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A 408 MHz All-Sky Continuum Survey. II. The Atlas of Contour Maps

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Summary. — We present an atlas of the radio continuum brightness of the whole sky at a frequency of 408 MHz. A set of both α, δ as well as l, b maps is shown. The angular resolution is 0°.85. The atlas combines data from four different surveys using the Jodrell Bank MkI, Bonn 100 meter, Parkes 64 meter and Jodrell Bank MkIA telescopes.

Key words : Radio continuum — All sky atlas — 408 MHz survey — Galactic structure.

1. **Introduction.** — Since the early days of radio astronomy only about four attempts at preparing maps of the radio continuum brightness of the whole sky have been made. The first all-sky map ever published is the 200 MHz map of Dröge and Priester (1956) using their measurements of the northern hemisphere and combining them with data from Allen and Gum (1950) for the southern hemisphere. Two other whole sky maps, one at 150 MHz (Landecker and Wielebinski, 1970) and one at 85 MHz (Yates, 1968), are closely linked, as both make use of the 178 MHz data of Turtle and Baldwin (1962) for the northern hemisphere and the 85 MHz data of Yates *et al.* (1967) for parts in the south. The 150 MHz map contains measurements made at 3 different frequencies and with three different resolutions, the scaling being achieved by the assumption of a spectral index $\alpha = 2.6$ ($T_b \approx \nu^{-\alpha}$). The resolution on the final maps varied from 5° × 1°.25 in the north, to 2°.2 × 2°.2 at the celestial equator and 3°.5 × 3°.8 at southern declinations.

The 30 MHz map of Cane (1978) also combined data taken at different frequencies and resolutions. The 38 MHz northern hemisphere survey of Milogradov-Turin and Smith (1973) having resolution 7°.25 × 8°.25, was combined with the 11° × 11° resolution southern sky survey of Mathewson *et al.* (1965) using spectral index $\alpha = 2.55$.

The usefulness of such maps has been demonstrated by the frequent use of the Landecker and Wielebinski map in many and diverse studies. In the present work we have used a series of observations made at a standard frequency of 408 MHz to produce a new all-sky map of the radio continuum brightness. All the observations were made with a similar observing technique, on large parabolic reflector telescopes, and used an identical calibration procedure. The data was brought to a standard resolution of 0°.85 × 0°.85 before combination to produce the final atlas. The atlas offers not only a considerable improvement in resolution over previous whole sky maps, but an improved level of consistency in resolution and calibration.

Many applications for the present atlas suggest themselves both as a contribution to future astrophysical studies and as a useful tool for observational astronomers. Among the most immediate of these could be its combination with the all-sky HI study of Cleary *et al.* (1979), which possesses a similar resolution to the present work, and its use in conjunction with the recent Gamma-ray maps of the Galactic plane (Mayer-Hasselwander *et al.*, 1979 ; Simpson, 1979).

2. **The basic observational data.** — The observational data combined into the final all-sky atlas were obtained through four separate experiments. These can be summarised in chronological order as follows :

Survey 1 Observations of the Galactic anticentre region made with the Jodrell Bank MkI telescope.

Survey 2 Observations of the remaining northern sky between declinations − 8° and + 48° using the Effelsberg 100 metre telescope.

Survey 3 Observations of the entire southern sky using the Parkes 64 metre telescope.

Survey 4 Observations of the north celestial polar region with the Jodrell Bank MkIA telescope.

Surveys 1 and 2 have already been published (Haslam *et al.*, 1970 ; Haslam *et al.*, 1974). The observations of Surveys 3 and 4 have been described in Haslam *et al.* (1981), which we will call Paper I. The observational parameters of these surveys are summarised in table I and the areas of sky used from each in preparation of the final atlas is shown in figure 1. All the surveys used the nodding scan technique (i.e. Haslam *et al.*, 1970) and measured the intensity of the left-hand circular polarised component of the celestial radiation.

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The antenna temperatures of these surveys have been calibrated into brightness temperature using the 404 MHz absolutely calibrated observations of Pauliny-Toth and Shakeshaft (1962). No corrections for sidelobe contributions of the survey telescope have been made. However, the excellent agreement in the overlap regions between the four surveys (made with virtually four different telescopes) and the consistency of all the data, when smoothed to a resolution of 8°.5 × 6°.5, with the map of Pauliny-Toth and Shakeshaft, suggest that no major distortions of the celestial brightness distribution have been introduced by this omission.

3. **Preparation of the 408 MHz atlas.** — Surveys 1 and 2 were smoothed to the 0°.85 × 0°.85 resolution of Surveys 3 and 4 before their combination to produce the all-sky atlas. This smoothing was achieved by convolution with a two-dimensional Gaussian function of appropriate half widths. For complete compatibility Surveys 1 and 2 have been recalibrated against the 404 MHz measurements of Pauliny-Toth and Shakeshaft. Small correction factors were applied to the published brightness temperatures as follows :

1) 1 K was subtracted from the brightness temperature scale of Survey 1 (Haslam *et al.*, 1970).

2) 1.75 K was subtracted from the brightness temperature scale of Survey 2 (Haslam *et al.*, 1974) which was then multiplied by 1.085.

Following these minor adjustments the temperatures in the overlap regions were found to be in excellent agreement. The details of Surveys 3 and 4 are described in Paper I.

The four independent surveys were then combined in the M.P.I.f.R. Cyber 172 computer using software of the NOD2 system (Haslam, 1974) to produce number grids in celestial coordinates. Contour plots of these were then made to give the 408 MHz α, δ plates. Each plate has a size of 32° × 22°, including a 1° wide *guard ring* at the map edges which overlap the surrounding plates. Also produced were polar plots of the north and south polar caps. In addition, a second library of maps was produced in Galactic coordinates, using the NOD2 program library as described in section 4c of Paper I.

4. **The all-sky atlas.** — The 408 MHz atlas is presented in equatorial coordinates, Epoch 1950.0, in figure 2. Rectangular plates of size 32° × 22° on the equator are given for $|\delta| \leqq 71°$, with extra polar plots for $|\delta| \geqq 70°$. The equivalent maps for Galactic coordinates are given in figure 3. Each set of maps is preceded by a finder chart with underlying major contours at 5° × 5° resolution. The contour lines are labelled of brightness temperature with the following contour intervals :

0 K to 60 K in 2 K steps, labelled every 10 K.
60 K to 100 K in 4 K steps, labelled 60 and 80 K.
100 K to 200 K in 10 K steps, labelled 100 and 150 K.
200 K to 500 K in 20 K steps, labelled 200, 300, 400 K.
500 K to 5000 K in 50 K steps, labelled every 250 K.

Arrows on contour lines point clockwise around minima in the brightness distribution and anticlockwise around maxima. In regions of strong temperature gradient, where contour lines become too congested, unlabelled contours are suppressed. The temperature scale of the atlas is believed to be accurate to better than 10 %, whilst the average zero-level has an uncertainty of ± 3 K. Positional pointing errors are ± 1′.

To give an easily assimilated overview of the general structure of the celestial brightness distribution, figure 4 shows the whole sky in Galactic coordinates displayed in rainbow colours at nearly full angular resolution. Figure 5 is a fold-out contour map of the whole sky in equal-area-projection at 2°.0 × 2°.0 resolution.

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TABLE I. — *Observational parameters of the four individual surveys.*

Date	Telescope	Beam width (')	Receiver ∿ 408 MHz	Zone α	Zone δ	Reference
Nov 64 Jan 65	Jodrell 250 feet (Mk1)	48	Single Channel Dicke	00^h - 12^h Anticenter	-20° +60°	Haslam, Quigley, Salter 1970, MNRAS 147, 405
Jan 71 Feb 72	Bonn 100 metre	37	Two Channel Correlator	12^h - 04^h G. Plane + N.P. Spur	- 8° +48°	Haslam, Wilson, Graham, Hunt 1974, A & A Suppl. 13, 359
Dec 73 Mar 75	Parkes 64 metre	51	Three Channel Correlator	00^h - 24^h G. Plane, Vela, LMC, SMC	-90° - 5°	Haslam, Wilson, Cooke, Cleary, Graham, Wielebinski, Day 1975, Proc. ASA 2 (6), 331 (see also below)
				12^h - 22^h G. Plane + N.P. Spur	- 5° +24°	
Jul 78 Sep 78	Jodrell 250 feet (Mk1A)	48	Three Channel Correlator	00^h - 24^h North Polar Cap	+45° +90°	Haslam, Klein, Salter, Stoffel, Wilson, Cleary, Cooke, Thomasson 1981, A & A 100, 209

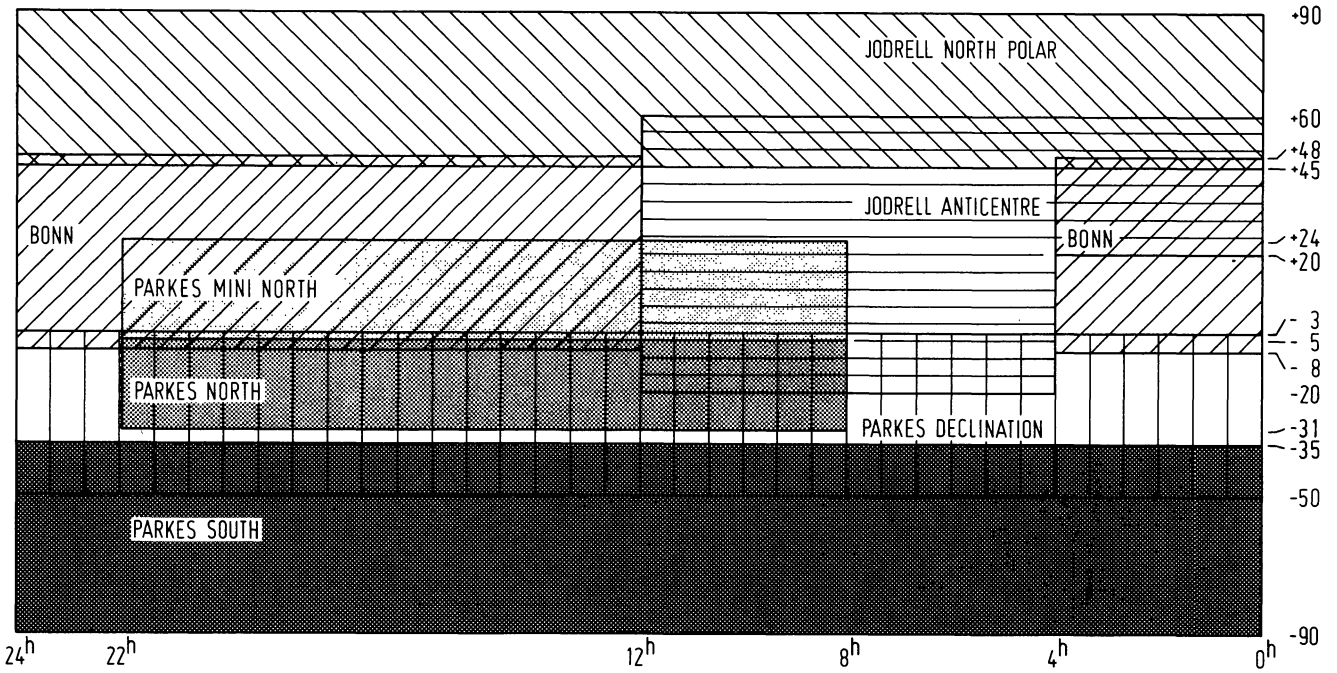

FIGURE 1. — This shows the zones covered by the component surveys. The Jodrell Anticentre survey has been described in Haslam *et al.* (1970), the Bonn survey in Haslam *et al.* (1974), the various component Parkes surveys and the Jodrell North Polar survey are described in Paper I (Haslam *et al.*, 1981).

