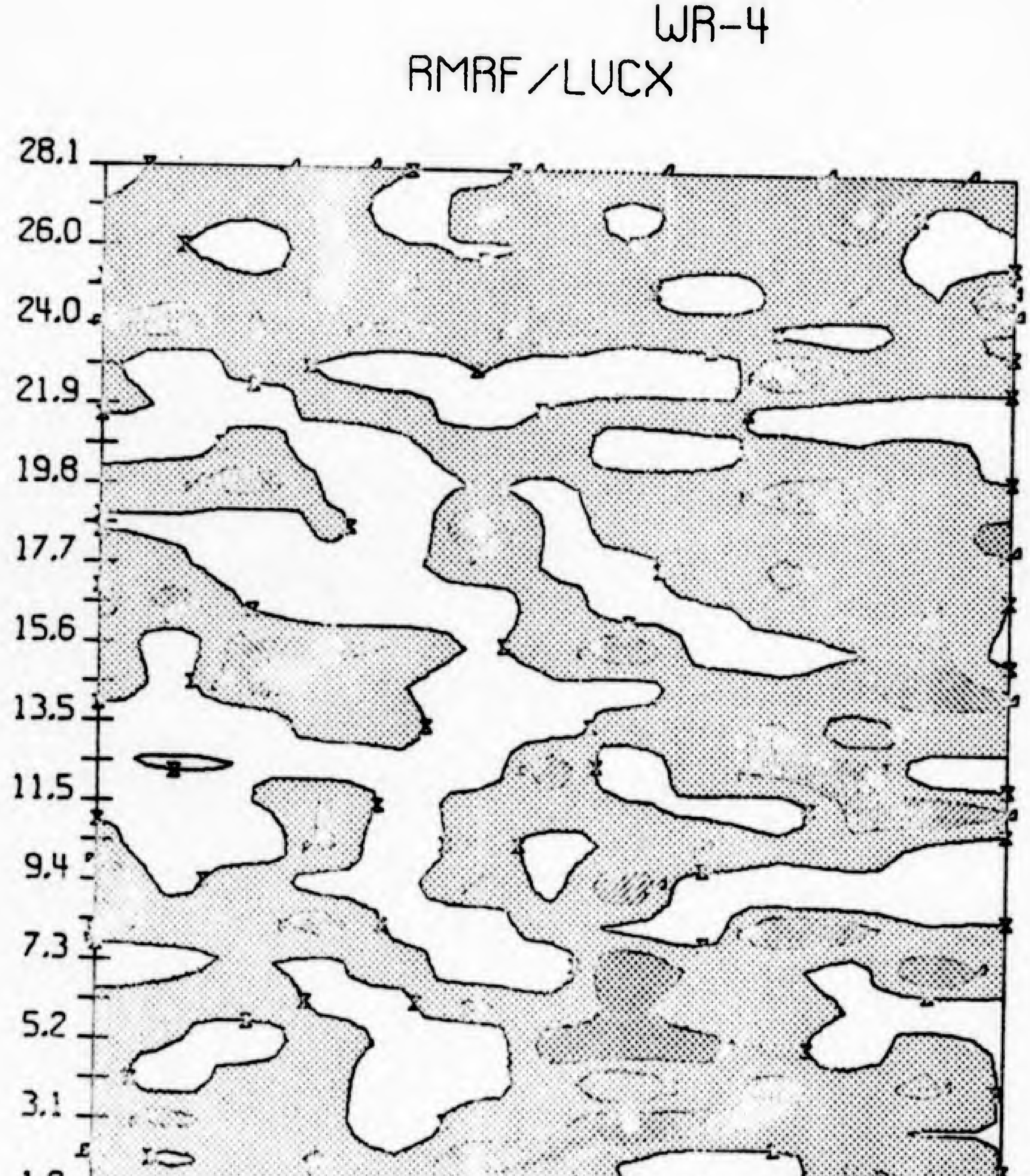
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RMRF/LVCX
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5.2
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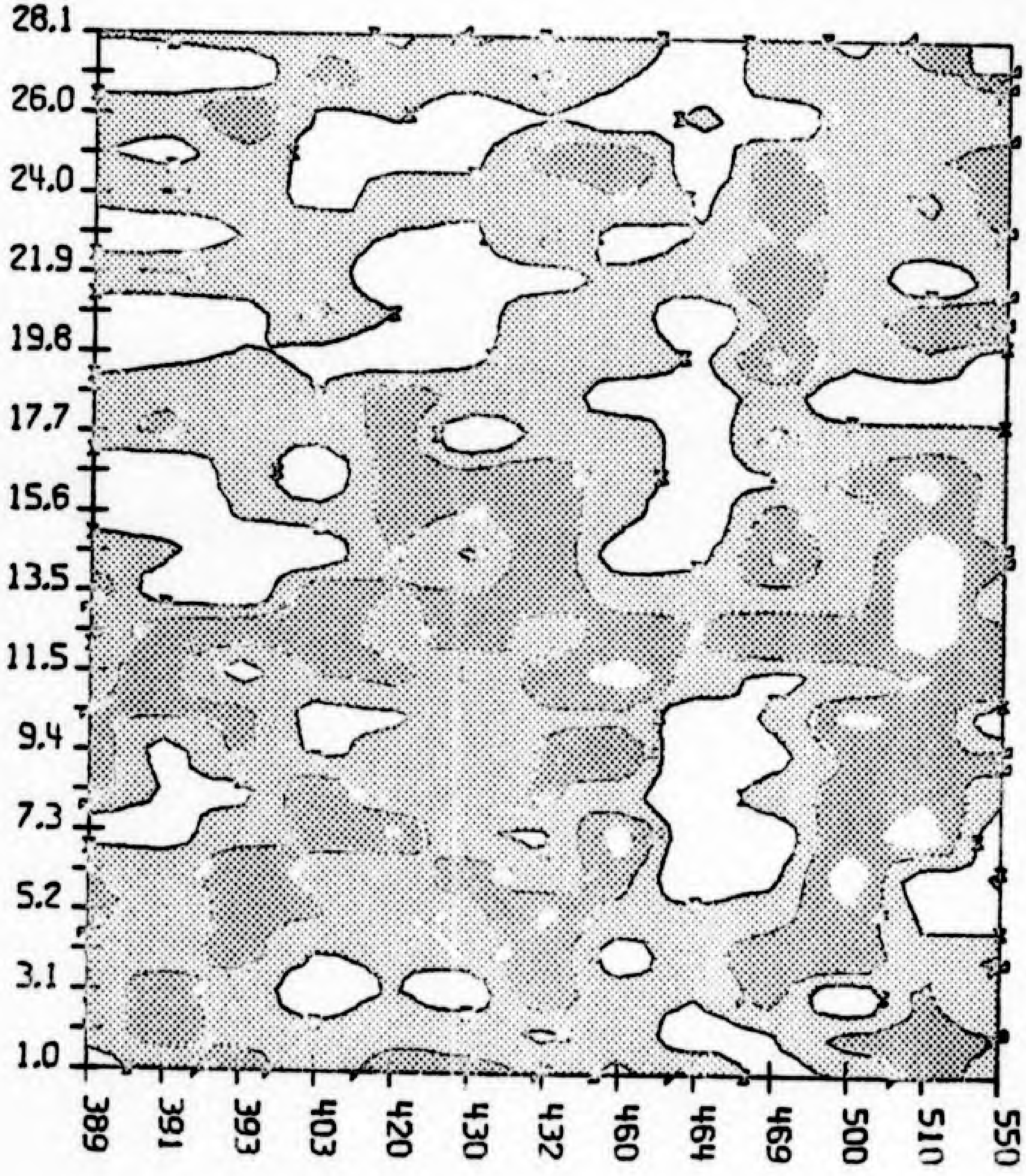
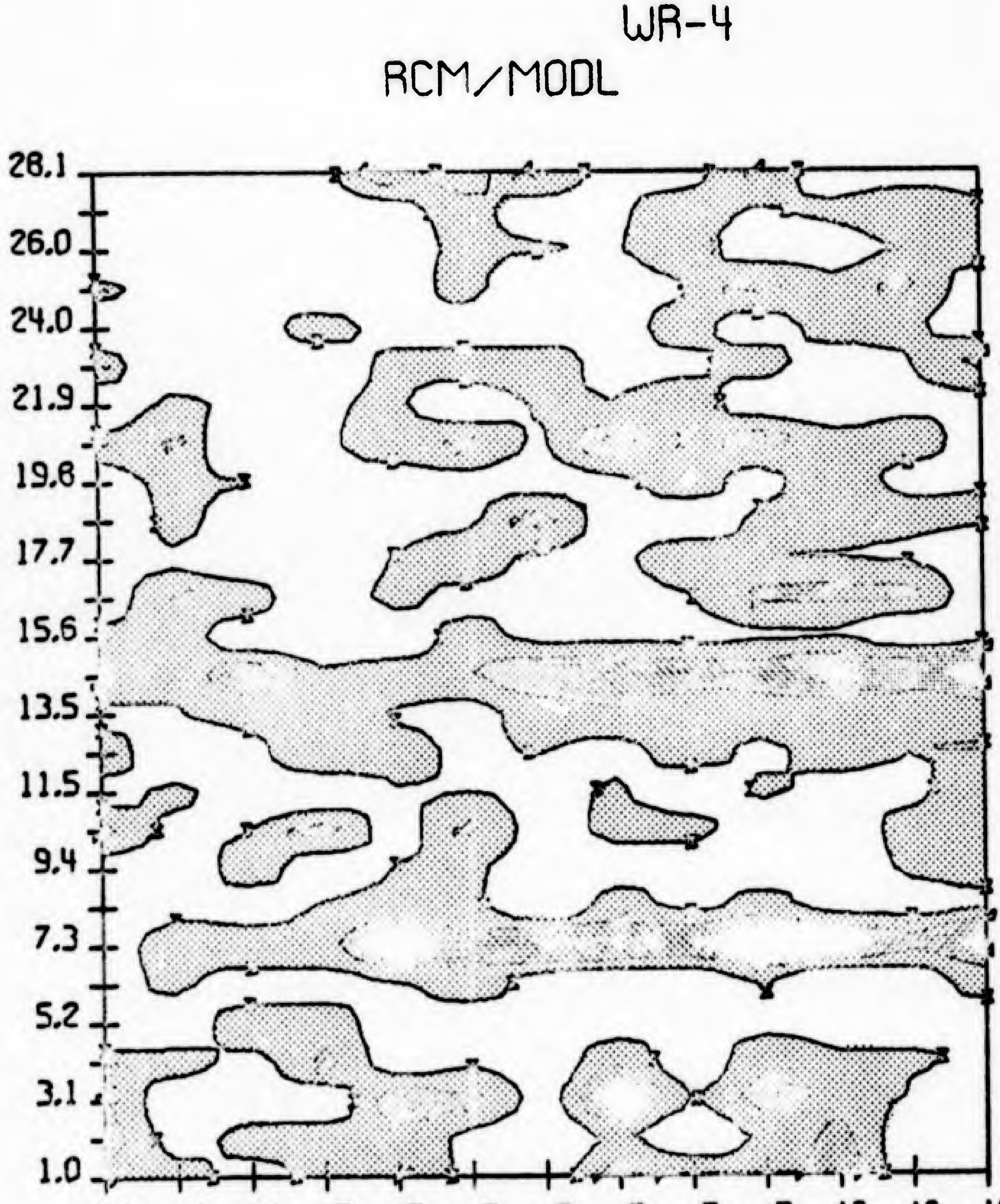
393
403
420
430
432
460
464
469
500
510
550

WR-4
RMRF/LMCX

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RCM/MODL
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11.5
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3.1
1.0
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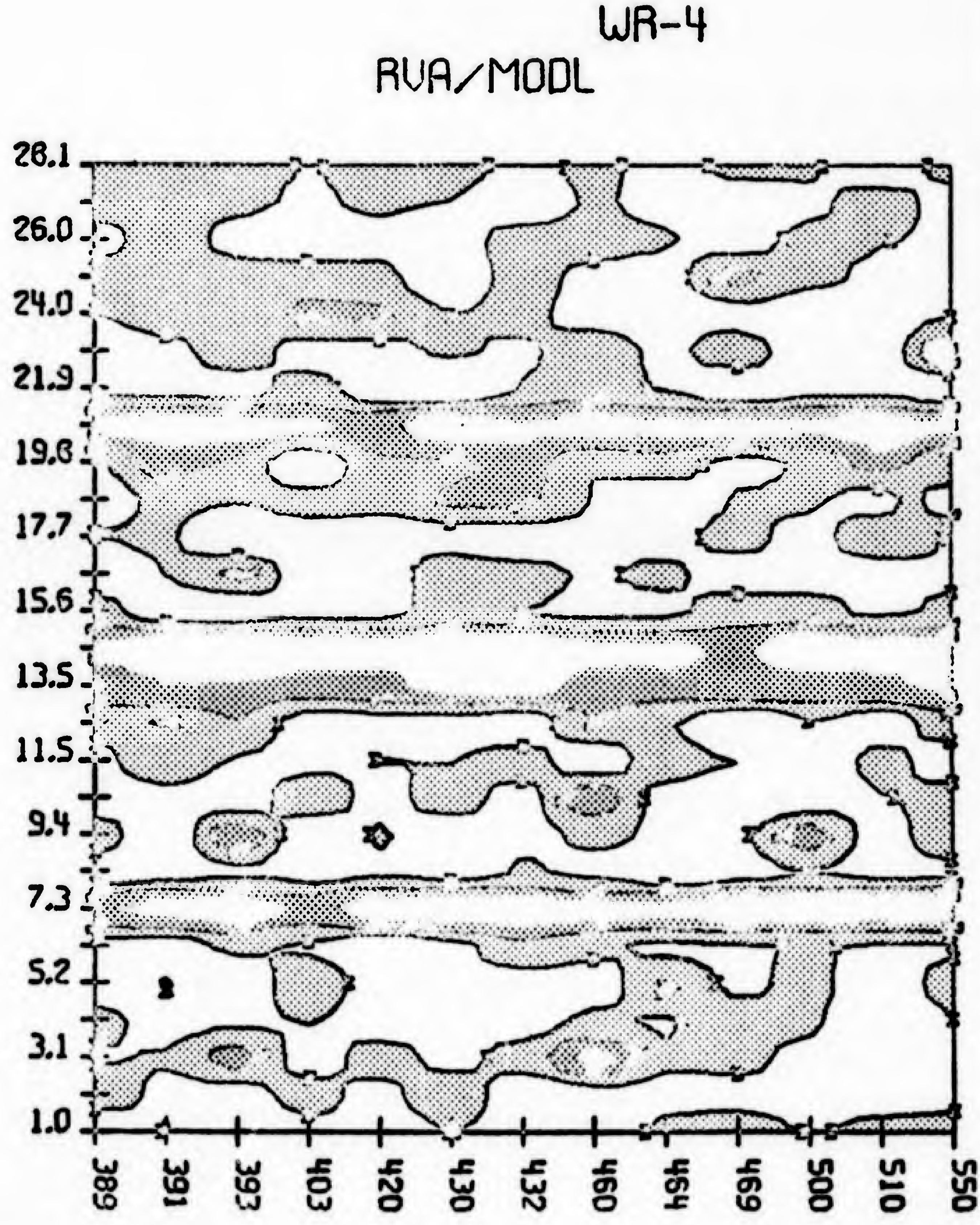
469
500
510
550


WR-4
RVA/MODL
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24.0
21.9
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17.7
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13.5
11.5
9.4
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3.1
1.0
389
391
393
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420
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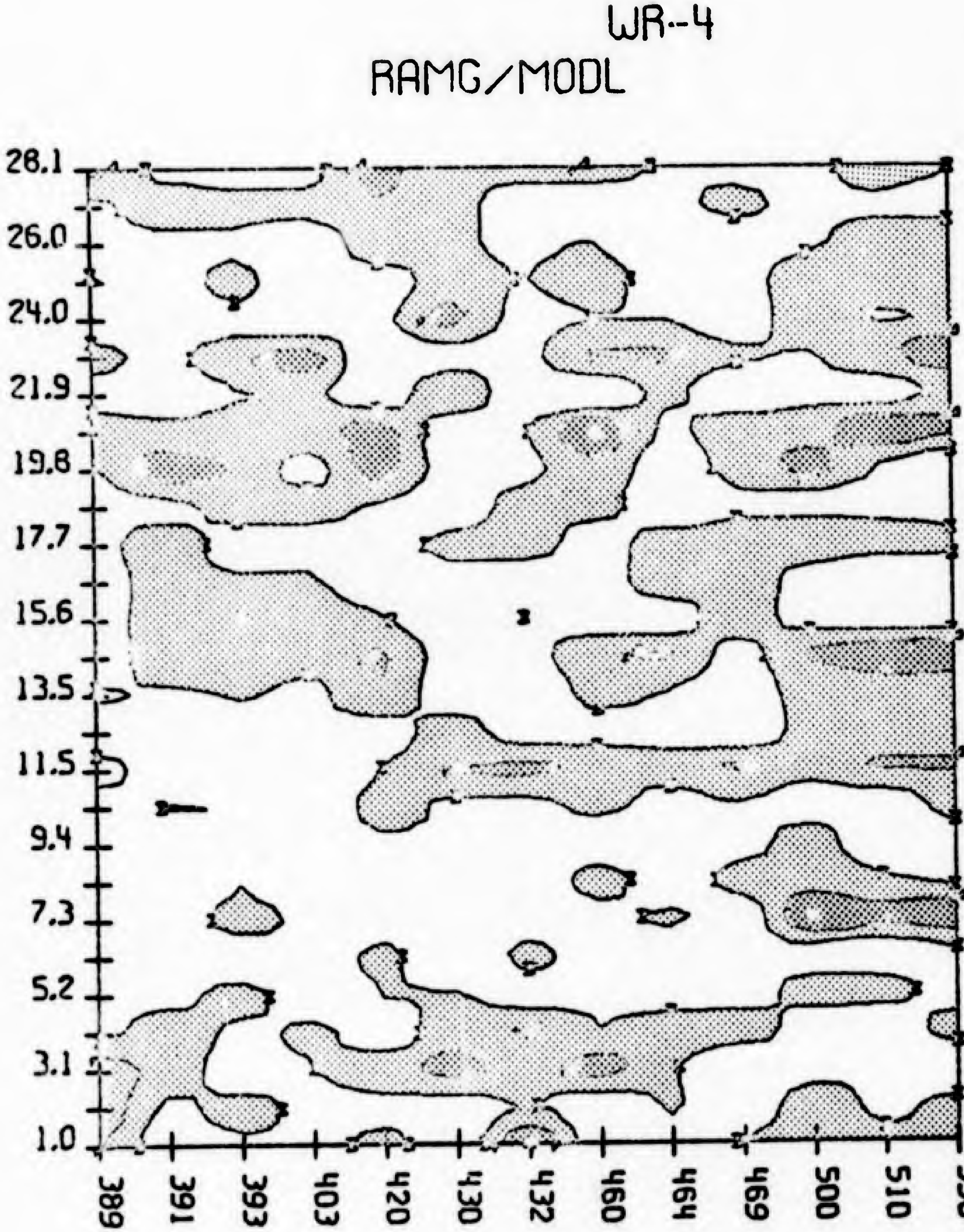
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RAMG/MODL
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391
393
403
420
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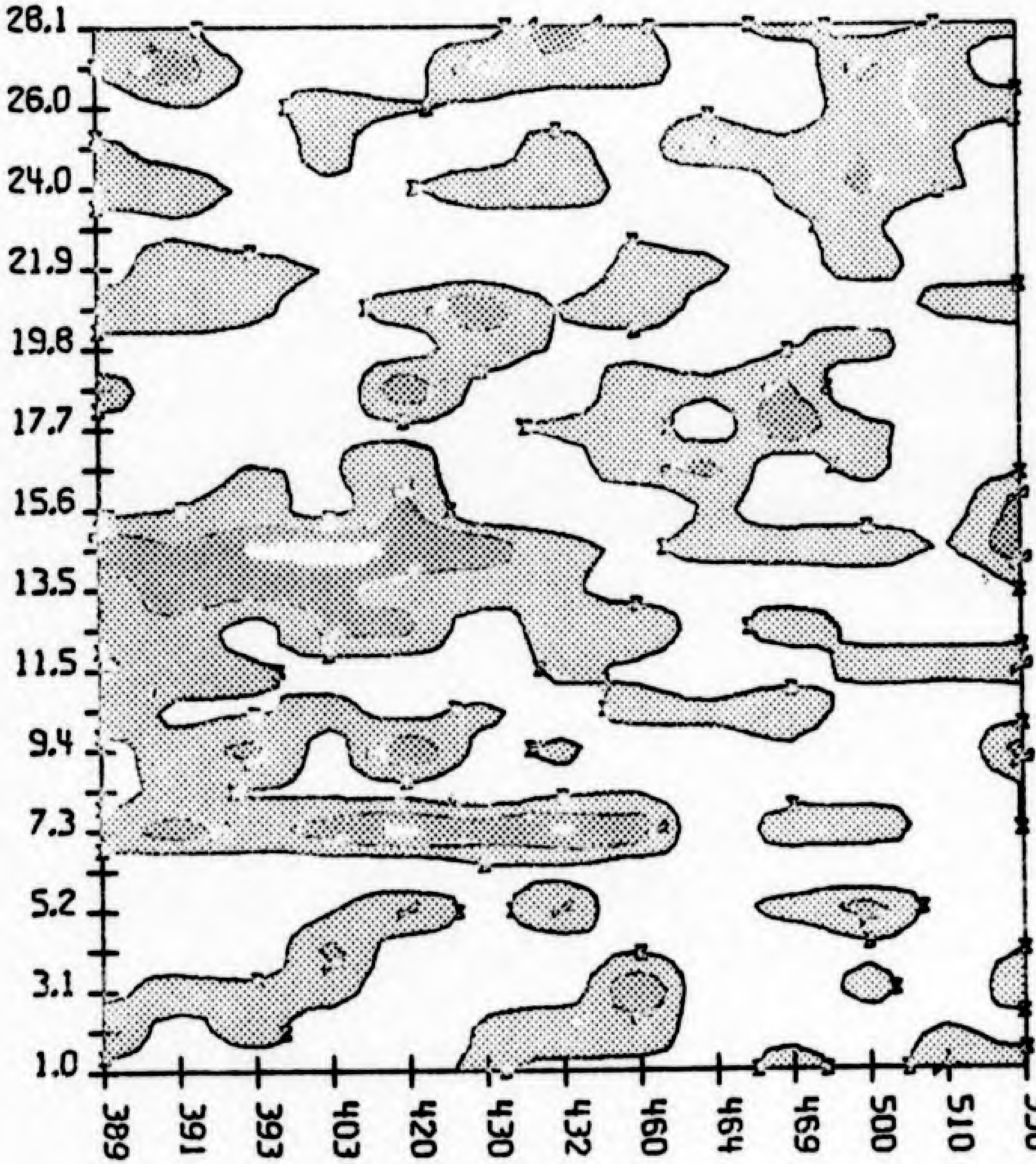
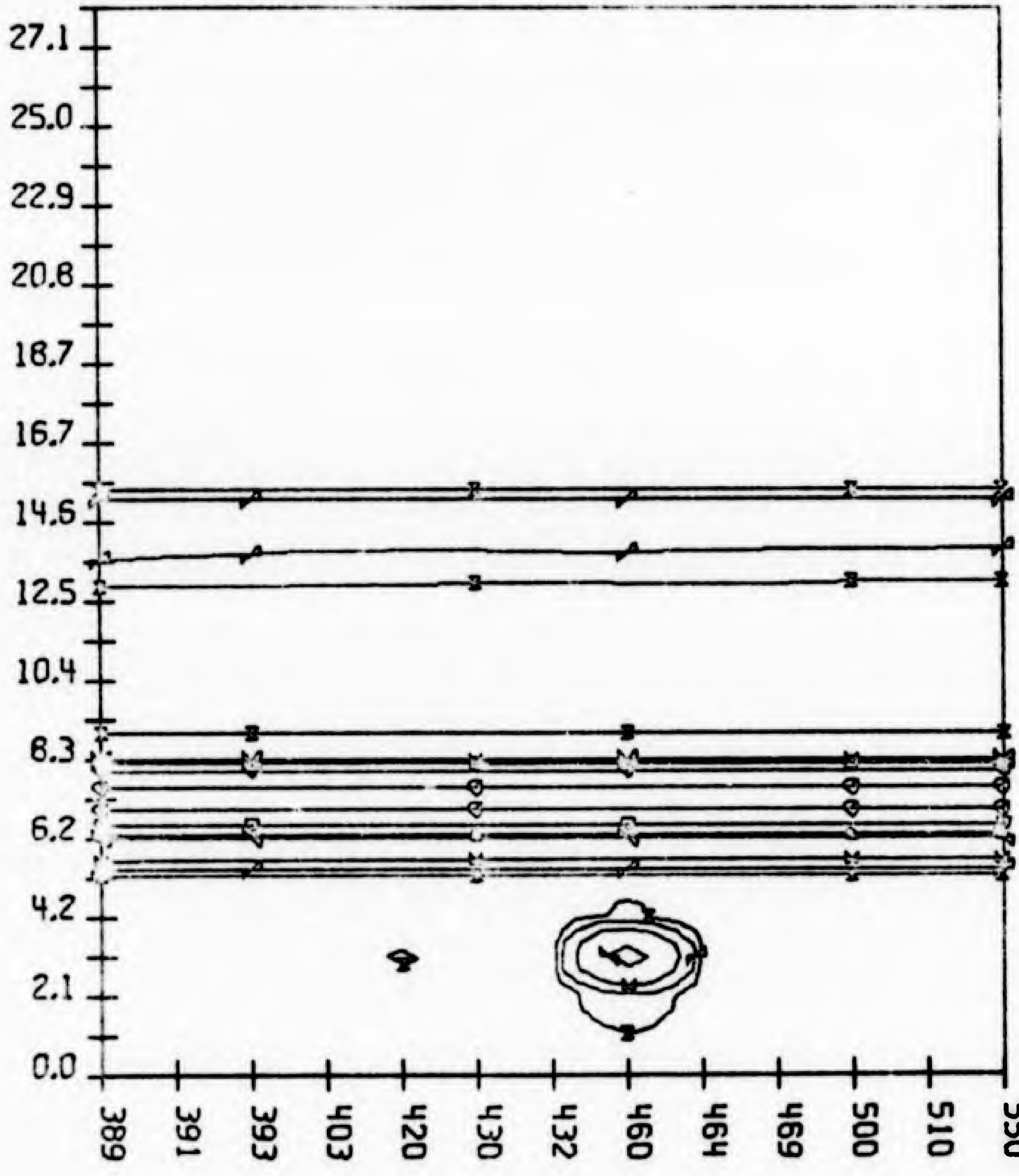
460
464
469
500
510
550

WR-4
RMRF/MODL



WR-4

MODL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14.6
12.5
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8.3
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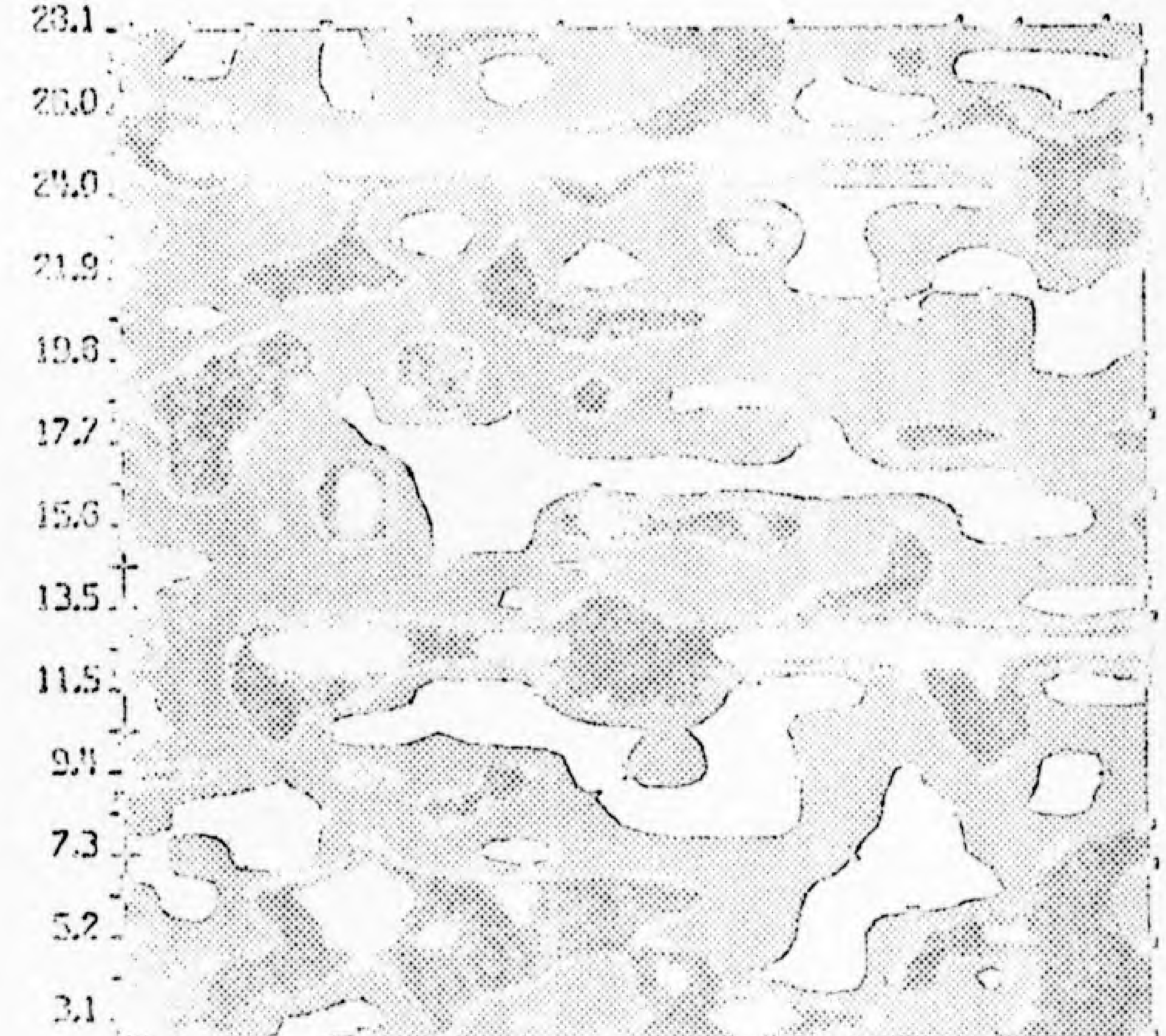
391
393
403
420
430
432
460
464
469
500
510
550

WR-5
RHIP/RVA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9.4
7.3
5.2
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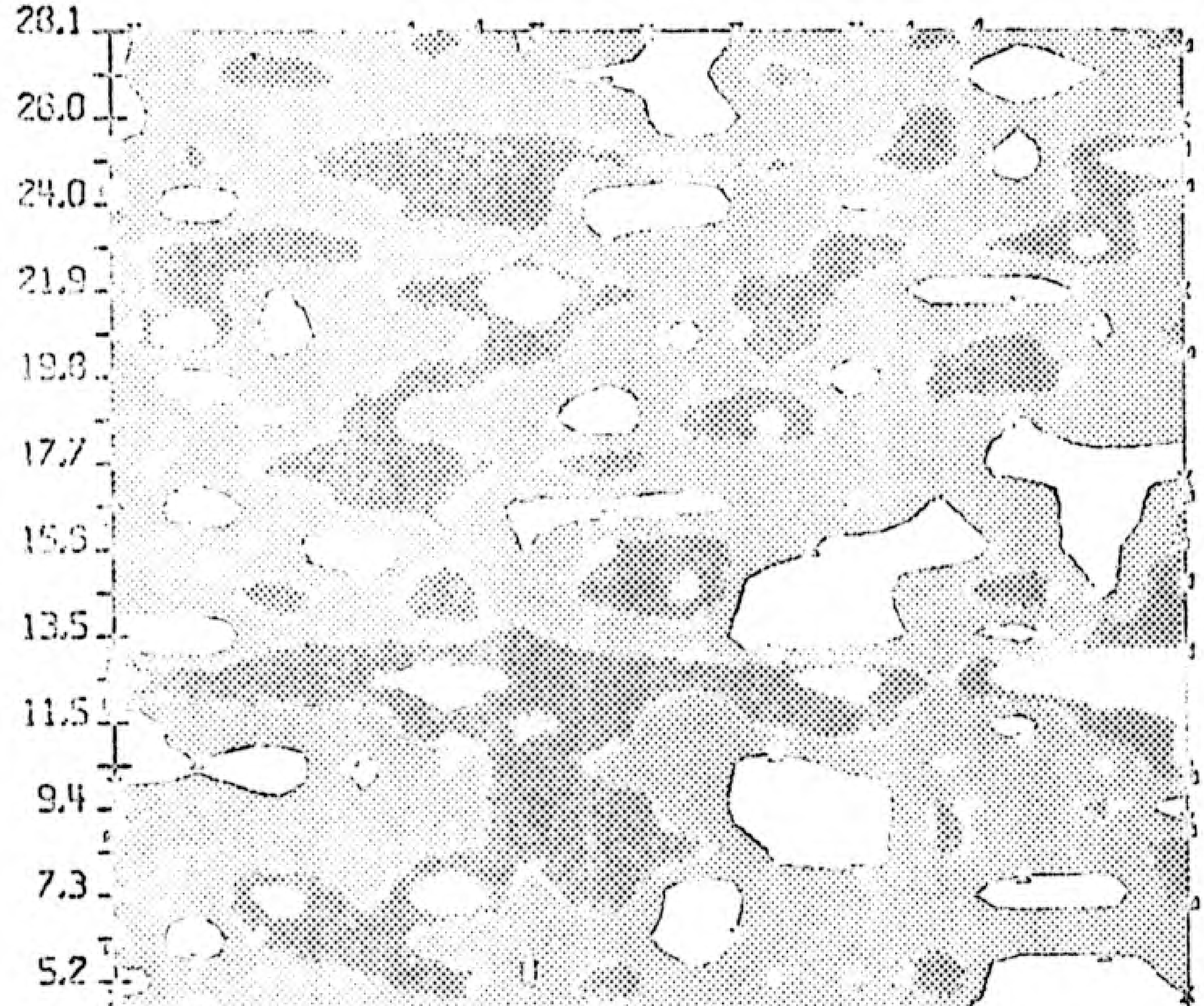
570
572
602
604
606
650
670
701
750
752
773
775

WR--5

RHIP/RCM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13.5
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9.4
7.3
5.2
3.1
1.0
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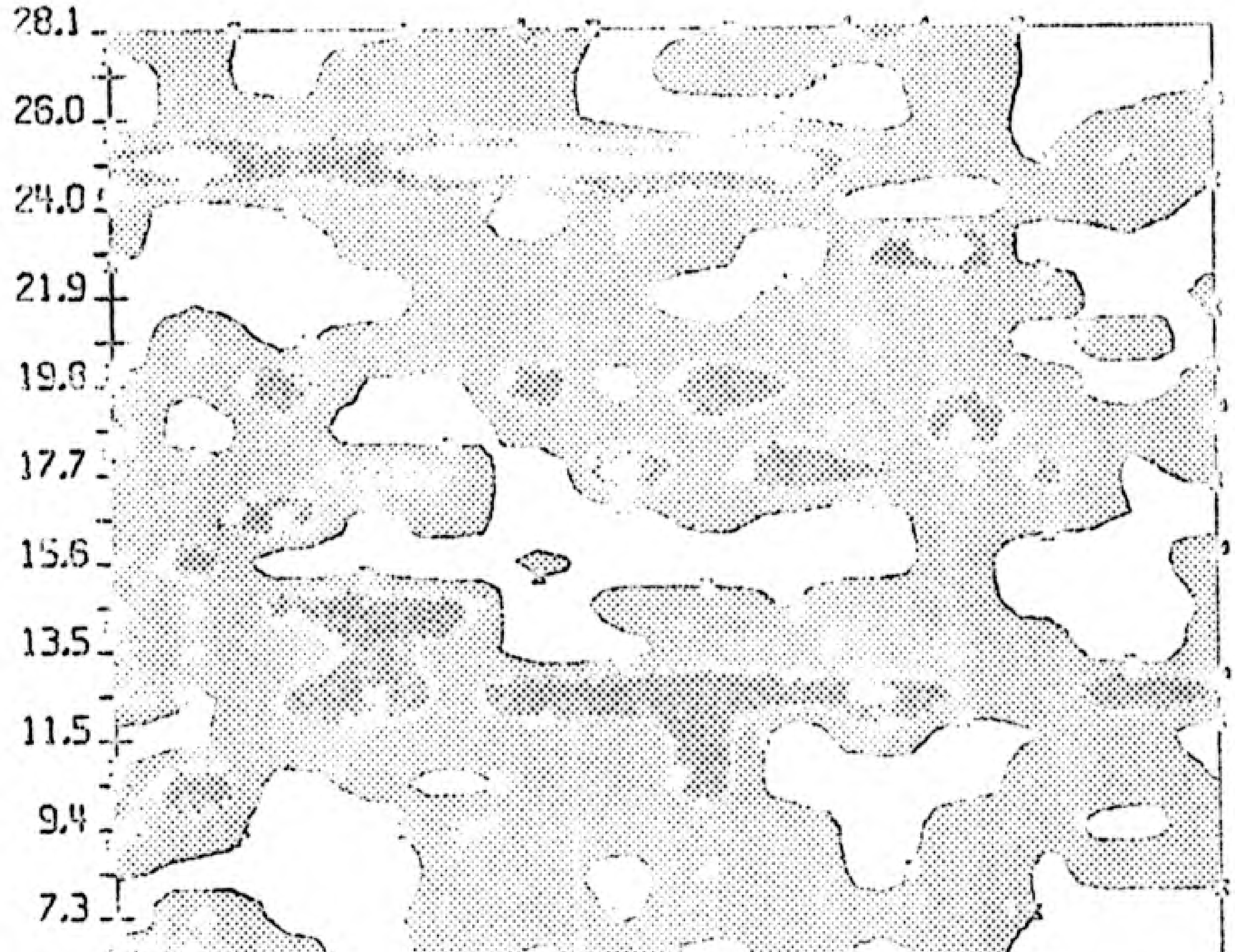
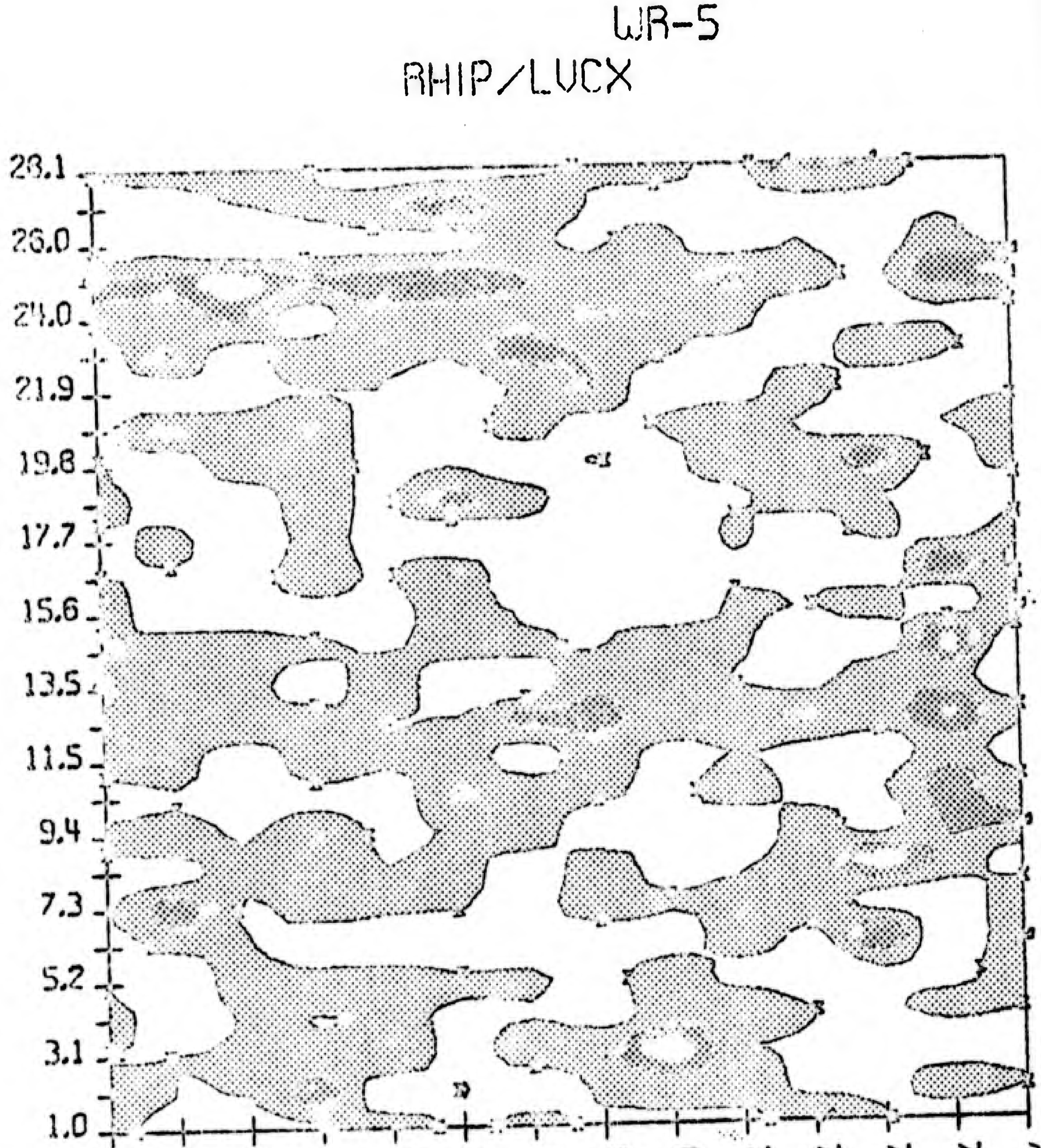
568
570
572
602
604
605
650
670
701
750
752
773
775

WR-5

RHIP/RMRF




WR-5
RHIP/LUCX
28.1
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
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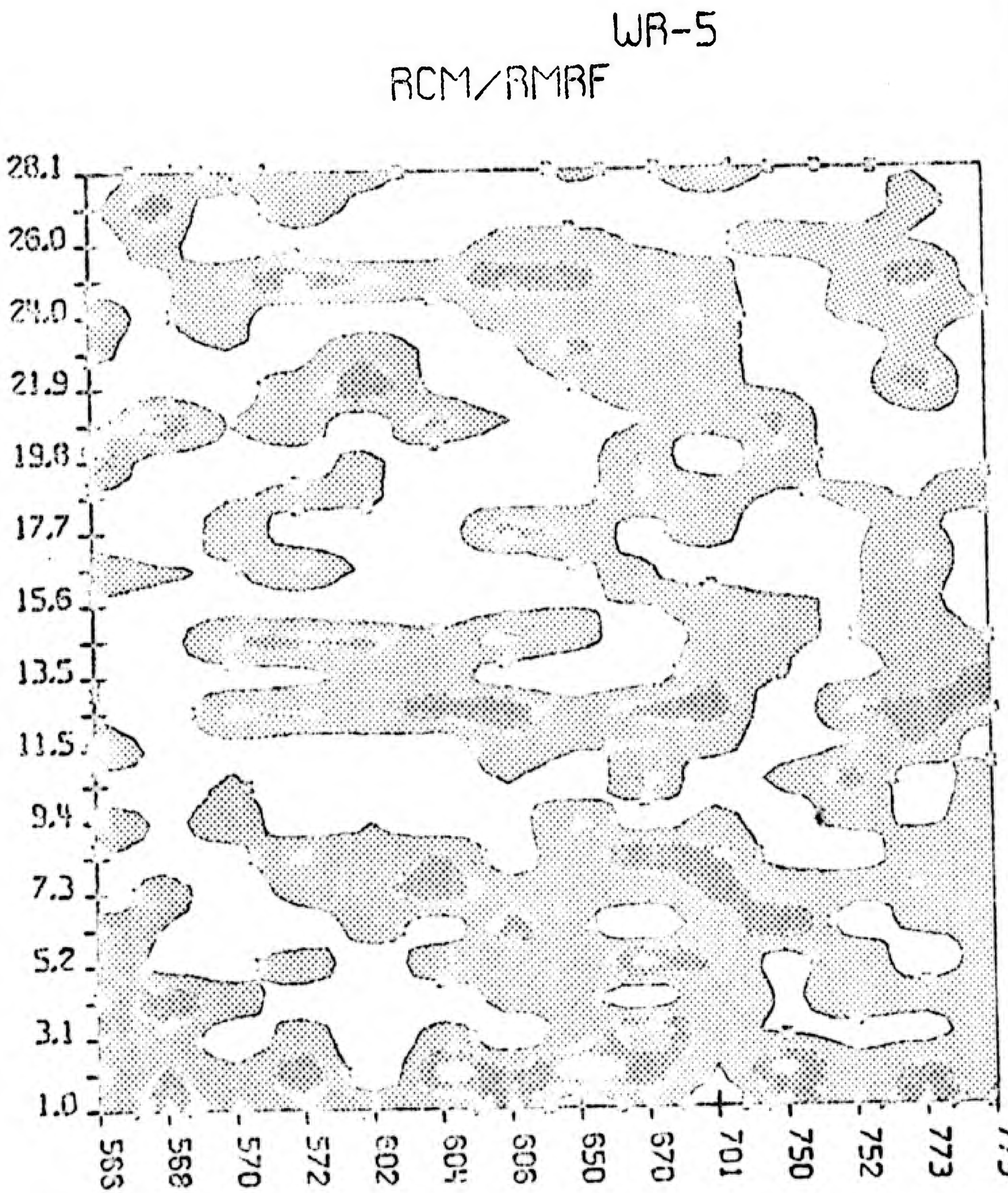
1.0
566
568
570
572
602
604
606
650
670
701
750
752
773
775