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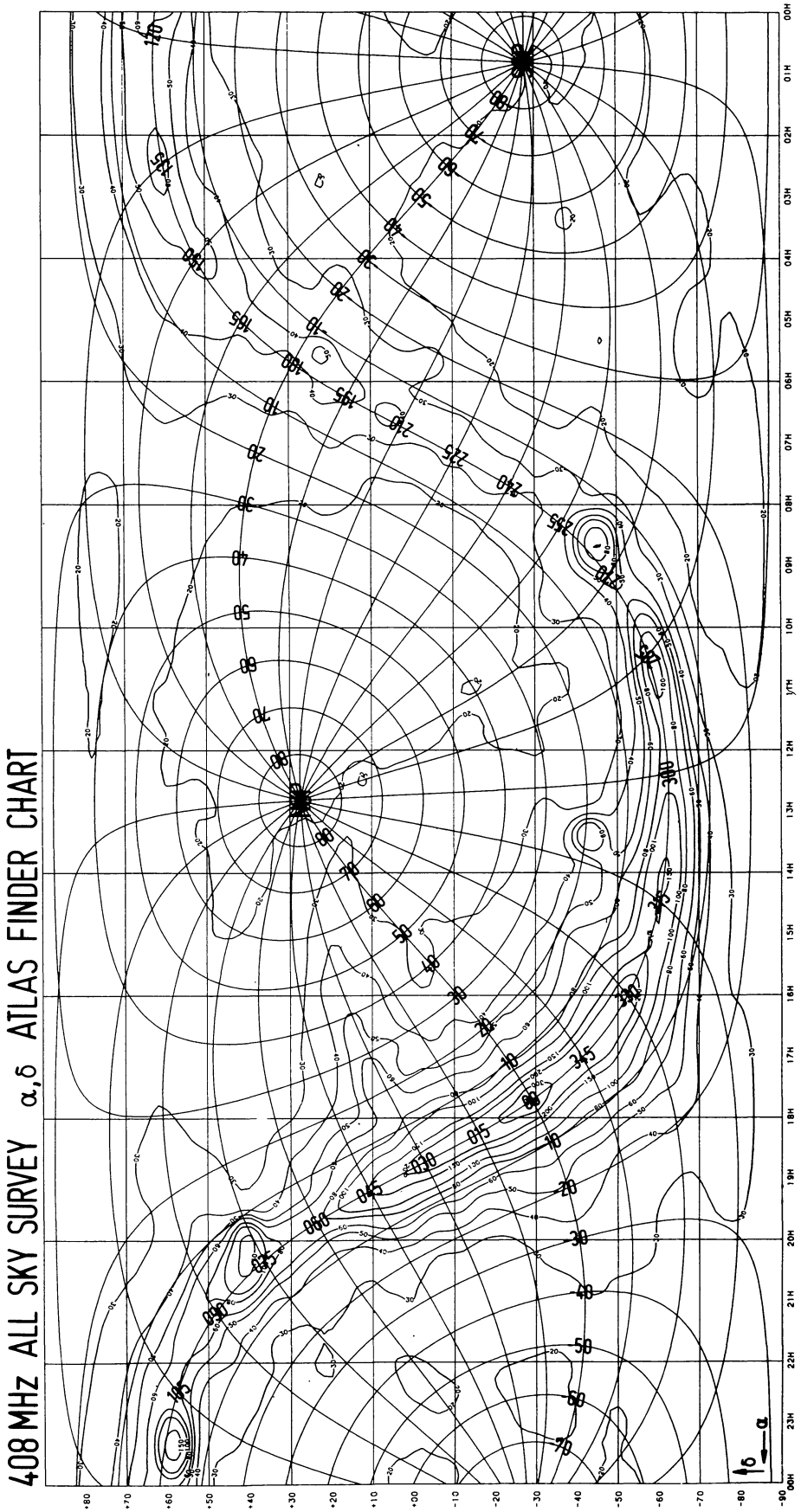

FIGURE 2. — The atlas of maps in celestial coordinates Epoch 1950.0. The details of contour levels and associated labelling have been described in the text. The atlas is preceded by a finder chart which marks the boundary of each basic 30° × 20° plate but excludes the guard rings. The plates are ordered in rows increasing in right ascension and subsequent rows in increasing declination. The rows | δ | ≧ 70° are, however, presented as half segment polar plots. To facilitate an overview of the atlas, and the interrelationship of the plates, the finder chart includes a map at 5° × 5° resolution giving only the major labelled contours and a 15° × 10° reference grid in Galactic coordinates.

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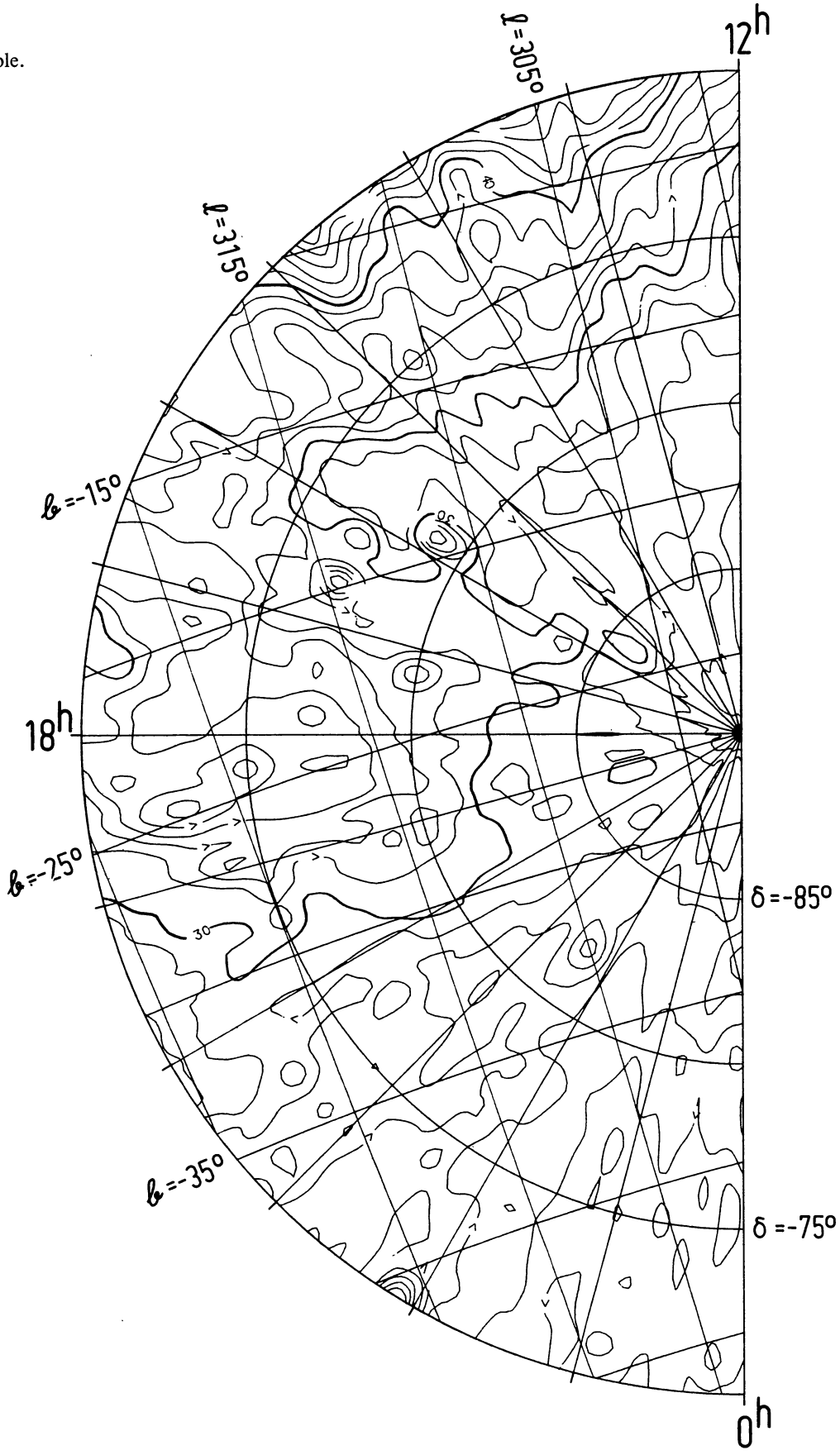
South celestial Pole.