WR-5
RCM/RMRF
28.1
26.0
24.0
21.9
19.8
17.7
15.6
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11.5
9.4
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1.0
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568
570
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602
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701
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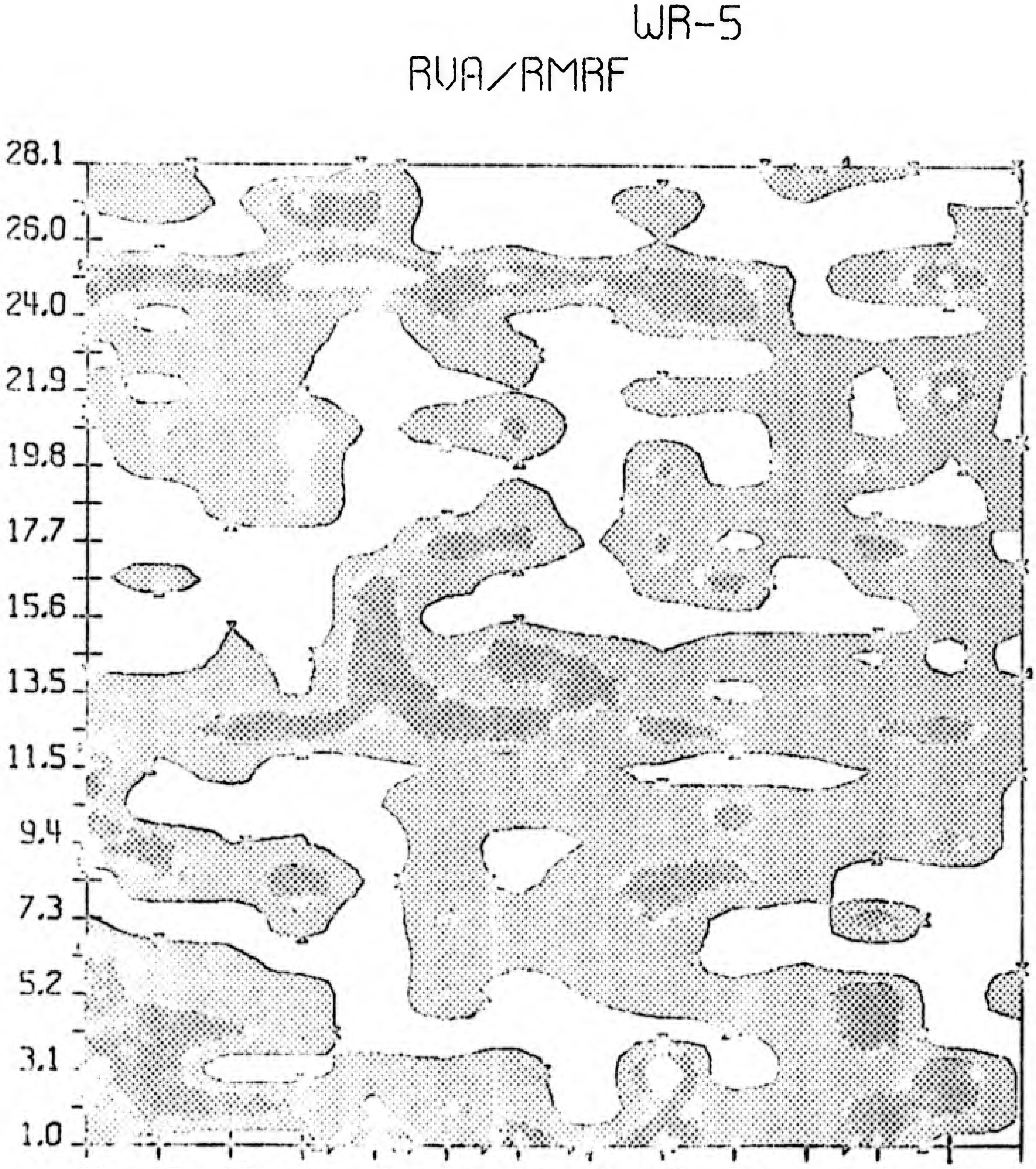
773


WR-5
RVA/RMRF
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9.4
7.3
5.2
3.1
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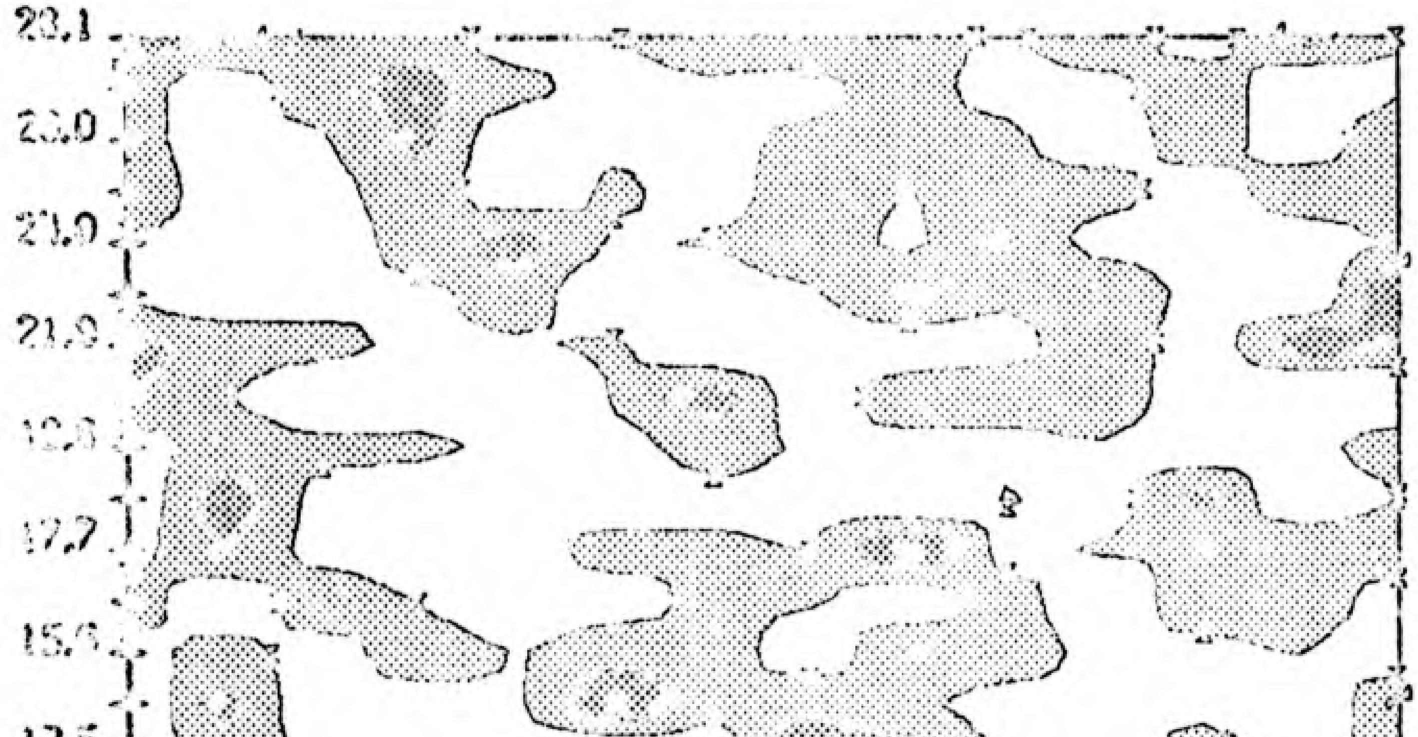
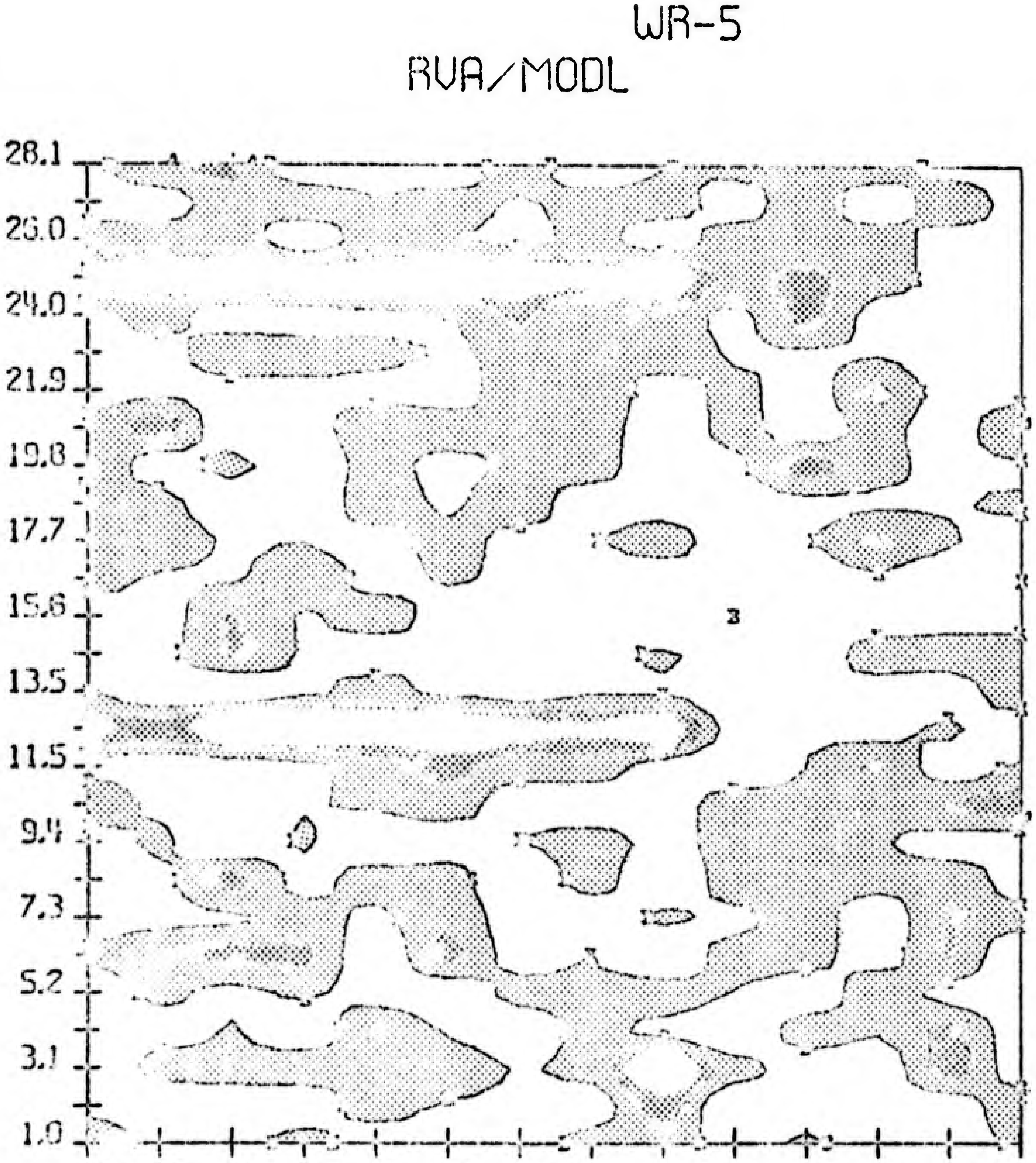
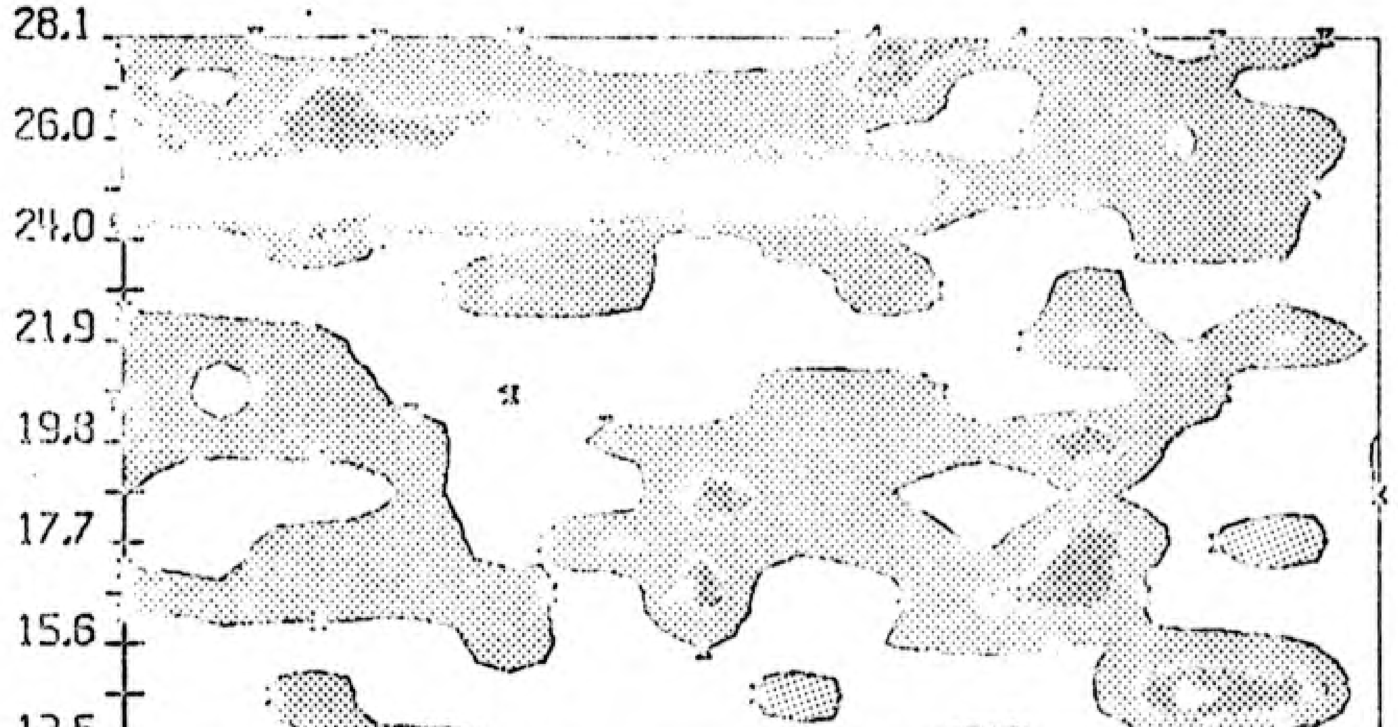
570
572
602
604
606
650
670
701
750
752
773
775

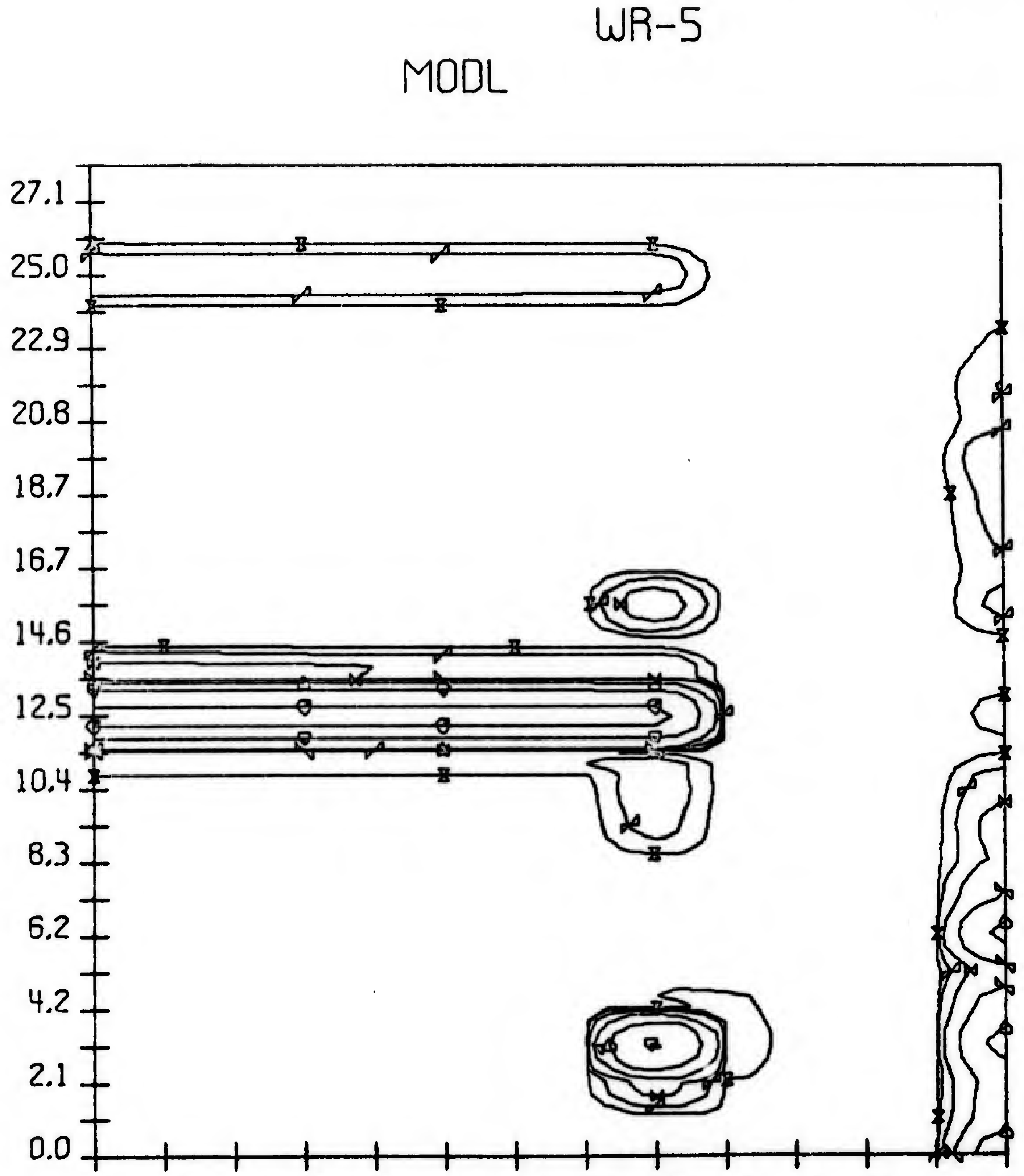
WR-5
LACX/LMCX




WR-5
RVA/MODL
28.1
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
566
568
570
572
602
604
606
650
670
701
750
752
773
775

WR-5
RHIP/MODL

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MODL
27.1
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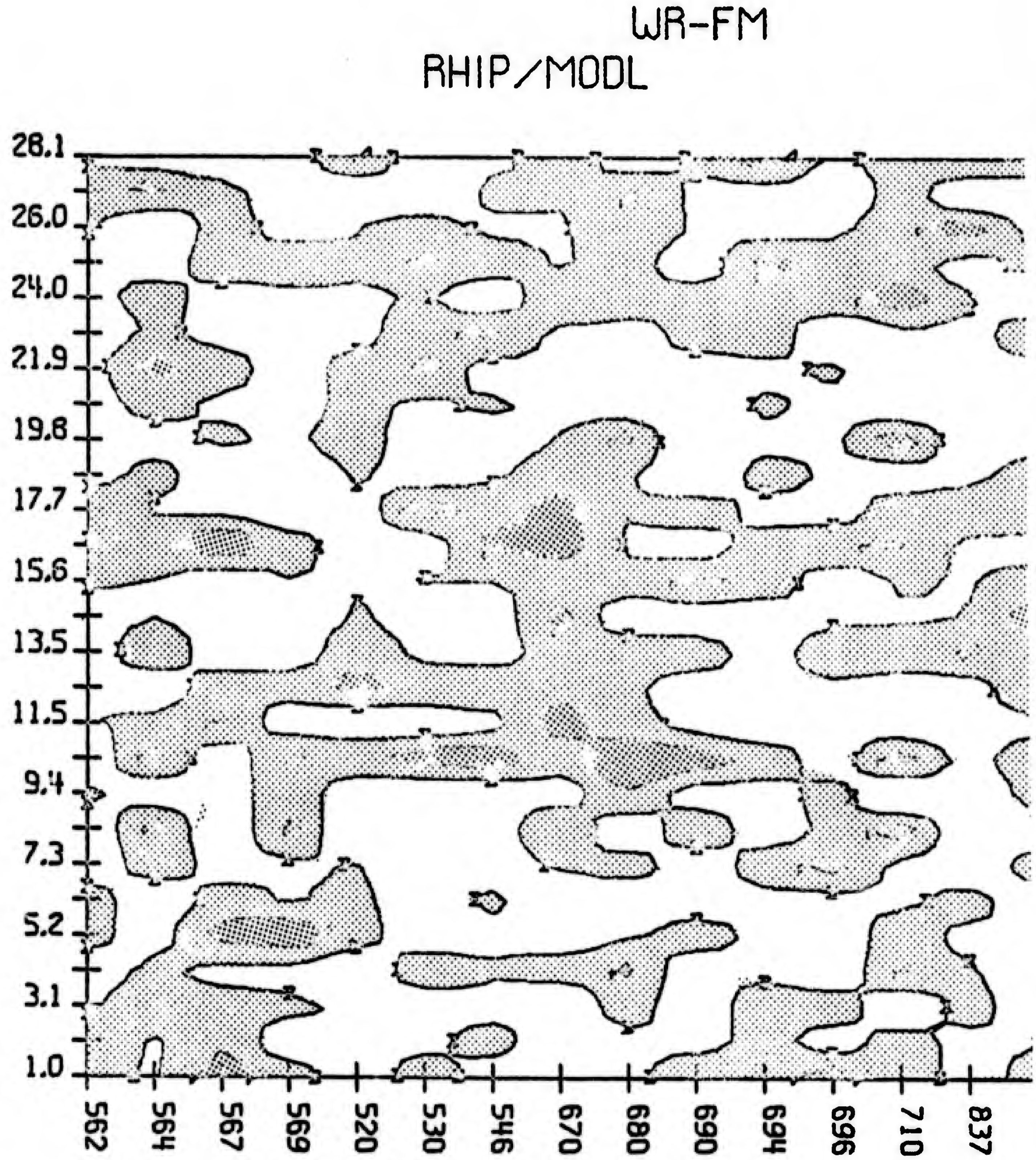
22.9
20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
0.0
566
568
570
572
602
604
606
650
670
701
750
752
773
775


WR-FM
RHIP/MODL
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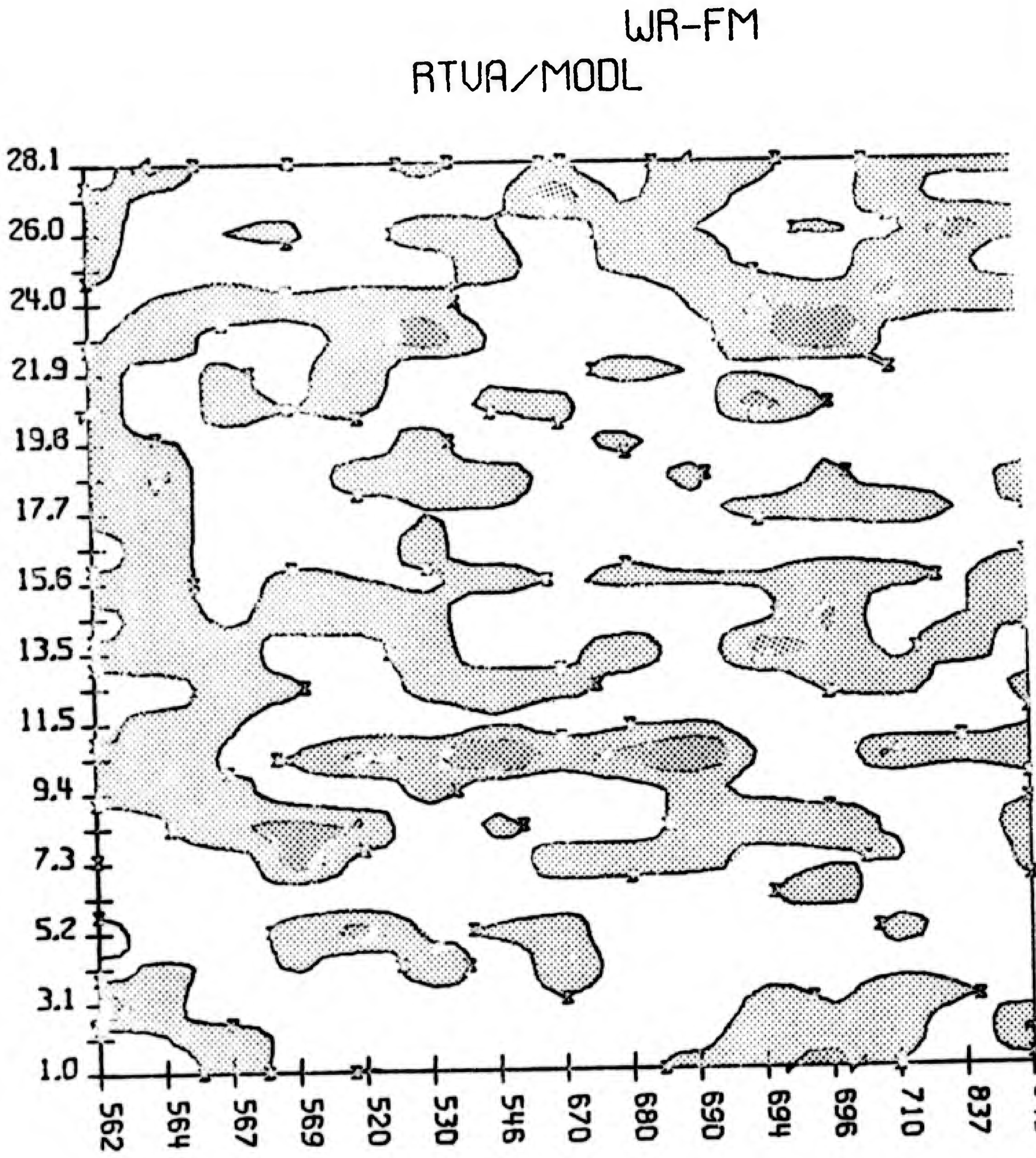
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
562
564
567
569
520
530
546
670
680
690
694
696
710
837


WR-FM
RTVA/MODL
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24.0
21.9
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17.7
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13.5
11.5
9.4
7.3
5.2
3.1
1.0
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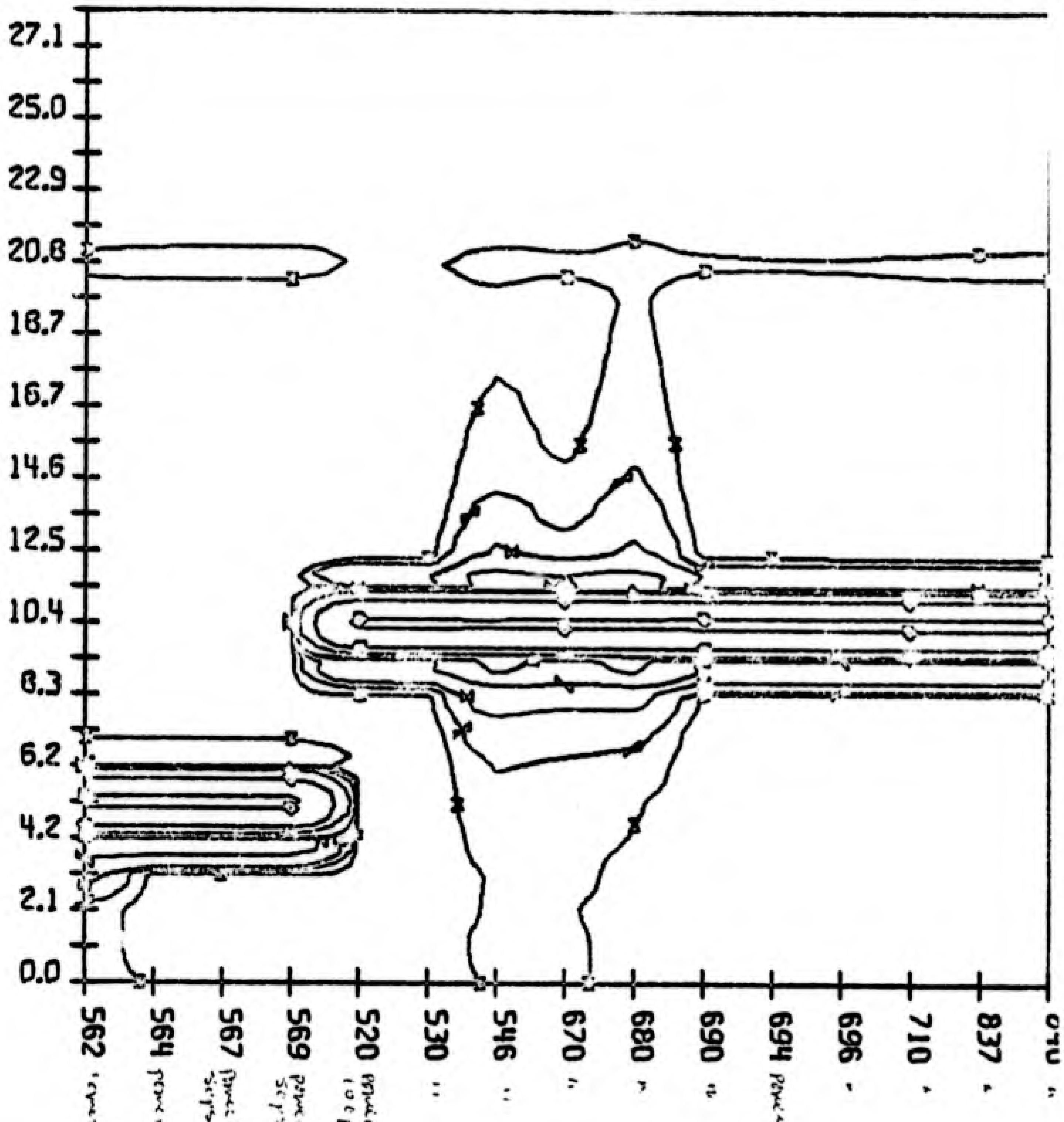
567
569
520
530
546
670
680
690
694
696
710
837

WR-FM

MODL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12.5
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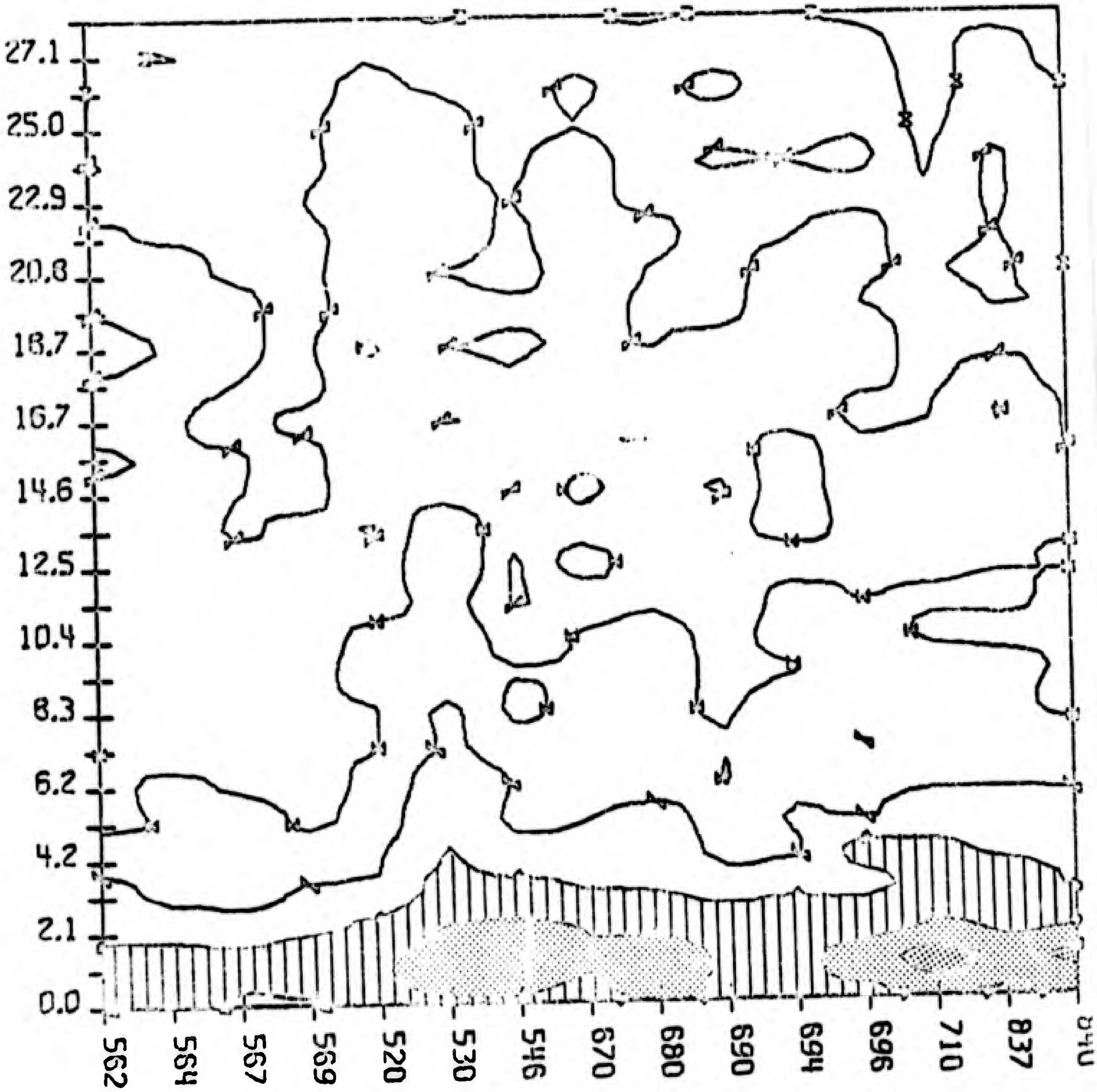
8.3
6.2
4.2
2.1
0.0
562
564
567
569
520
530
546
670
680
690
694
696
710
837

WR-FM

LVCX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20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
0.0
562
564
567
569
520
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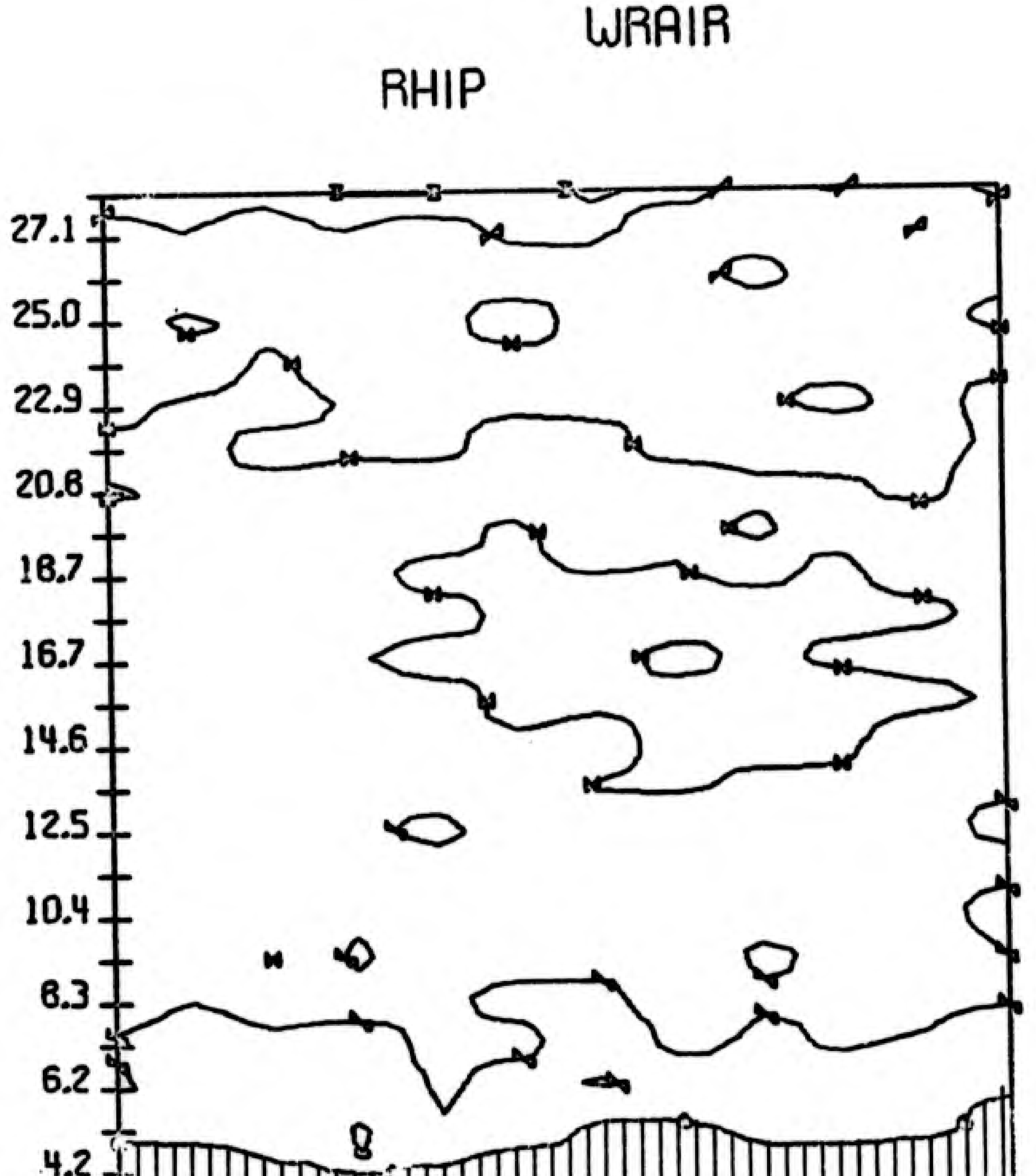
546
670
680
690
694
696
710
837


WRAIR
RHIP
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22.9
20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
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992
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996
446
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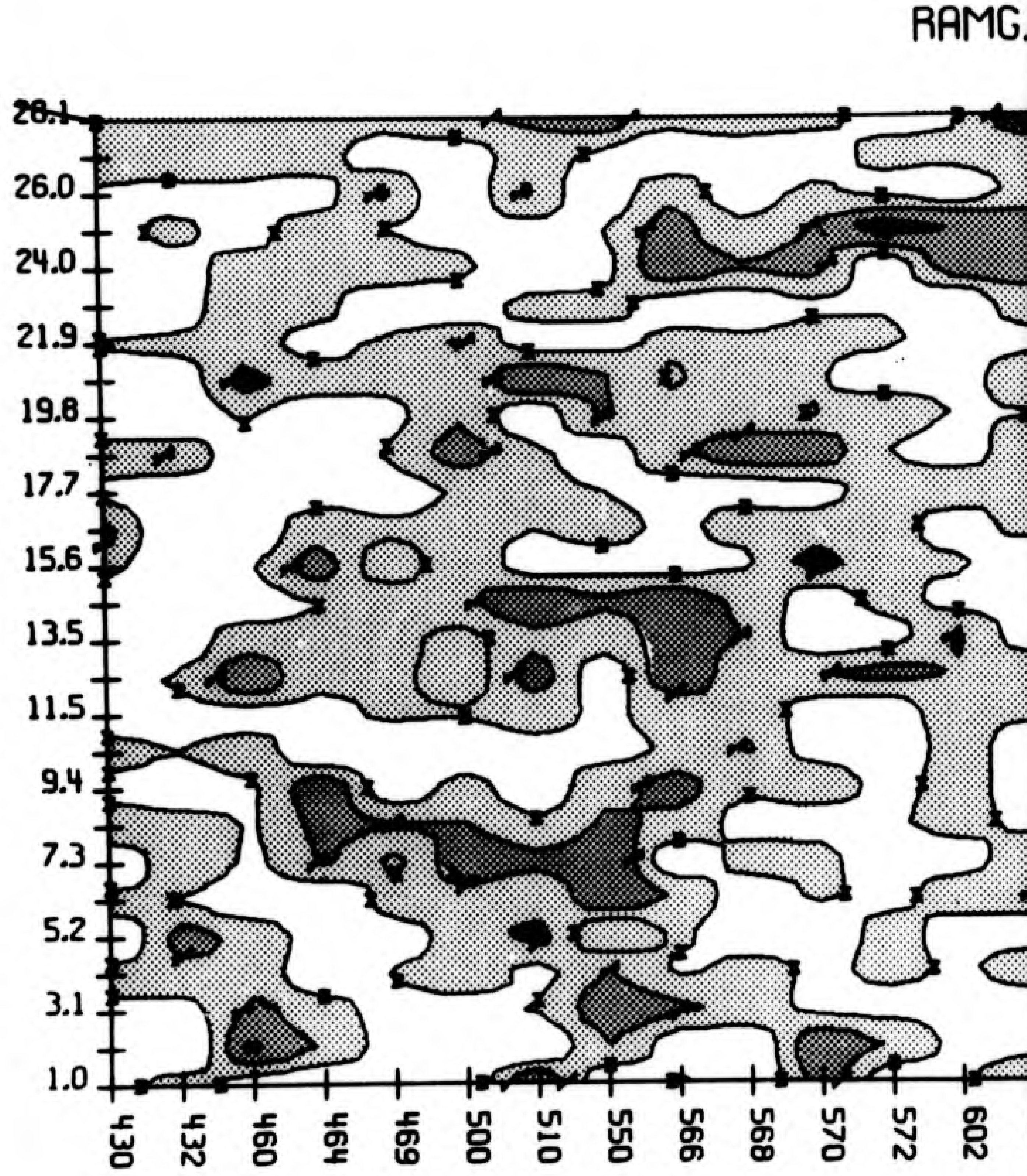
454
456
490
530

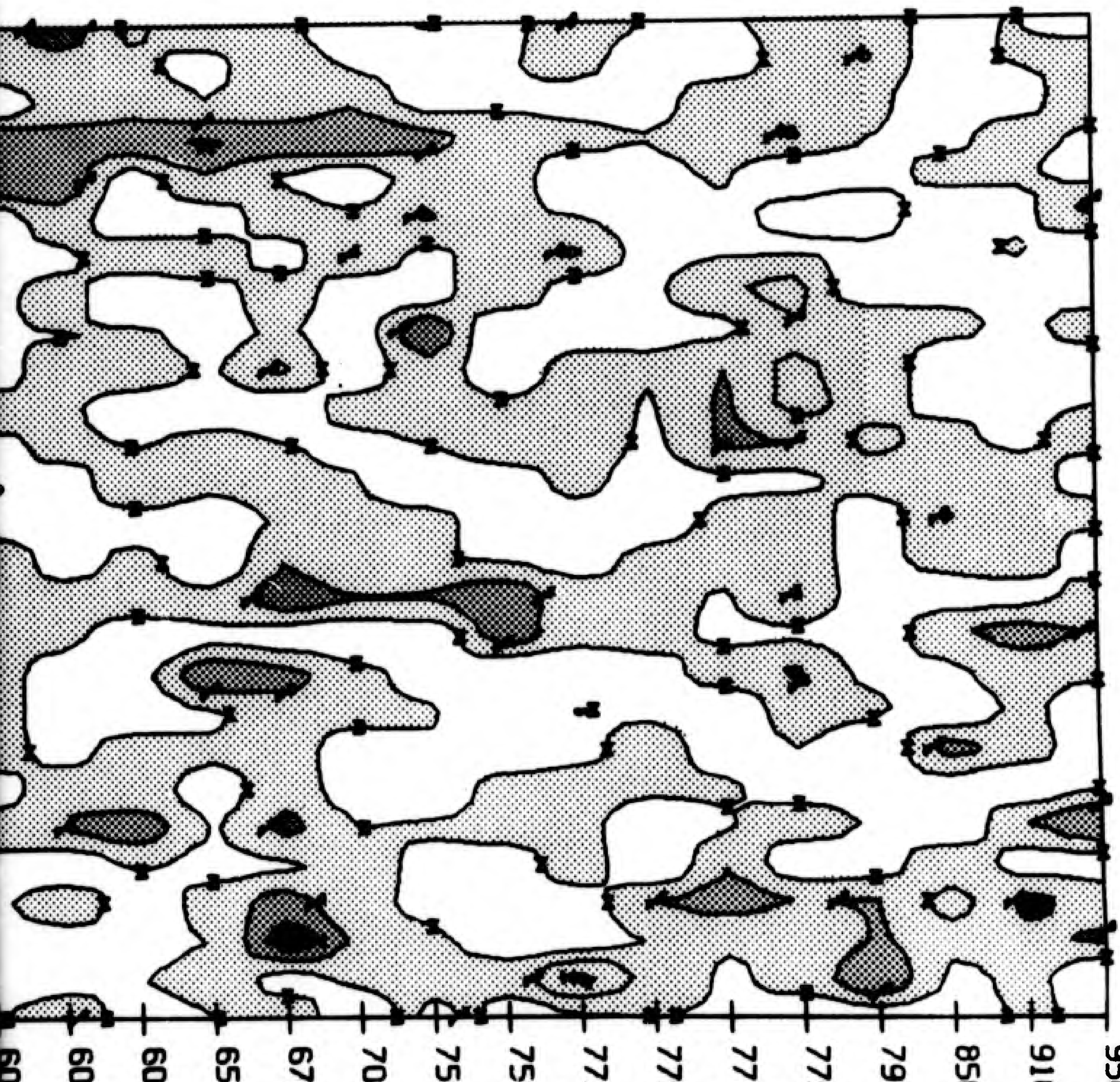
A

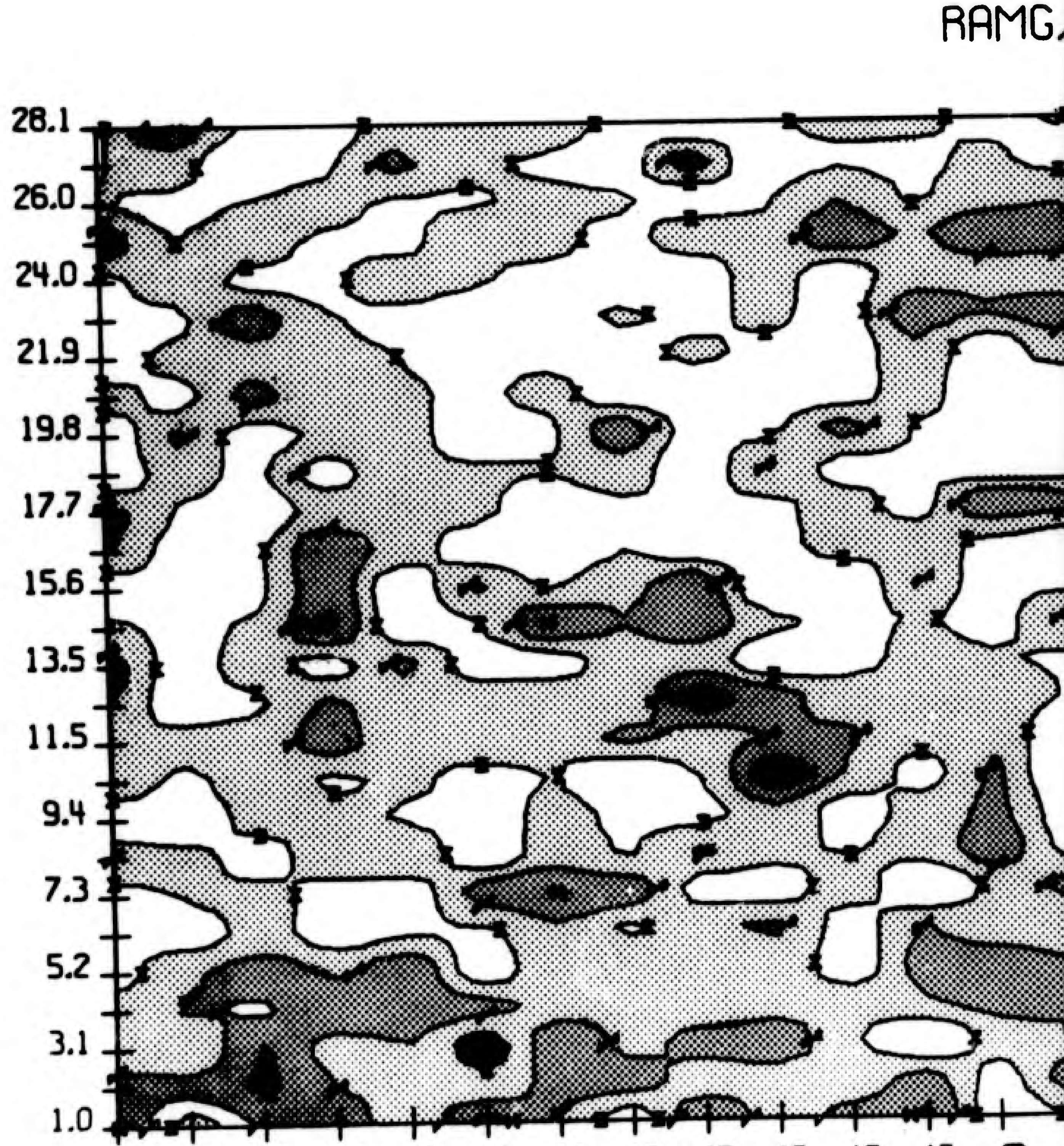

RAMG.
28.1
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
430
432
460
464
469
500
510
550
566
568
570
572
602