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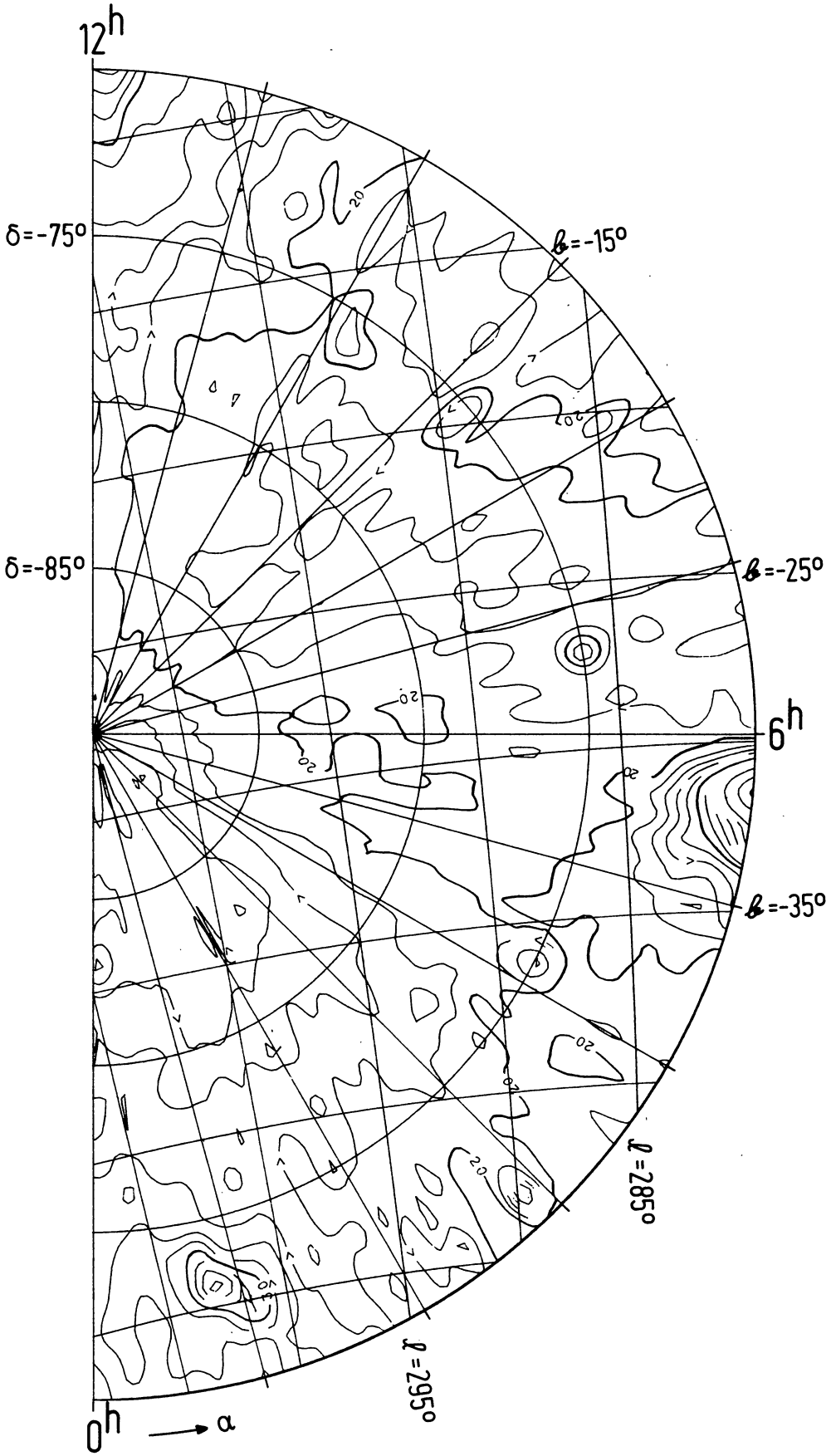

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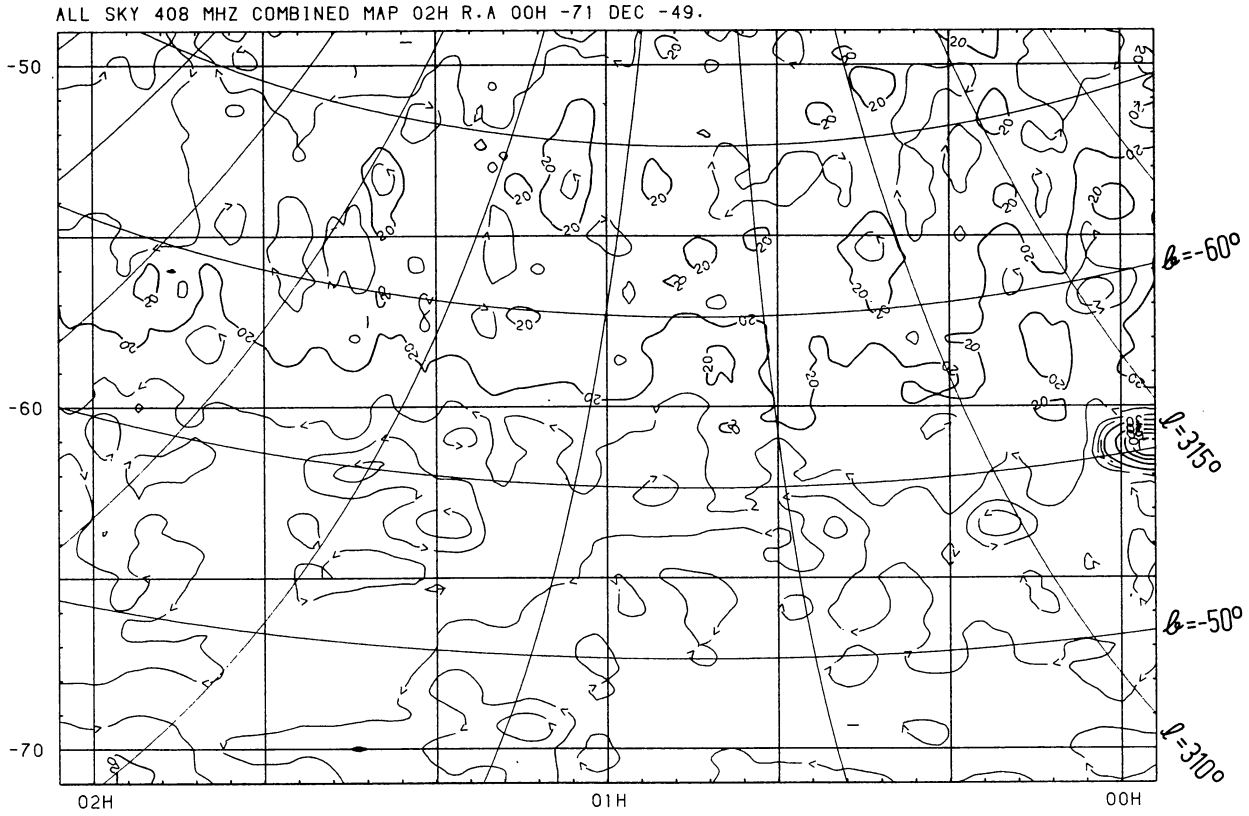

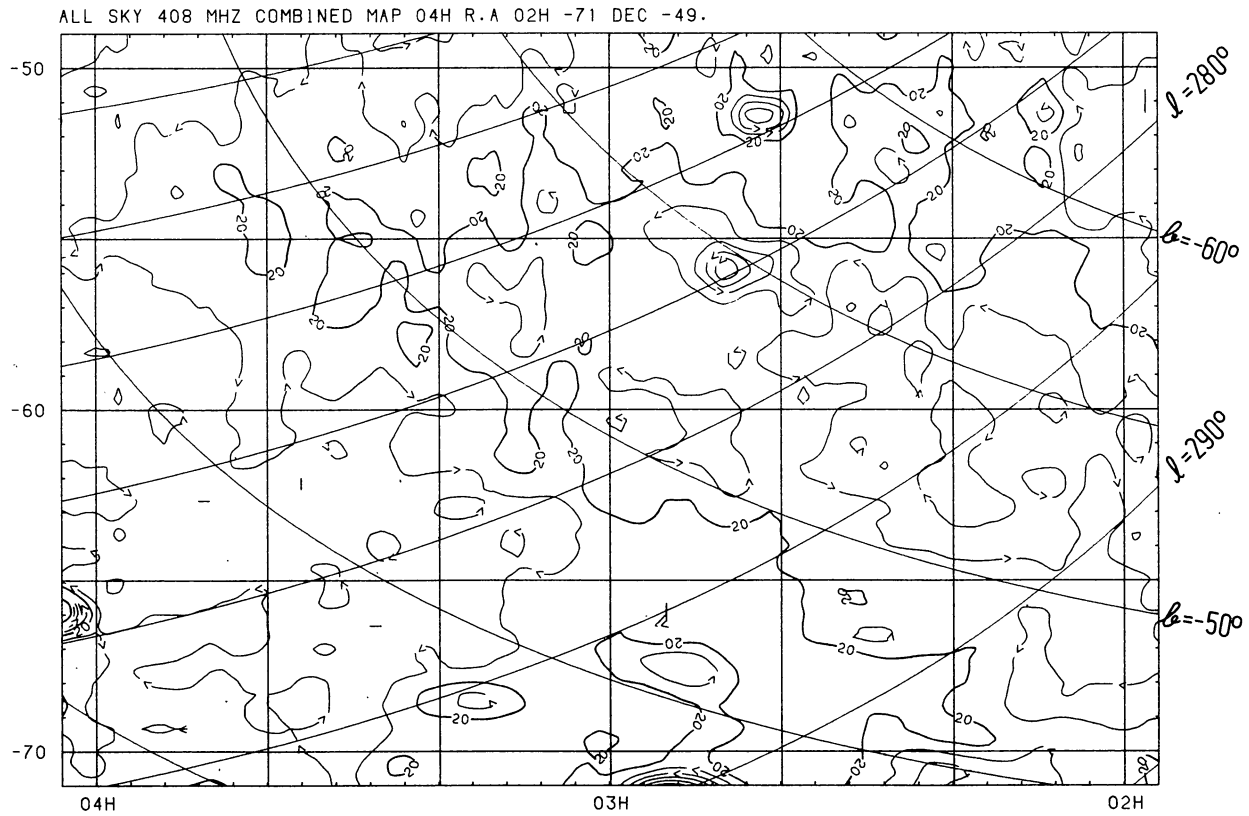

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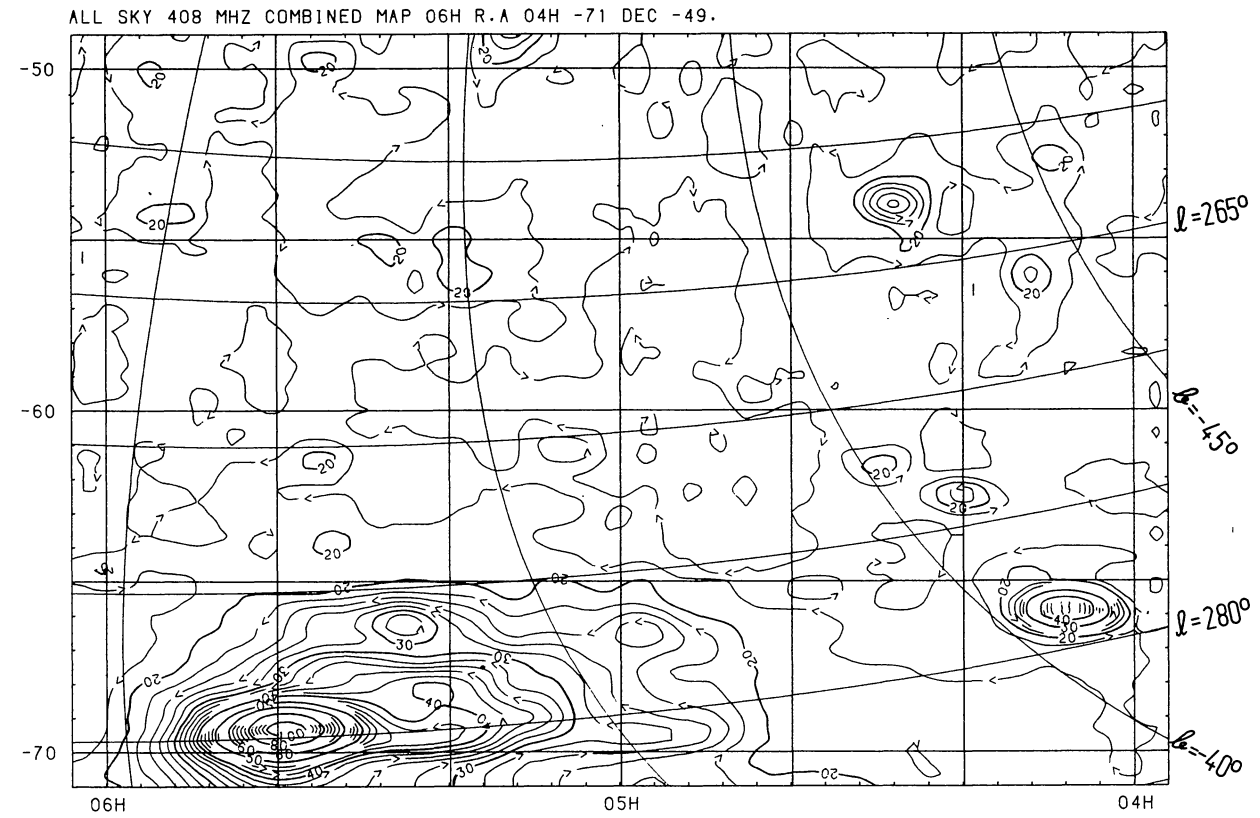

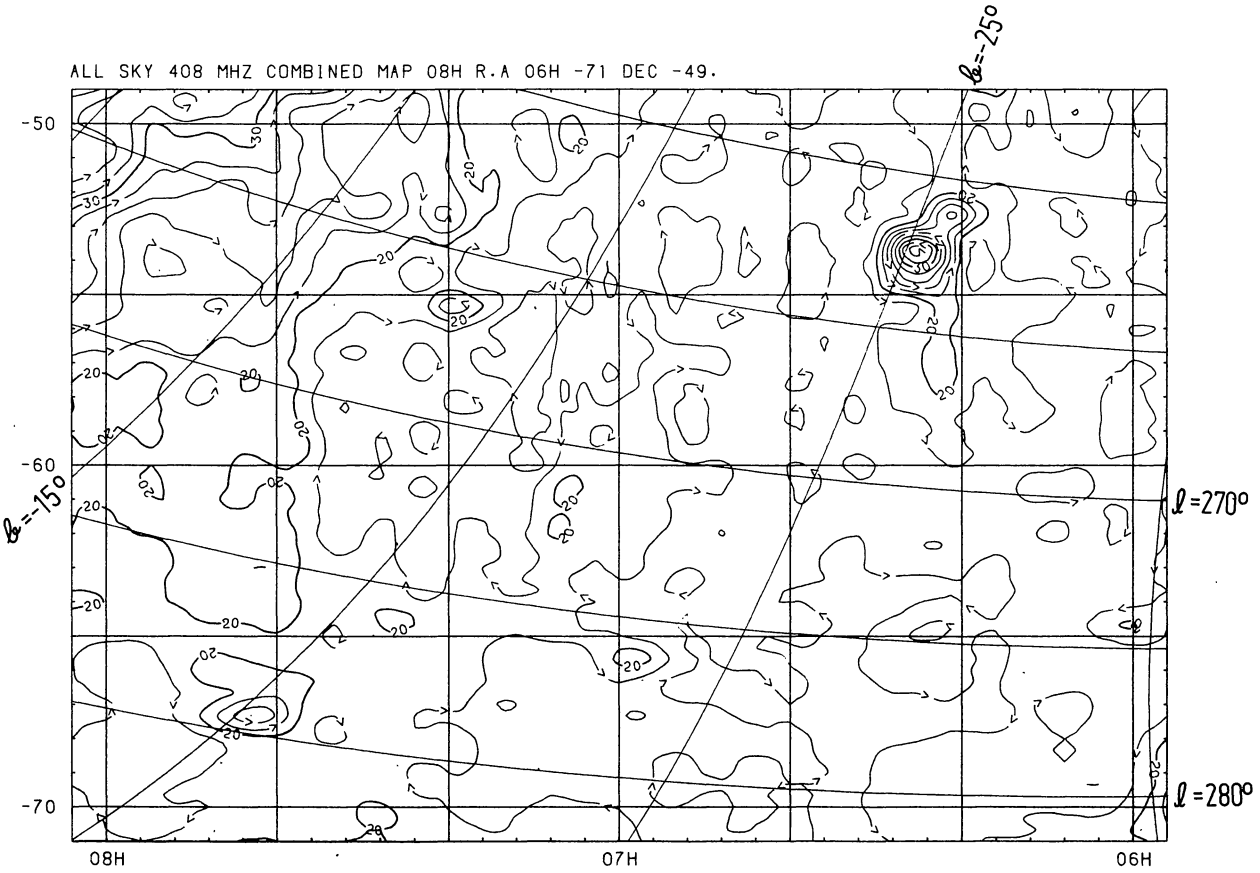

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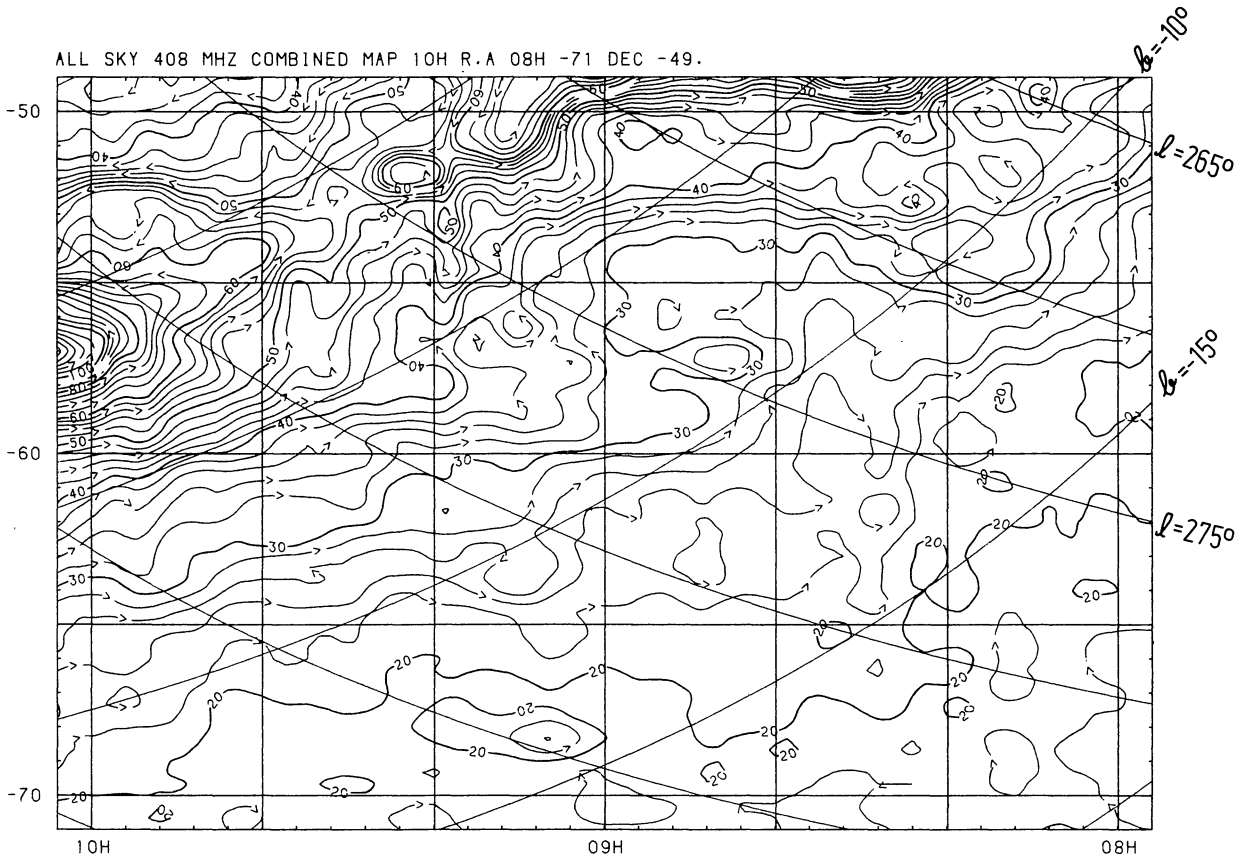