B

WR-6

MG/RVA



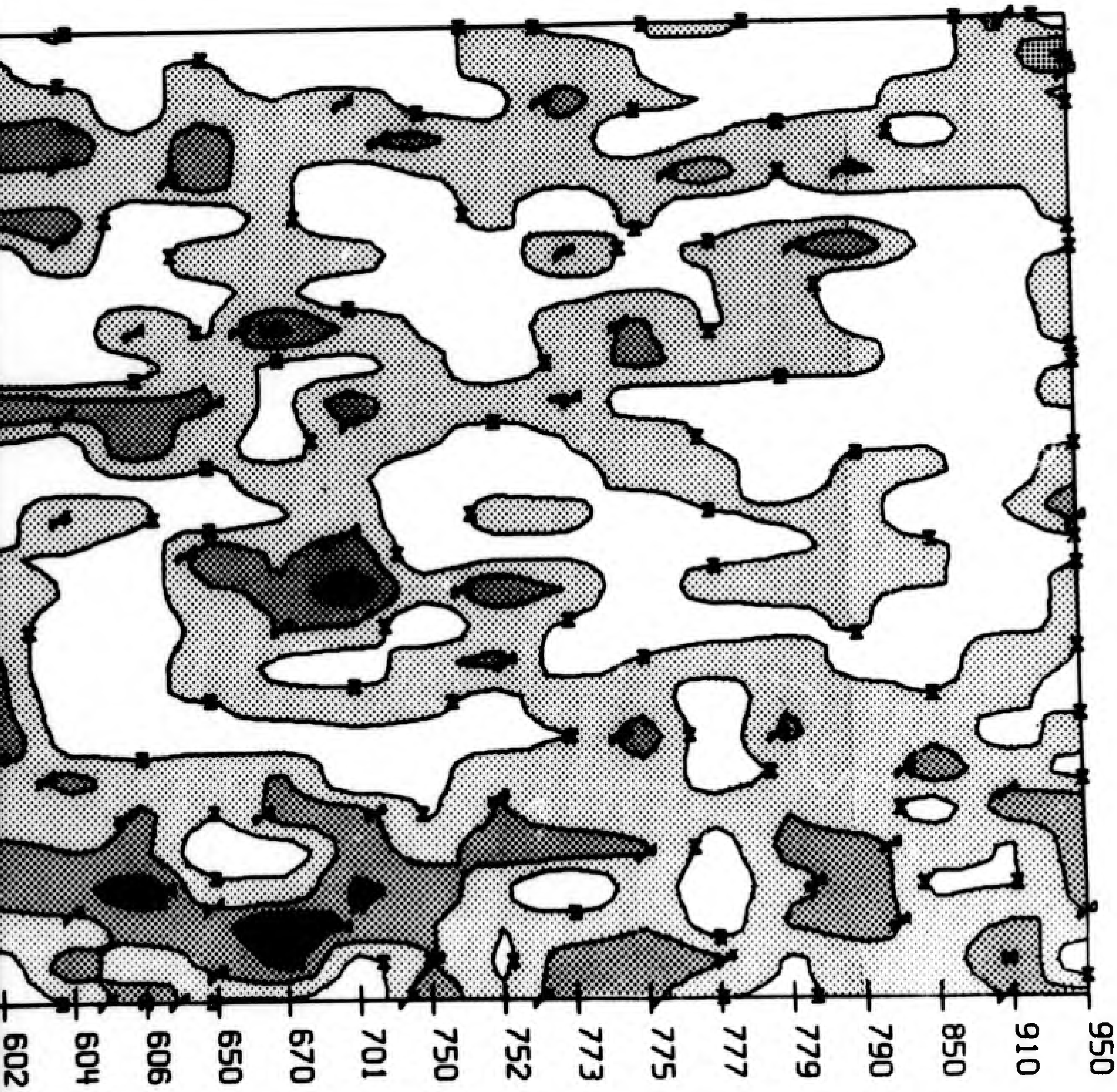


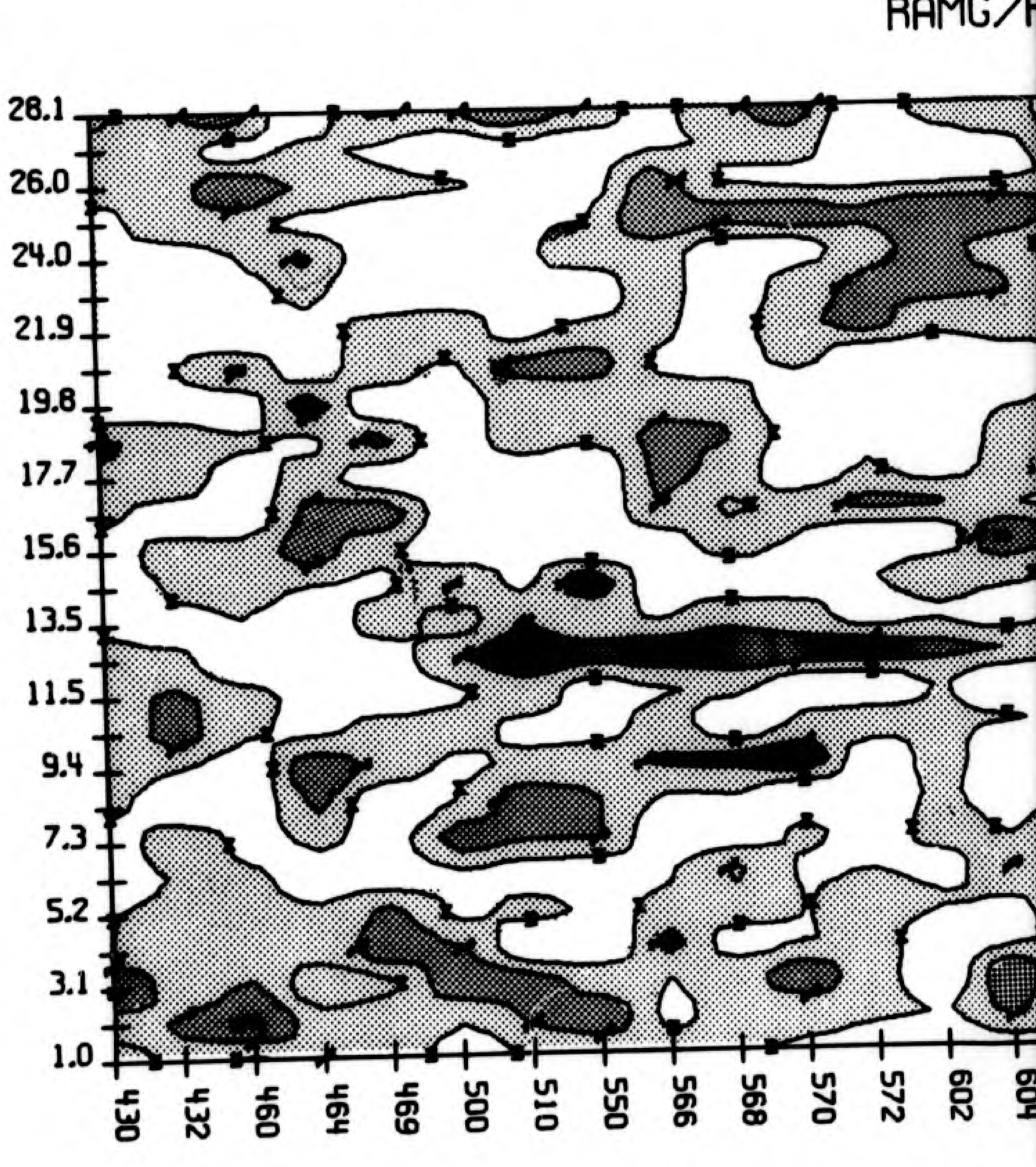
RAMG
28.1
26.0
24.0
21.9
19.8
17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
430
432
460
464
469
500
510
550
566
568
570
572
602

B

WR-6

MG/RCM




RAMG/R
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17.7
15.6
13.5
11.5
9.4
7.3
5.2
3.1
1.0
430
432
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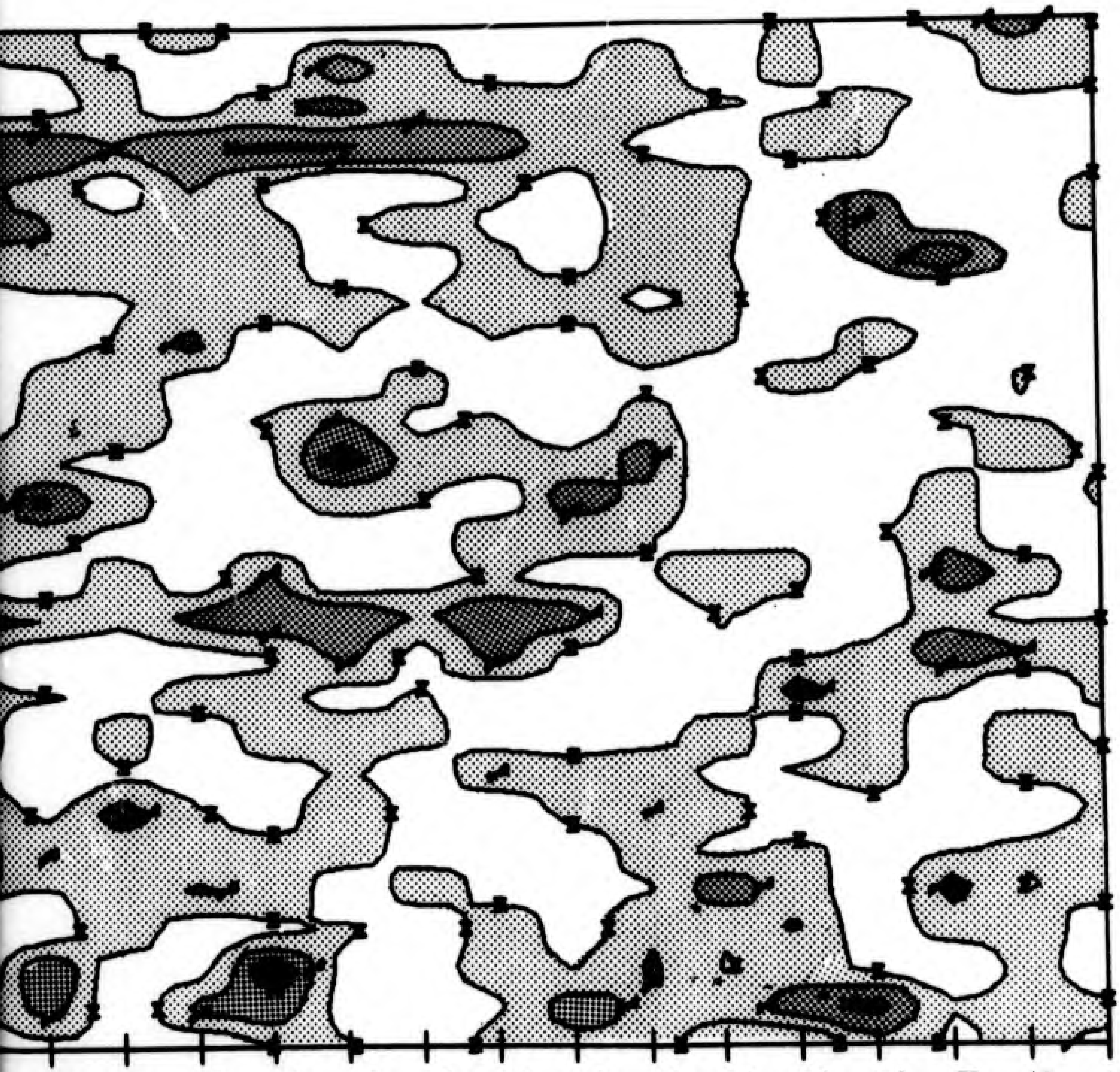
464
469
500
510
550
566
568
570
572
602
604

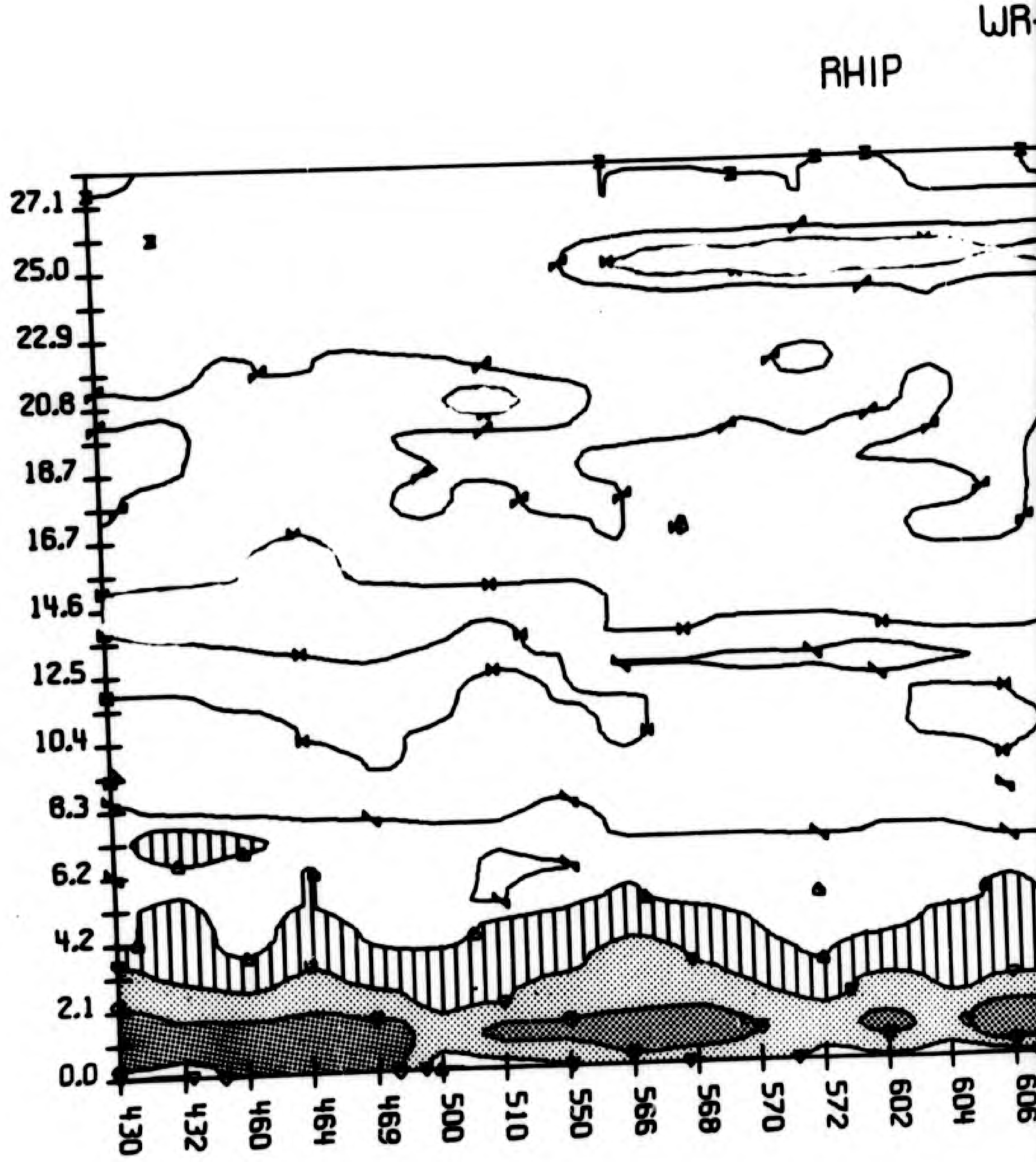
B

WR-6

IG/RHIP



A


WR-
RHIP
27.1
25.0
22.9
20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
0.0
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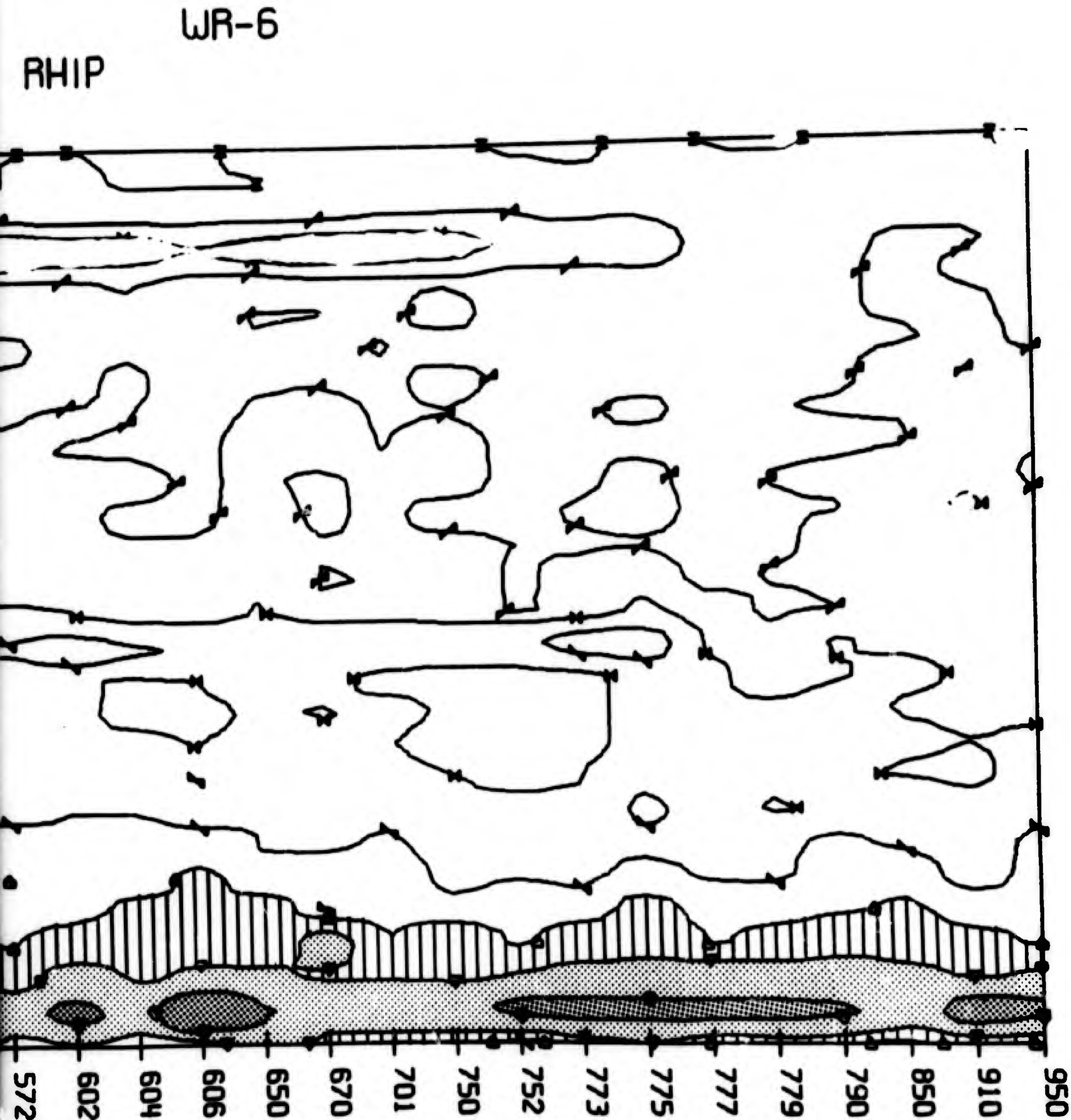
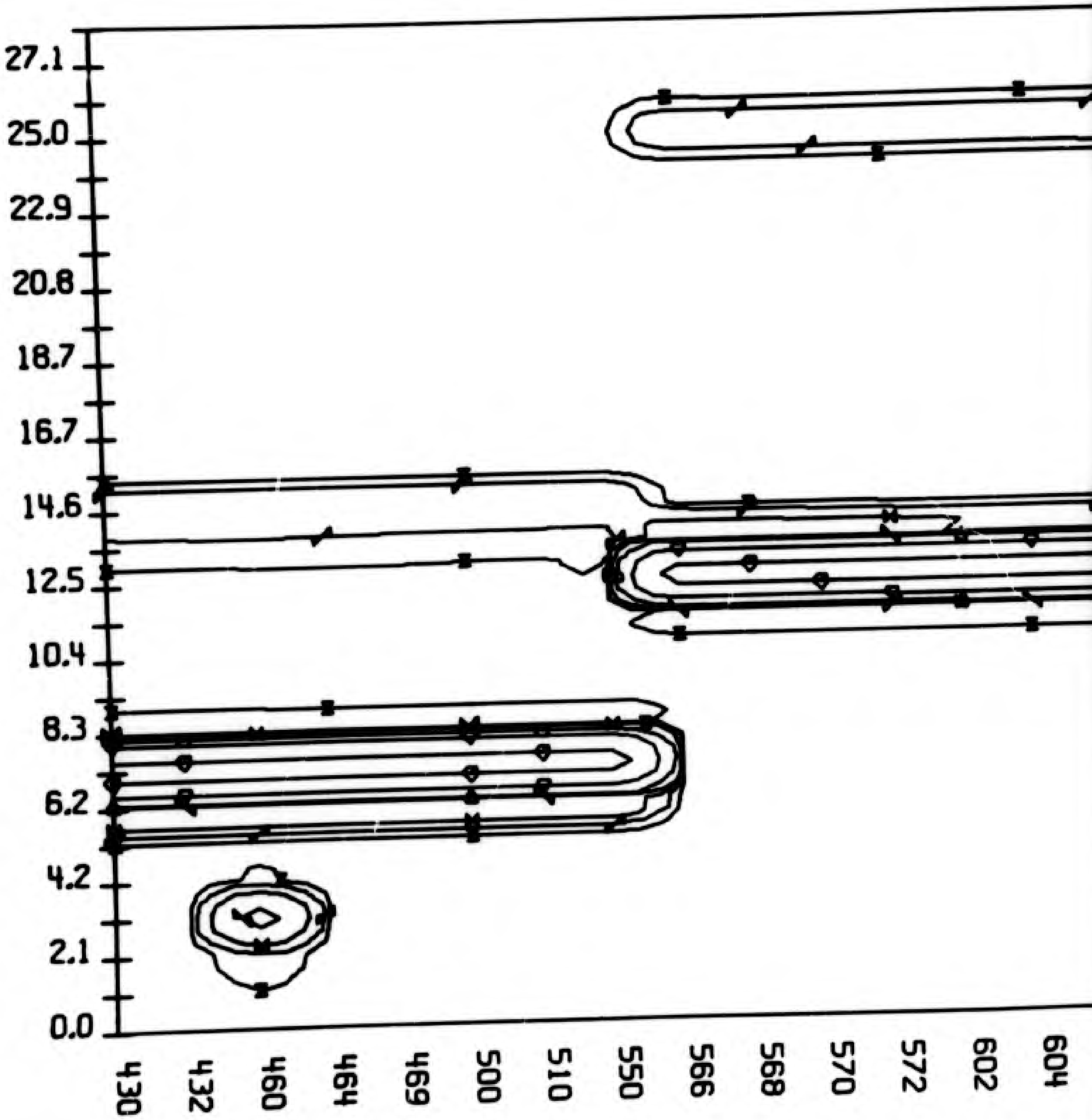
432
460
464
469
500
510
550
566
568
570
572
602
604
606

B


WR-6
RHIP
572
602
604
606
650
670
701
750
752
773
775
777
779
790
850
910
950

A

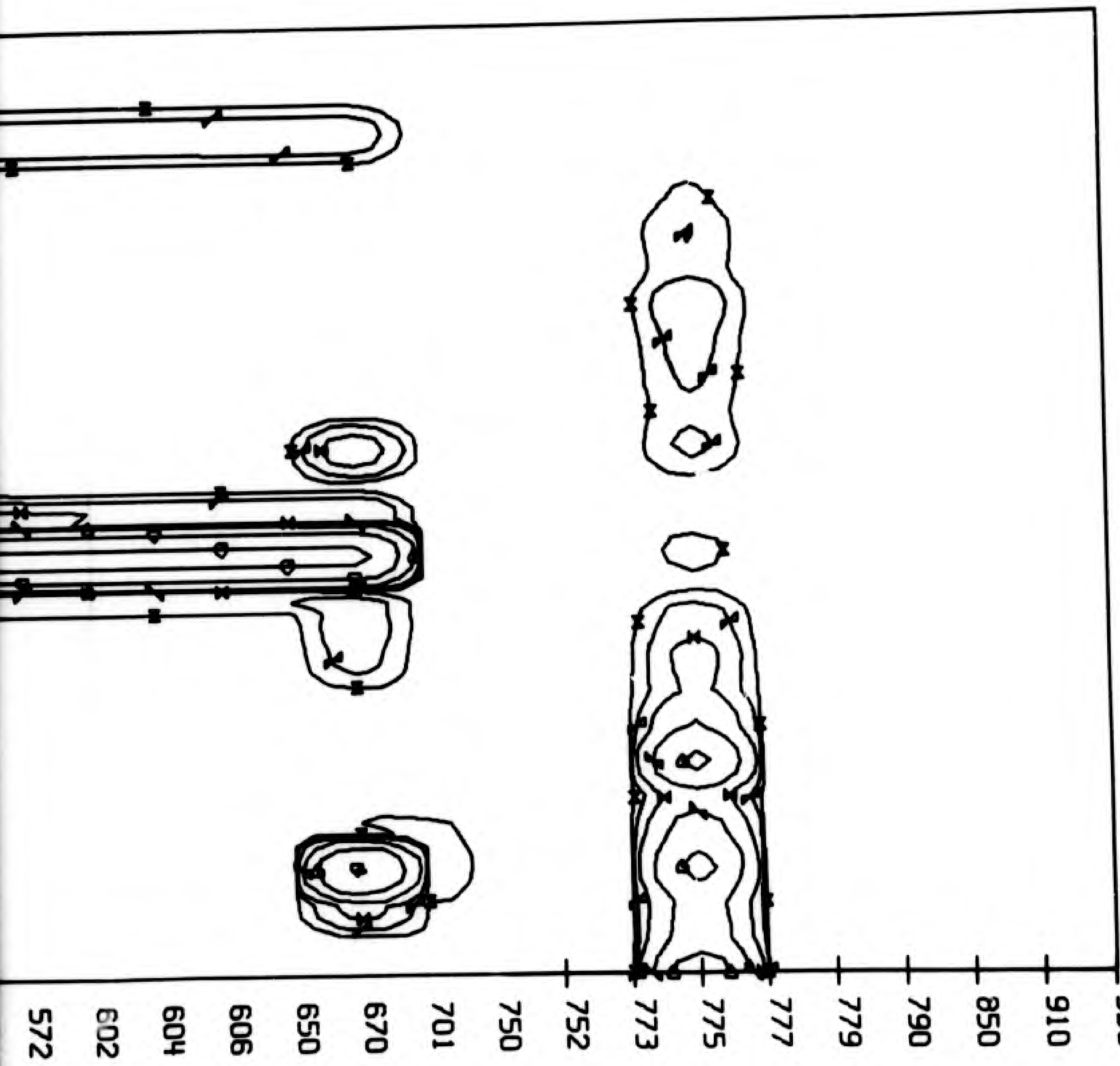
MODL


27.1
25.0
22.9
20.8
18.7
16.7
14.6
12.5
10.4
8.3
6.2
4.2
2.1
0.0
430
432
460
464
469
500
510
550
566
568
570
572
602
604

B

WR-6

MODL


572
602
604
606
650
670
701
750
752
773
775
777
779
790
850
910
950

APPENDIX II

ANALYSES OF DATA FROM MONKEYS AT WRAIR

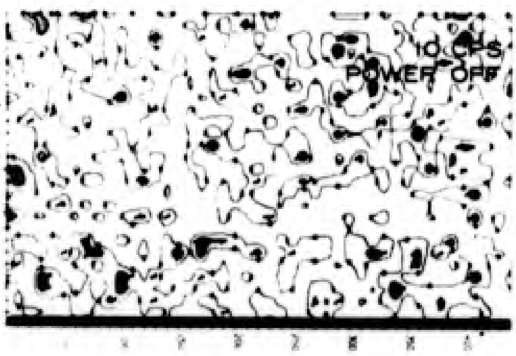
The contour plots on the following pages are representative samples from (1) records with fields off; (2) records with fields on at 1.0 Hz; (3) records with fields on at frequencies ranging from 2 to 15 Hz, using 50% amplitude modulation of the S-band Carrier (3.03 GHz).

These contour plots display cross-spectral relations through the coherence function. Time in seconds is plotted on abscissae and spectral frequencies on the ordinates. The shading scale from white to black shows 3 levels, with black zones indicating statistically significant coherence.

Data are shown from monkeys WR 280, WR 464, and WR 648. Coherence calculations relating EEG data to the modulating signal are shown for different brain regions, and as an index of electrical relations between different brain regions.

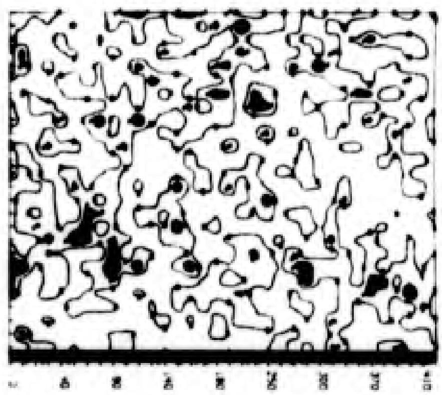
These plots indicate that coherence between the brain wave records and the modulating signal, and between different brain regions at the modulation frequency, remained below statistically significant levels throughout most of the exposure time.

WR 280 RVA/MODL



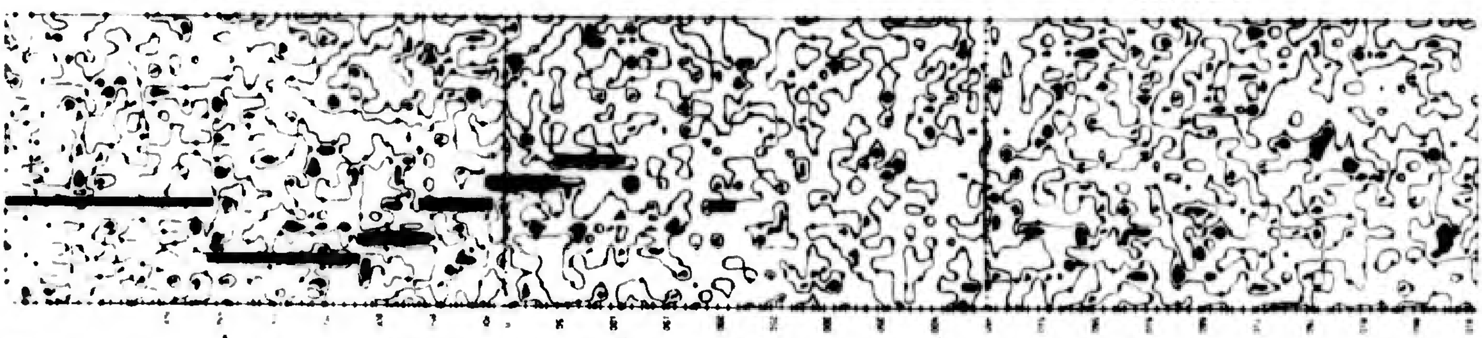
10 mw/cm²
50% AMP MOD.
CARRIER FREQ = 3.03 GHz

WR 648 RVA/MODL

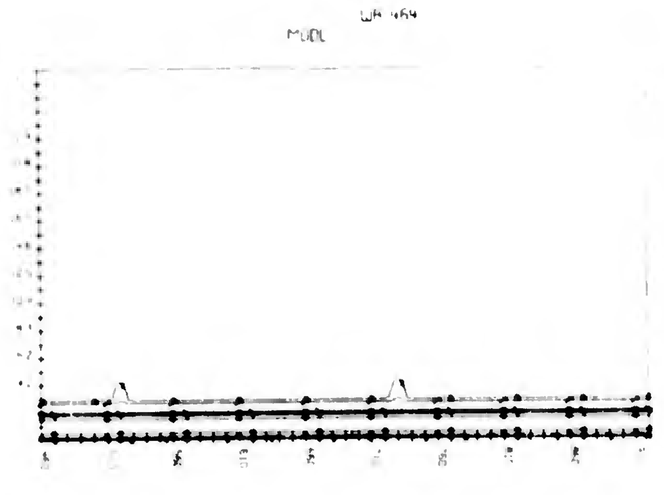


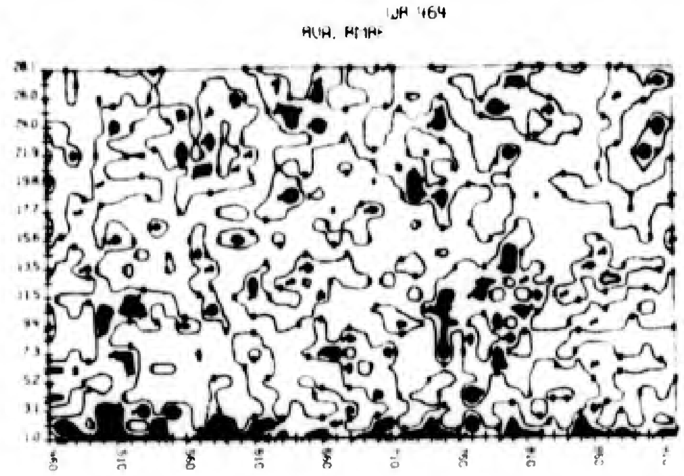
1 Hz POWER ON

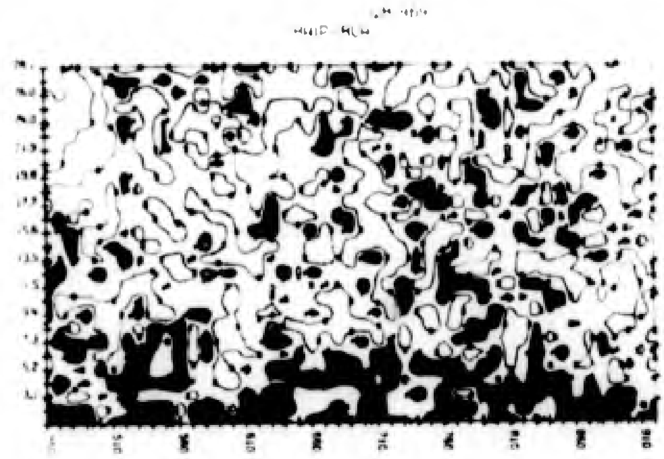
WR 280 WR 464 WR 464

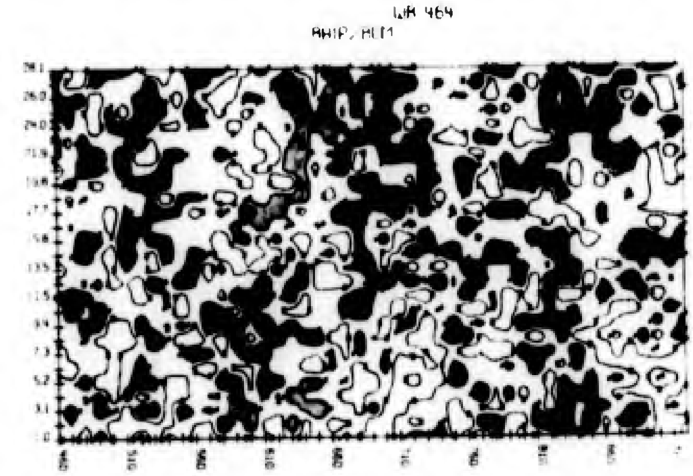


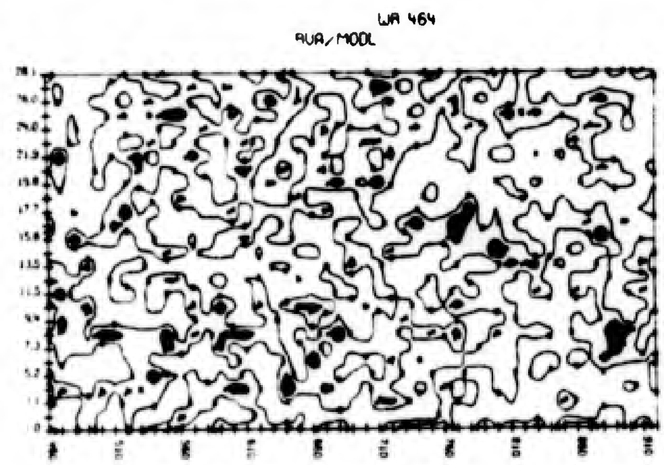
min
5 Hz 7.5 Hz 10 12.5 15 Hz 1 Hz
POWER ON
POWER OFF
POWER ON

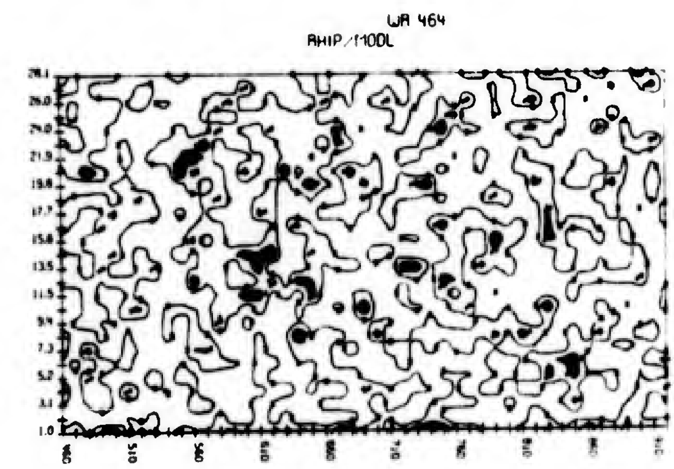


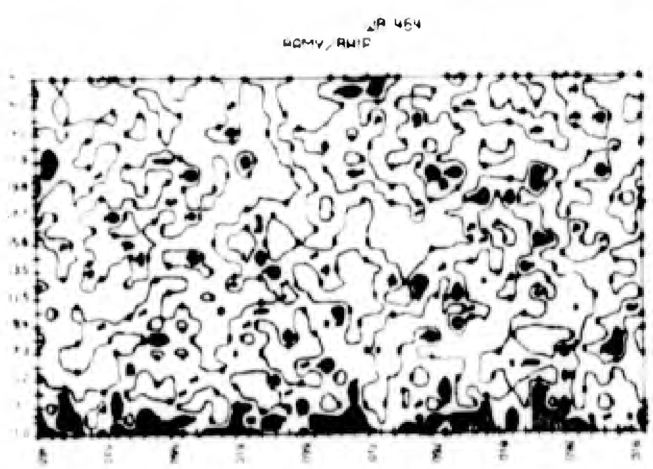


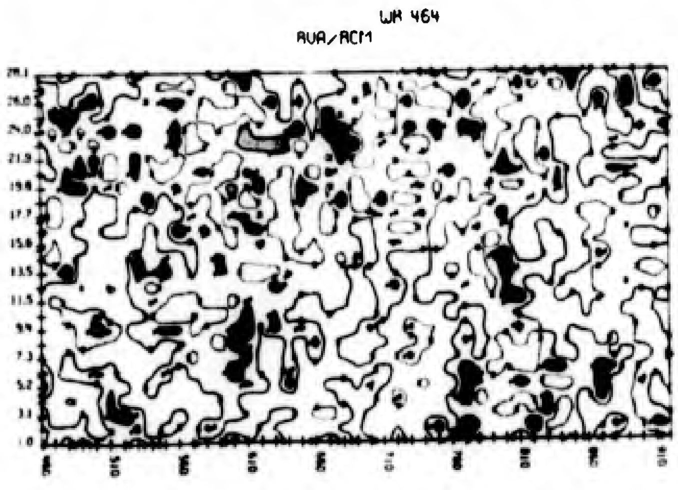



WR 464
AHIP/ACM


WR 464
AVA/MODL


WR 464
AHIP/MODL

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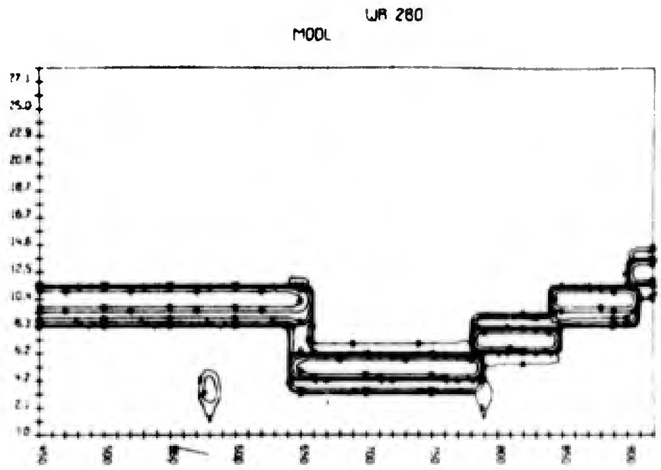
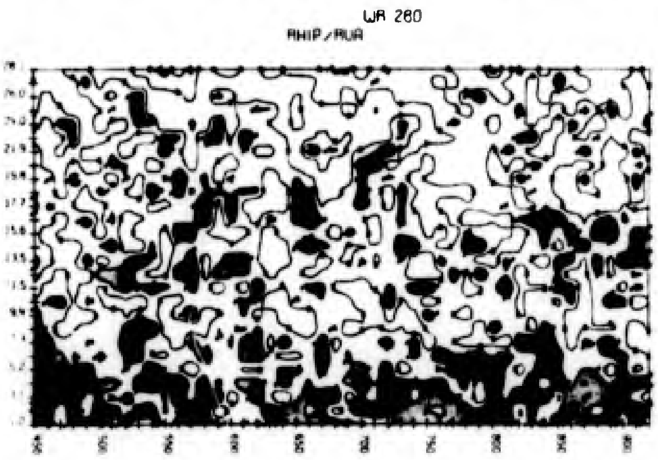
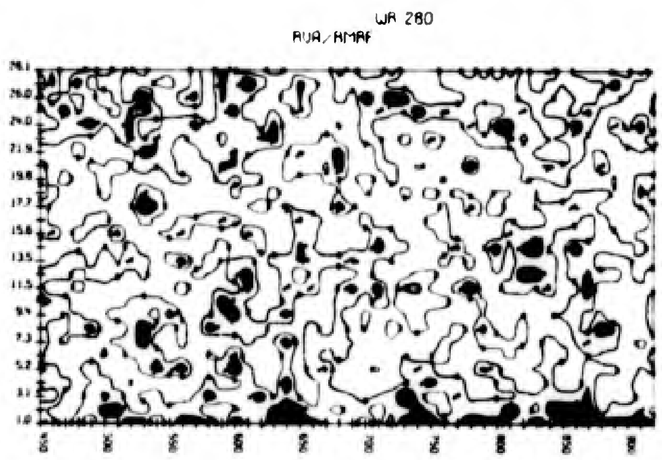
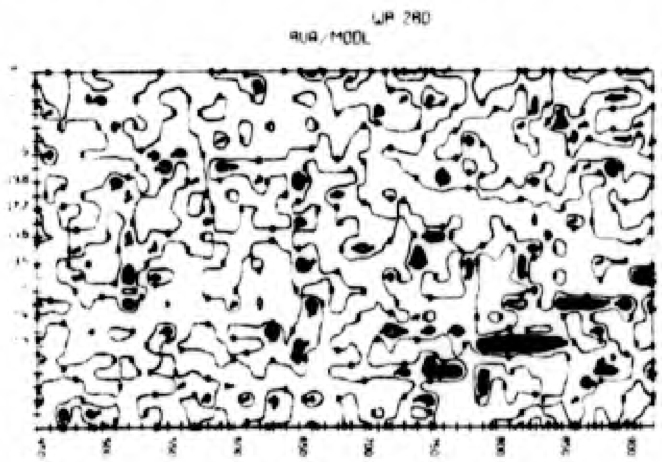
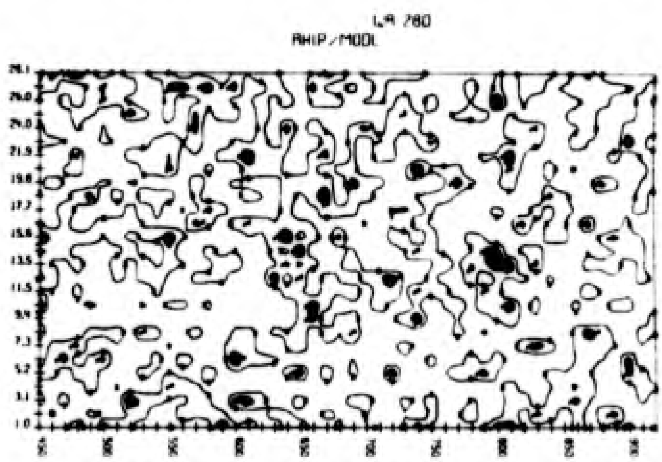
AVA/ACM


WR 280
MODL


WR 280
AHIP/AVA


WR 280
AVA/AMAF


WR 280
AVA/MODL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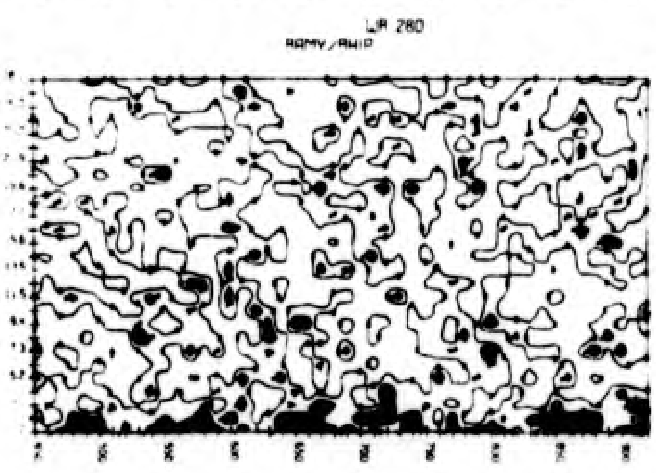
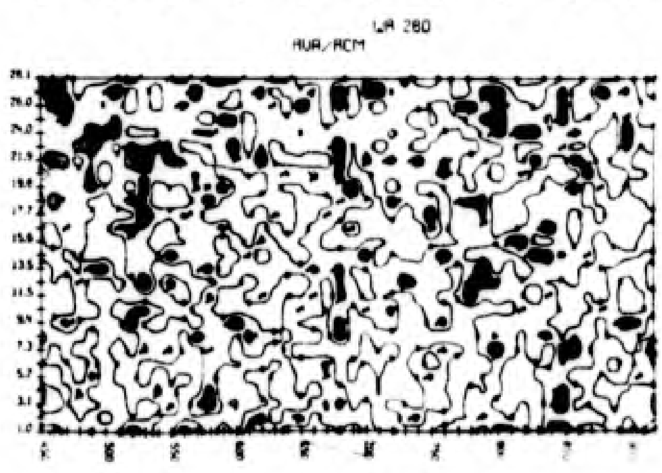
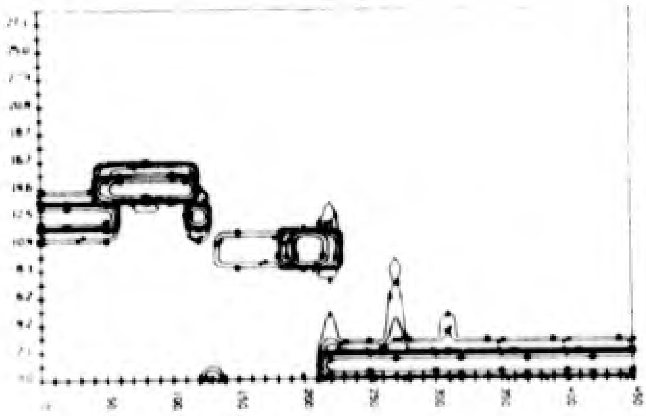
AHIP/MODL

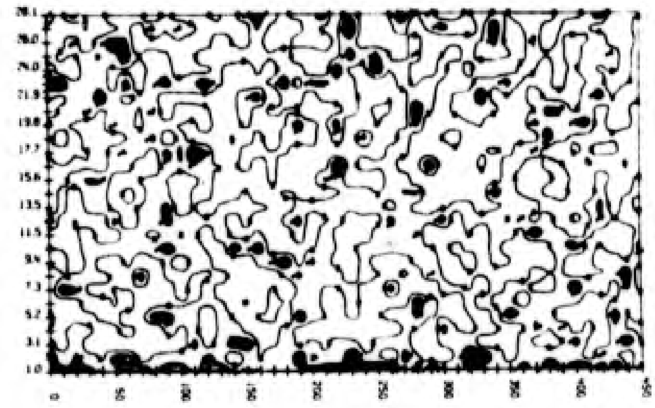

WR 280
AAMY/AHIP


WR 280
AVA/ACM

WA 464
MODL



WA 464
AVA/AMAF



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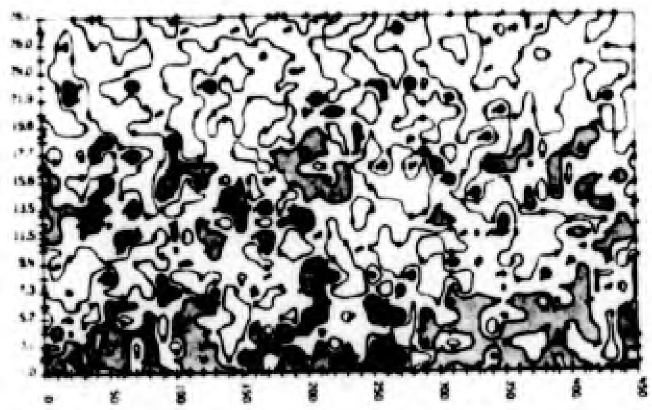
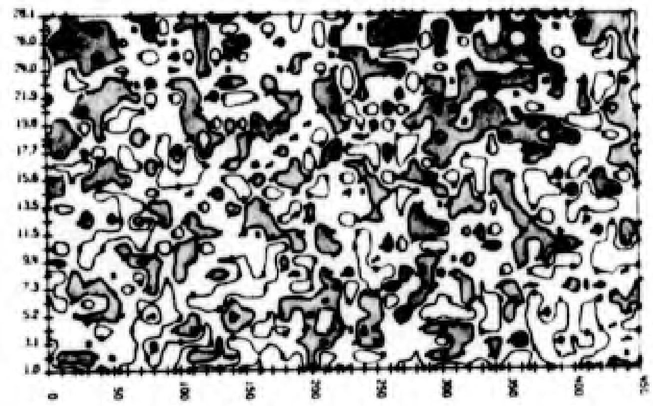
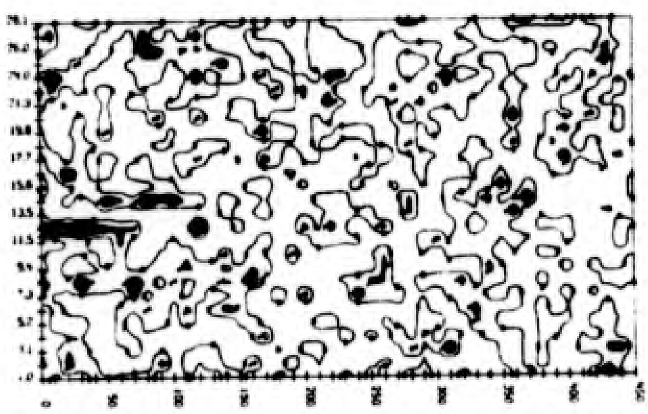
AHIP/AVA



WA 464
AHIP/ACM



WA 464
AVA/MODL



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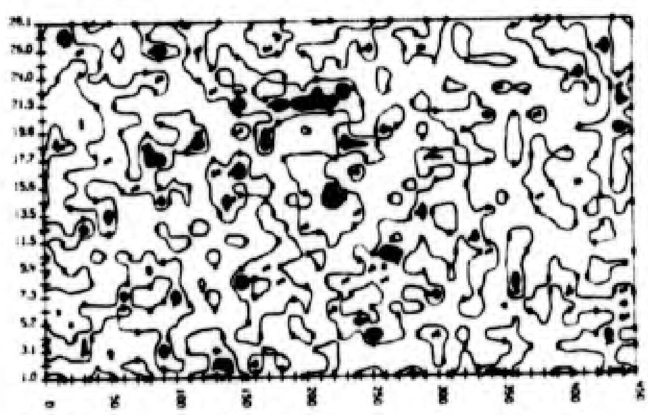
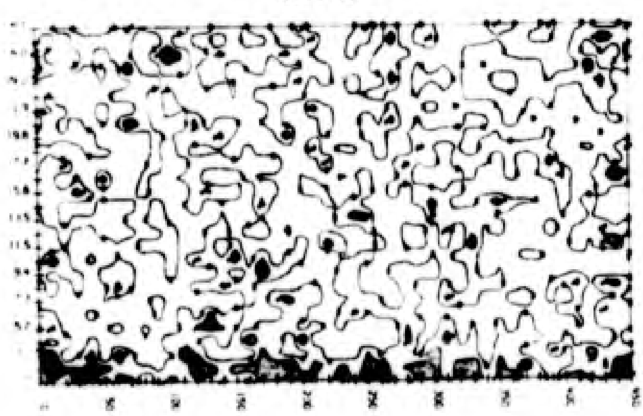
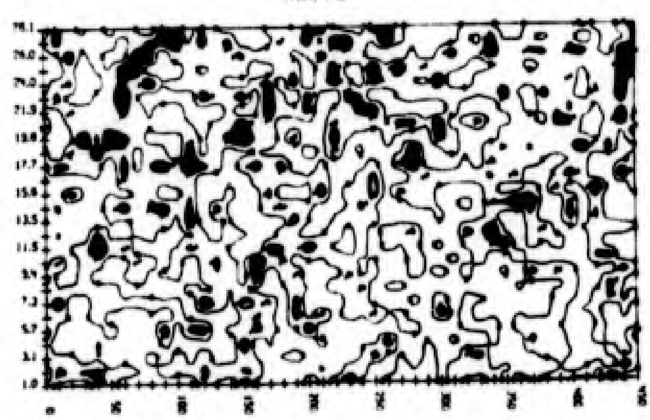
AHIP/MODL



WA 464
AAMY/AHIP



WA 464
AVA/ACM



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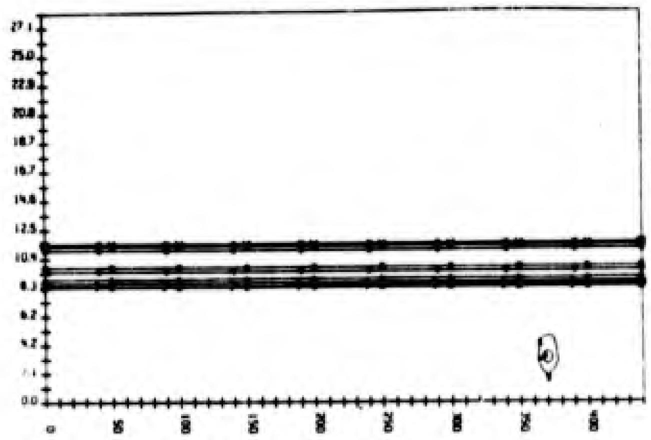
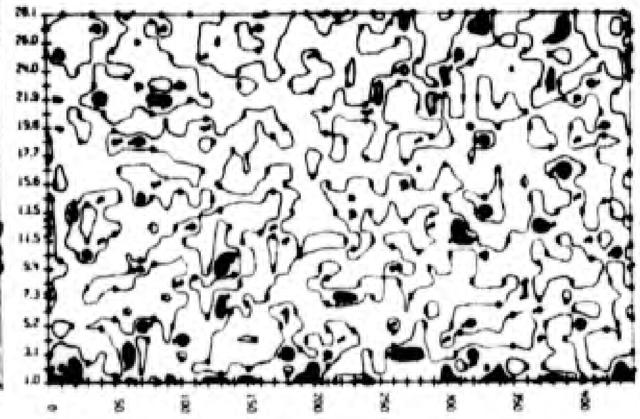
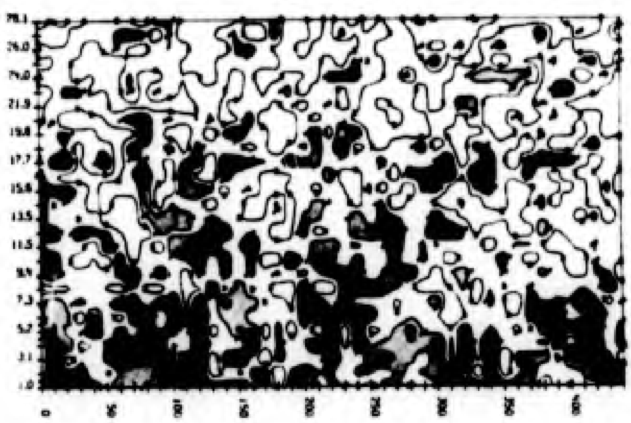
MODL



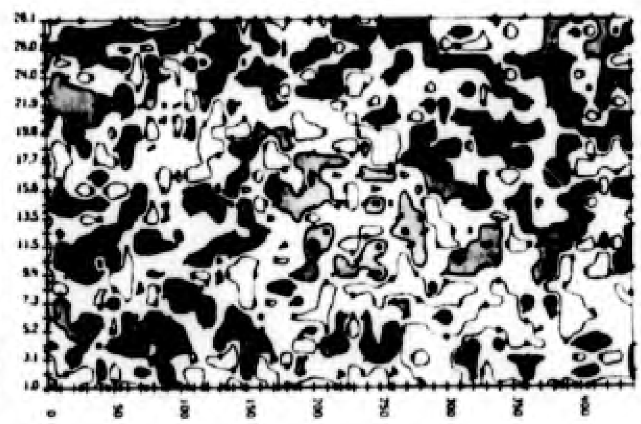
WR 280
RVA/RMAF



WR 280
RHIP/RVA



WR 280
RHIP/RCM



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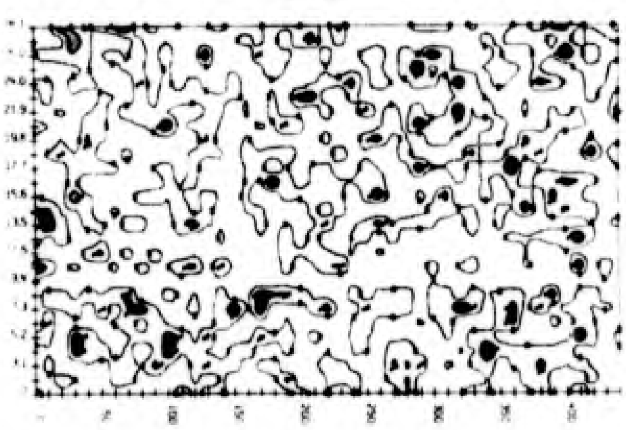
RVA/MODL



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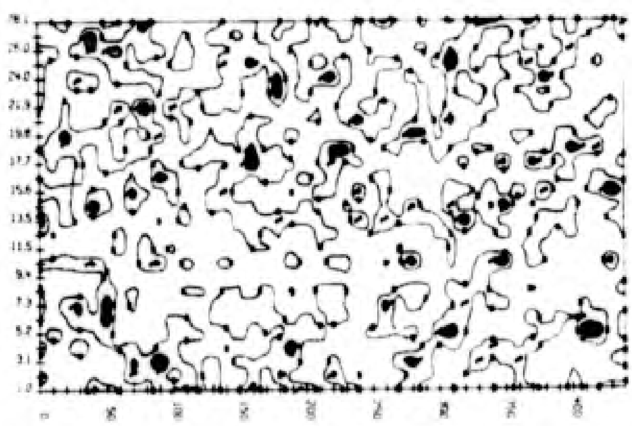
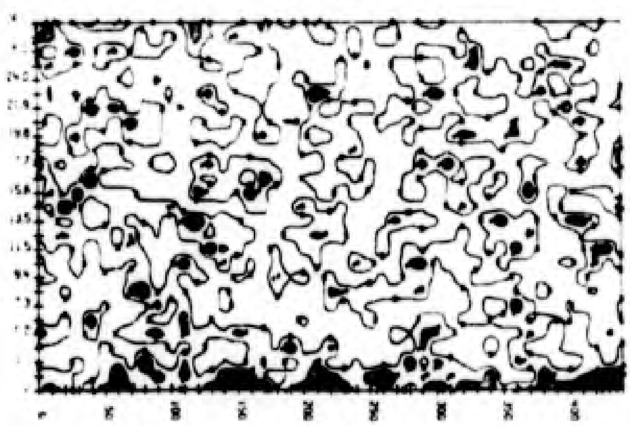
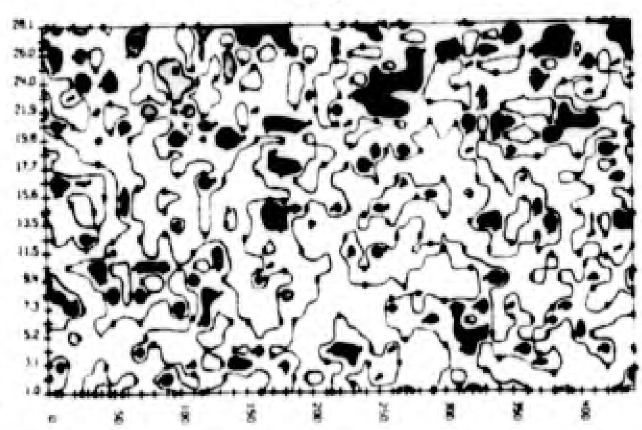
RHIP/MODL



WR 280
RAMV/RHIP



WR 280
RVA/RCM



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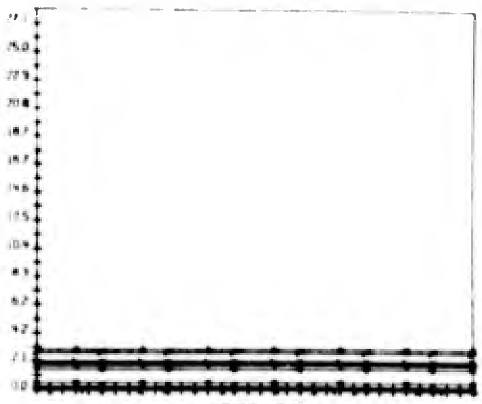
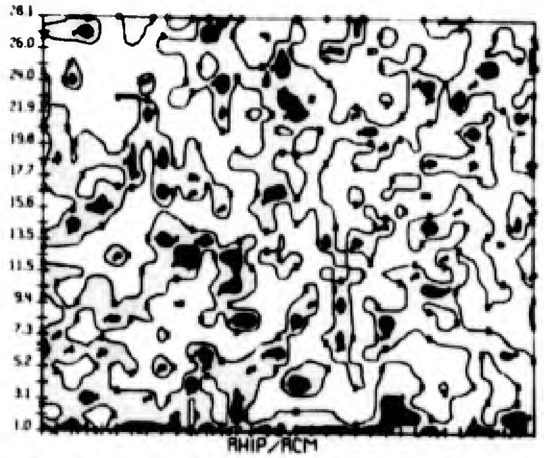
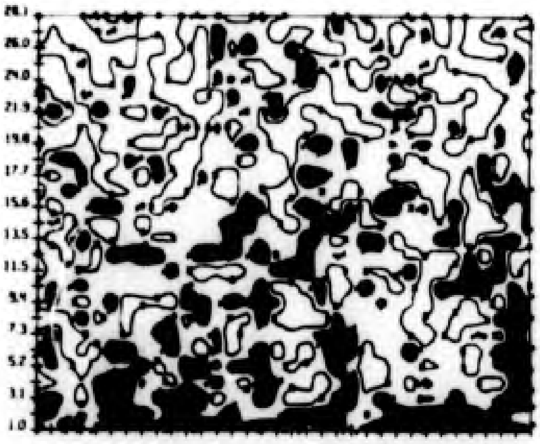
MODL



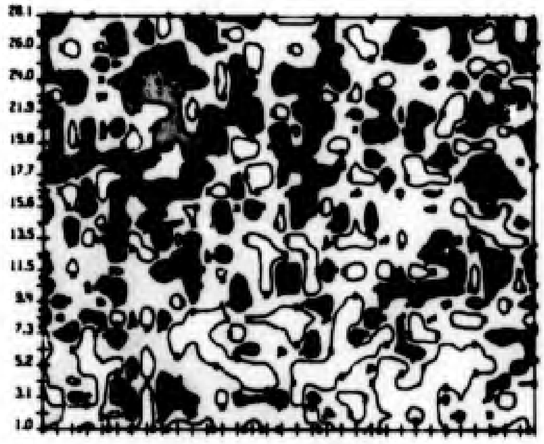
WR 648
AVA/AMAF



AHIP/AVA



AHIP/ACM



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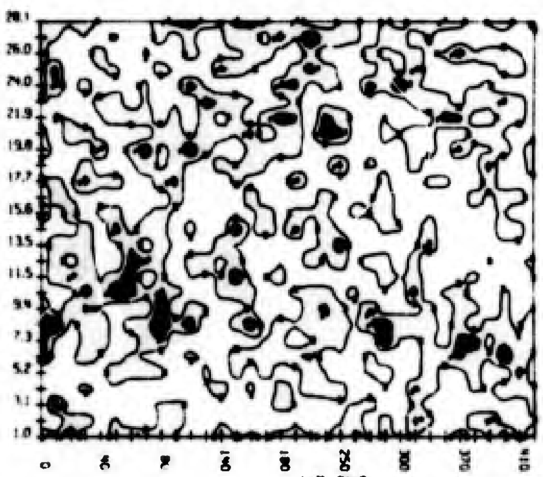
AVA/MODL



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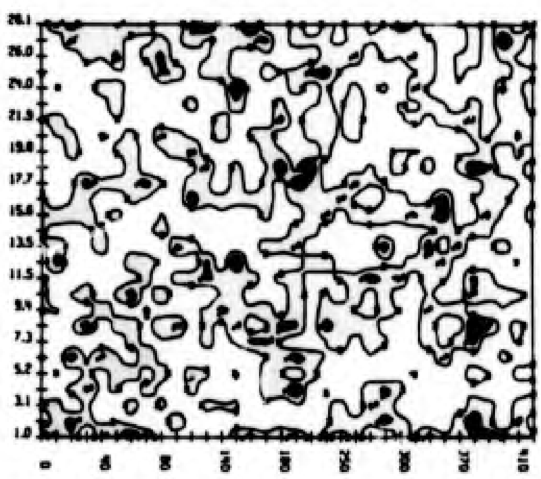

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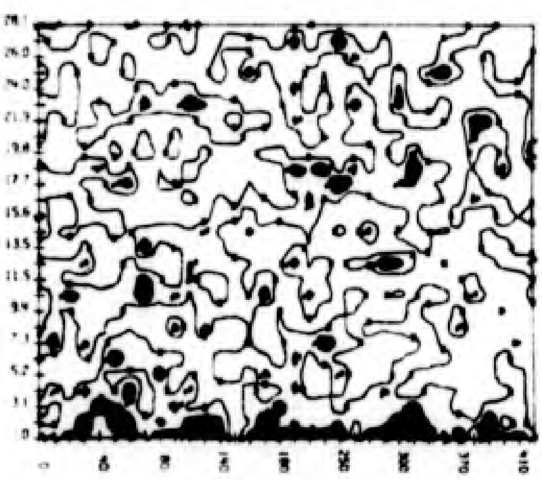
AAMY/AHIP



EFFECT OF LOW-LEVEL, LOW-FREQUENCY ELECTRIC FIELDS
ON EEG AND BEHAVIOR IN MONKEYS

APPENDIX III

I. Autospectra: Percent power graphs. Incorrect and correct responses. Responsive and nonresponsive structures. 7 Hz fields on vs. fields off. End of run.

II. Autospectra: Percent power graphs. Incorrect and correct responses. Responsive and nonresponsive structures. 7 Hz fields on vs. fields off. Beginning of run.

III. Autospectra: Percent power graphs and P values for peak quotients. 10 Hz fields.

IV. Fast vs. slow responses. Peak quotients.

V. Two-hour experiments. IRT's and peak quotient P values.

VI. Twenty-four hour experiments. IRT's.

VII. Sleep studies. Autospectra contour plots.

VIII. A. Engineering and instrumentation development, Figures 1 - 6.

B. Addendum: Schematics for completed screened room and VHF apparatus.

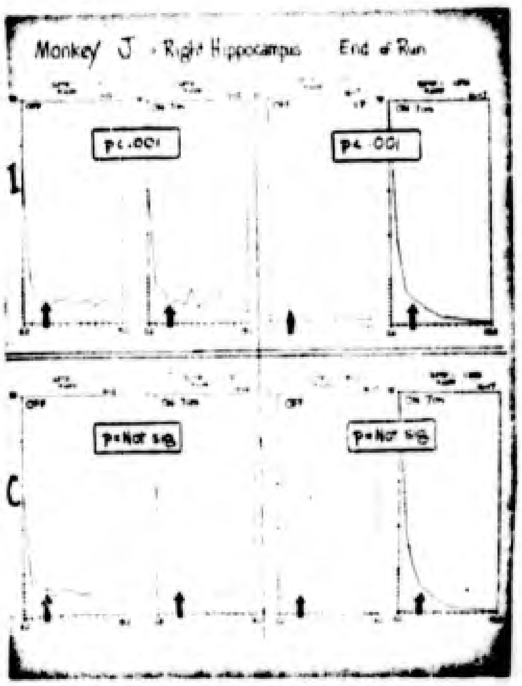
1. Autospectra: Percent power graphs. Incorrect and correct responses. Responsive and nonresponsive structures. 7 Hz fields on vs. fields off. End of run.

P values indicate probability of observed differences in peak quotients for fields on vs. fields off for two combined experiments for each animal for each brain structure. (See *Brain Research* for further description of statistical analysis.)

Monkeys J, Z, and A.

PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
<u>END OF RUN</u>
MONKEY J(B): RESPONSIVE STRUCTURES

INC
COR



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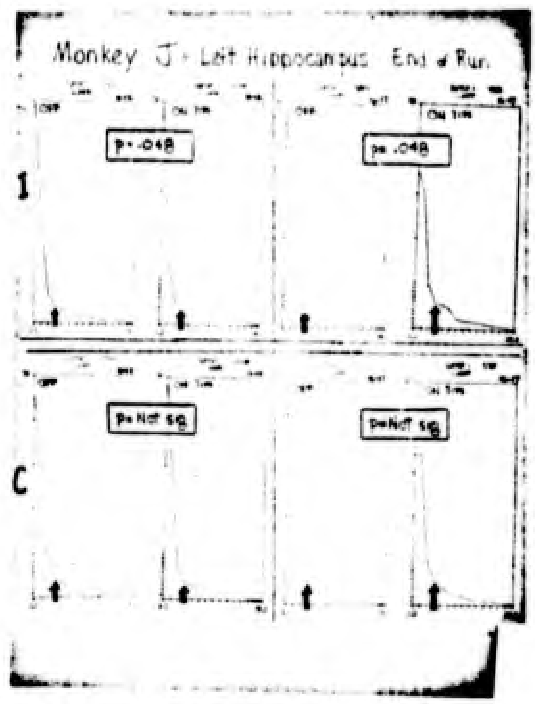

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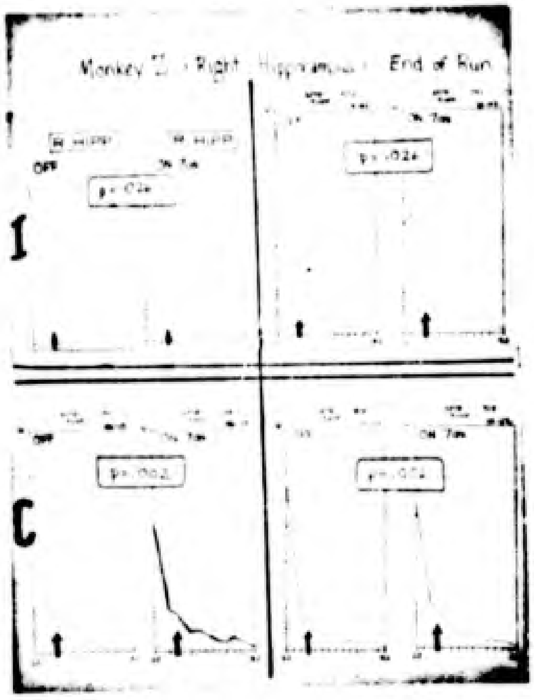
COR

PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY Z(B): RESPONSIVE STRUCTURES

INC

COR



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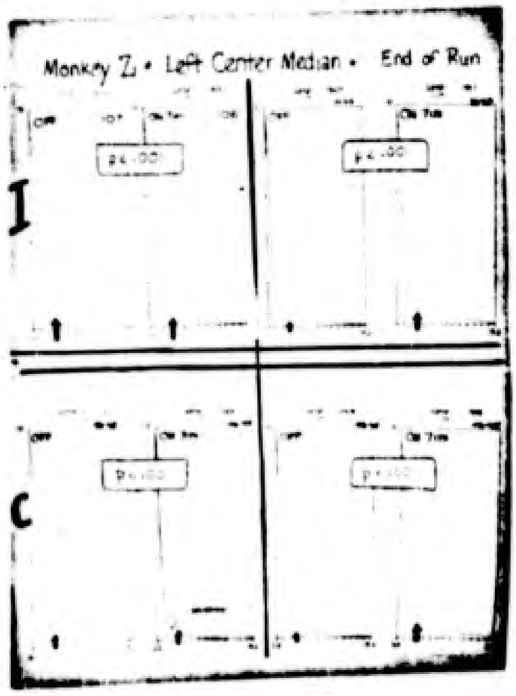
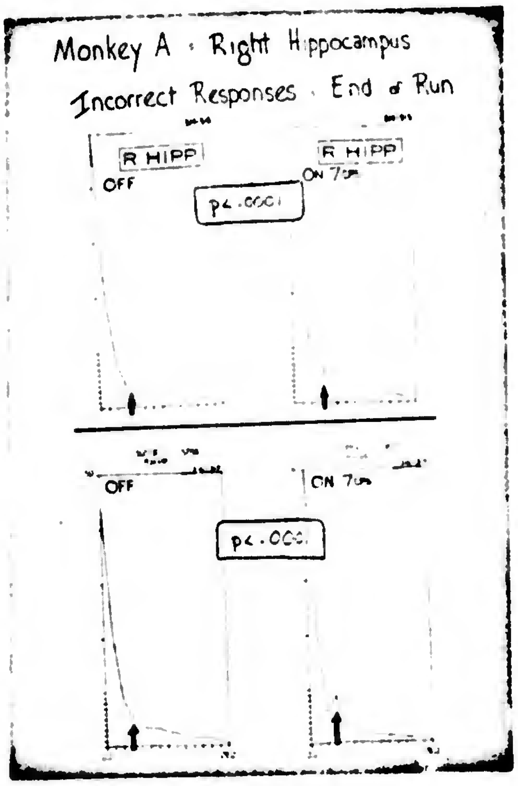


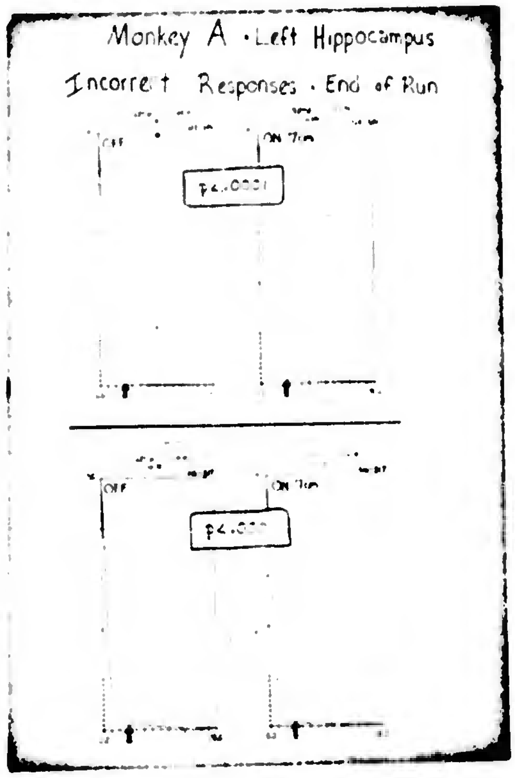
PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT RESPONSES

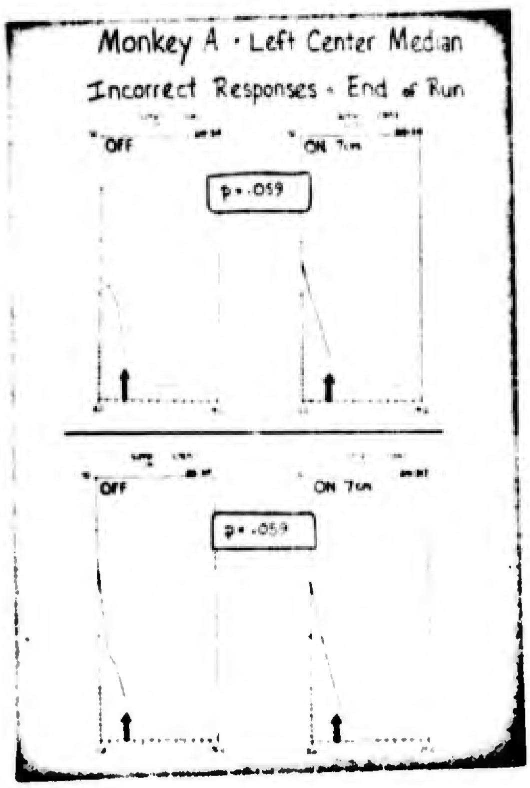
END OF RUN

MONKEY A: RESPONSIVE STRUCTURES

INCORRECT RESPONSES ONLY -- NO CORRECT RESPONSES SAMPLED



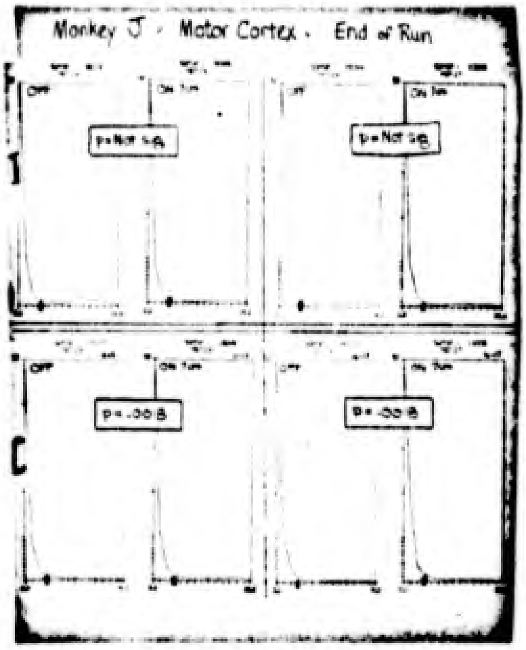




PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY J(B): NONRESPONSIVE STRUCTURES

INC

COR



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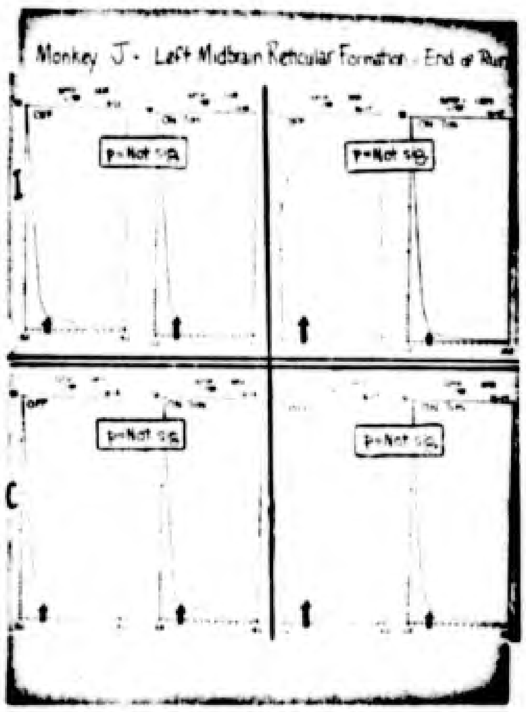

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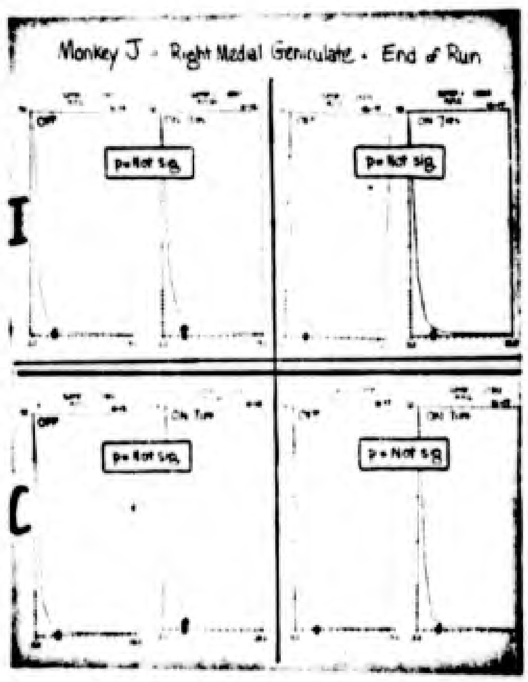
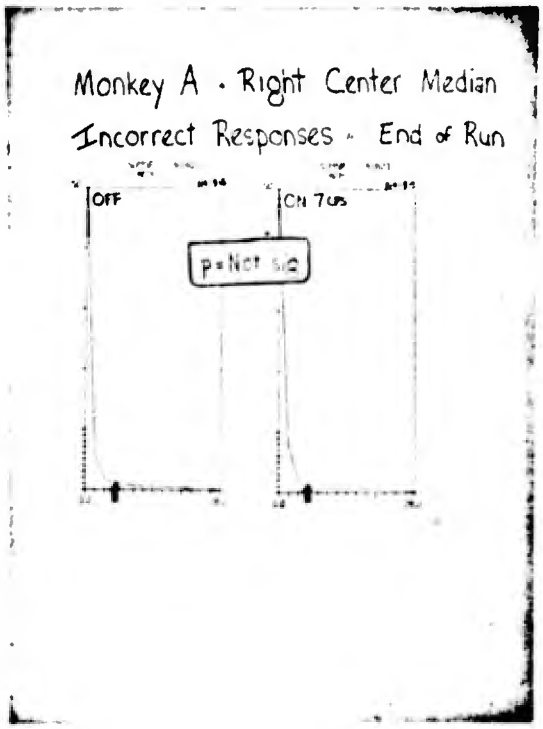
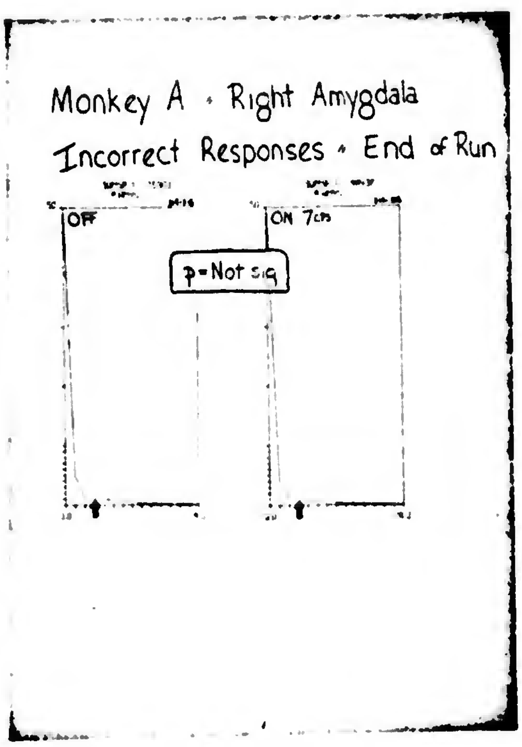
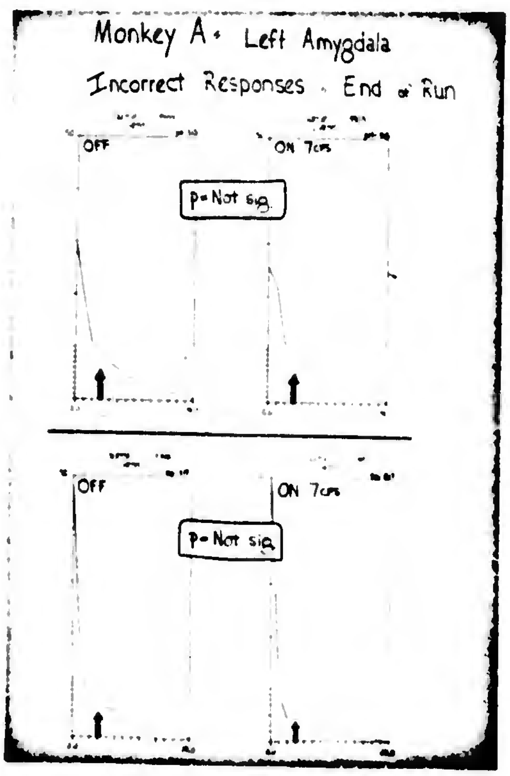


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT RESPONSES
END OF RUN
MONKEY A: NONRESPONSIVE STRUCTURES

INCORRECT RESPONSES ONLY -- NO CORRECT RESPONSES SAMPLED







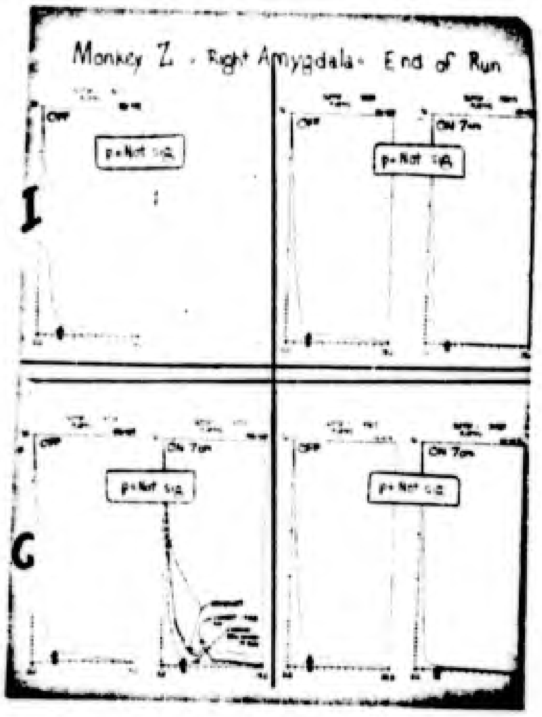
PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
<u>END OF RUN</u>
MONKEY Z(B): NONRESPONSIVE STRUCTURES

INC I

COR C

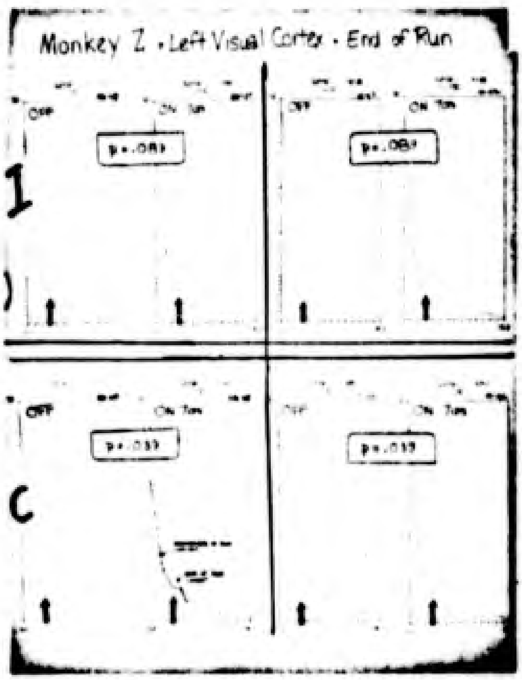
INC I

COR C



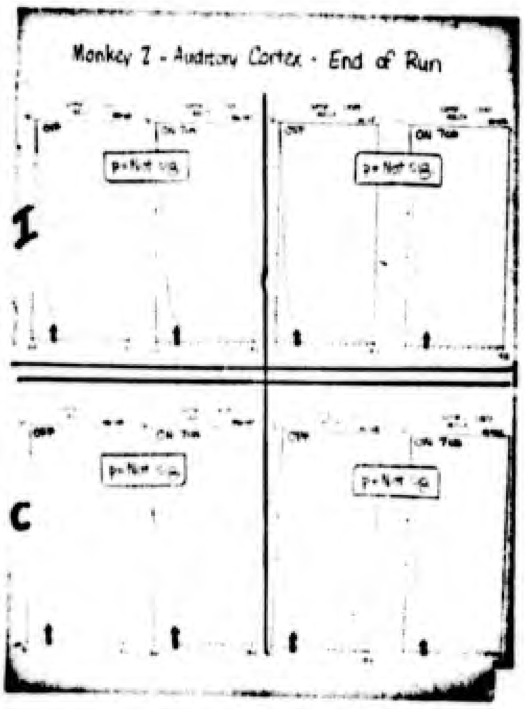
INC I

COR C



INC I

COR C



II. Autospectra: Percent power graphs. Incorrect and correct responses. Responsive and nonresponsive structures. 7 Hz fields on vs. fields off. Beginning of run.