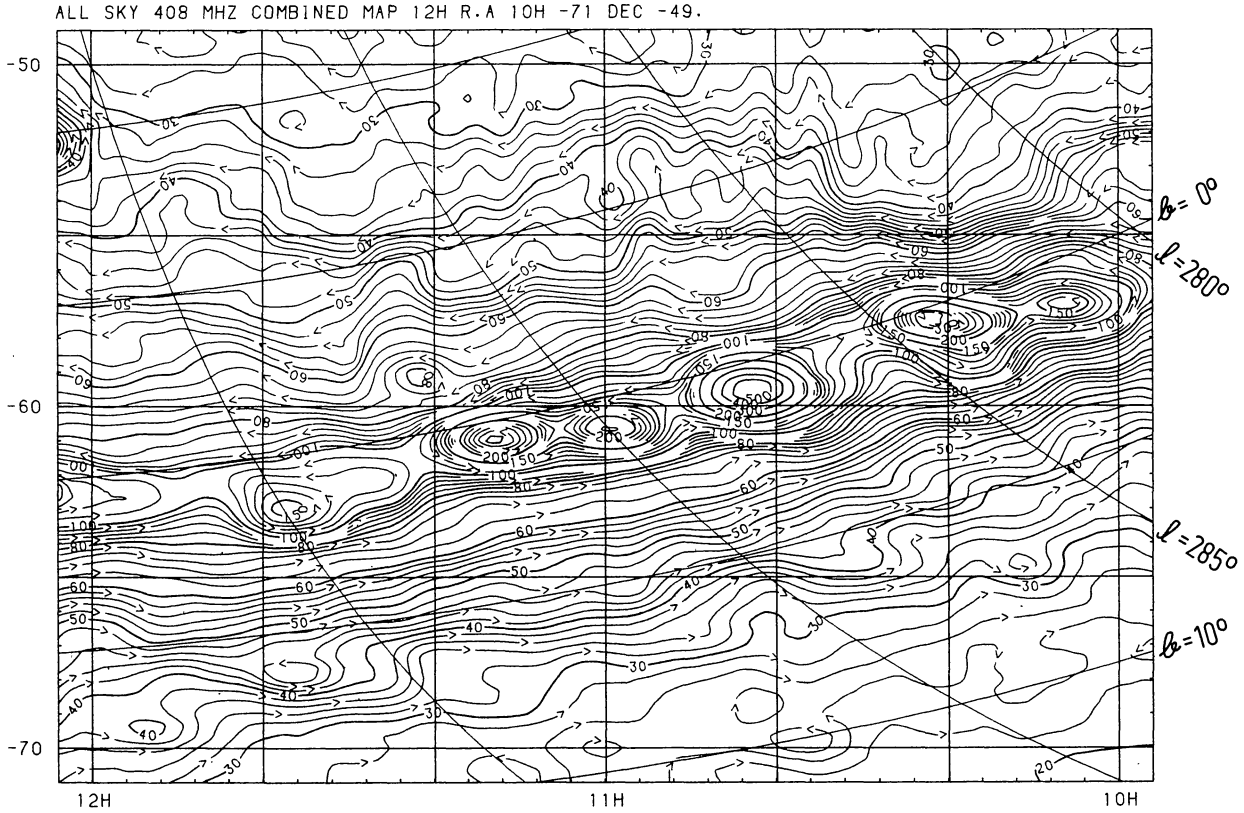

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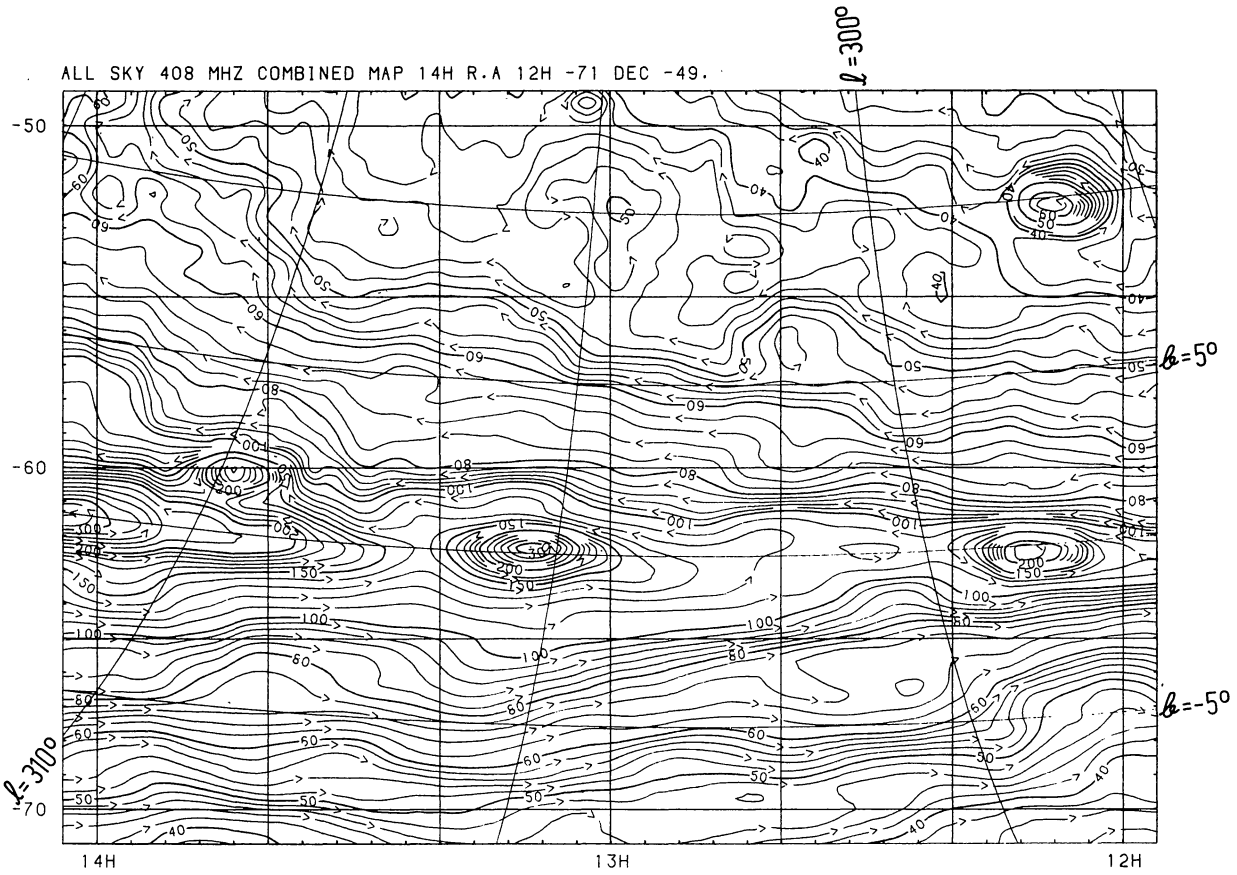