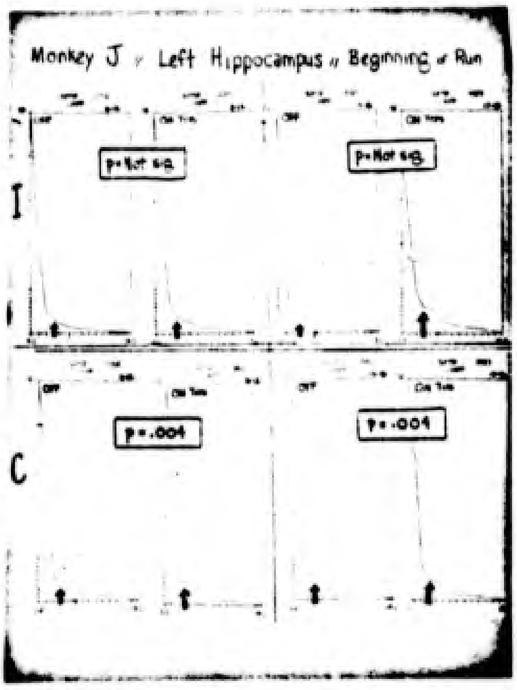
P values indicate probability of observed differences in peak quotients.

Monkeys J and Z only.

PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY J(B): RESPONSIVE STRUCTURES

INC
COR

INC
COR



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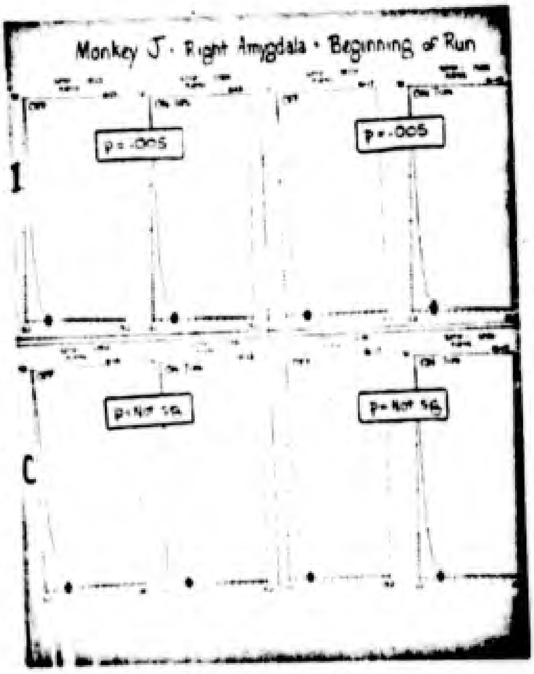
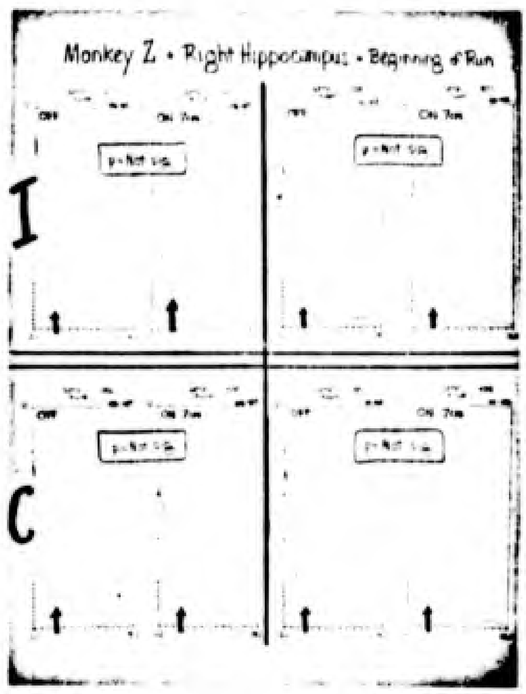


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY Z(B): RESPONSIVE STRUCTURES

INC

COR



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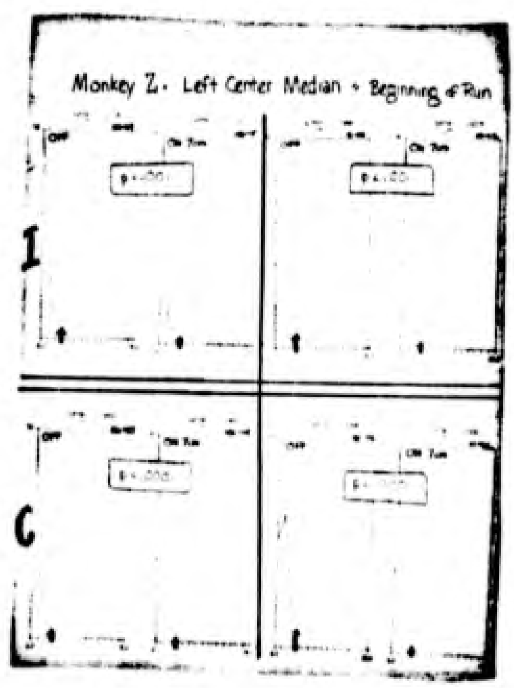
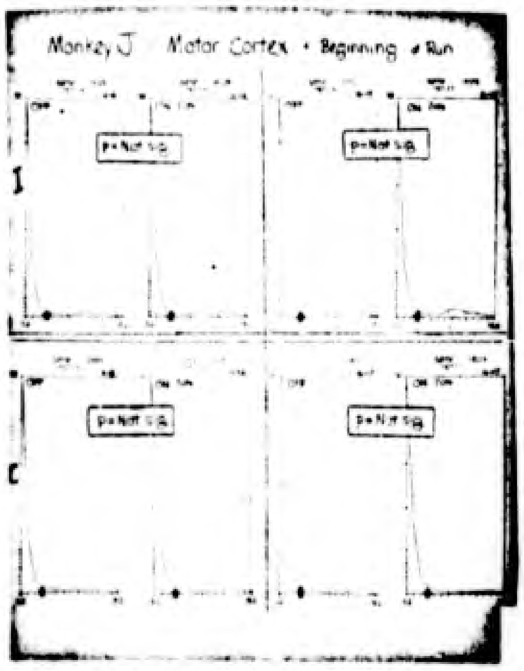


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY J(B): NONRESPONSIVE STRUCTURES

INC

COR



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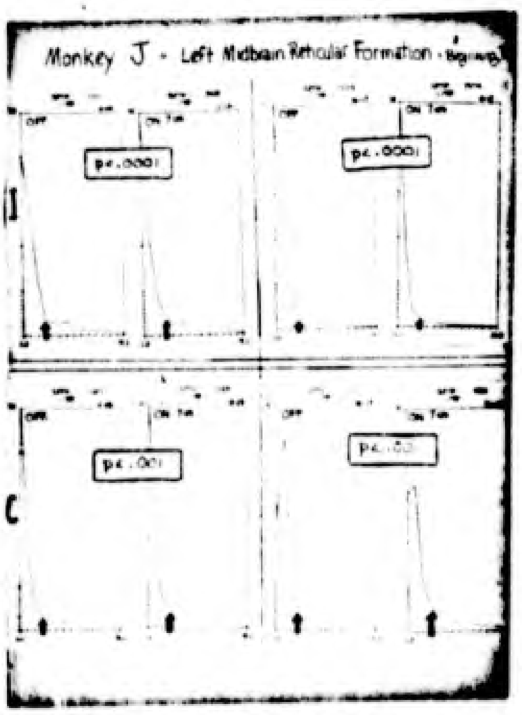

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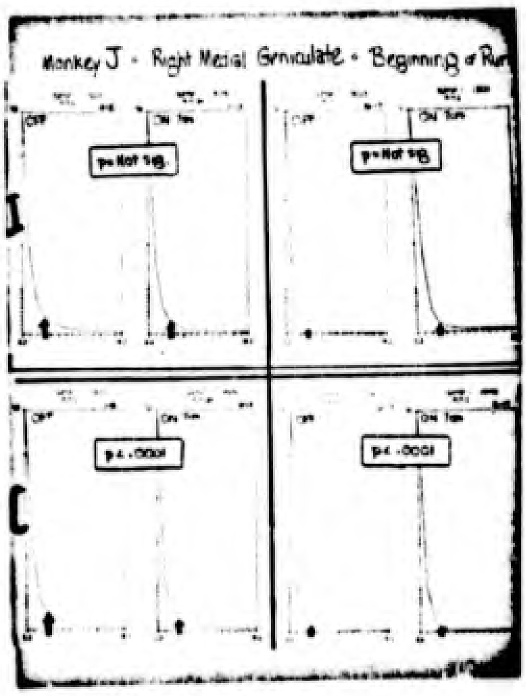
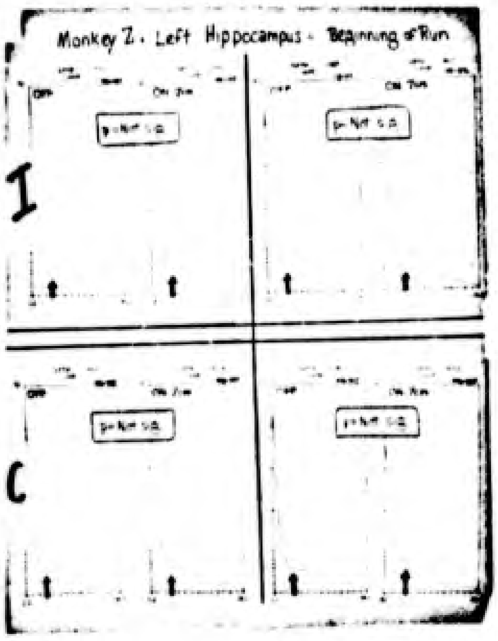


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-7 Hz-
INCORRECT & CORRECT RESPONSES
<u>BEGINNING OF RUN</u>
MONKEY Z(B): NONRESPONSIVE STRUCTURES

INC
COR



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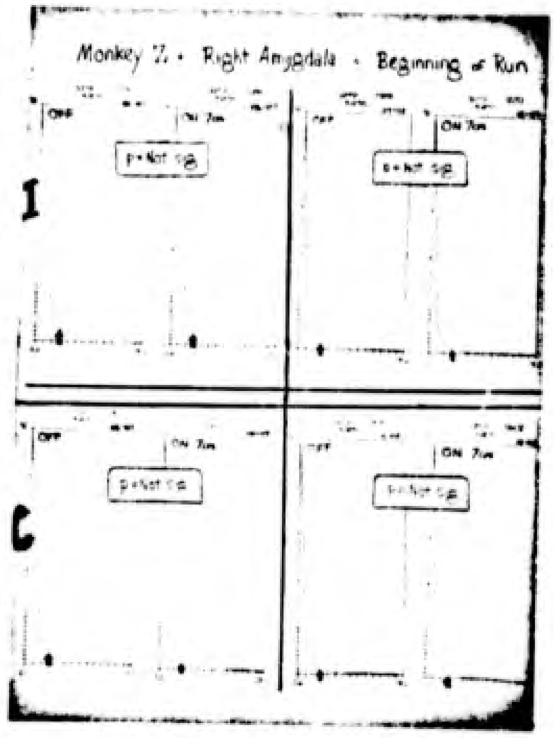

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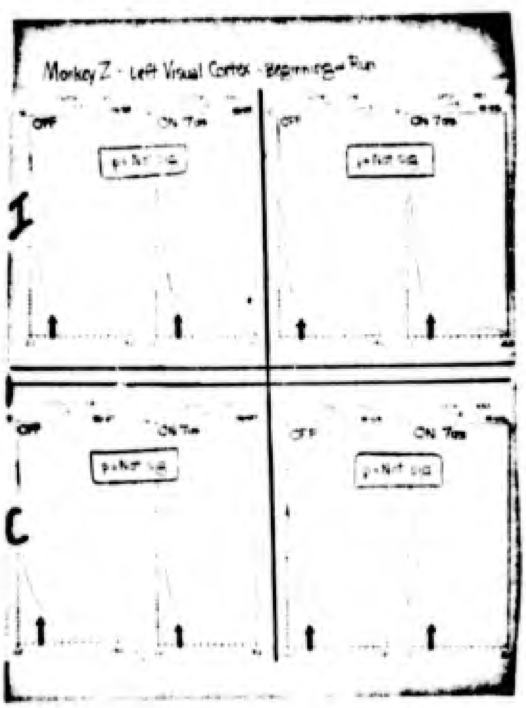

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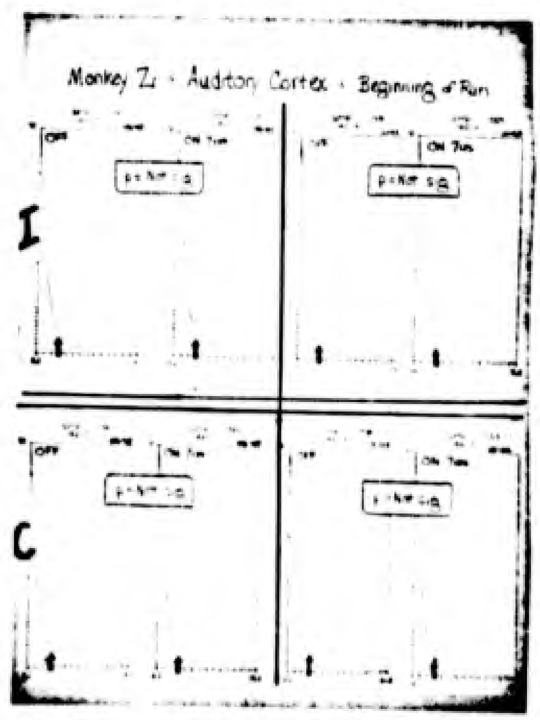


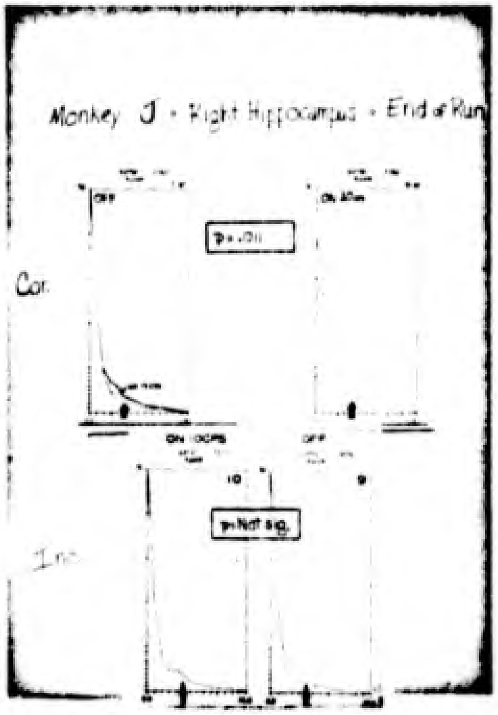
III. Autospectra: Percent power graphs and P values for peak quotients. 10 Hz fields.

Monkeys J and Z.

PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY J(A): RESPONSIVE STRUCTURES

CORRECT

INCORRECT



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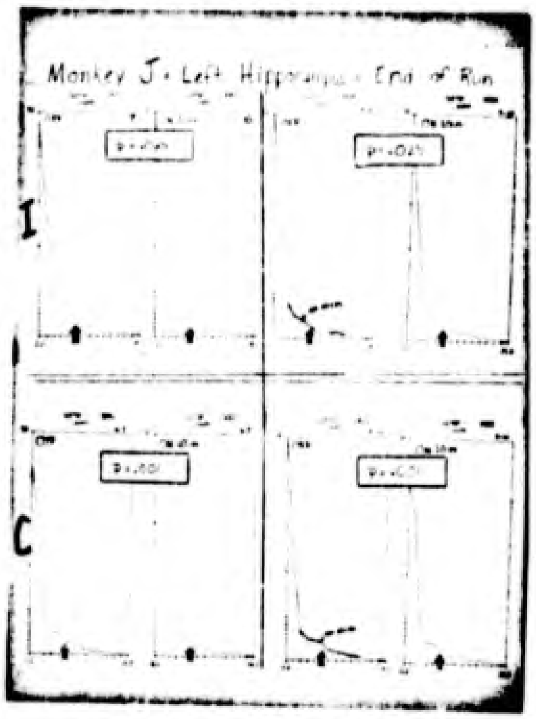

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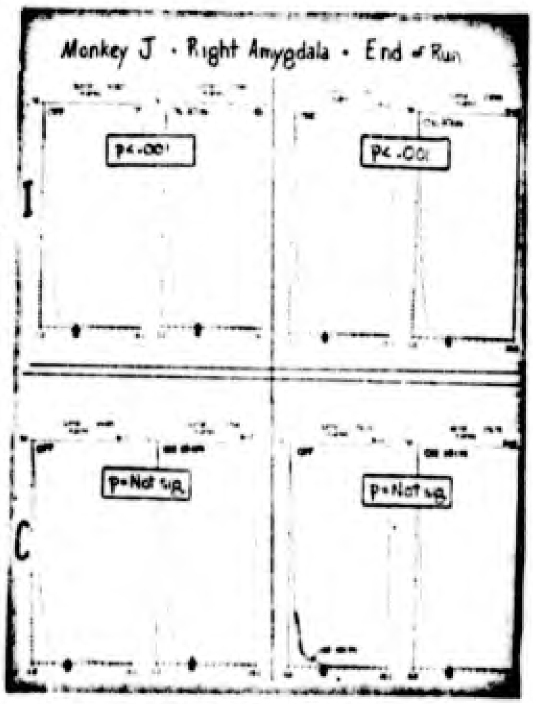
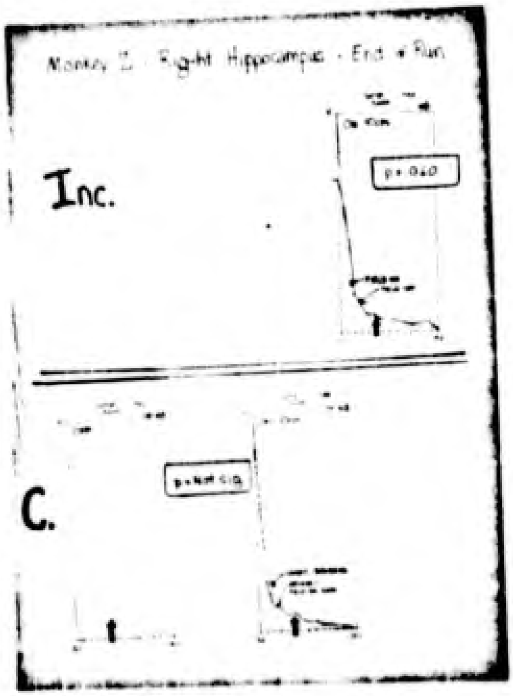


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY Z(A): RESPONSIVE STRUCTURES

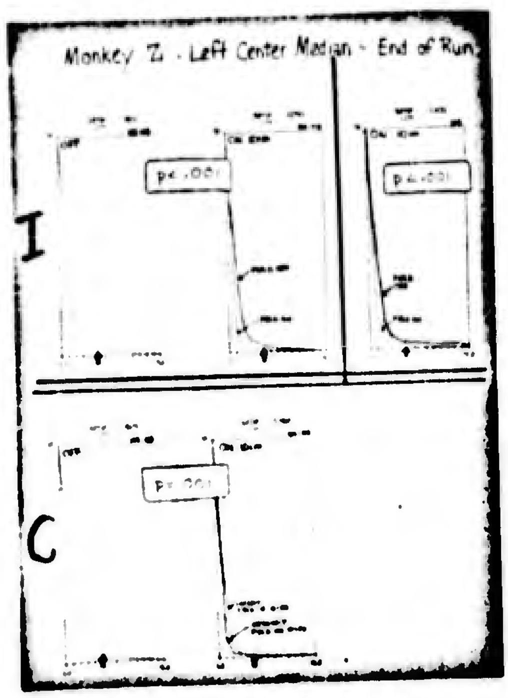
INC

COR



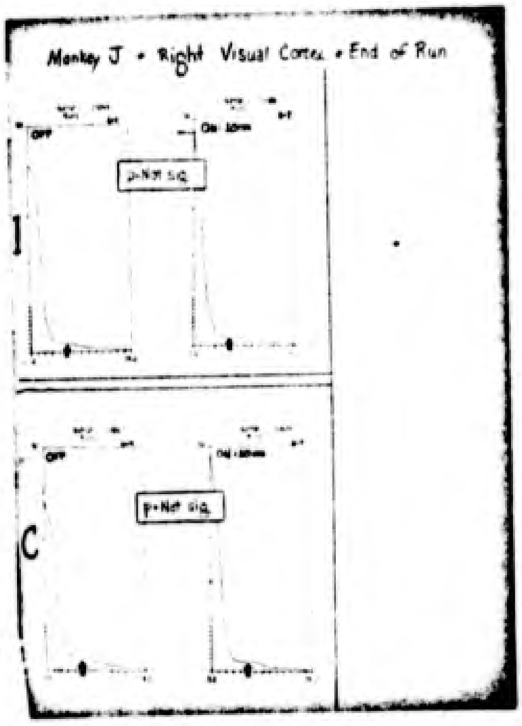
INC

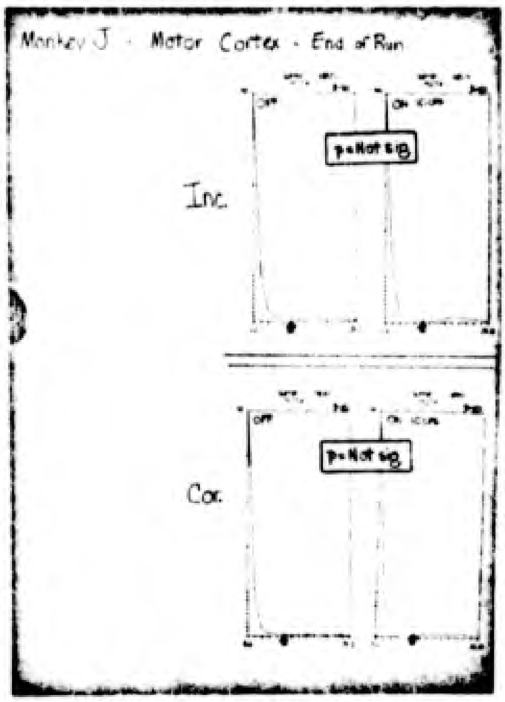
COR

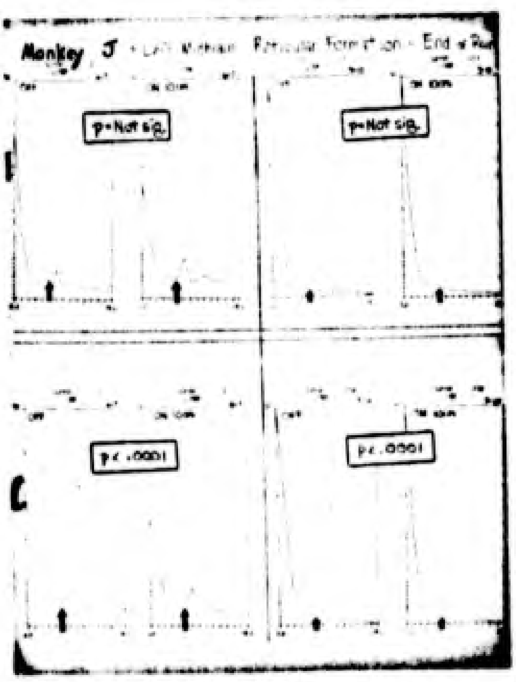


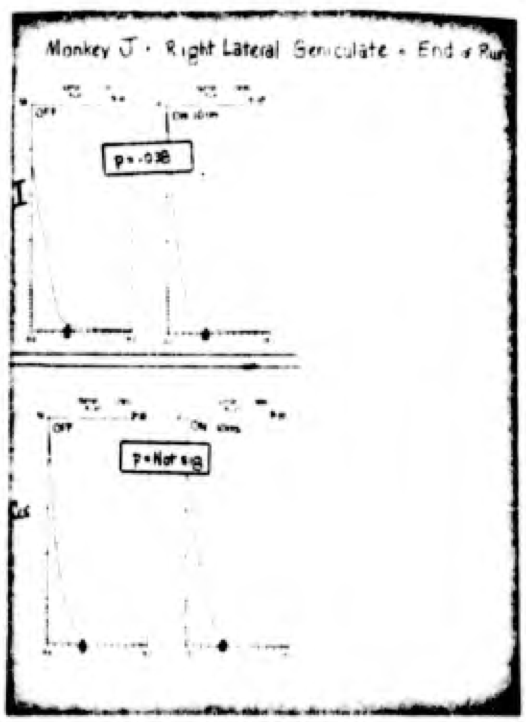
PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-

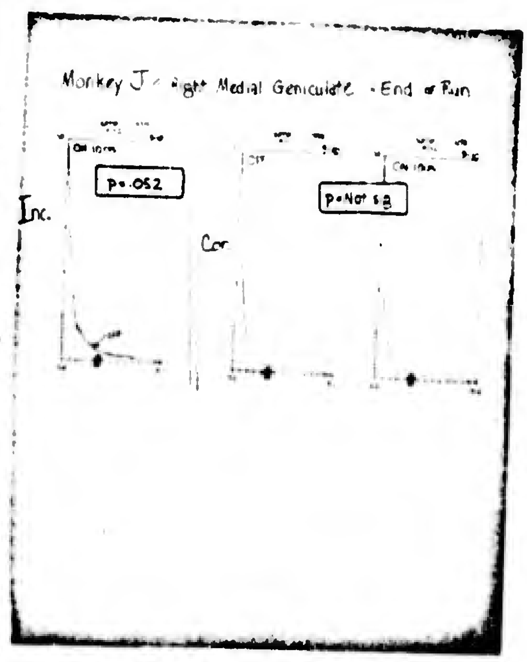
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY J(A): NONRESPONSIVE STRUCTURES







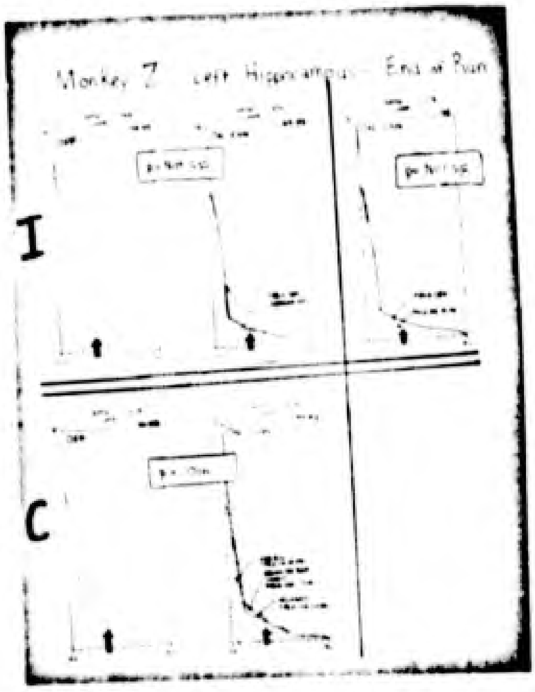




PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
END OF RUN
MONKEY Z(A): NONRESPONSIVE STRUCTURES

INC I

COR C



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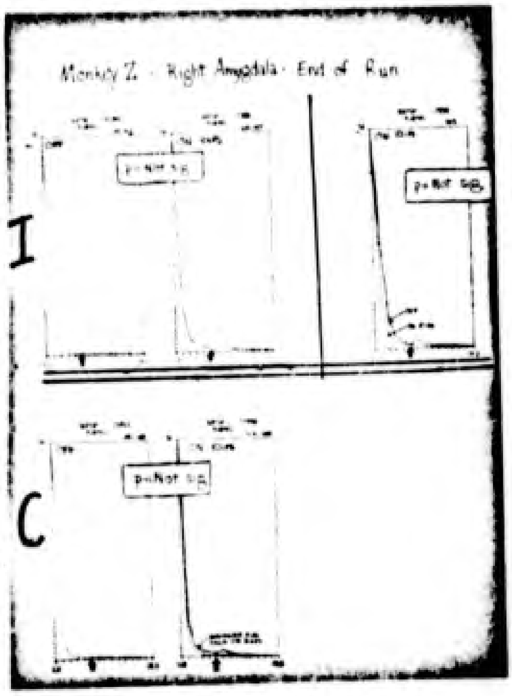
COR C



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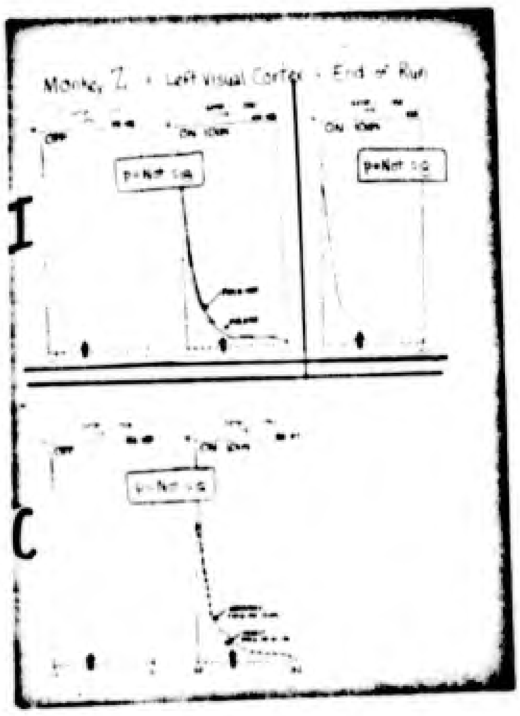

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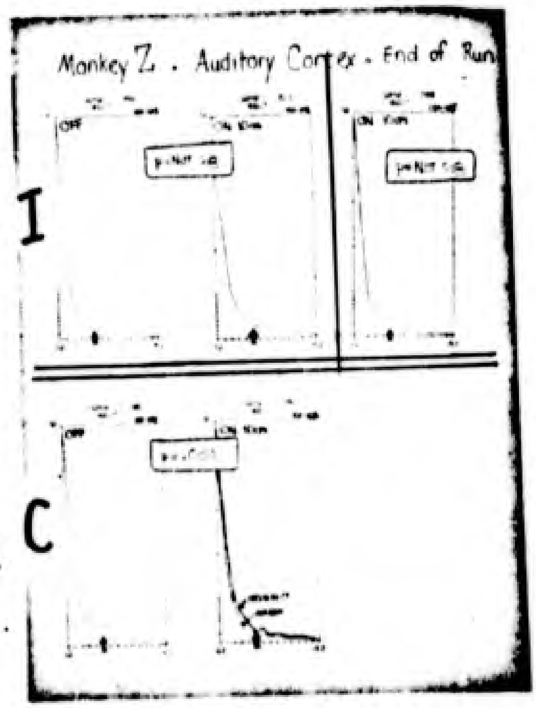
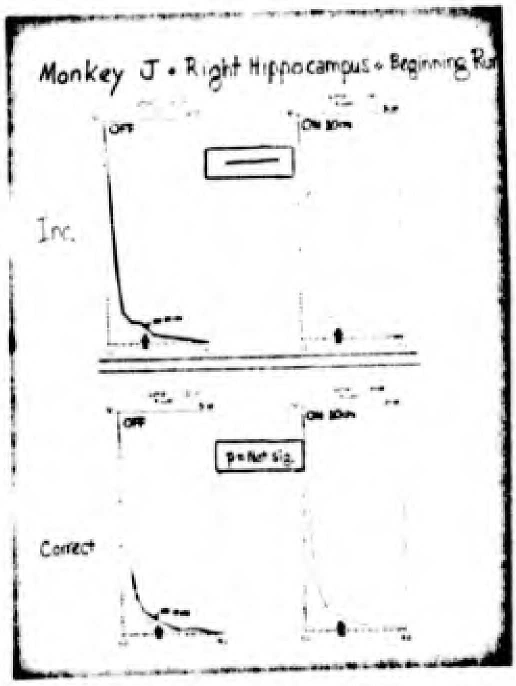
COR C



PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
<u>BEGINNING OF RUN</u>
MONKEY J(A): RESPONSIVE STRUCTURES

INC

COR



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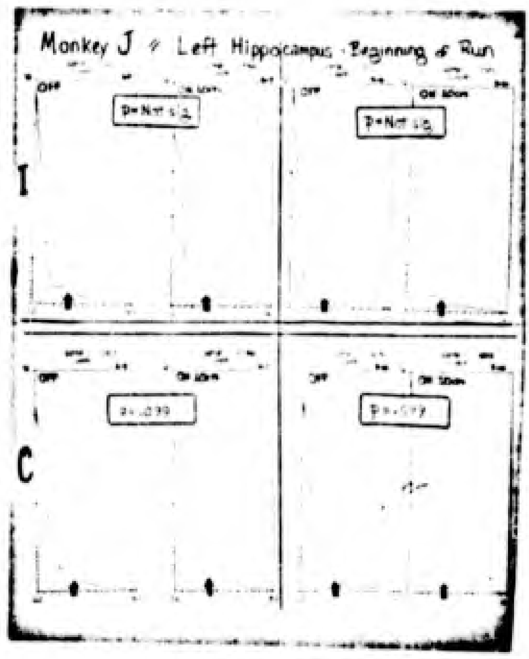

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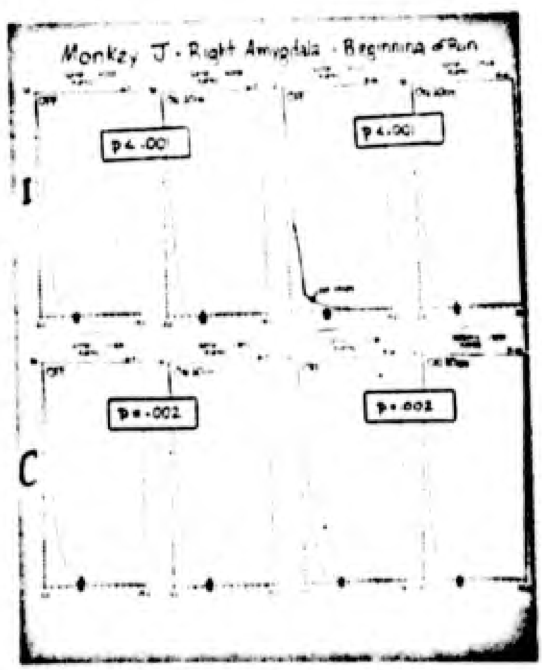
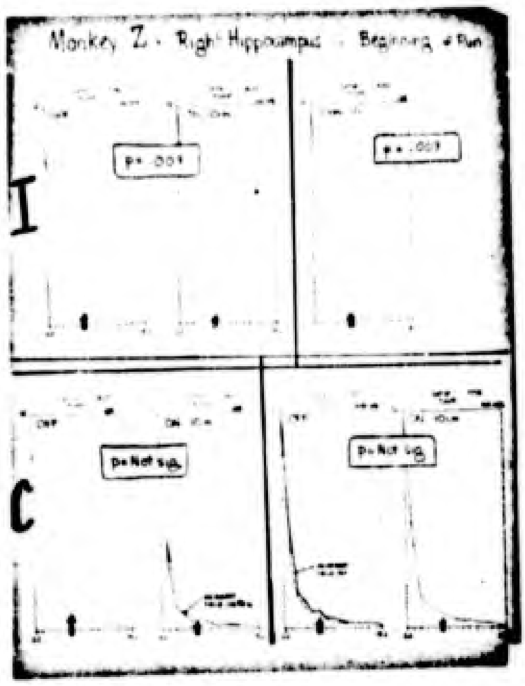


PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY Z(A): RESPONSIVE STRUCTURES

INC

COR



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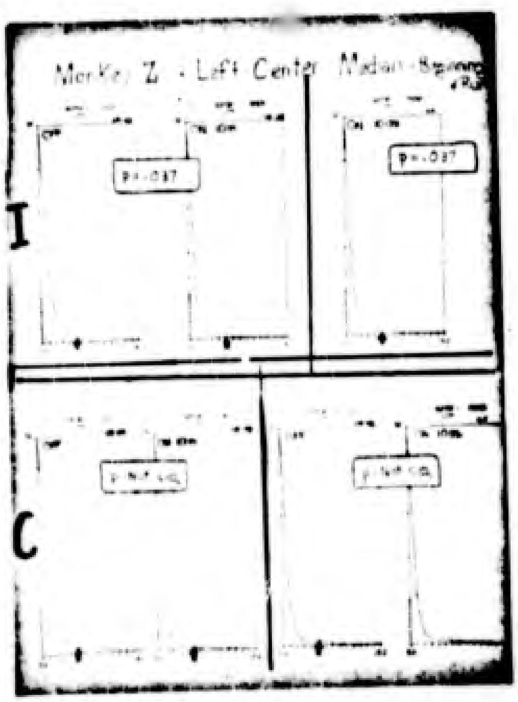
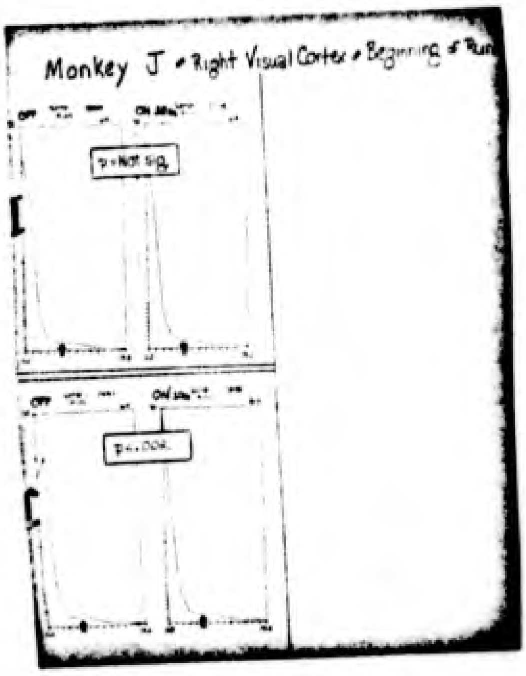
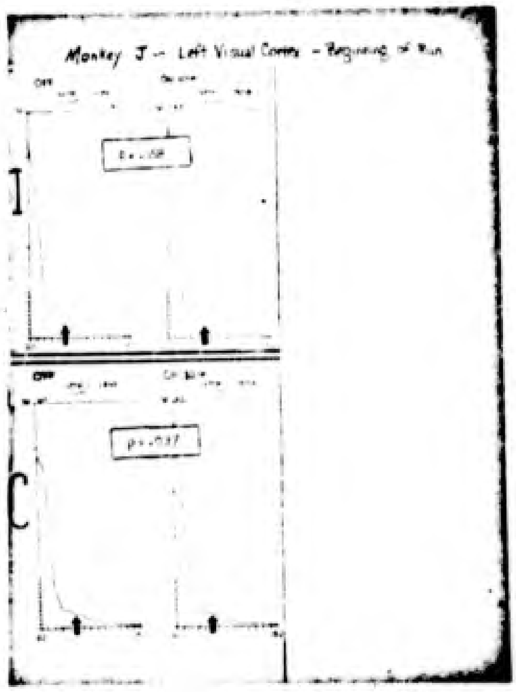
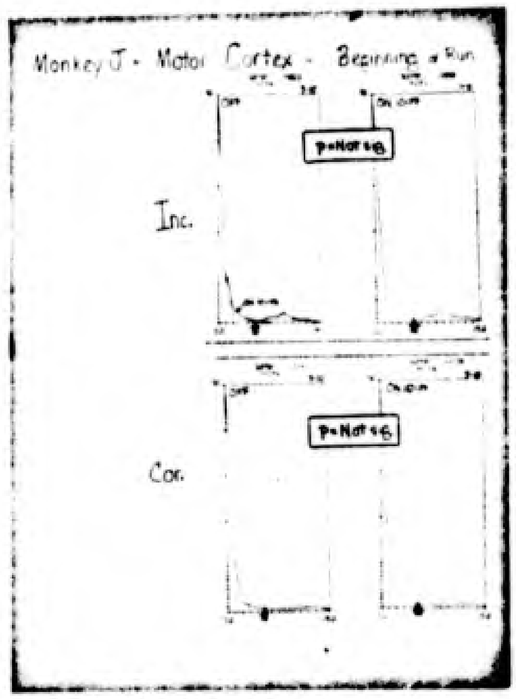
COR

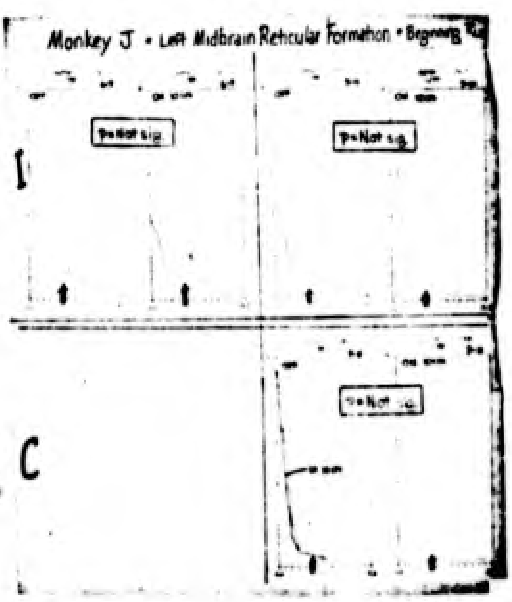


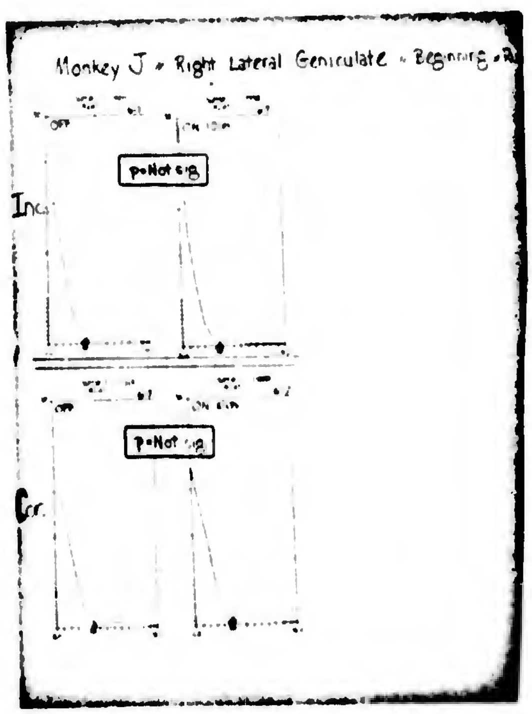
PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY J(A): NONRESPONSIVE STRUCTURES

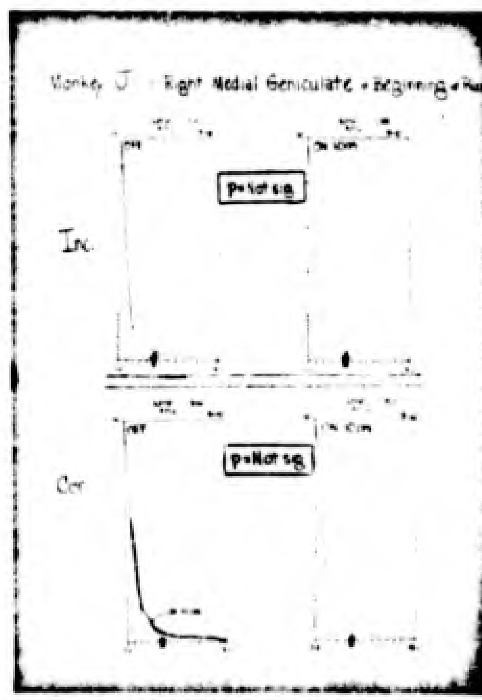








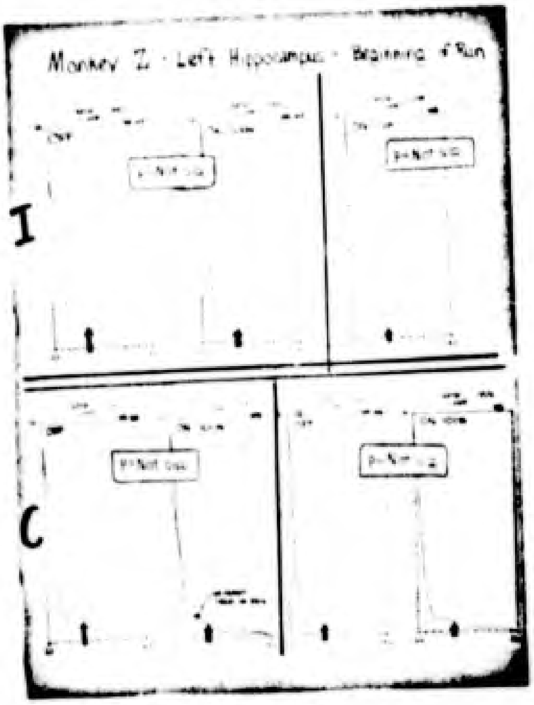




PEAK QUOTIENTS: 4-HOUR EXPOSURE
FIELD ON VS. FIELD OFF
-10 Hz-
INCORRECT & CORRECT RESPONSES
BEGINNING OF RUN
MONKEY Z(A): NONRESPONSIVE STRUCTURES

INC

COR



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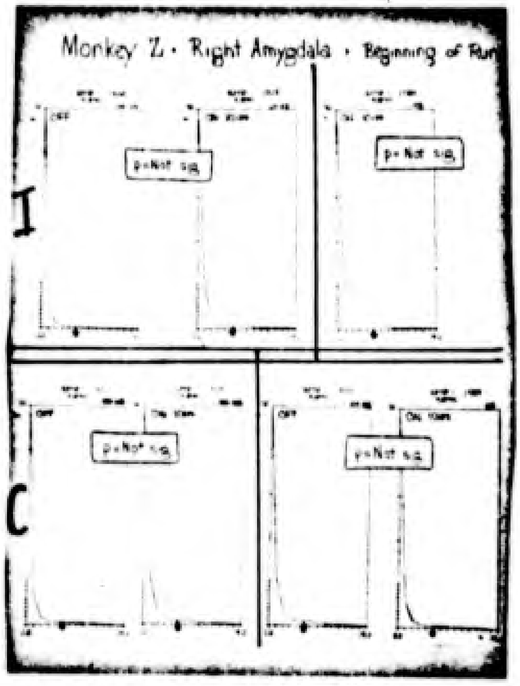
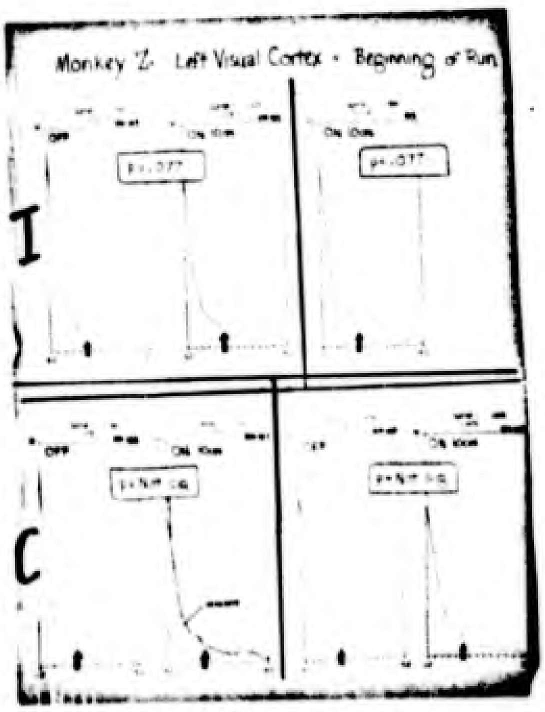


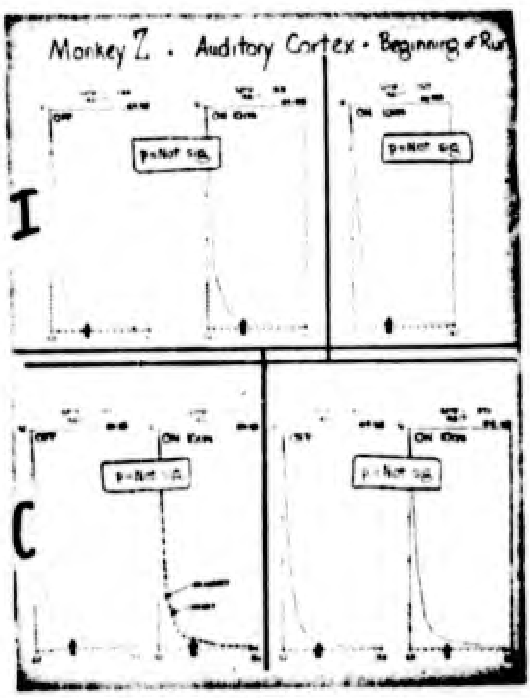
INC

COR



INC

COR



IV. Fast vs. slow responses. Peak quotients.

P values for observed differences. 7 Hz fields on and fields off. Responsive and nonresponsive structures.