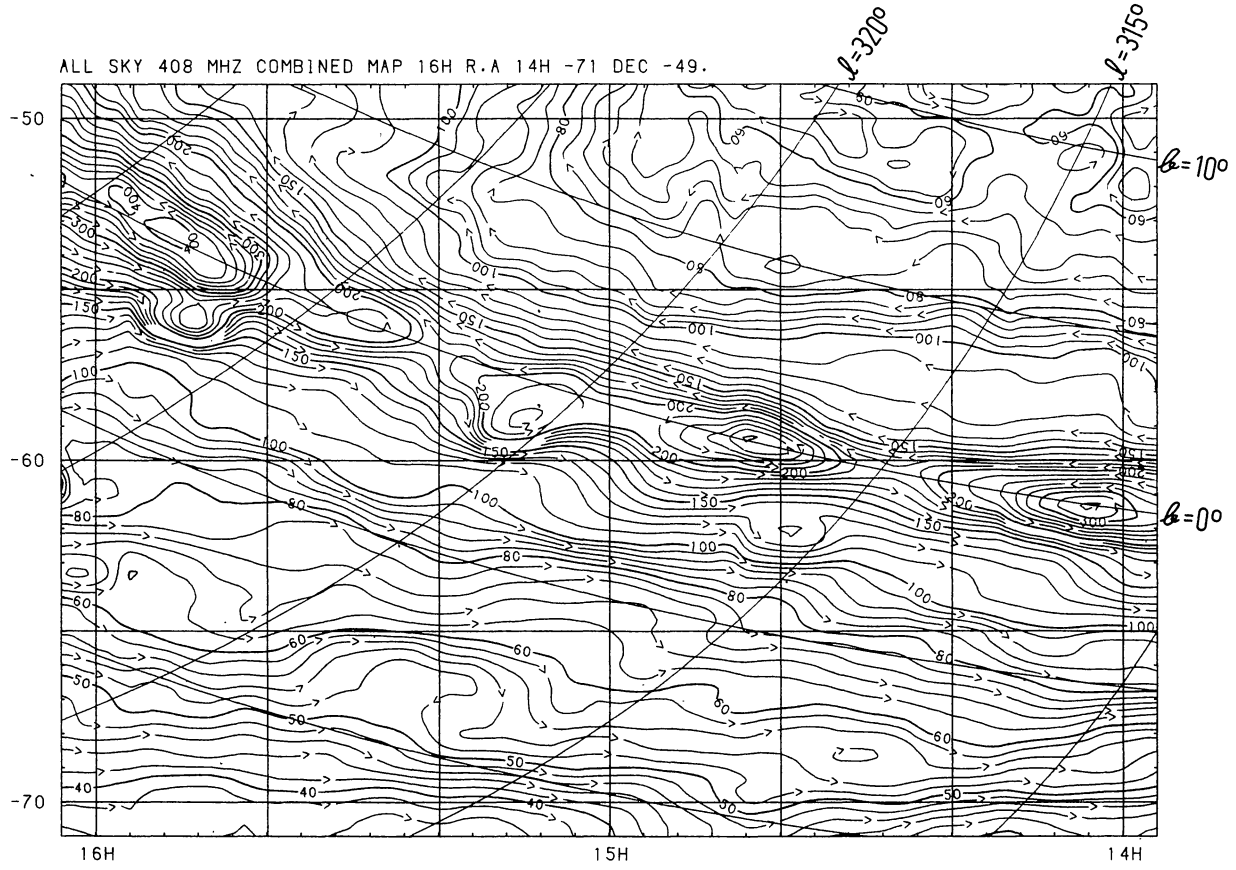

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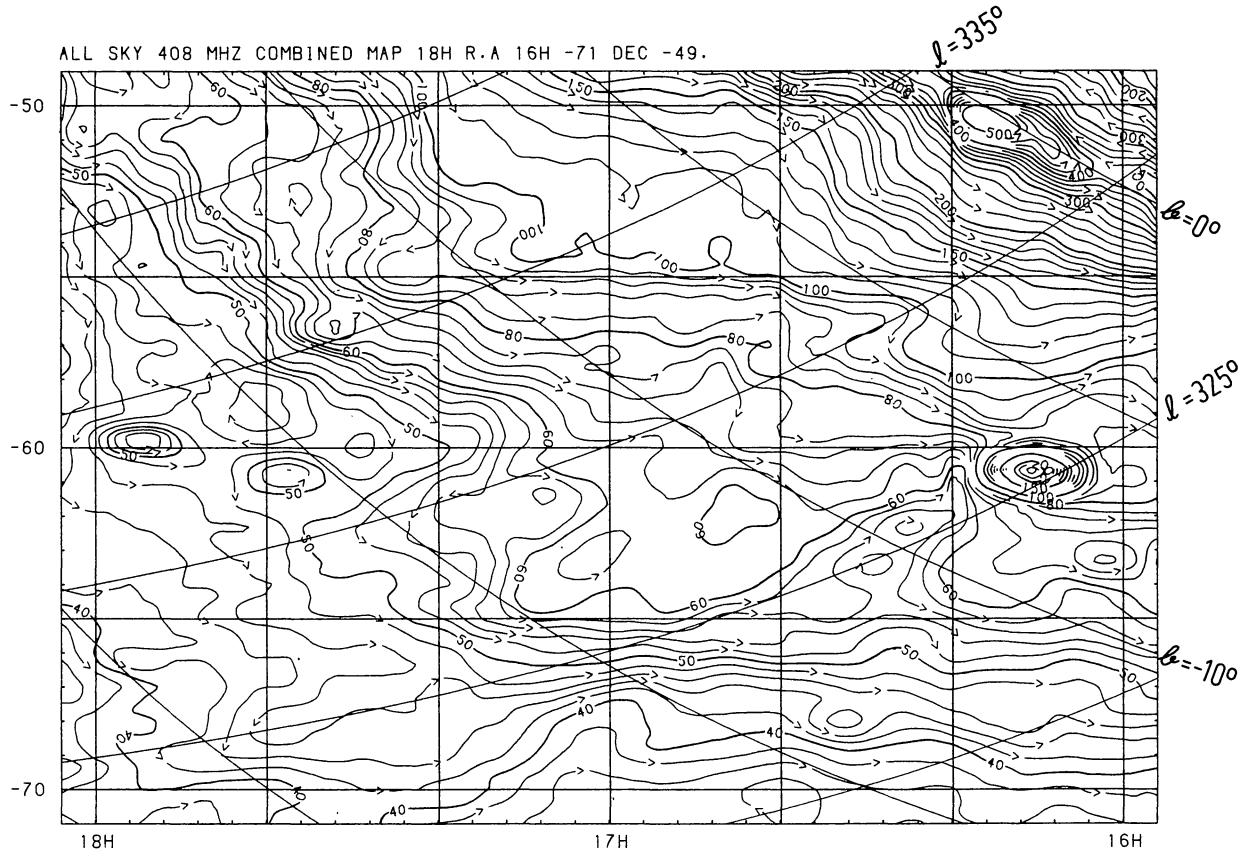

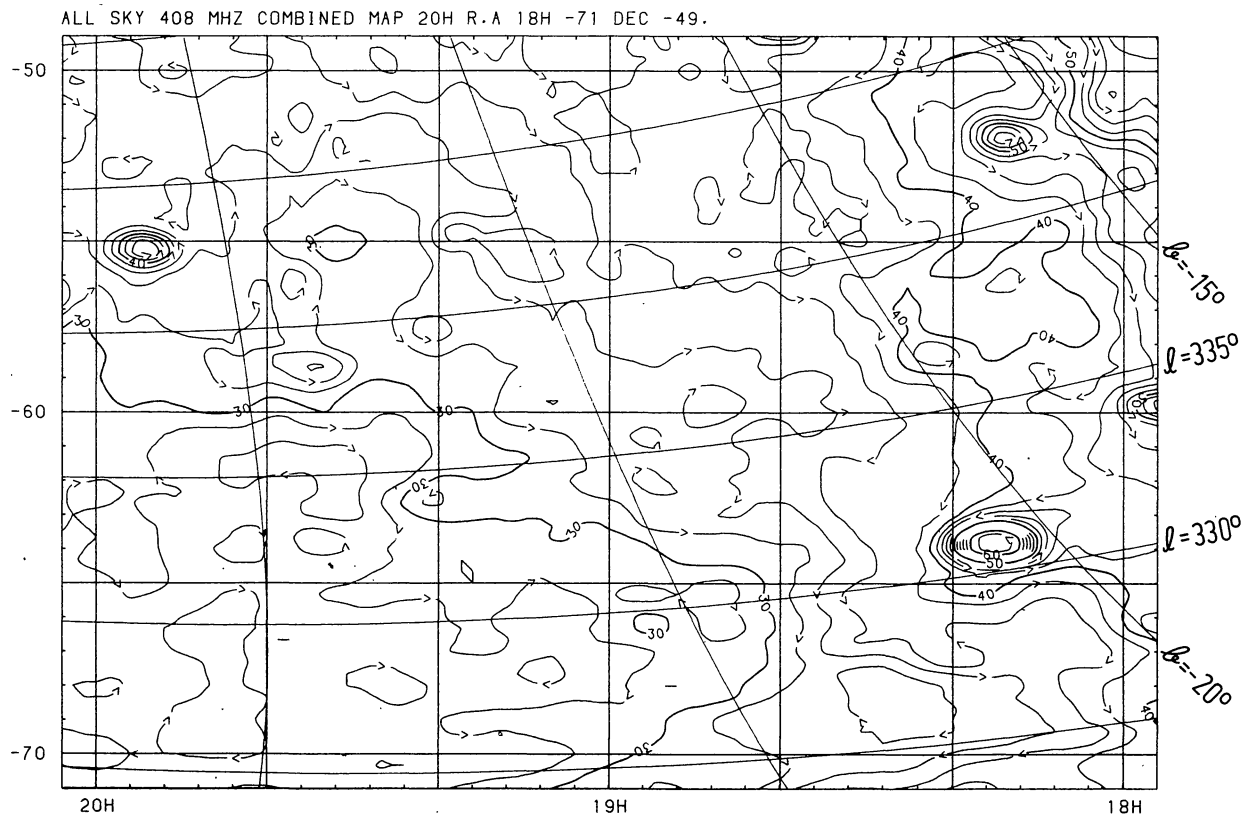

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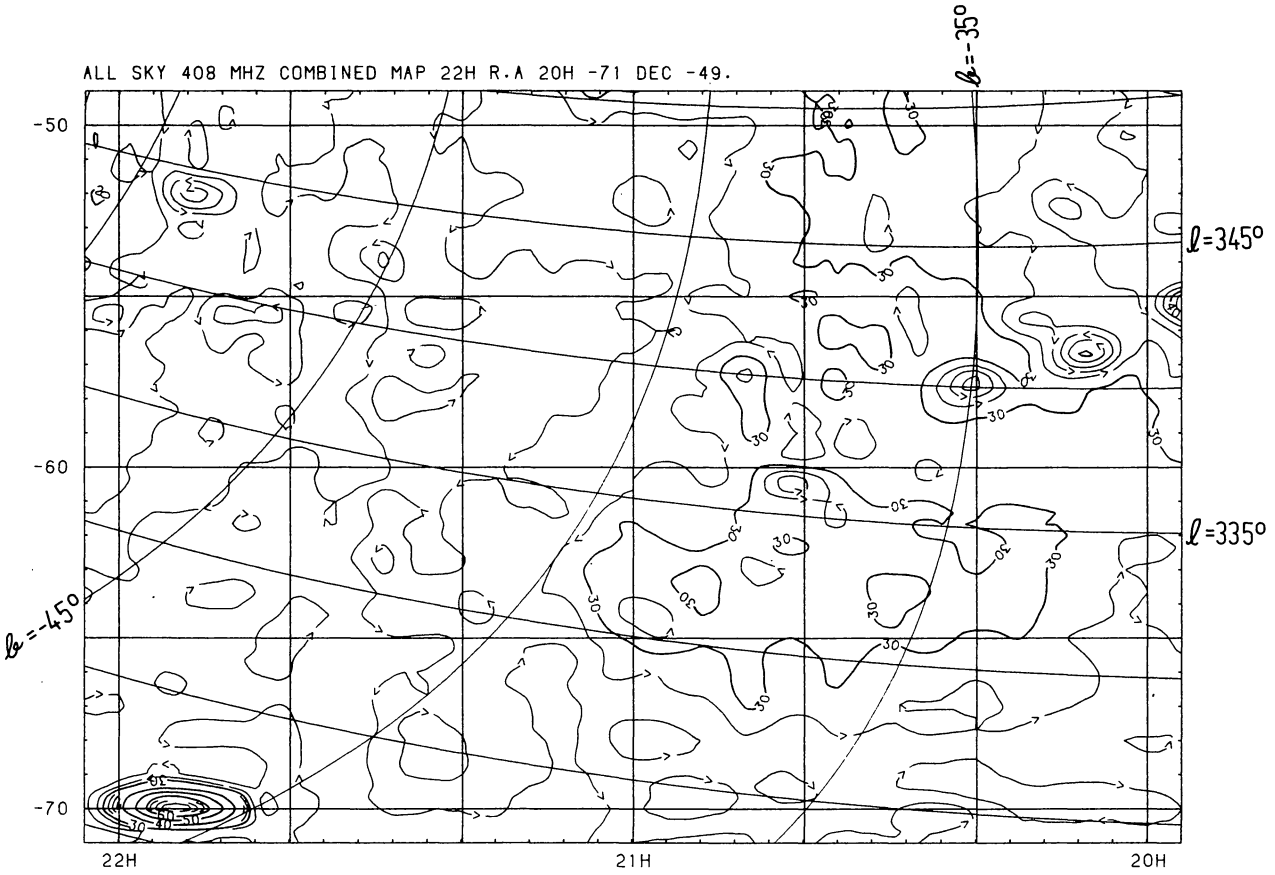