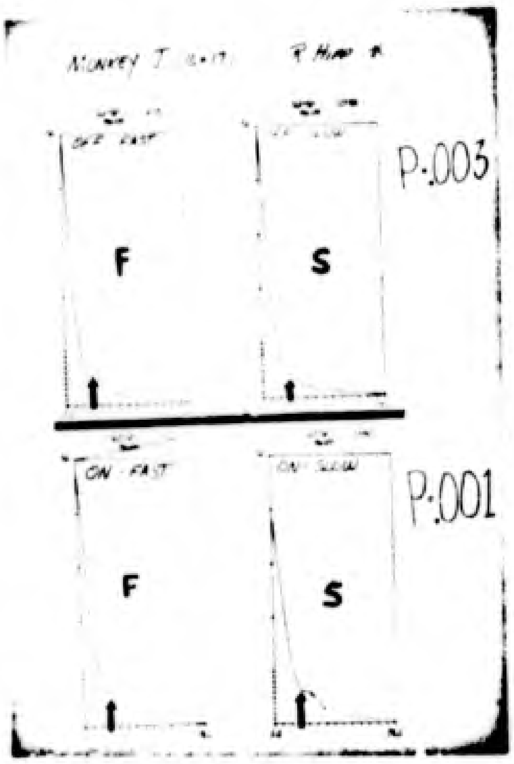
Monkeys J, Z, and A.

FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5) RESPONSES

MONKEY J -- RESPONSIVE STRUCTURES

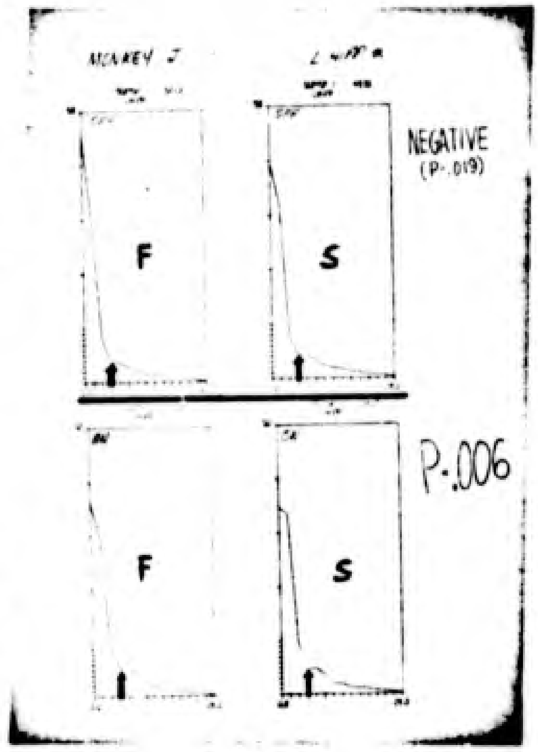
OFF

ON



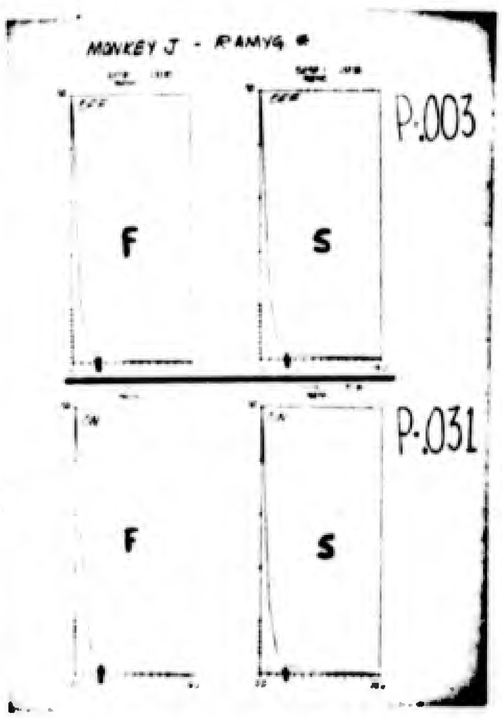
OFF

ON



OFF

ON

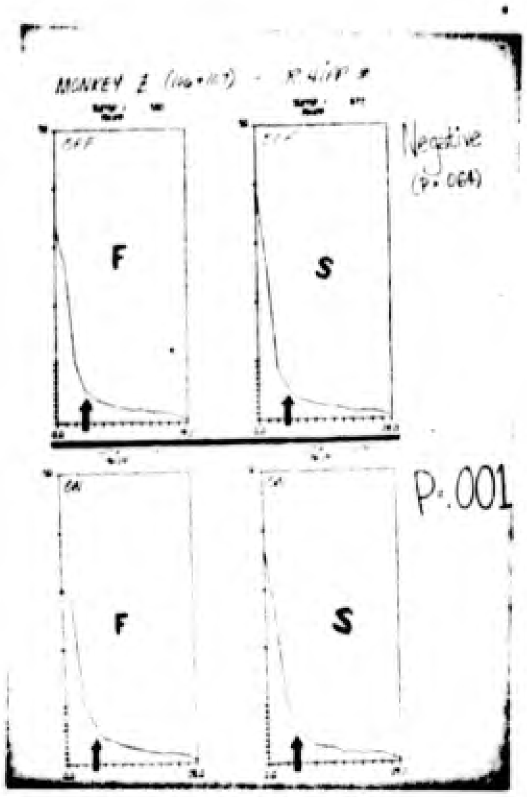


FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5 sec) RESPONSES

MONKEY Z -- RESPONSIVE STRUCTURES

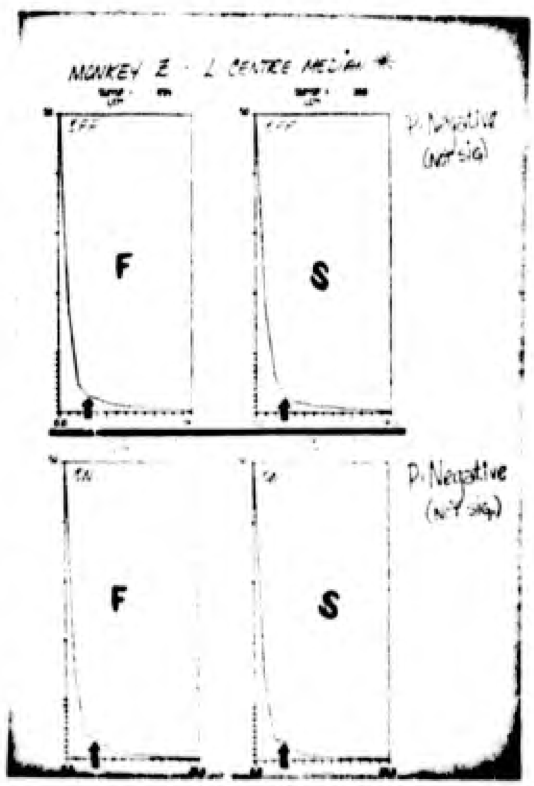
OFF

ON



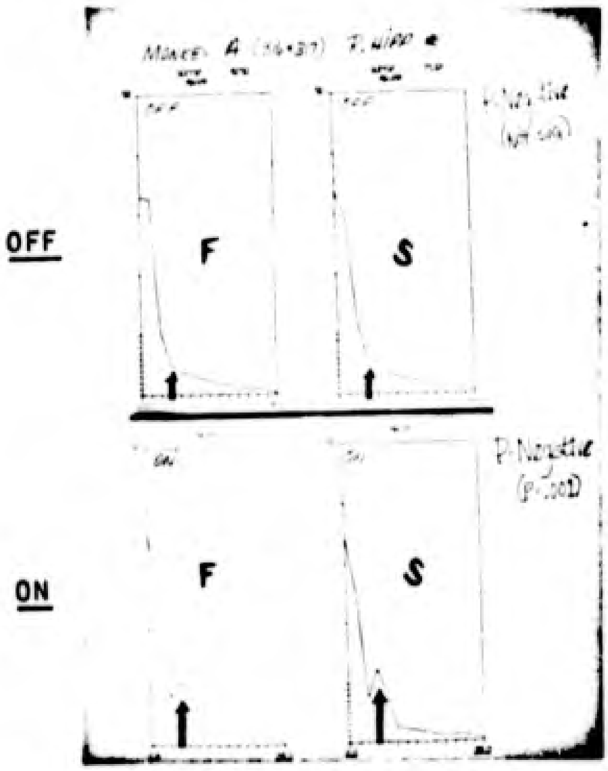
OFF

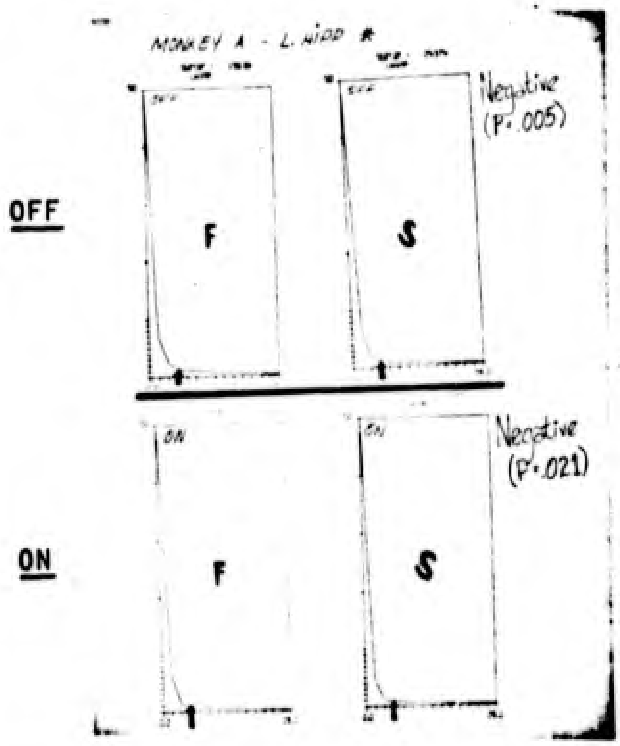
ON

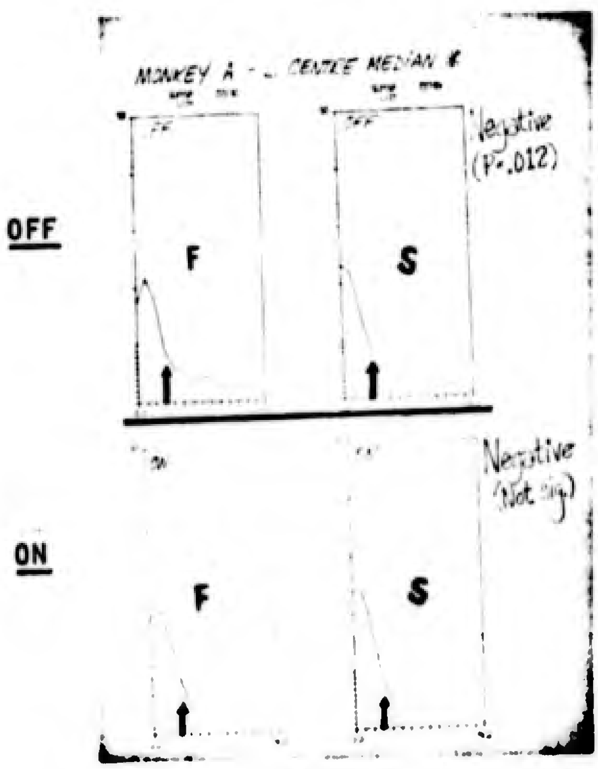


FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5 sec) RESPONSES

MONKEY A -- RESPONSIVE STRUCTURES





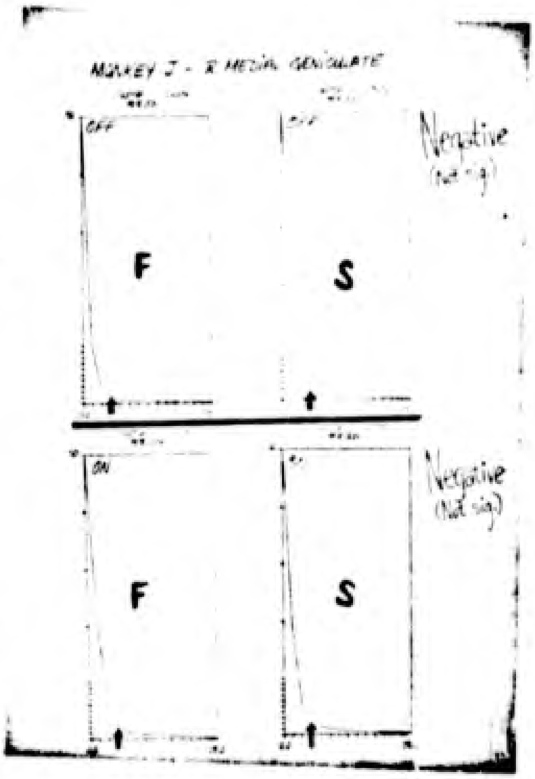


FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5 sec) RESPONSES

MONKEY J -- NONRESPONSIVE STRUCTURES

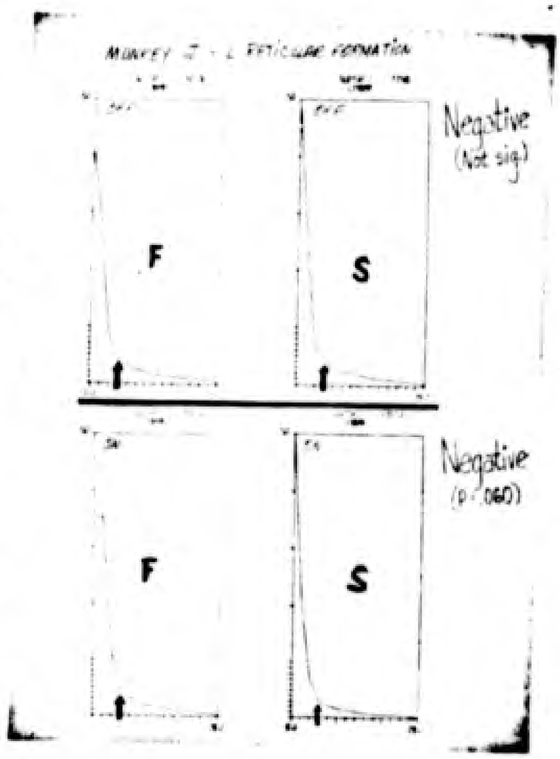
OFF

ON



OFF

ON



OFF

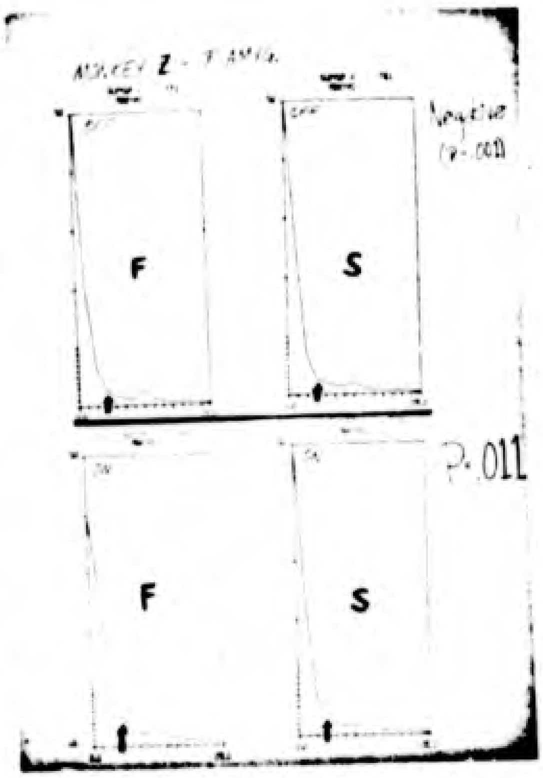
ON

FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5 sec) RESPONSES

MONKEY Z -- NONRESPONSIVE STRUCTURES

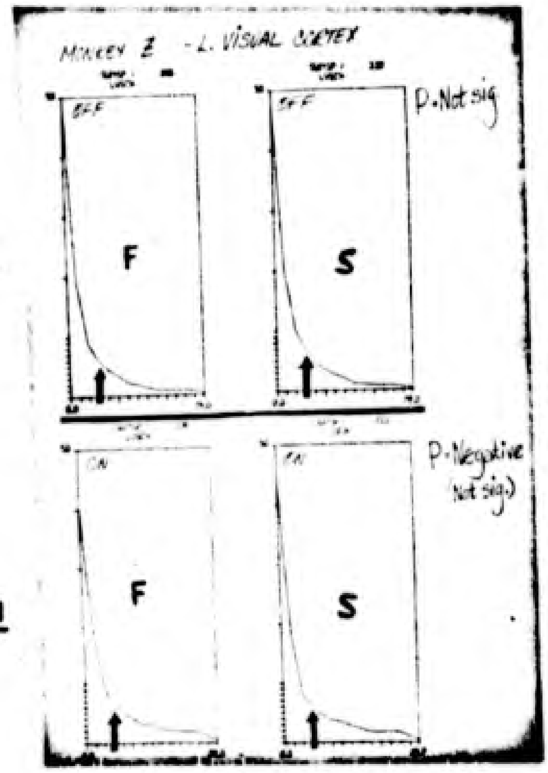
OFF

ON



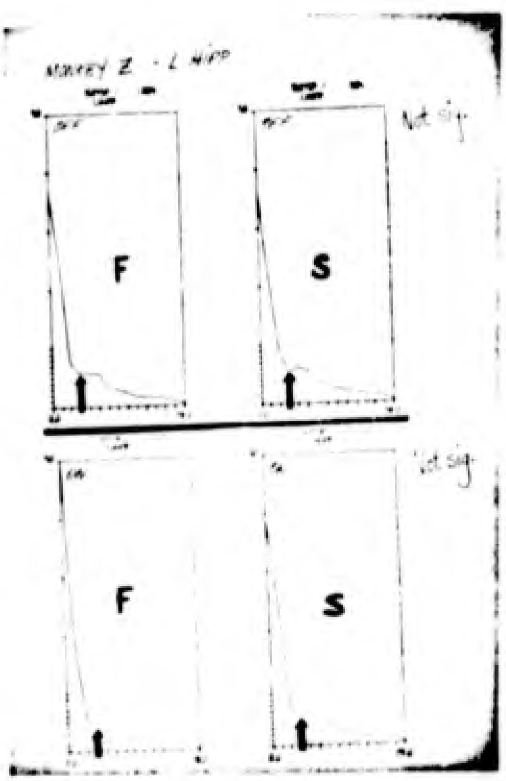
OFF

ON



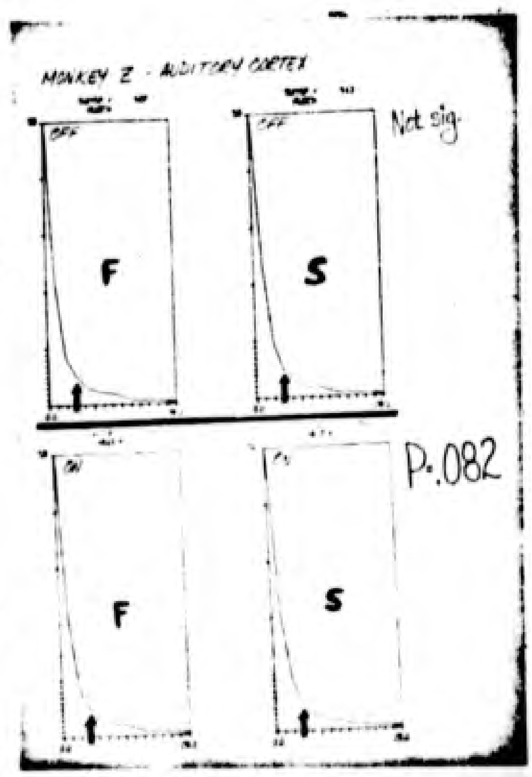
OFF

ON



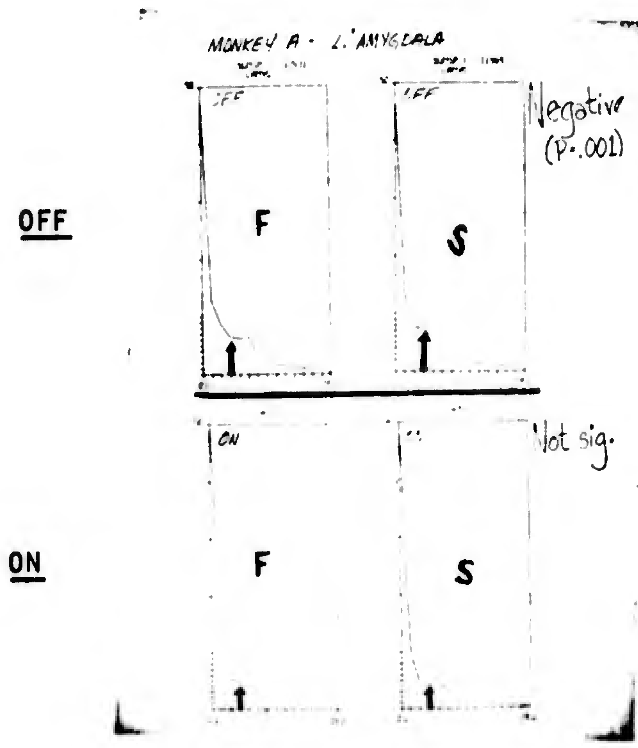
OFF

ON



FAST (5.0-5.5 sec) VS. SLOW (6.0-6.5 sec) RESPONSES

MONKEY A -- NONRESPONSIVE STRUCTURE



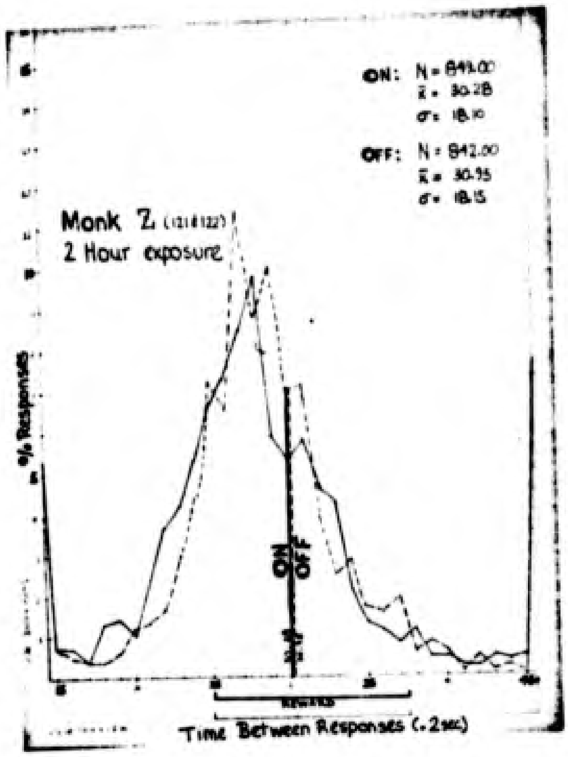
V. Two-hour experiments. IRT's and peak quotient P values. 7 Hz fields on vs. fields off.

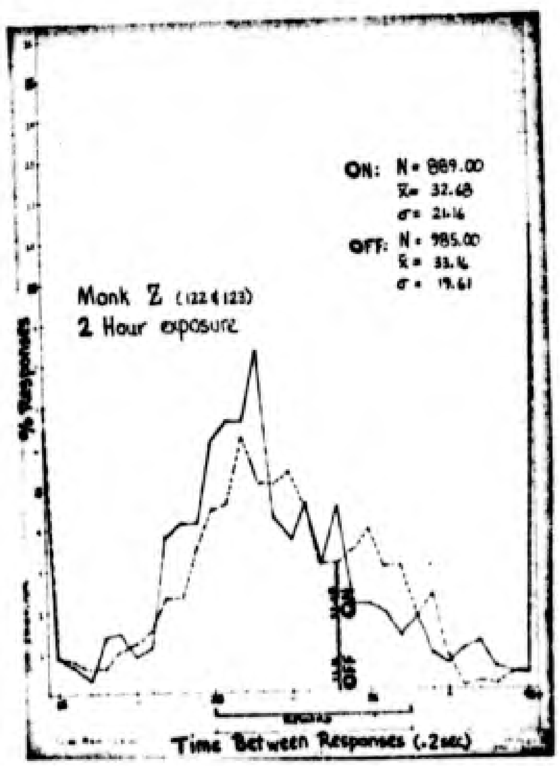
Monkeys Z, B, and A.

INTERRESPONSE TIMES

2 HOUR EXPOSURE (7 Hz)

MONKEY Z

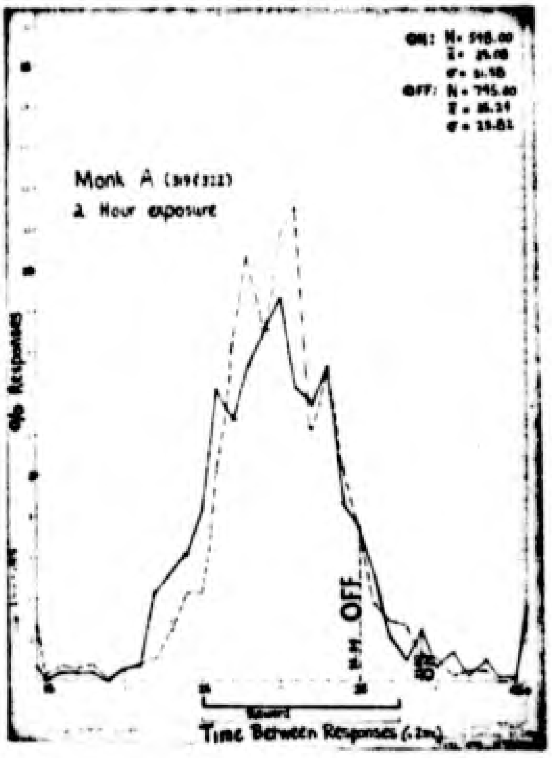


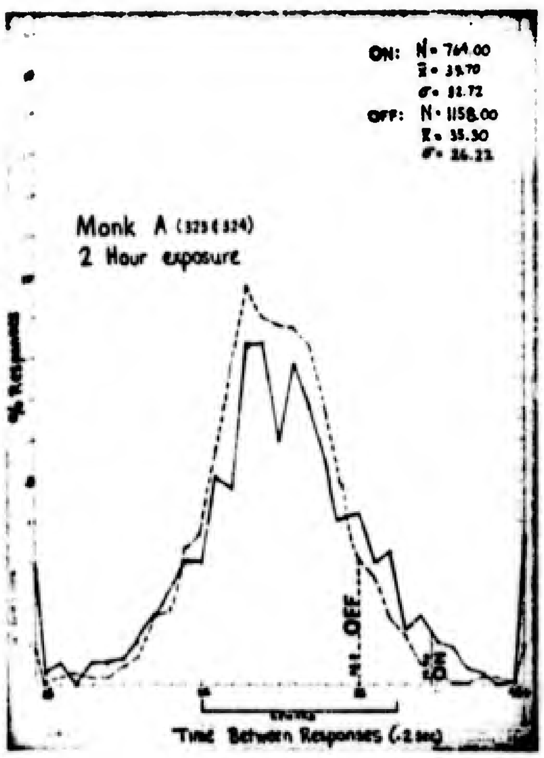


INTERRESPONSE TIME DISTRIBUTIONS

2 HOUR EXPOSURE (7 Hz)

MONKEY A

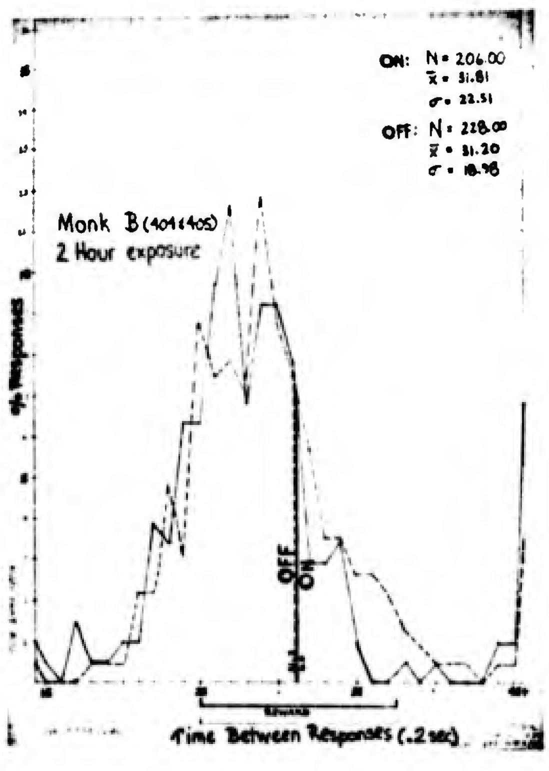




INTERRESPONSE TIMES

2 HOUR EXPOSURE (7 Hz)

MONKEY B



P VALUES FOR JIM JR., ZSA ZSA, ACE, BABETTE

PEAK QUOTIENTS: 2 HOURS OFF - 2 HOURS ON

JIM JR.	21	22	23	24
R. Hipp.	neg Not sig	neg .0920	.0384	Not sig
L. Hipp.	neg .0681	neg Notsig	neg <.0001	neg Not sig
R. Amyg.	neg .0002	Not sig	neg .0351	Not sig
Mot. Cx.	neg Not sig	neg <.0001	neg .0808	.0007
L.Midbr. R.F.	neg .0071	<.0001	.0823	neg Not sig
R. Med.Gen.	neg Not sig	neg .0110	neg .0735	.0045

ZSA ZSA	121	122	123
R. Hipp.	Not sig	neg Not sig	Not sig
L. Hipp	neg Not sig	neg Not sig	neg Not sig
R. Amyg.	neg Not sig	Not sig	Not sig
R. Vis. Cx.	neg Not sig	Not sig	.0018
Aud. Cx.	Not sig	.0505	.0262
L. Vis. Cx.	.0351	.0281	<.0001

ACE	319	322	323	324
R. Hipp.	<.0001	<.0001	neg Not sig	neg Not sig
L. Hipp.	neg Not sig	neg <.0001	neg Not sig	Not sig
RCM	.0329	neg Not sig	.0985	Not sig
LCM	Not sig	neg Not sig	Not sig	Not sig
R. Amyg.	.0054	.0968	neg .0808	.0526
L. Amyg.	.0002	neg .0043	neg Not sig	Not sig

BABETTE	402	403	404	405
R. Sup.Col.	.0051	neg Not sig	neg Not sig	Not sig
L. Amyg.	neg .0031	neg <.0001	neg Not sig	neg .0059
RCM	Not sig	neg .0089	neg Not sig	neg Not sig
R. Hipp.	Not sig	Not sig	neg Not sig	Not sig
L.Midbr.R.F.	Not sig	.0694	neg Not sig	neg Not sig
R.L.Vis.Cx.	neg Not sig	Not sig	Not sig	Not sig

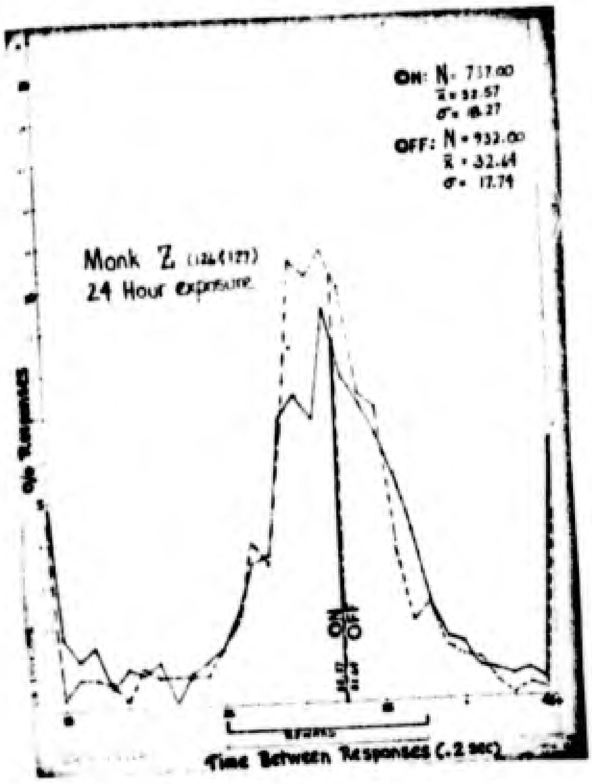
VI. Twenty-four hour experiments. IRT's.

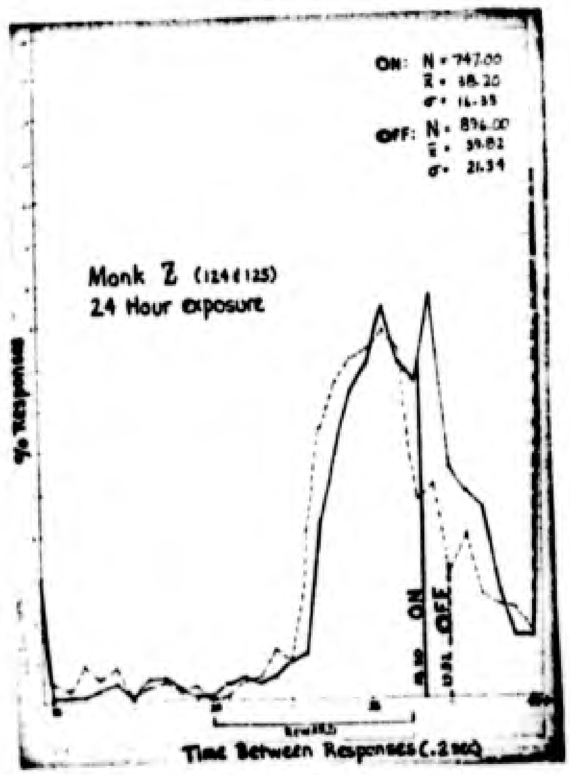
Monkeys Z and A.

INTERRESPONSE TIMES

24 HOUR EXPOSURE

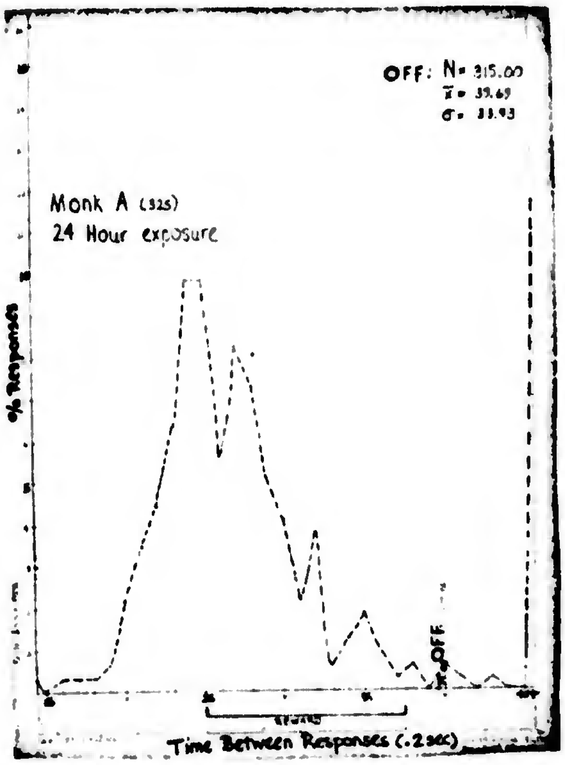
MONKEY Z

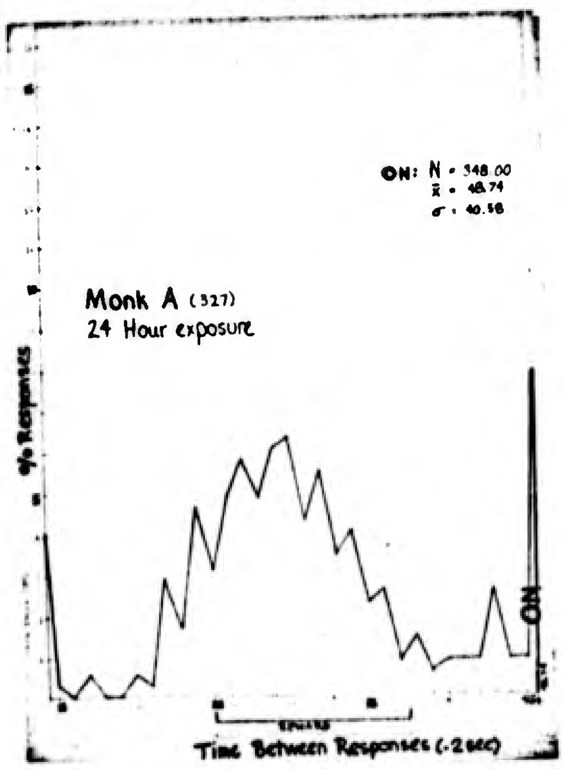




INTERRESPONSE TIMES

24 HOUR EXPOSURE (7 Hz)
MONKEY A





VII. Sleep studies. Autospectra contour plots.

Shaded area represents power level at 7 Hz at beginning of the experiment.

Ordinate = Frequency 0-32 Hz.

Abscissa = consecutive 10 second samples.

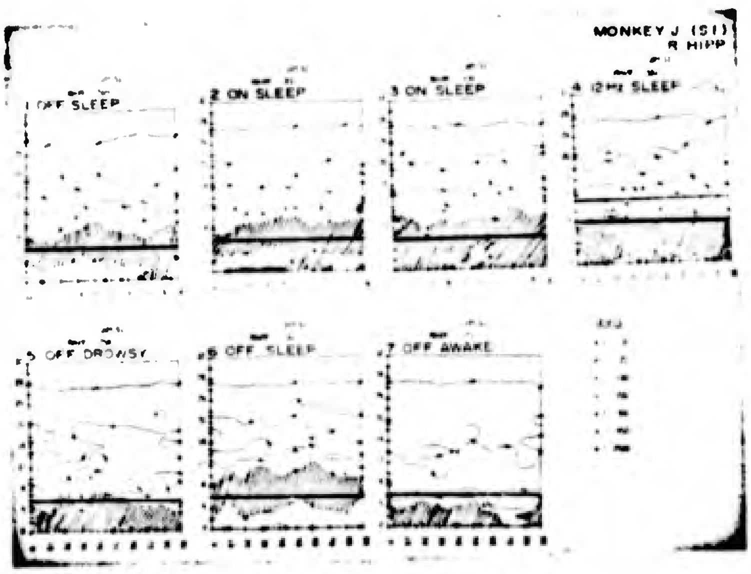
Responsive and nonresponsive structures.

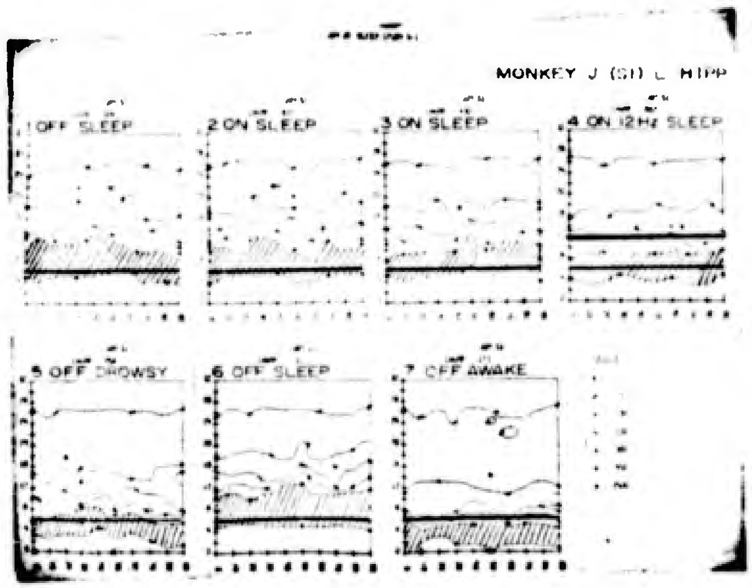
Two experiments (A and B) for each animal.

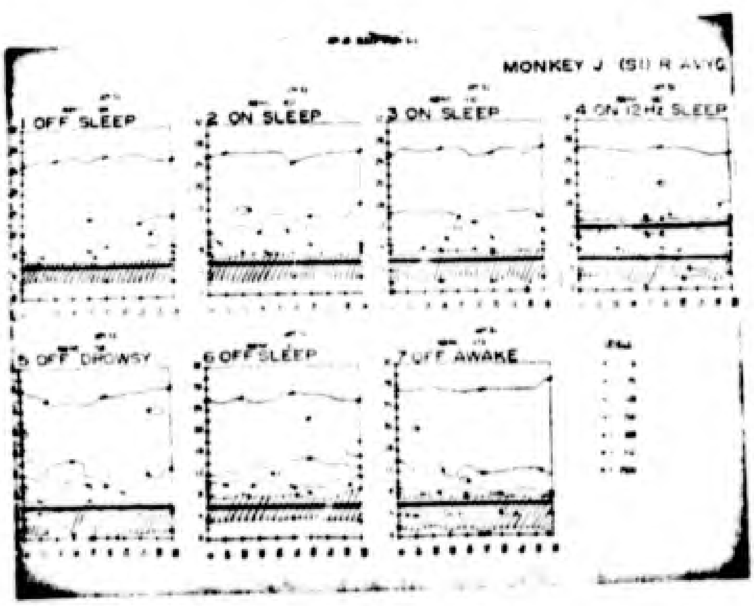
Monkeys J, A, and B.