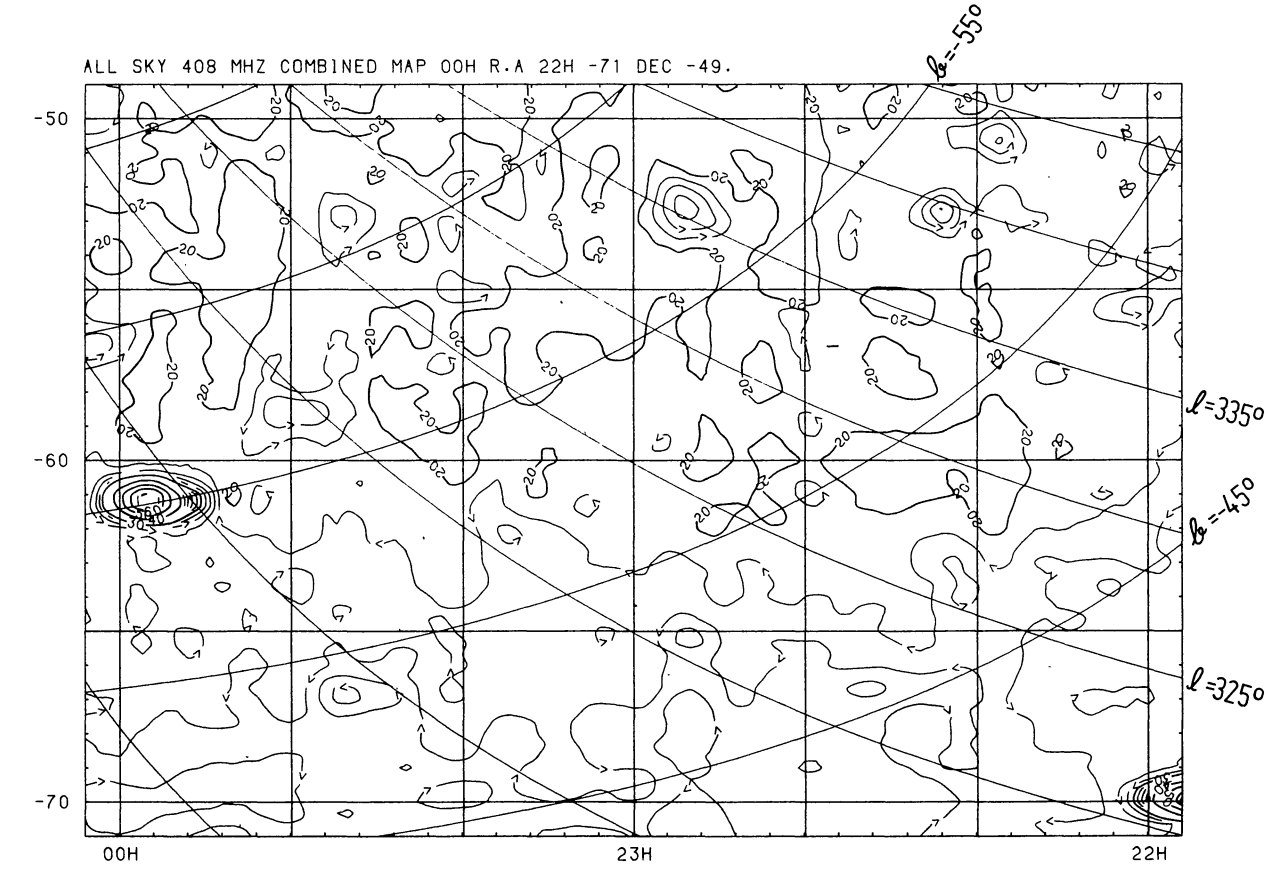

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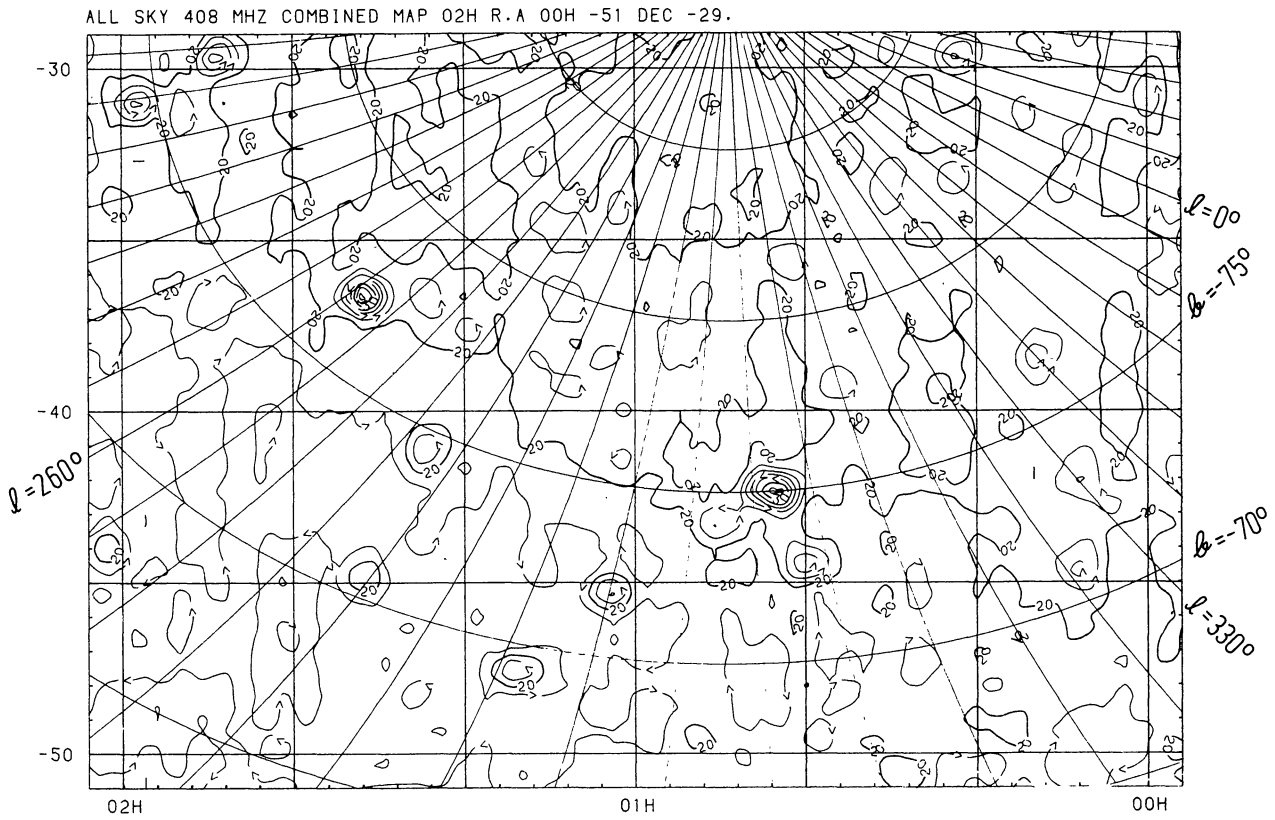