SLEEP STUDY

MONKEY J(A) -- RESPONSIVE STRUCTURES

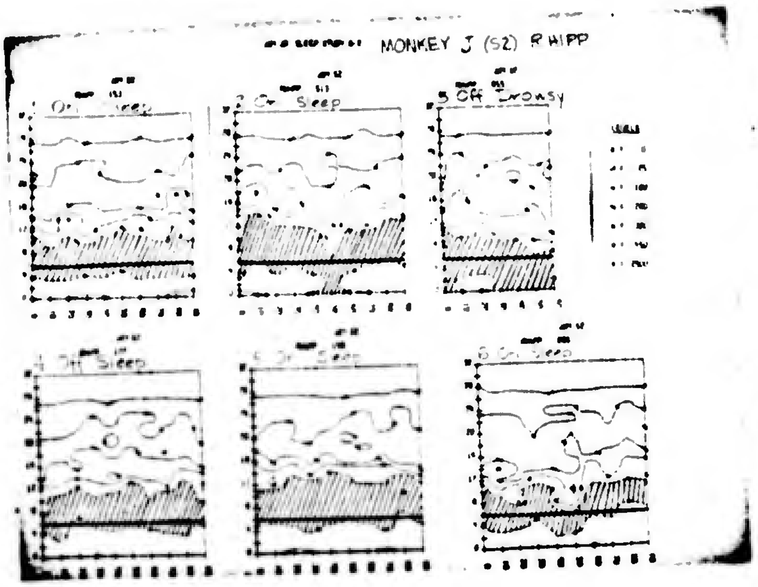


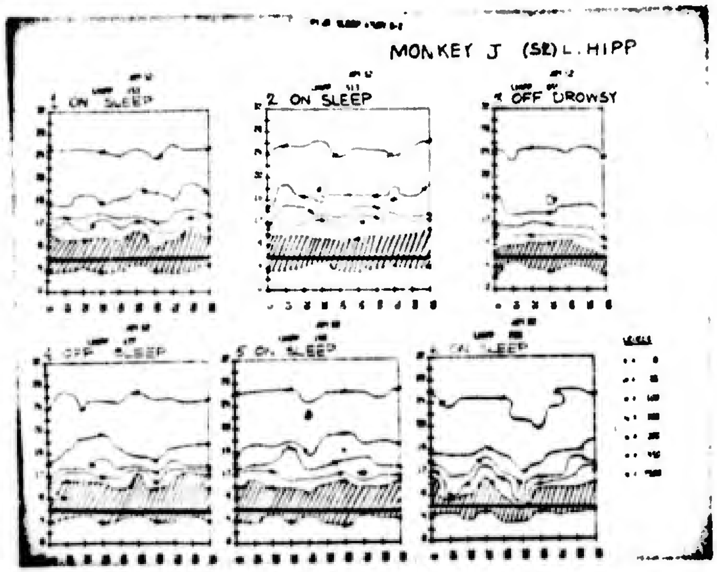


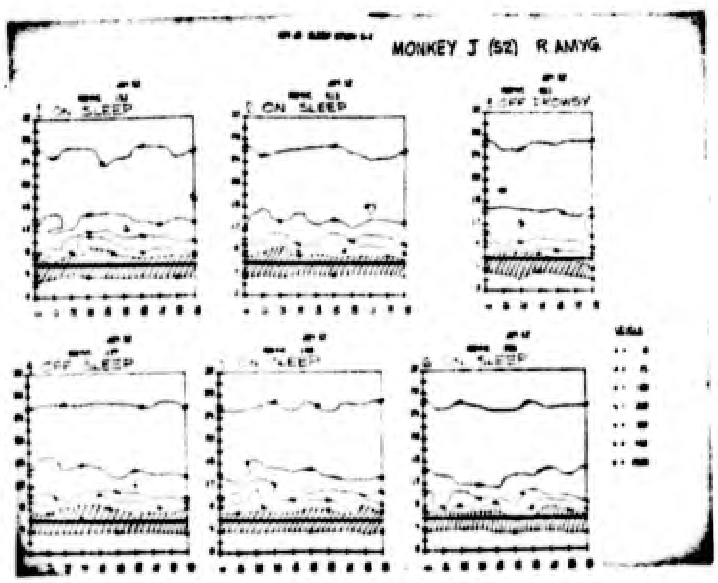


SLEEP STUDY

MONKEY J(B) -- RESPONSIVE STRUCTURES

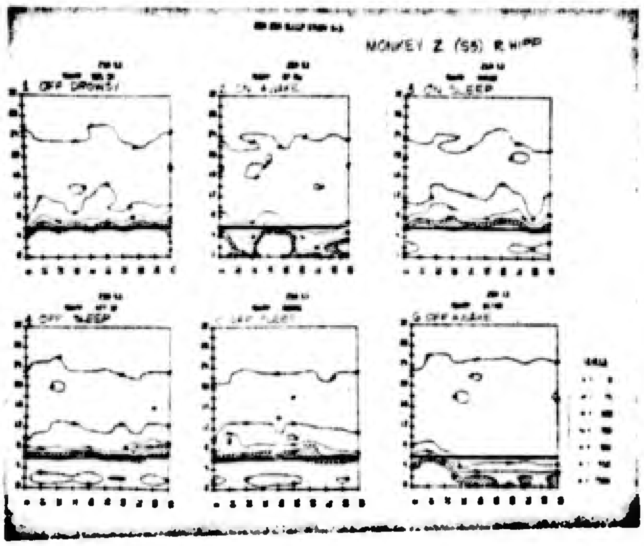






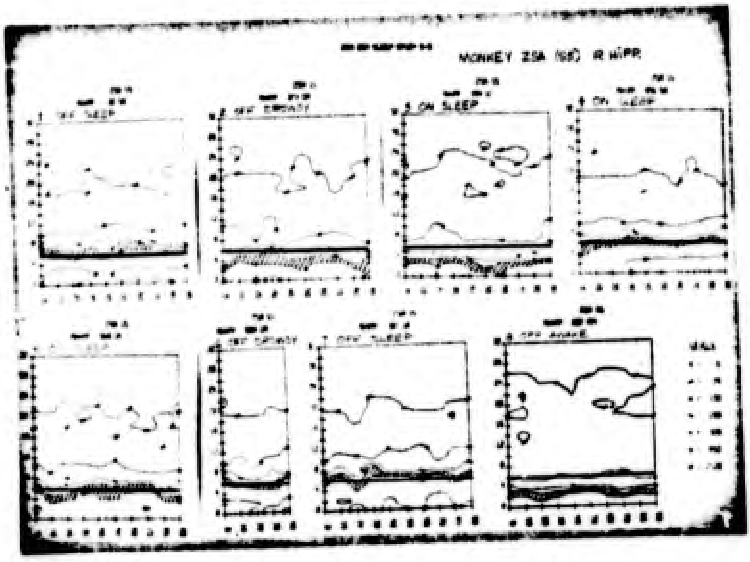
SLEEP STUDY

MONKEY Z(A) -- RESPONSIVE STRUCTURE



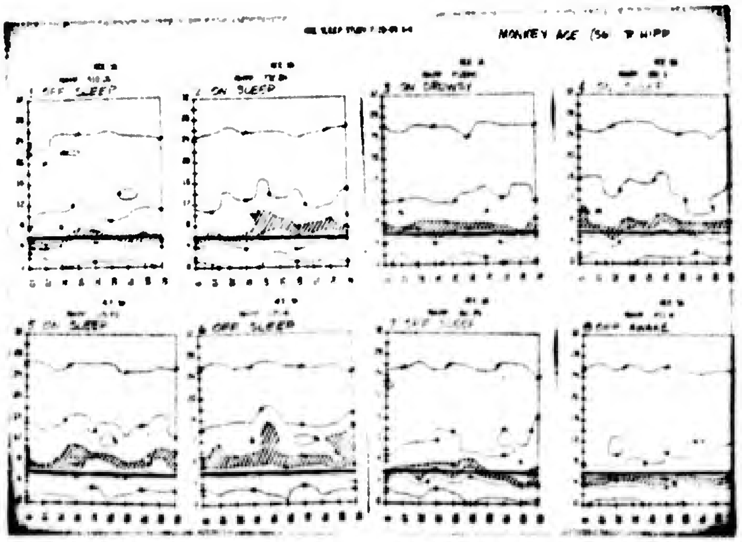
SLEEP STUDY

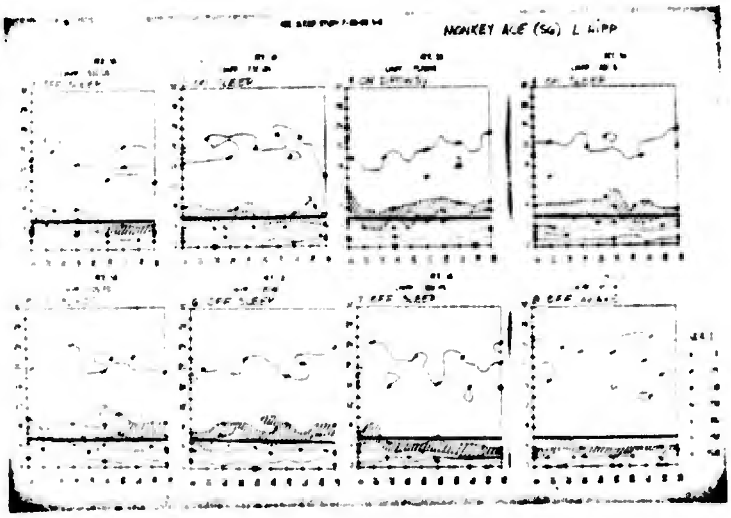
MONKEY Z(B) -- RESPONSIVE STRUCTURE

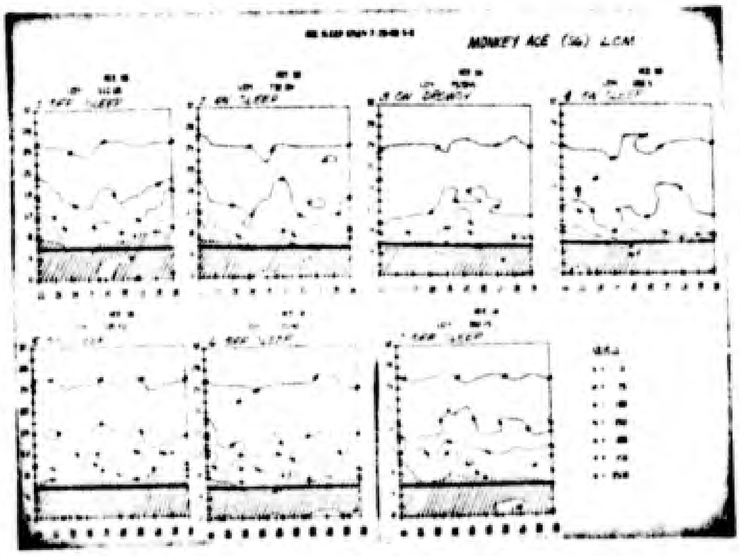


SLEEP STUDY

MONKEY A(A) -- RESPONSIVE STRUCTURES

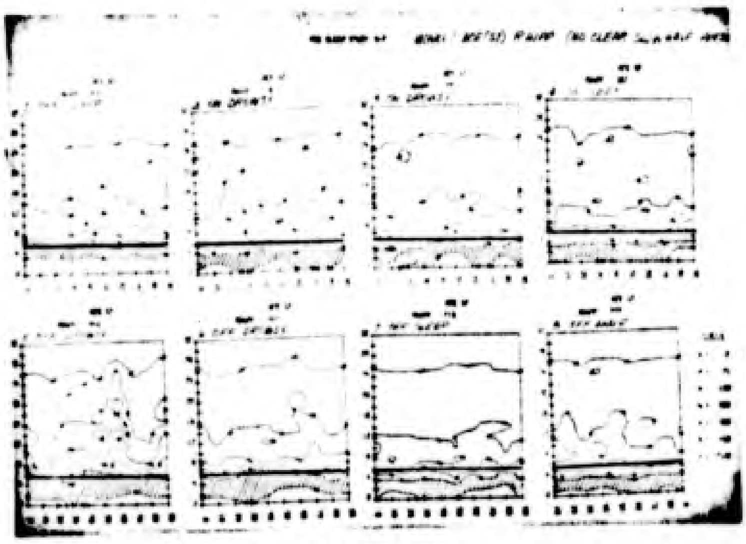


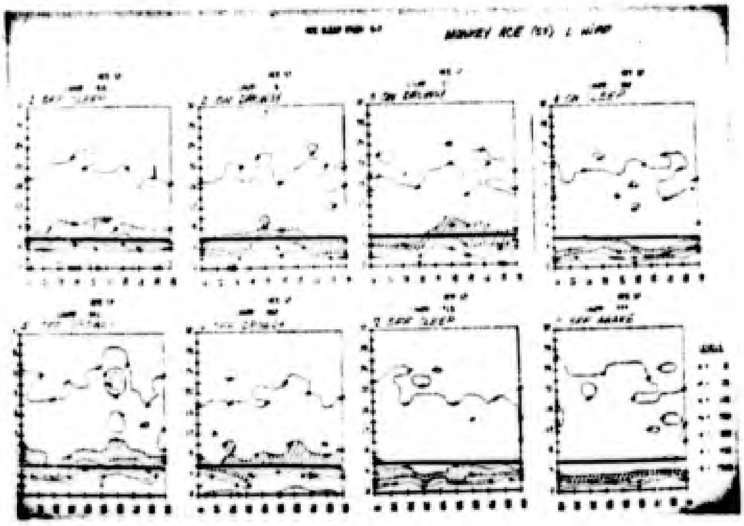


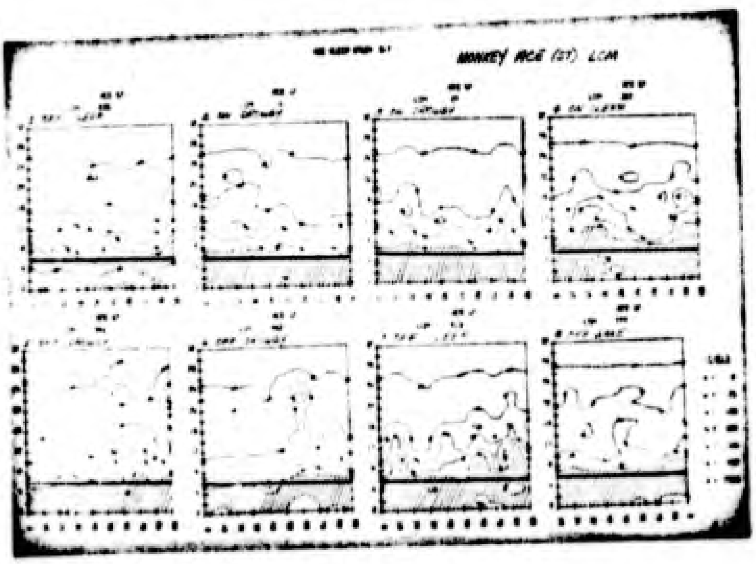


SLEEP STUDY

MONKEY A(B) -- RESPONSIVE STRUCTURES

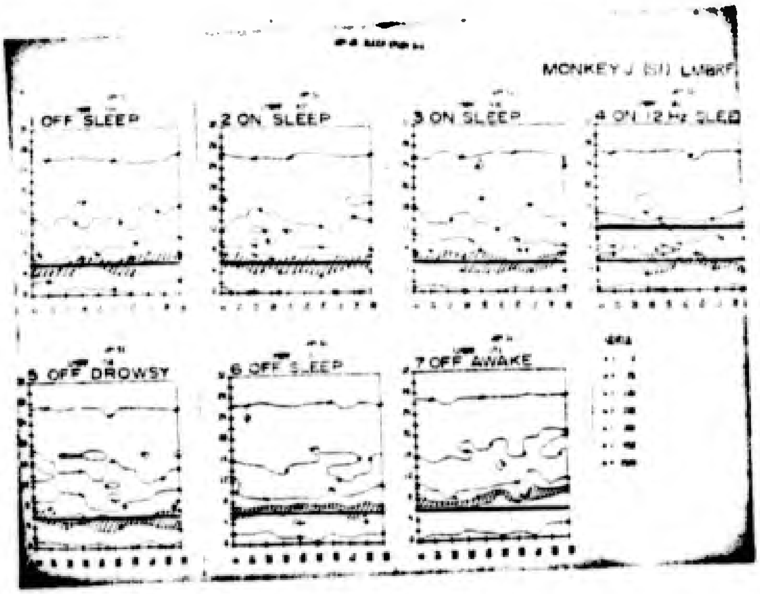


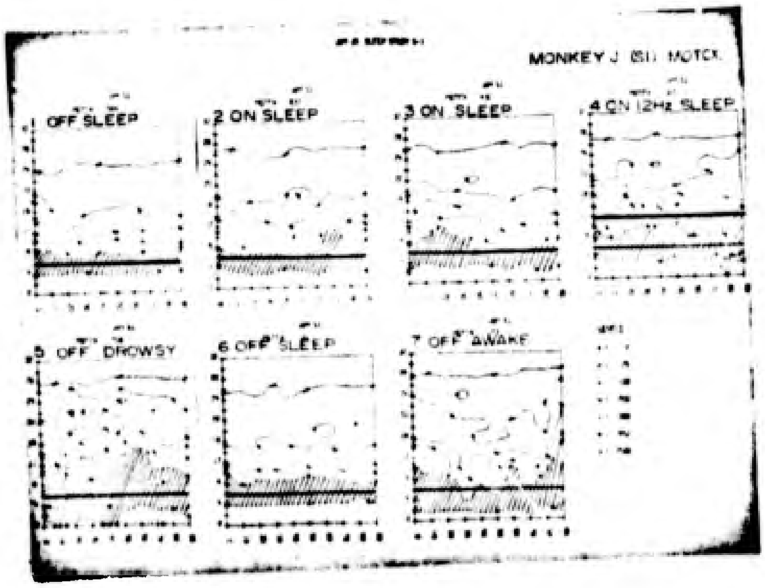




SLEEP STUDY

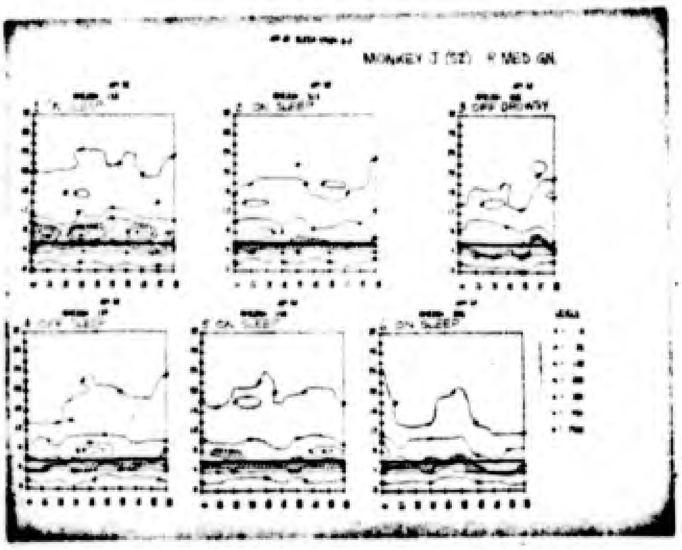
MONKEY J(A) -- NONRESPONSIVE STRUCTURES

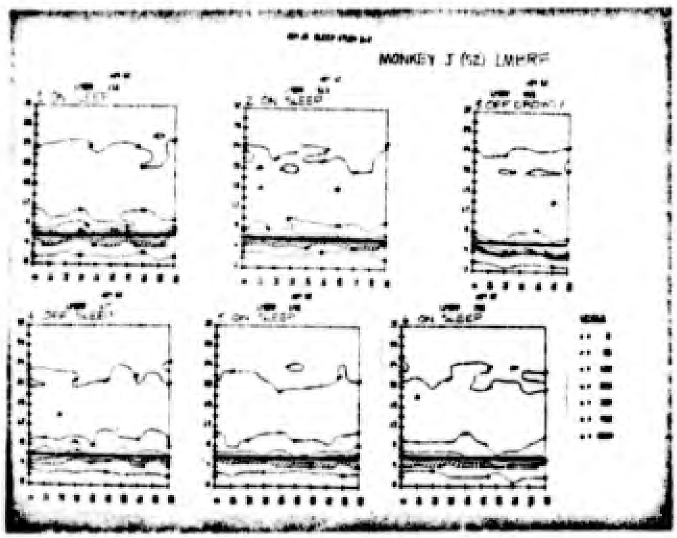


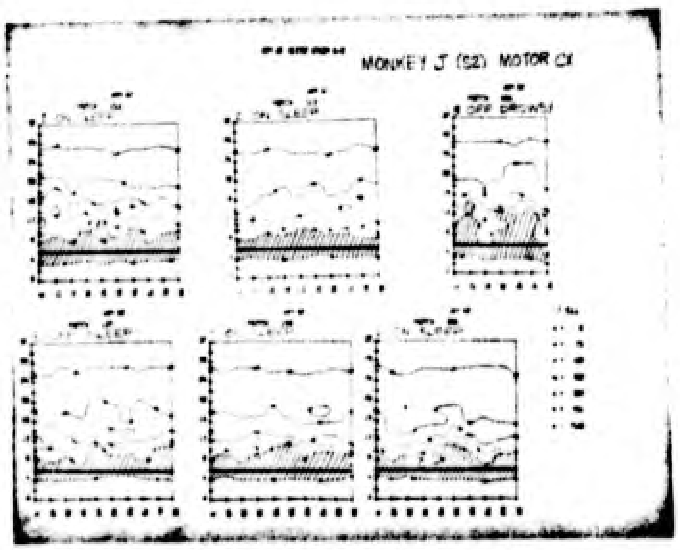


SLEEP STUDY

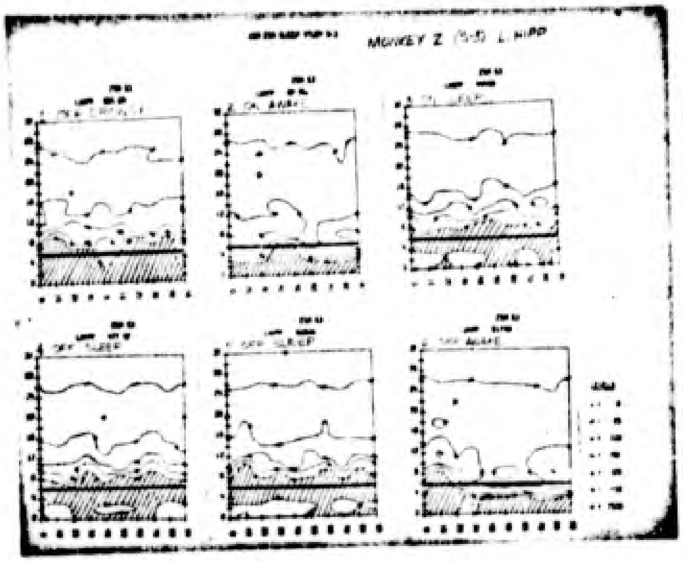
MONKEY J(B) -- NONRESPONSIVE STRUCTURES

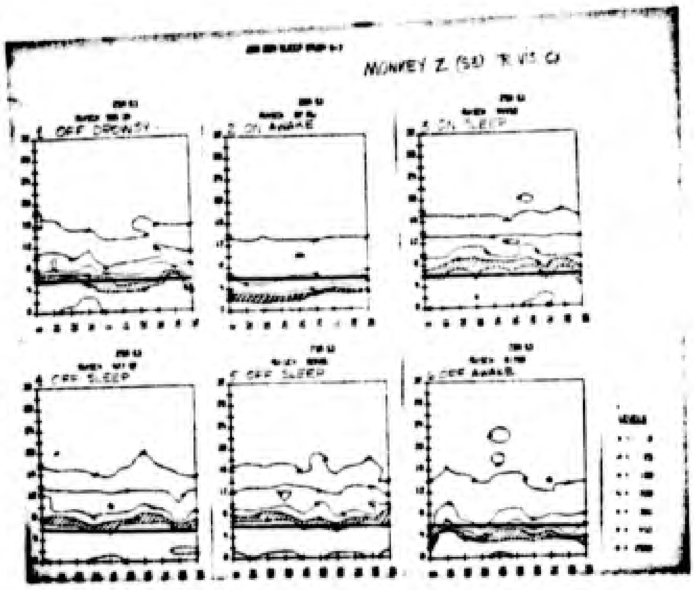


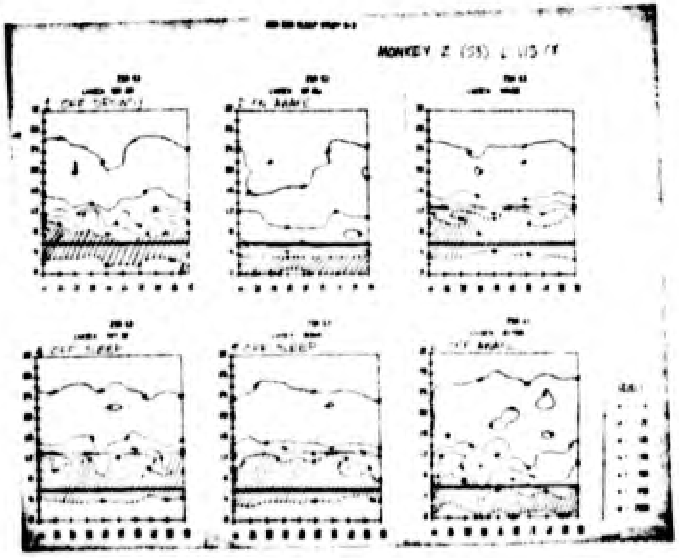




MONKEY Z(A) -- NONRESPONSIVE STRUCTURES

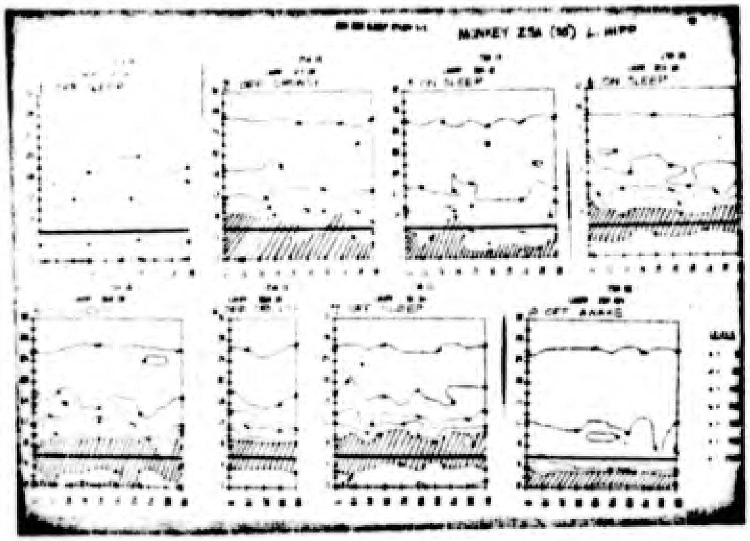


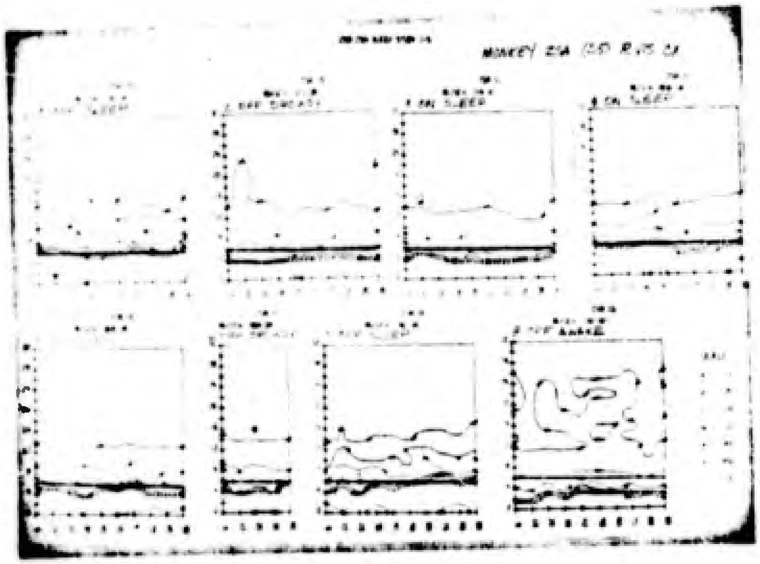


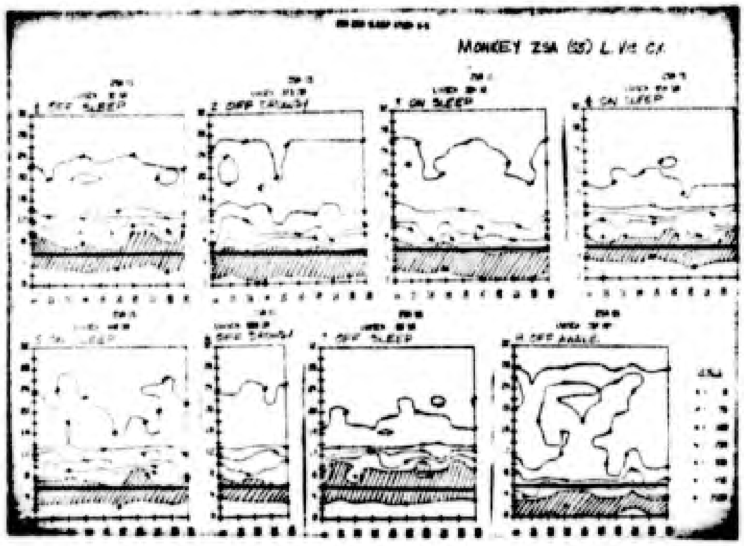


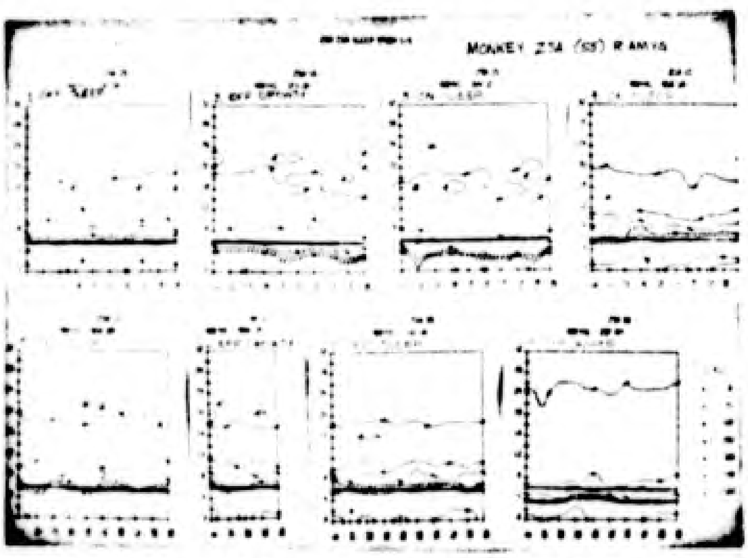
SLEEP STUDY

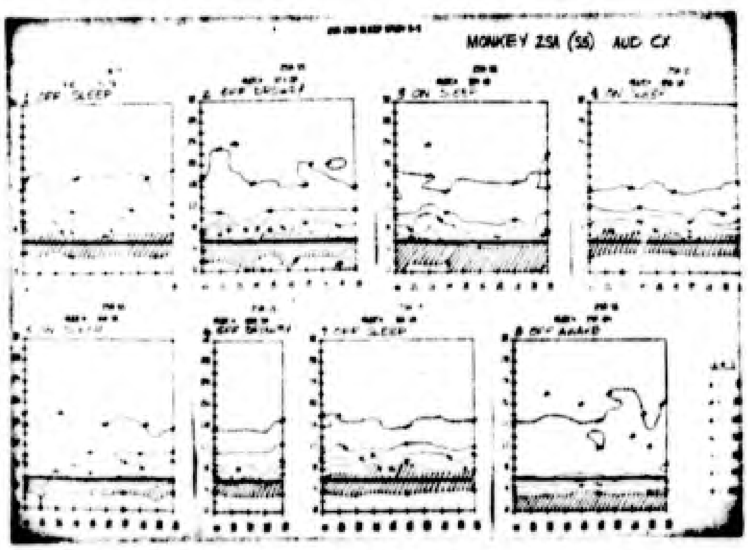
MONKEY Z(B) -- NONRESPONSIVE STRUCTURES





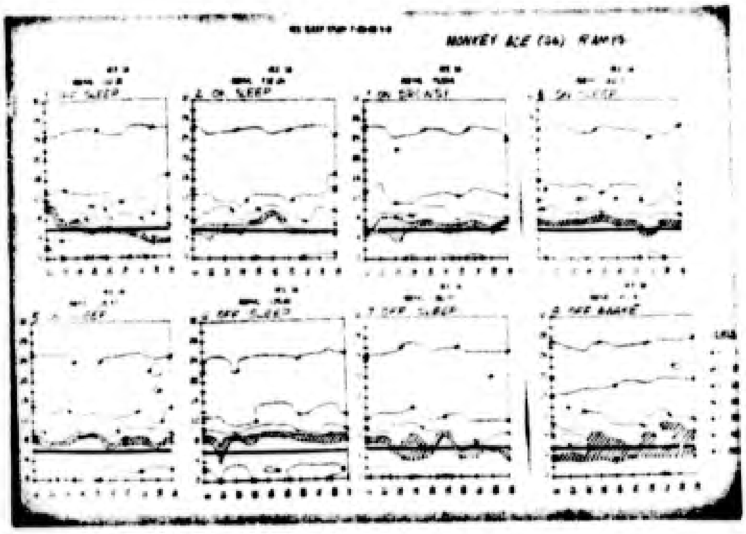


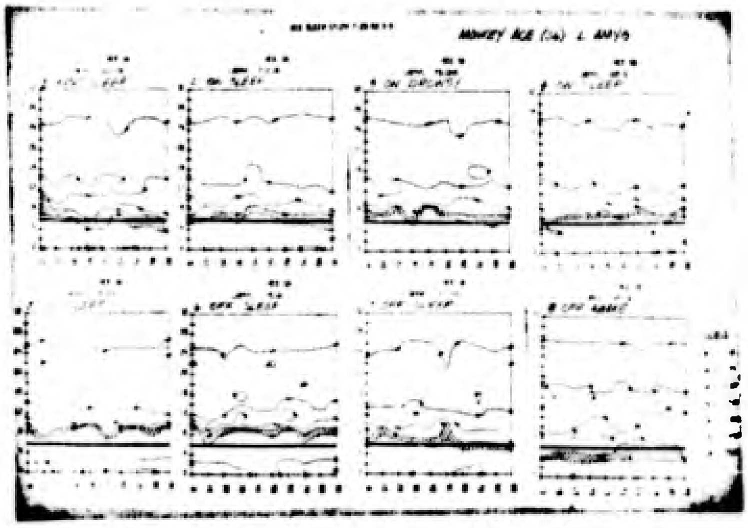


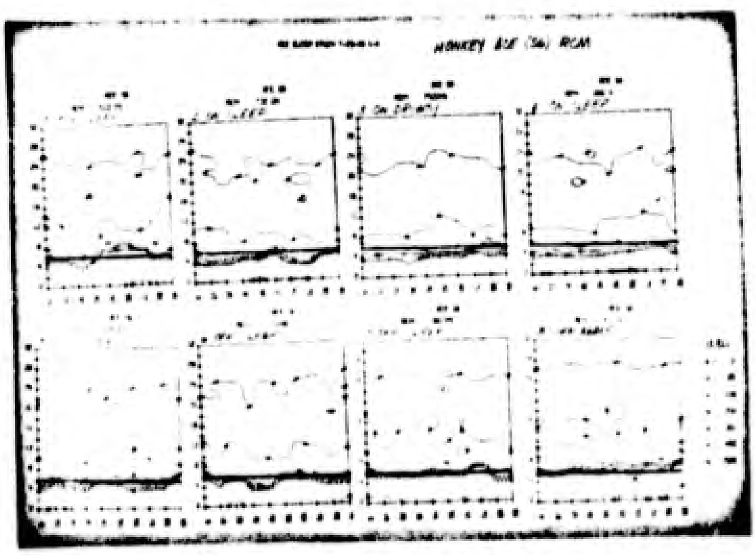


SLEEP STUDY

MONKEY A(A) -- NONRESPONSIVE STRUCTURES

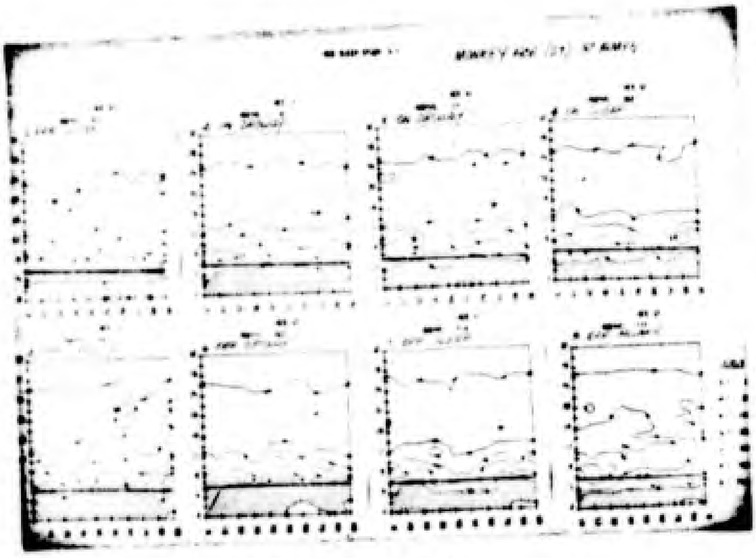


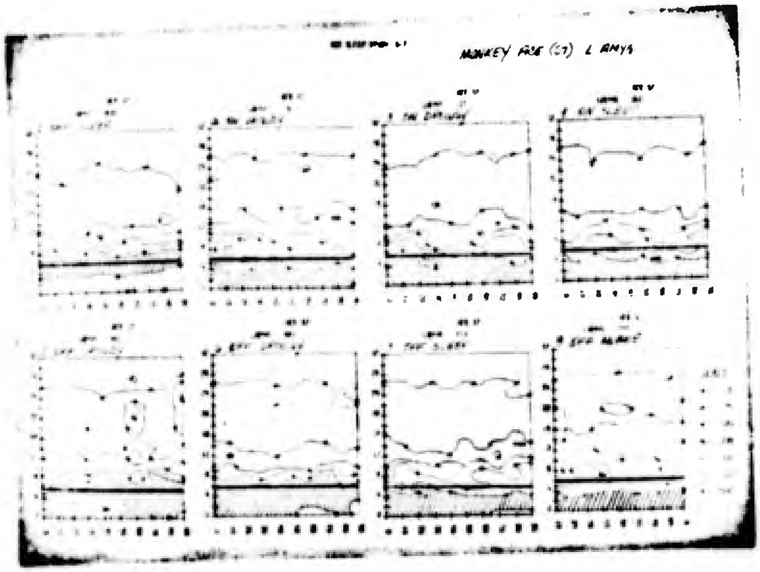


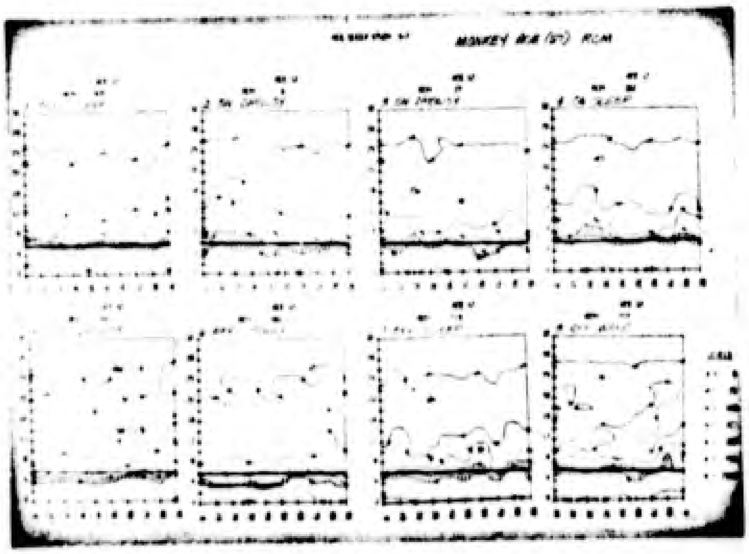


SLEEP STUDY

MONKEY A(B) -- NONRESPONSIVE STRUCTURES







VIII. A. Engineering and Instrumentation Development, Figures 1 - 6.

B. Addendum: Schematics for completed screened room and VHF apparatus.

Design and fabrication of apparatus for VHF studies have been completed, and we have successfully recorded artifact-free EEG from monkeys exposed to low-frequency modulated VHF fields in this environment.

FIGURE 1

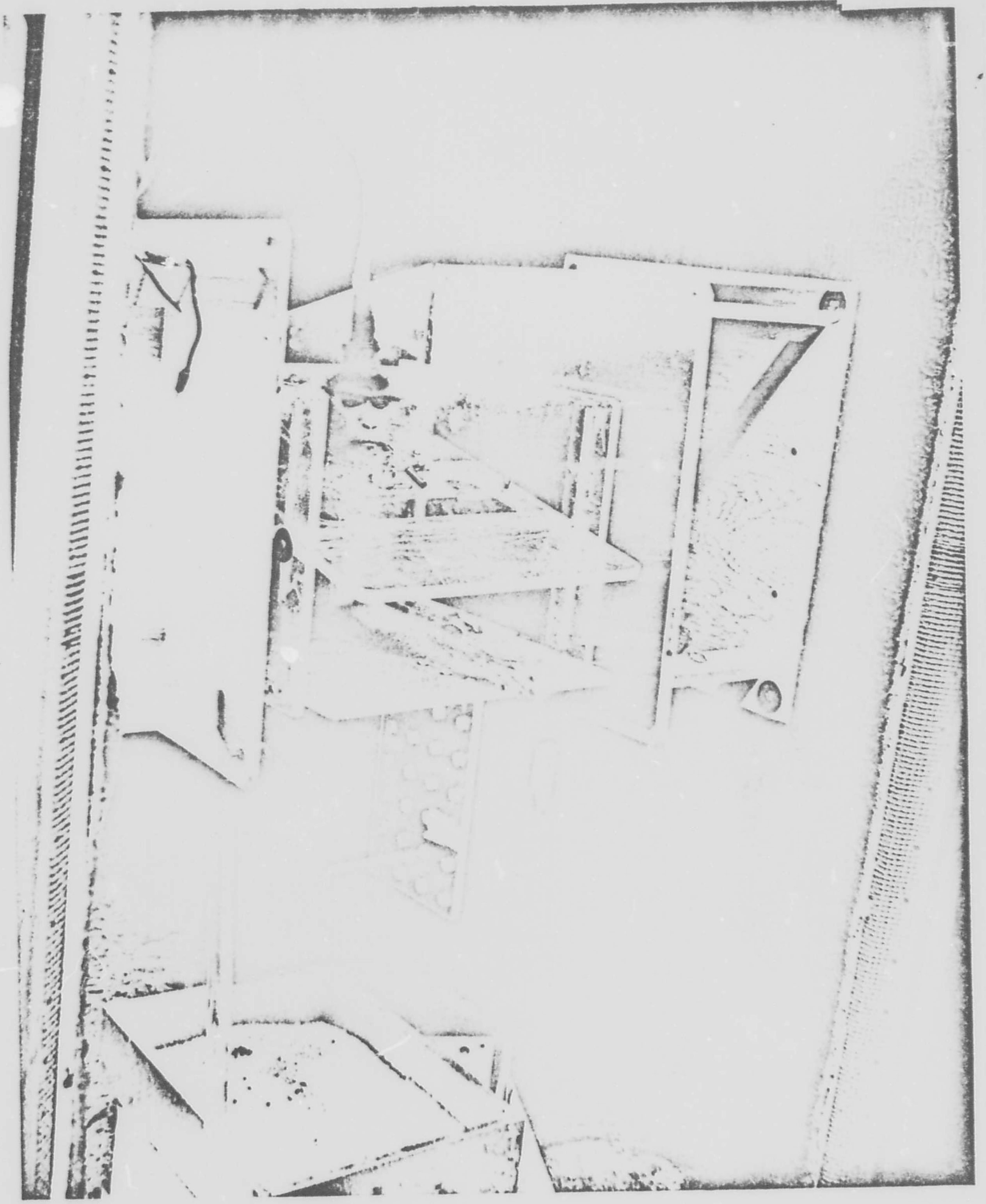


FIGURE 2

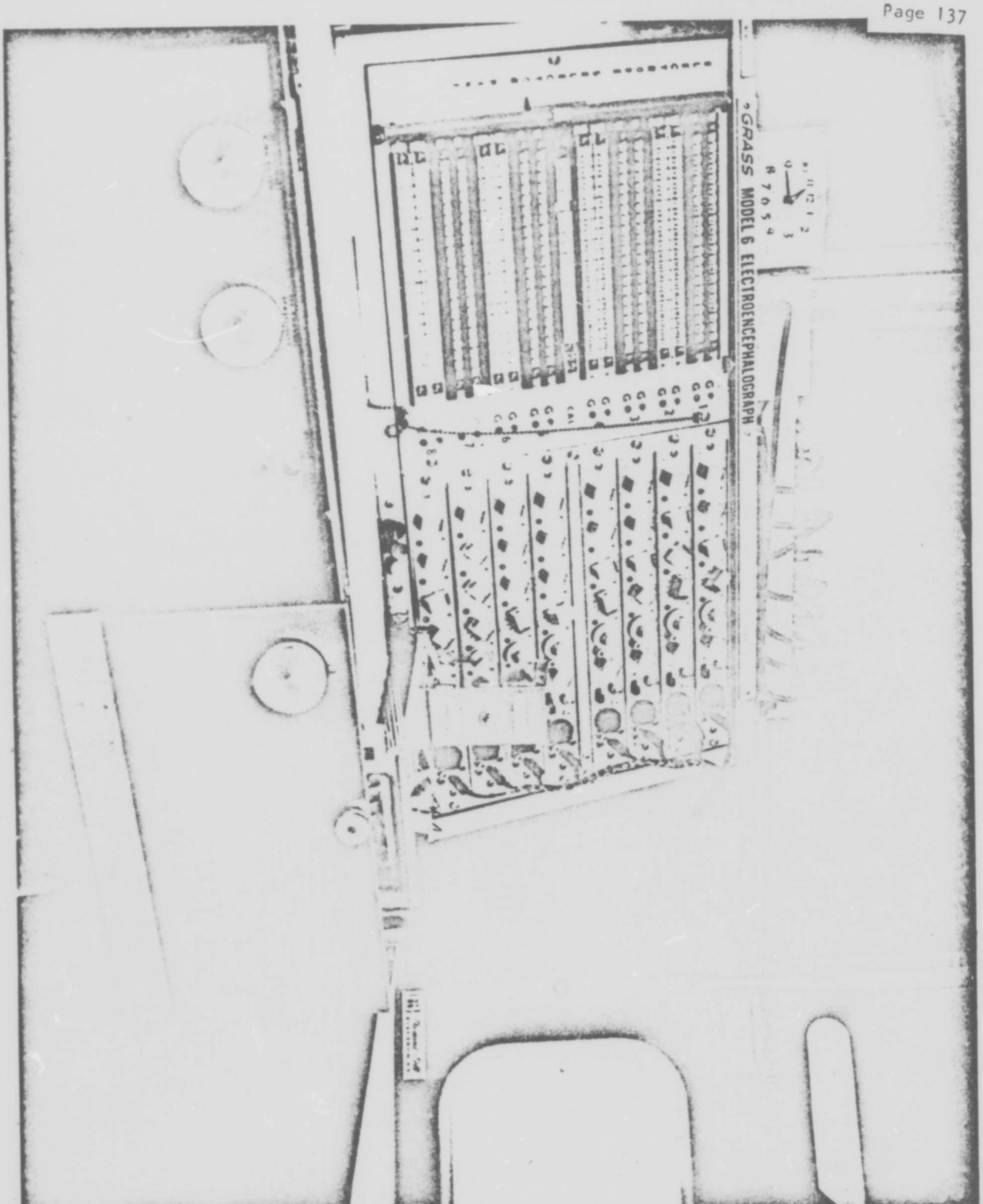


FIGURE 3

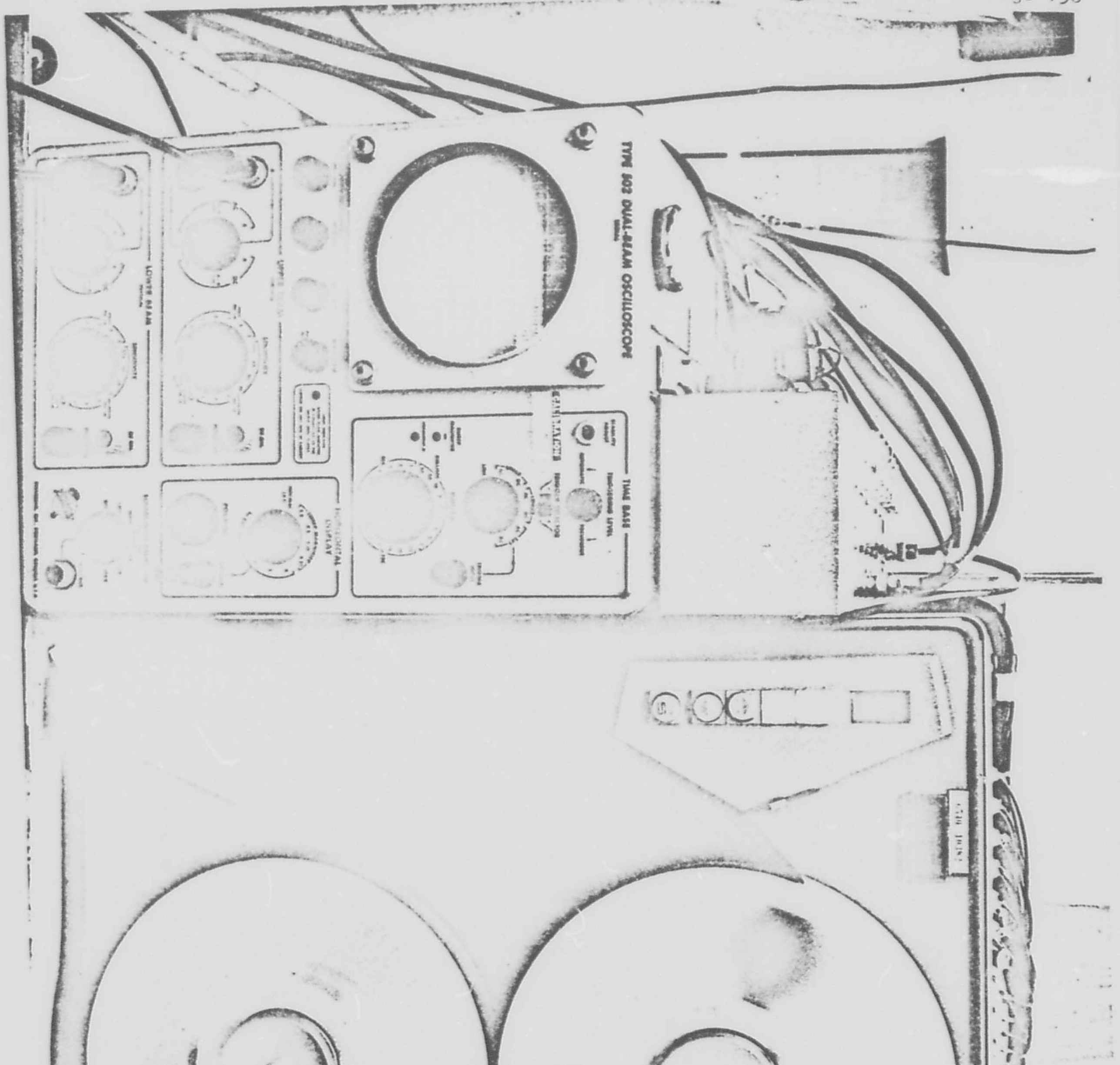


FIGURE 4

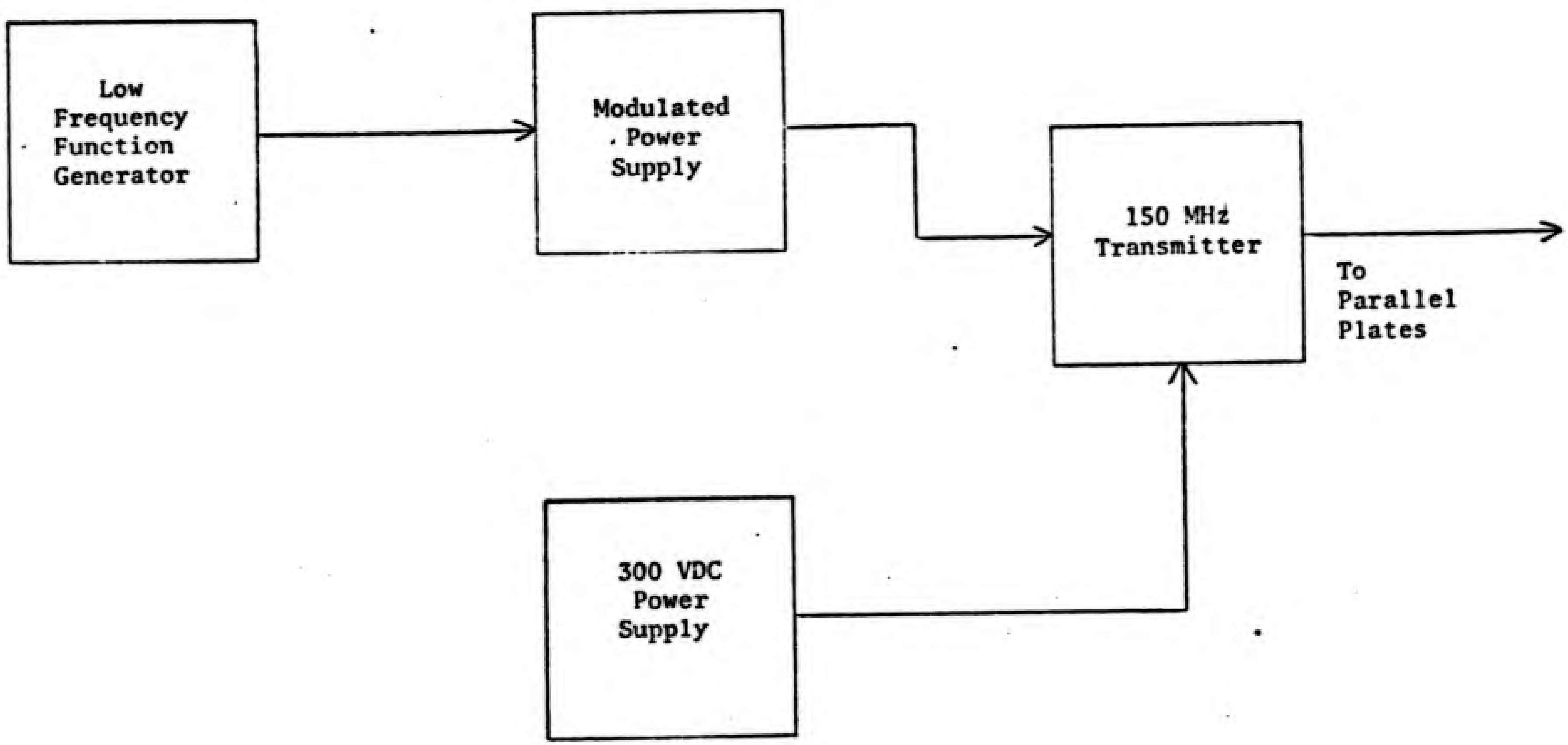

Low
Frequency
Function
Generator
Modulated
. Power
Supply
150 MHz
Transmitter
To
Parallel
Plates
300 VDC
Power
Supply

FIGURE 5

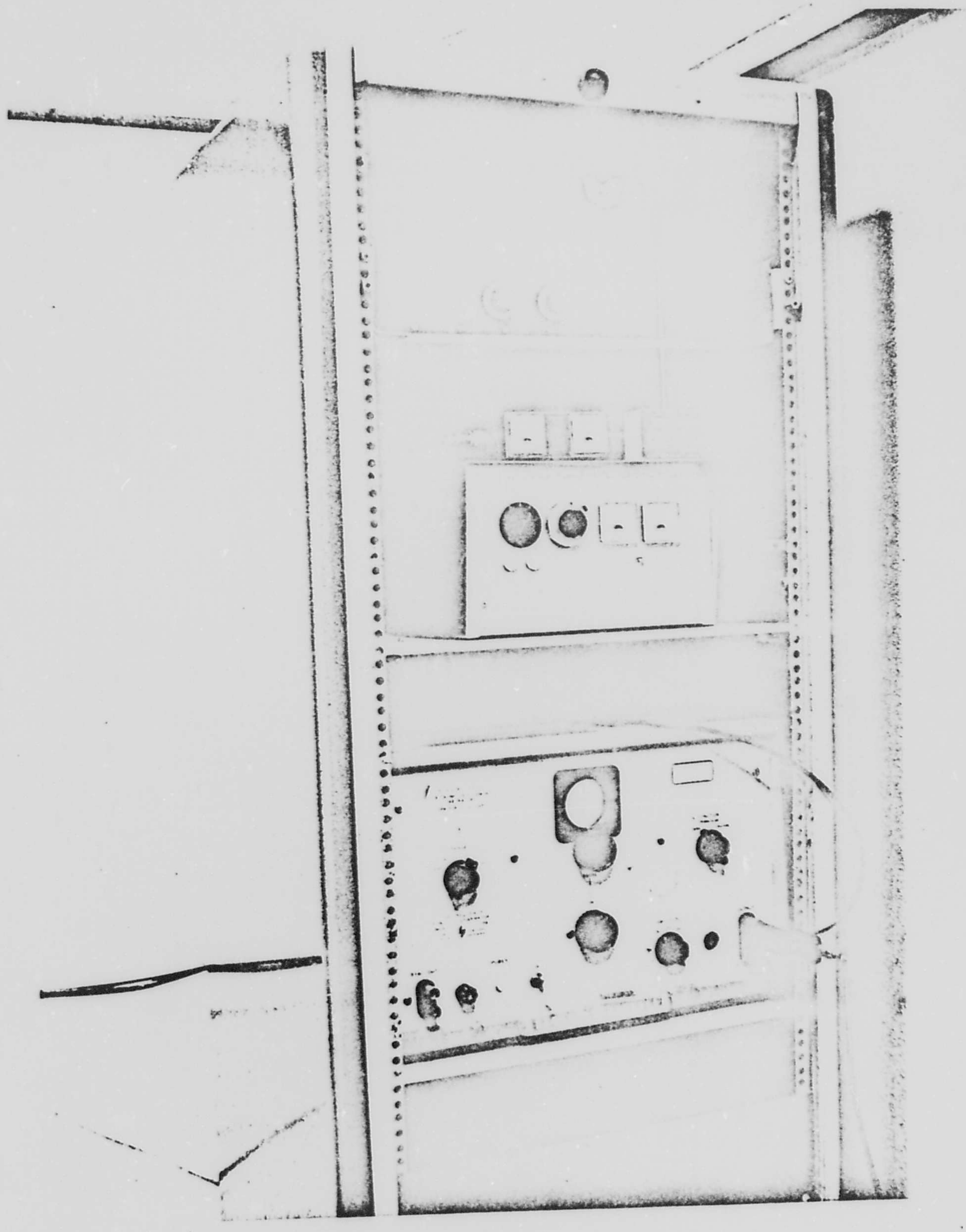
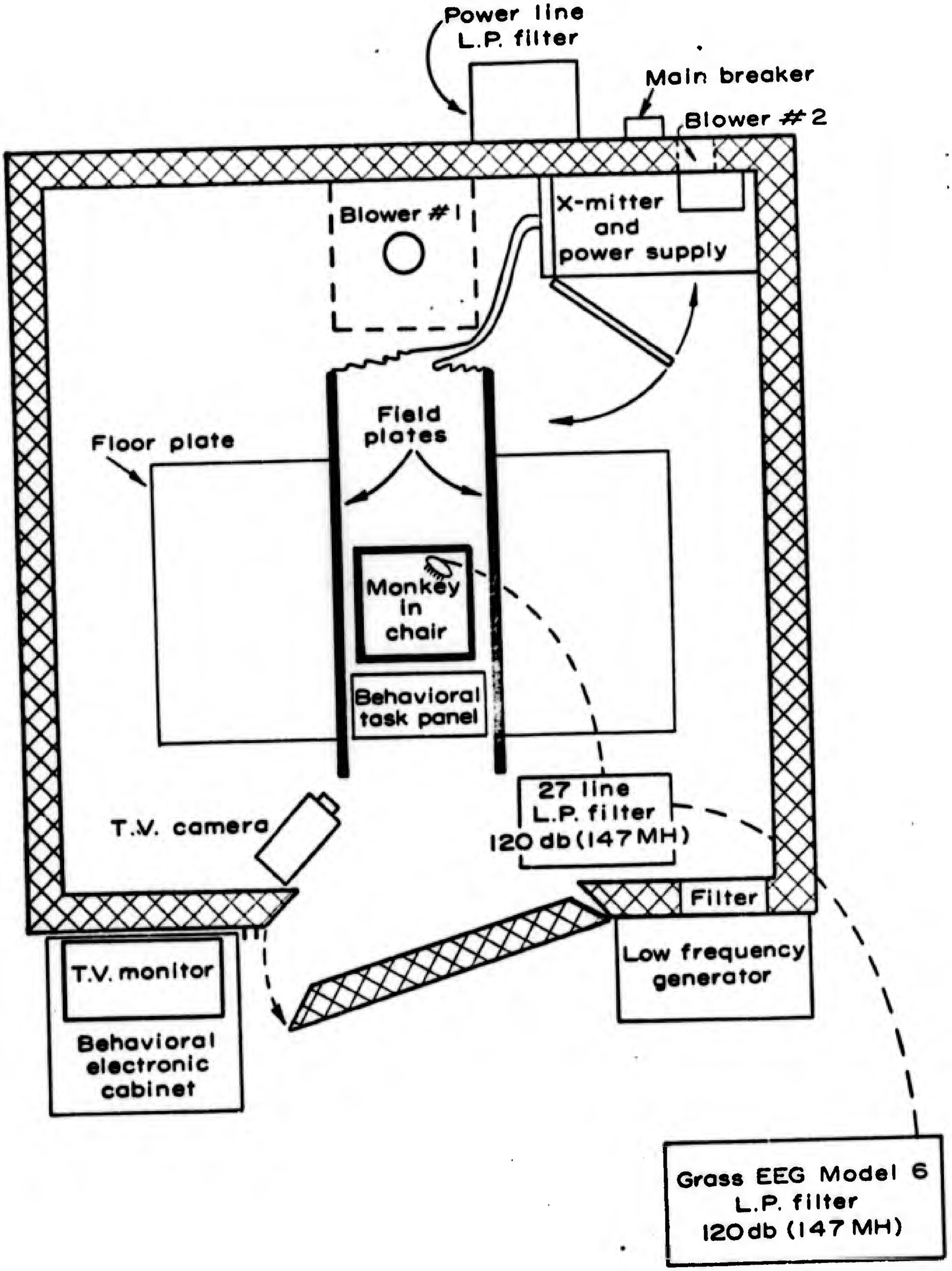


FIGURE 6

DESCRIPTION OF VHF APPARATUS AND SCREENED ROOM



Inside Dimensions: 7'11" x 7'11" x 6'9"

Construction: 2" x 4" lumber.
Double copperscreen, 10 mesh spaced 3" apart.
All lines in and out have low-pass filters ($\approx$120 db attenuation at 147 mega hertz) which are located either between the 2 screens or attached to the inner screen. Attenuation > 70 db (for 147 mega hertz).

Lighting: 2 or 3 12 volt 25 watt lamps, supplied from 12 volt car battery (inside of the room). Intensity is adjustable from outside.

Ventilation: 1 blower 160 cubic feet/minute pushing air in.
1 blower 80 cubic feet/minute as suction blower.

Field Plates: Approximately 4100 cm^2 area each adjustable as to distance and horizontal location.

Field Monitors: A connector at the outside permits monitoring of the modulated 147 mHz carrier, attenuated 10:1 with a suitable HF scope. Another connector shows the rectified carrier, that is the modulation and can be used with any scope.

Temperature: Both the inside and outside temperature are shown on an instrument mounted at the outside.

Closed Circuit TV: Similar filter-techniques are used between the video camera inside the screen room and the monitor and control box outside.

Field Specifications (Tentative): Maximum unmodulated transmitter output at 144 mHz $\approx$10 watts.
Modulation: up to 90%
Modulation frequency: 4 Hz (adjustable)
Effective field between 2 plates: not measured at this time. Estimated after losses at 4-5 watts, equal to $\approx$1-1, 2 milliwatts per cm^2.

Second Filter: A second 120 db lowpass filter is located directly at the 16 inputs to the Grass Model 6 polygraph.

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EFFECT OF LOW-LEVEL, LOW-FREQUENCY ELECTRIC FIELDS ON EEG AND BEHAVIOR IN *MACACA NEMESTRINA*

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(Accepted September 12th, 1969)

INTRODUCTION

A series of preliminary experiments has been done in an attempt to determine whether or not low-level electric fields have an effect on behavior and/or patterns of electrical activity in the brain of monkeys.

Very few studies of this kind have been done on either animals or man. Experimentally produced changes in reaction time in humans exposed to low-level, low-frequency (less than 12 c/sec) fields have been reported[7,9]. Changes in human reaction time have also been observed under low-frequency modulated magnetic fields[6]. Wever[19] has described the modification of circadian periods of activity in man under weak 10 c/sec electric fields. It was not known what kind of primate behavior, if any, would be sensitive to field effects so that selection of a suitable behavioral task was a first consideration. Earlier pilot studies in this laboratory suggested that subjective time estimation in humans was influenced by the presence of fields. In the present study, we attempted to devise an analogous time estimation task suitable for use with monkeys, so that electrodes implanted deep in the brain could monitor brain electrical activity throughout the experiments. It is known that scheduling of reinforcements for a simple lever press can alter an animal's rate of response, or the timing of that response, or both. In the present study, monkeys were trained to press a lever under a variation of a fixed-interval (timing) schedule of reinforcement. Under this schedule there are no external cues or signals presented to the animal; he must 'time' his responses from the occurrence of his own last response. It is a schedule which has been widely employed in studies of animal behavior and has been especially useful in detecting effects of small dosages of drugs[13]. It was expected that if there were an effect of the fields it would be seen as a shift in the distribution of the monkey's interresponse times.

Other questions of research strategy arose; it was not obvious what brain structures, if any, would show an effect of the presence of the fields. Nor was it clear what kind of changes one might expect to see in the EEG — other than a possible direct driving by the applied field — or how to assess such changes. Consequently, an array of 7 bipolar cortical and subcortical electrodes was implanted in the 1st monkey. A slightly different array was implanted in a 2nd monkey and electrode sites for the 3rd monkey were selected on the basis of results from the first 2. Computerized spectral analysis of the EEG was done and some special statistical tests were devised to compare fields-on *vs.* fields-off changes in EEG.

Low-level (2.8 V p–p) fields were used at 2 frequencies, both within the range of frequencies usually evaluated in EEG work (0–33 c/sec). In some of the experimental runs, 10 c/sec fields were used, to correspond to Hamer's earlier experiments[8]. In other runs, 7 c/sec fields were used because they were in the range of hippocampal theta (4–7 c/sec), a characteristic electrical activity of the brain that has been shown to be important in orienting and discriminating responses[10,17].

METHODS: EXPERIMENTAL DESIGN, BEHAVIORAL DATA ANALYSIS, AND EEG ANALYSIS

(1) *Experimental design*

Three pigtailed macaques were implanted with cortical and subcortical bipolar electrodes, and were adapted to Foringer monkey chairs. They were then trained to push a panel in front of them on a fixed interval-drl (differential reinforcement of low rates) limited hold schedule of reinforcement (drl-h schedule). The animal was gradually conditioned to wait 5 sec between pushes, and to push within a 2.5 sec reward-enable interval. If the animal pushed within the specified time interval, he was rewarded with a squirt of apple juice. If he pushed too early, or too late, he did not receive a reward, and the timer recycled to the beginning of another 5 sec interval. The behavioral task was completely automated with logic modules manufactured by B.R.S. Electronics. The monkeys were maintained throughout training and experiments on a standard controlled diet of monkey pellets, fruit, and restricted fluids. A liquid reinforcer was chosen in order to eliminate chewing artifacts in the EEG. The animal was trained until he was performing at a high rate of accuracy (70–80%) and his performance was relatively stable from one day to the next. All of the training was done in an isolated and sound-proofed booth. Task electronics and recording apparatus were in an outer room and the monkey's behavior was continuously monitored on closed-circuit TV.

After the animal was performing well, his behavioral records over a 24 h period were examined to determine periods of free responding during the day, and a 4 h segment of time was selected for scheduling daily experimental runs. The low-level (2.8 V p–p), low-frequency fields were administered by applying the voltage to 2 large metal plates, 40 cm apart, which were fastened to the monkey's chair so that the head of the animal was completely within the fields. Four hour daily tests with the fields on were randomly interspersed with 4 h daily control runs without the fields. A total of 20 such tests were done on the 3 well-trained monkeys. All monkeys were given 2 tests with 7 c/sec fields and 2 comparable control tests without fields. Two of the 3 monkeys were also given 2 tests with 10 c/sec fields and 2 control runs without the fields. EEG and behavioral data were continuously monitored throughout all runs.

In addition, EEG was monitored in 1 monkey during two 4 h non-performance runs (7 c/sec fields-on and fields-off) before he was trained to the drl-h task.

(2) Data analysis of behavioral changes

Interresponse time data (IRTs) were collected by the computer for each experimental run; each response of the animal was tallied as a function of time elapsed since the immediately preceding response. Two-tenths of a second bin widths were used; 144 bins were counted and interresponse times greater than that were tallied as 144 (28.8 sec). Mean and standard deviations were calculated for each 4 h run, and *t* tests were used to compare IRT distributions for experimental runs and the appropriate matched control runs.

(3) Data analysis of EEG changes: spectral intensity, coherence, discriminant analysis

EEG data were continuously recorded on a Grass polygraph and an Ampex analog tape recorder. In the 1st monkey (J) EEG was recorded from the left hippocampus, right hippocampus, right amygdala, midbrain reticular formation, right visual cortex, left visual cortex and motor cortex. In the 2nd monkey (Z) EEG was monitored from the right hippocampus, left hippocampus, left centre median, right visual cortex, and right amygdala. In the 3rd monkey (A) records were taken of the electrical activity of the right hippocampus, left hippocampus, right centre median, left centre median, right amygdala, and left amygdala.

Four sets of EEG data from comparable epochs from each day's run were selected for computer analysis. A set of correct (*i.e.*, properly timed) responses was selected from the beginning of the run and a 2nd set from the end of the run; similarly, a set of predominantly incorrect responses was sampled from the beginning of the run and a comparable set from the end of the run. Each epoch was approximately 80 sec in length. These epochs were spectrally analyzed in consecutive 10 sec samples and then averaged over the total 80 sec.

The selected data epochs were converted to digital form by the SDS 930 computer system of this laboratory and spectral analysis of this data was performed, using the BMDX92 program and the IBM 360/91 computer of the Health Sciences Computing Facility. Spectral resolution was set at 2 c/sec over the range 0–28 c/sec for survey purposes. Spectra and coherences[18] were averaged for each structure, within condition, and plotted; spectra were converted before plotting to relative units (by dividing by the total intensity in that structure in that condition) in order to compensate for day-to-day variations in total intensity; the result is called 'percent power' at each frequency.

Spectral intensity. A specialized statistical test for the effect of the imposed field on recorded activity was devised as follows. In the frequencies from 4 to 20 c/sec, at least, the spectra were close to exponential in shape, in the absence of fields. If this were exactly true, the logarithm of the spectral curve would be a linear function of frequency, over this range. Then any activity contributed by the field would be above the line containing those points not at the field frequency (or its harmonics). Accordingly, we tabulated the statistic ('peak quotient') for the 10 c/sec field.

$$\ln(S_{10}) - 1/2[\ln(S_{12}) + \ln(S_8)]$$

When the field was at 7 c/sec, more care was required. The 7 c/sec signal appeared both in the filter band centered at 6 c/sec and (to a lesser extent) in that centered at 8 c/sec. We chose to test only the value at 6 c/sec, and to compare it with the line based on 4 c/sec and 10 c/sec; thus, the peak quotient for the 7 c/sec field became

$$\ln(S_6) - [2/3 \ln(S_4) + 1/3 \ln(S_{10})]$$

The spectral estimates have a sampling distribution like χ^2/d.f., with d.f. calculated by the program (according to formulas adapted from Blackman and Tukey[4]) as approximately 200 in our case. Thus, the natural logarithm of a single spectral intensity has an approximately normal distribution, with variance 2/d.f., and a coefficient of skewness of —0.1 (ref. 1). Our peak quotient statistic, then, is close to normally distributed with variance 0.01. Its response to application of the field in the 2 experiments for each animal could be tested by the t-statistic, with the 2 fields-off values providing the mean corresponding to the null hypothesis of no effect of the field.

Coherence. An additional parameter calculated by the spectral analysis program is the coherence between the imposed field and the activity in each structure, as well as between the brain structures themselves. It is essentially analogous to the squared coefficient of correlation, and hence, a measure to the linear predictability between the 2 wave forms, taking into account spectral intensity, frequency and phase lag. Although the purity of the imposed sinusoidal field invalidates the usual distributional assumptions about the coherence statistic, we felt these results might be suggestive.

Discriminant analysis. In seeking for less obvious field effects, we applied stepwise discriminant analysis[2,11] to spectral and cross-spectral parameters, with the exclusion of the frequency band containing the field frequency, or else of that band and all bands containing any harmonics of that frequency. Applications of this computer program, Discan (based on BMD 07M, Dixon[5]), to spectral analysis of EEGs have been described previously[3,9,12,17].

RESULTS

Behavioral data

Consistent differences in interresponse time distributions were observed in the 7 c/sec experiments. The 10 c/sec field condition failed to produce a reliable effect on the behavior. For one animal (Z) the mean interresponse time was unchanged by the 10 c/sec field; responses were slightly faster (but not significantly so) in the replication. In animal J, interresponse times were faster in the first 10 c/sec experiment and slower in the second.

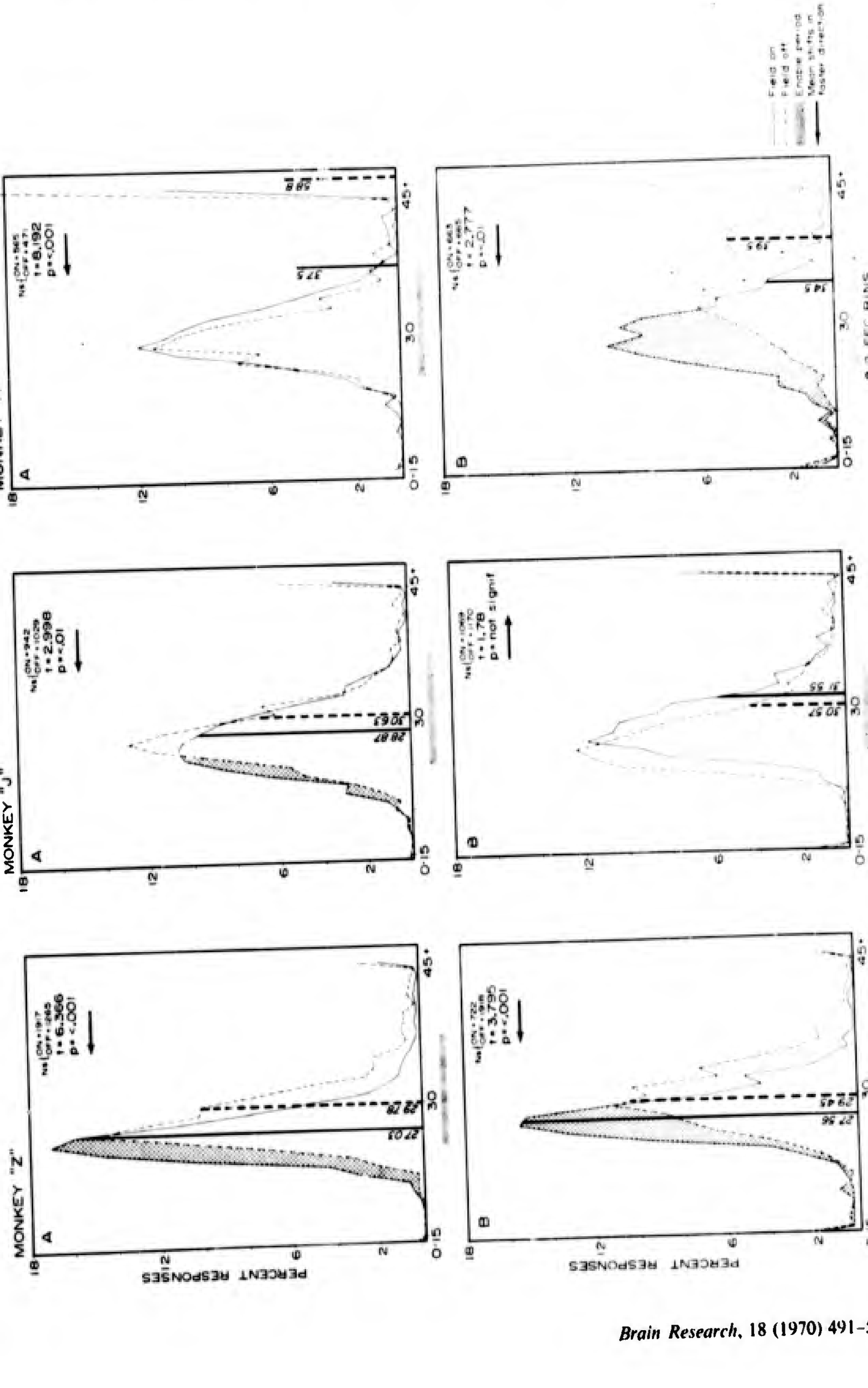

Fig. 1. Behavioral data showing shifts in interresponse time under 7 c/sec fields. The abscissa shows time between responses in 0.2 sec bins; the ordinate shows percent of total responses at each interval. (Note that only bins 15–45 are plotted; bins 0–144 were used in calculation of means and standard deviations.)

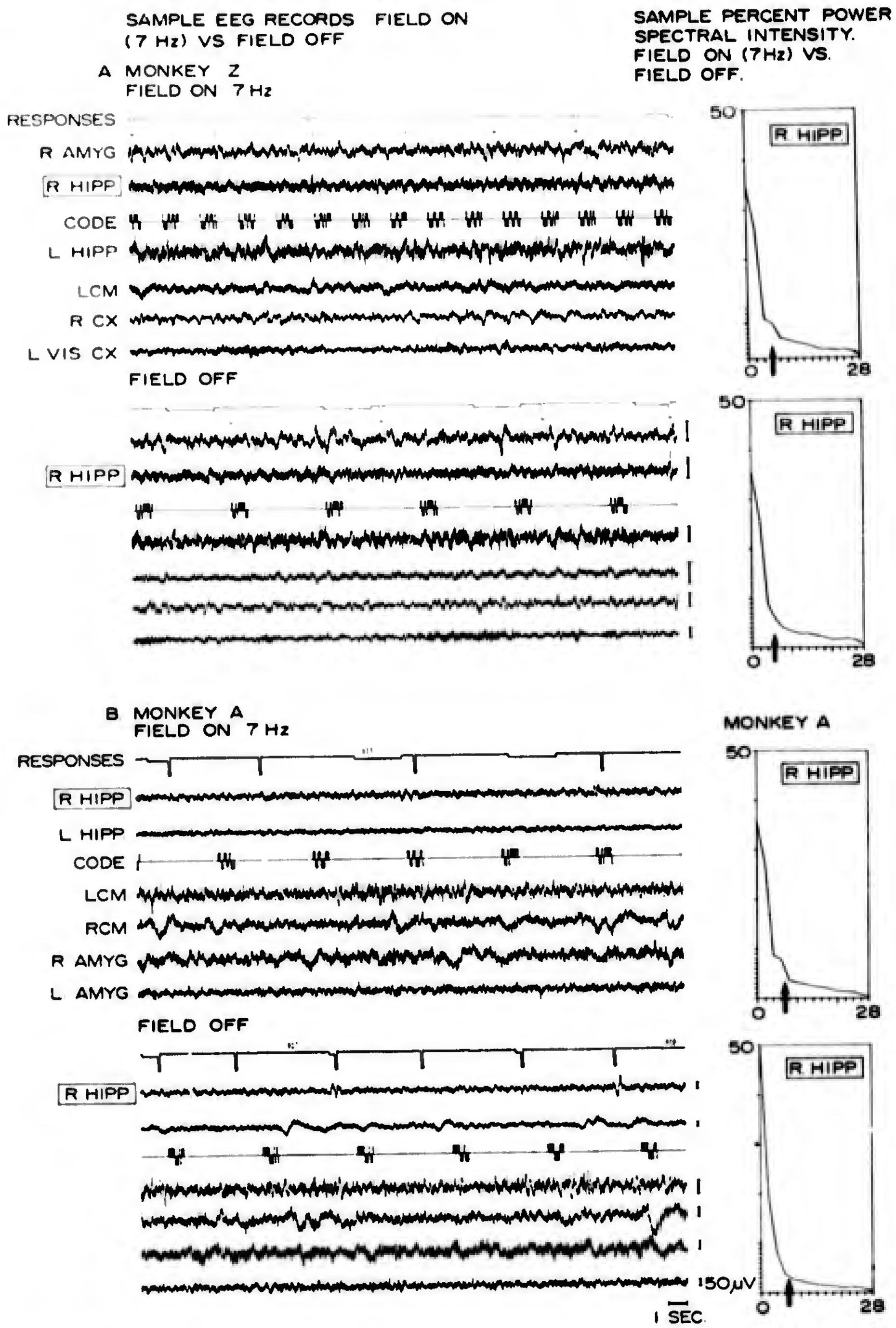

Fig. 2. Sample records of EEG and percent power graphs before conversion to peak quotients.

Under the 7 c/sec condition, however, rather large and consistent differences were observed in all animals. Animal Z showed a shift in mean interresponse time toward shorter IRTs; the difference was approximately 0.5 sec in the 1st experimental-control run. This finding was replicated in a 2nd experiment (see Fig. 1) and these dif-

Performing DRL task 80 sec segments near end of the 4 hr runs Combined data from 2 experimental-control runs		7 CPS On vs Off	10 CPS On vs Off
MONKEY J	L. HIPPOCAMPUS	p = .048	p = .025
	R. HIPPOCAMPUS	p = 001	p = 011
	R AMYGDALA	p = 003	p = 001
	(OTHER STRUCTURES OBSERVED LMBRF, L V CX, R M CX, R V CX)		
MONKEY Z	R. HIPPOCAMPUS	p = .006	p = 020
	L. CENTRE MEDIAN	p = .001	p = 001
	(OTHER STRUCTURES OBSERVED. AUD CX, R V CX, R AMYG, L HIPP)		
MONKEY A	R. HIPPOCAMPUS	p = 001	No run
	L HIPPOCAMPUS	p = 001	
	L. CENTRE MEDIAN	p = 059	
	(OTHER STRUCTURE OBSERVED L AMYG)		

Non-performing: Sitting quietly		7 CPS On vs Off
MONKEY A	R. HIPPOCAMPUS	p = .001
	L. HIPPOCAMPUS	p = .036
	R. CENTRE MEDIAN	p = .045
	L AMYGDALA	p = .003
	(OTHER STRUCTURES OBSERVED LCM, R AMYG)	

Fig. 3. Significance levels for EEG peak quotients: fields-on *vs.* fields-off.

ferences were highly significant statistically ($P = 0.01$ or better). In general, the whole distribution was shifted towards faster responses, while overall number of responses did not increase or decrease consistently. For the 2nd animal (J), the IRT mean shifted significantly in the direction of faster responses in the 1st experiment; however, this difference was not replicated in the 2nd experiment. The 3rd animal (A), like the 1st, showed a shift in the direction of faster responses under the 7 c/sec field. This difference was statistically significant and was replicated in the 2nd experiment. Percent of correct responses (those falling between 5 and 7.5 sec) did not differ significantly under fields-on conditions for monkeys J and Z; monkey A, who had a large number of very long IRTs in the fields-off condition, showed gains of 16% correct and 21% correct when the fields were on. In summary, 5 of the 6 experiments showed a shift to significantly faster interresponse times under the 7 c/sec fields compared with fields-off performance. All of these mean differences were 0.4 sec or greater. Shifts in modal values also occurred in all 5 experiments and were all 0.2 sec or greater. The distributions and means for all monkeys are shown in Fig. 1. It may be observed that the overall output of responses and the variability of those responses differ considerably from monkey to monkey. Nevertheless, the direction of the mean shift under the fields is remarkably consistent and the size of the shift is relatively large.

EEG data

Visual inspection of the EEG data during the experiments did not reveal any marked effects due to the fields. An examination of the percent power graphs, however,

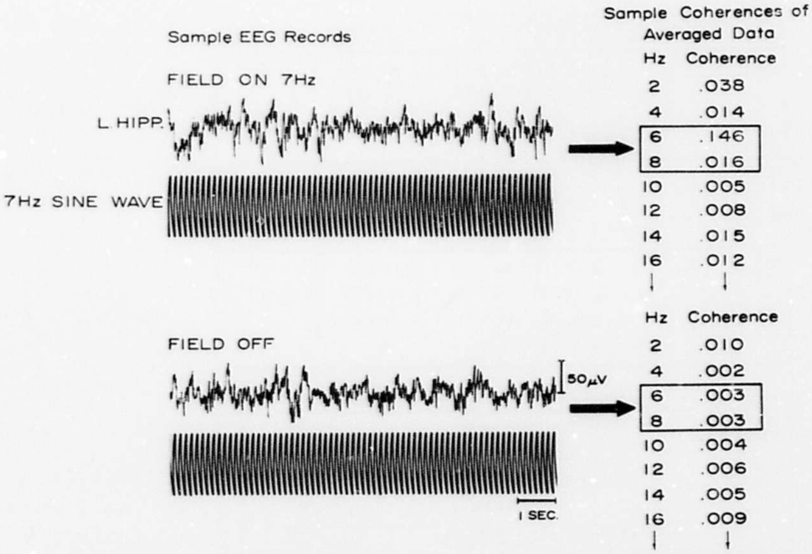

Fig. 4. Sample records of EEG and 7 c/sec sinusoidal wave form with corresponding coherence tables.

revealed small peaks in power from some brain structures at the fields frequency, for epochs of predominantly incorrect responses near the end of the run. A sample of EEG data and percent power graphs is shown in Fig. 2.

Peak quotients (as described in the Methods section) were compared via t-tests for these epochs in fields-on *vs.* fields-off conditions, for each animal and for each structure (see Fig. 3). In the 1st animal (J), significant differences were observed in the left hippocampus, the right hippocampus and the right amygdala for both the 7 c/sec and the 10 c/sec condition. In the 3rd animal (A), 7 c/sec fields only were tested. Differences at the 0.01 level or better were observed in right hippocampus, left hippocampus, and left centre median. EEG records were also evaluated for this animal while he was sitting quietly and before he had been trained to do the drl-h task. Differences in peak quotients for 7 c/sec fields-on *vs.* fields-off were observed in 4 of 6 structures tested: right hippocampus, right centre median, left hippocampus, and left amygdala.

Coherence measures between the 7 c/sec sinusoidal wave form and the responsive EEG structures were always higher for the fields-on condition than for the fields-off condition. Sample measures are shown in Fig. 4. Coherences between responsive brain structures did not reveal a consistent pattern of change.

No effects on EEG at non-field frequencies were visually noticeable, but the discriminant analysis program Discan (see Methods) was applied to the data of one animal (J), and identified strong driving (increased intensity and increased coherences) at harmonics of the field frequency. Although such harmonic response is perfectly compatible with biological transduction[15,16], it does not exclude artifactual transduction. Further application of Discan, this time excluding all bands containing any harmonics of the field frequency, still showed a clear discriminability of fields-on from fields-off EEGs, principally in that intensity was raised in the fields-on condition, even in non-harmonic frequency bands.

DISCUSSION

The behavioral results suggest that imposing a 7 c/sec field on the performing animal resulted in shorter interresponse times. Results with 10 c/sec fields were not reliable. Experimental/control differences for the 7 c/sec runs were statistically significant for 5 of 6 experiments, and these differences could be observed in all 3 monkeys. In spite of large differences in total output of responses from monkey to monkey, the shift in interresponse times was very consistent (towards faster responses) and rather large (0.4 sec or greater).

Increases in EEG intensity (peak quotients) at the frequency of the fields were observed in all 3 animals in the hippocampus, and less consistently in the amygdala and centre median. These differences were observed both in the 7 c/sec and 10 c/sec conditions. Coherences between the sine wave and responsive brain structure at the fields frequency were always higher in the fields-on condition.

The analysis of the EEG data presents special problems. The difficulty of isolating effects of biological transduction from those of transduction at the electrode–tissue fluid interface is considerable, being almost parallel to the impossible question of 'what the tree looks like when no one is looking at it'. Nevertheless, the discriminant analysis program has provided preliminary evidence of subtle EEG changes at non-field frequencies that cannot be easily explained as electrode–tissue artifacts.

The concordance of evidence for a fields effect on behavior and on electrical activity of the brain is encouraging. We intend to pursue additional demonstrations of the same kind as well as others. One new technique to be applied is a frequency 'sweep' from 5 to 20 c/sec, with enough time spent at each frequency to allow coherence estimates to be reliably made there; our prediction is that, as occurred with whole-body vibration in the monkey[16], and as seems to occur with sinusoidally modulated light stimulation in the human[15] there will be a band of incoherent driving. It may even be possible to establish some specific non-linear model, along the lines successfully pursued by Spekreijse[14] for the visual system.

SUMMARY

A series of experiments has been done to assess the effects of low-level, low-frequency electric fields on the behavior and EEG of monkeys. Three monkeys were implanted with subcortical and cortical EEG electrodes and trained to press a panel on a fixed interval-limited hold schedule. The monkeys were rewarded for pressing the panel once every 5 sec within a 2.5 sec enable period. After the animals were performing well, they were tested under low-level electric fields (2.8 V p–p);

the voltage was applied to 2 large metal plates 40 cm apart so that the monkey's head was completely within the field. Fields frequency was set at 7 or 10 c/sec within the range of typical EEG recording (0–33 c/sec). Four hour daily tests of fields-on were randomly interspersed with 4 h runs with fields-off. Under the 7 c/sec fields, the monkeys showed a significantly faster interresponse time in 5 of 6 experiments. Mean differences between fields-on and fields-off were 0.4 sec or greater. The 10 c/sec fields did not produce a reliable effect on behavior. Analysis of the EEG data showed a relative peak in power at the frequency of the fields (10 c/sec and 7 c/sec) for the hippocampus in all 3 monkeys. Similar peaks were seen less consistently in the amygdala and the centre median.

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13. ABSTRACT

A series of experiments has been done to assess effects of low-level (2.8 v.p-p. across 40 cm), low-frequency (7 and 10 Hz) electric fields on behavior and electrical brain activity of monkeys. Monkeys were implanted with cortical and subcortical EEG electrodes and then trained to perform a precise behavioral task (a five sec, fixed interval, limited hold scheduling of rewards for lever pressing). After the animals were well trained, they were tested in a set of 4-hour experiments with fields on and fields off. Behavioral inter-response time distributions shifted in the direction of significantly faster responses under the 7 Hz fields. Peaks in power of EEG autospectra were observed at the frequency of the field in certain brain structures, especially the hippocampus.

Other experiments evaluated length of exposure to fields, EEG changes with fast and slow responses, effects on sleep patterns and effects on evoked visual responses in cats. New experiments are currently underway on effects of modulated VHF (150 MHz) fields.

In addition, a collaborative study was done with the Walter Reed Army Institute of Research. EEG was monitored from monkeys during exposure to amplitude modulated (5-15 Hz) and unmodulated microwaves. Results suggested an interaction of modulated microwaves with certain brain structures. However, the question of rectification effects at the electrode-tissue interface was left unanswered.

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