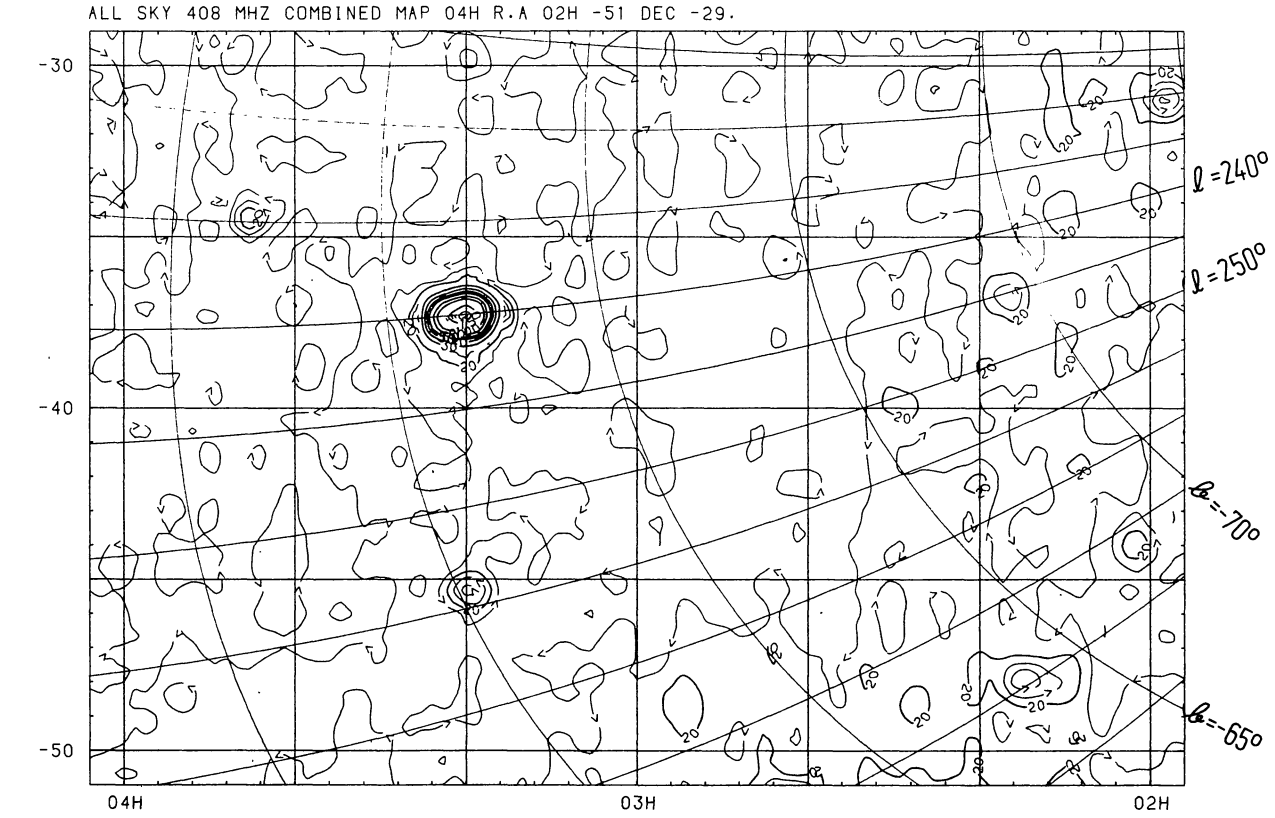

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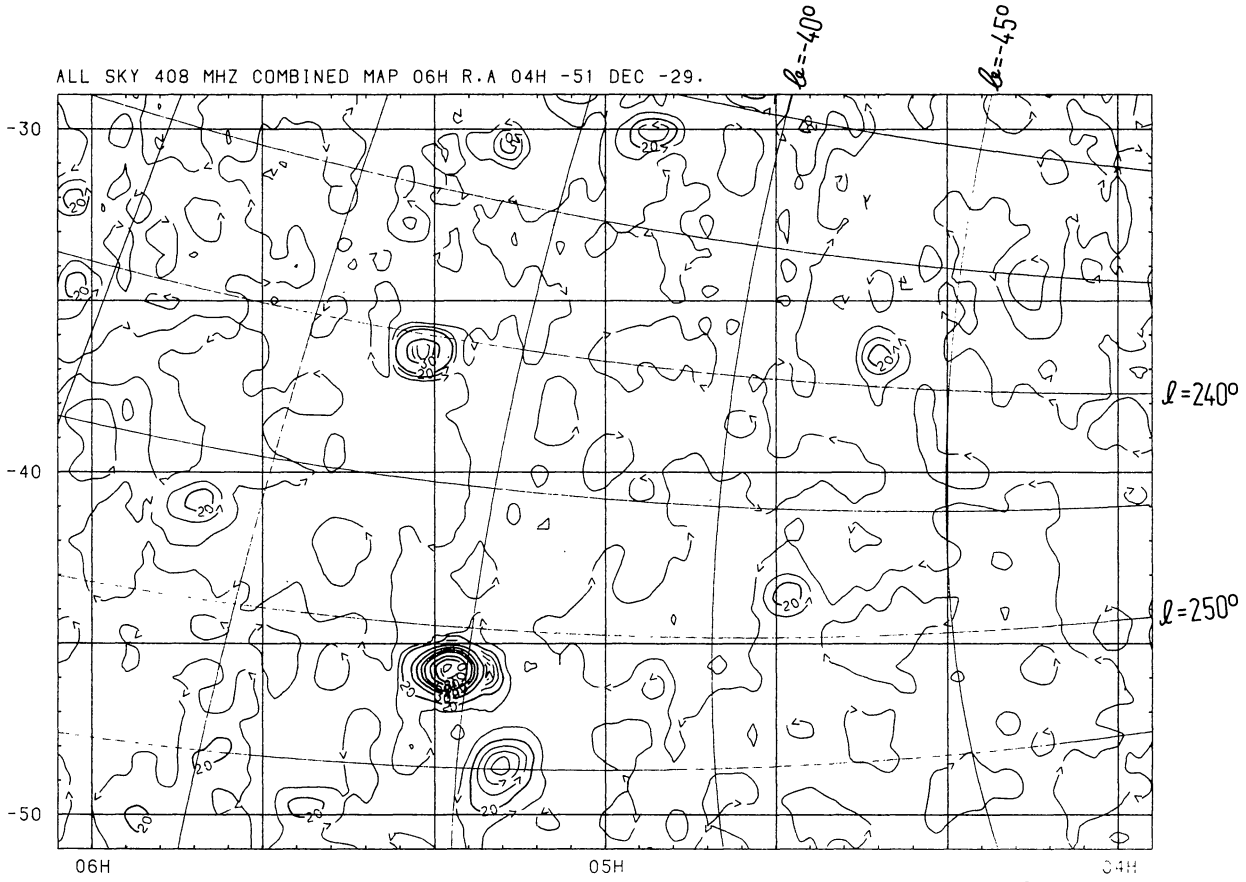

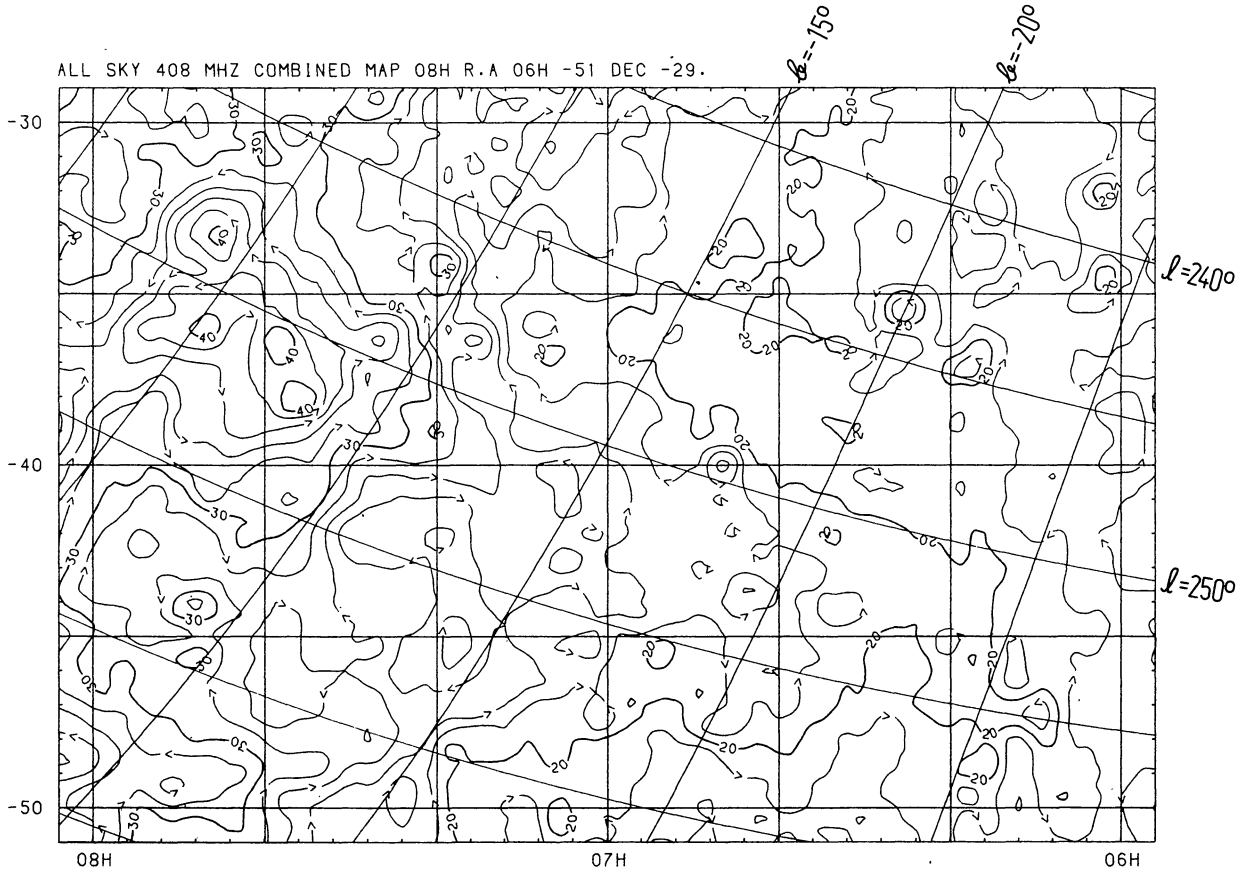

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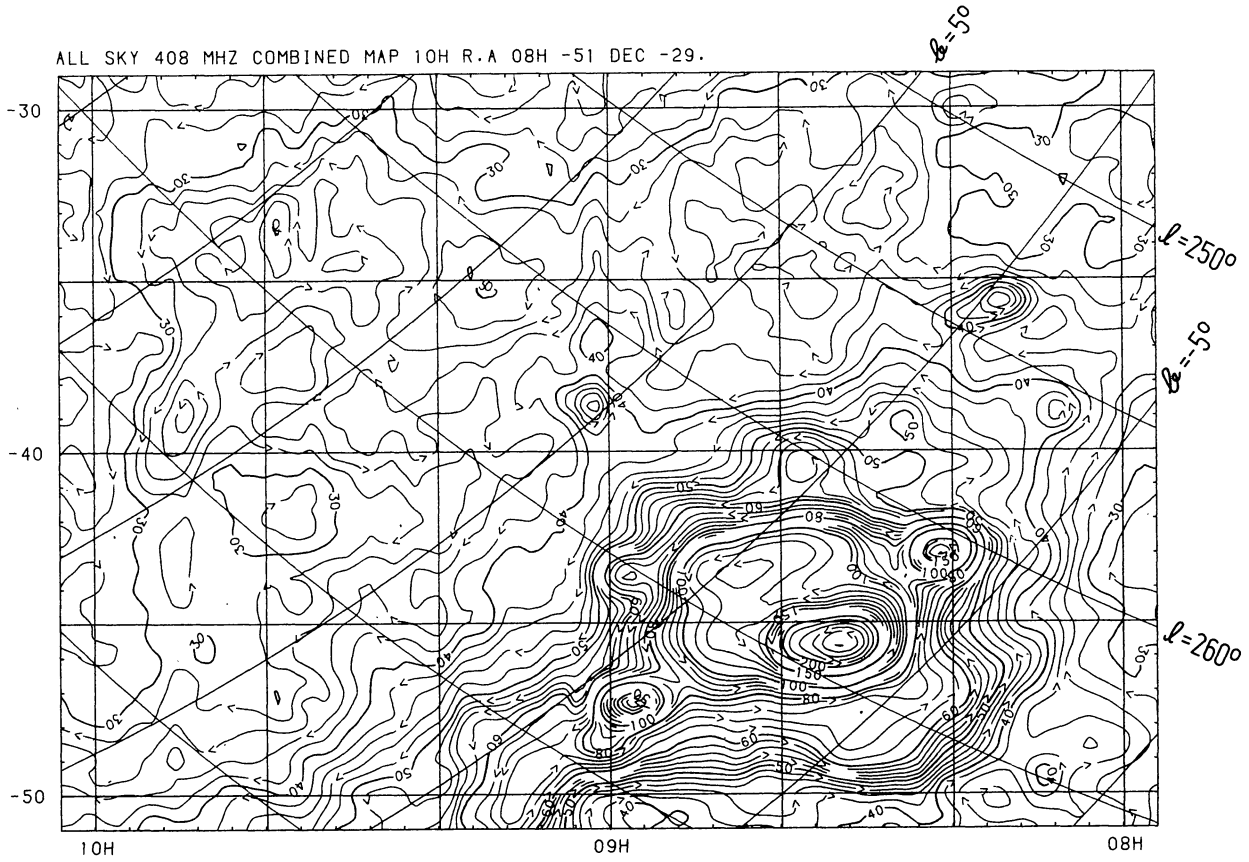

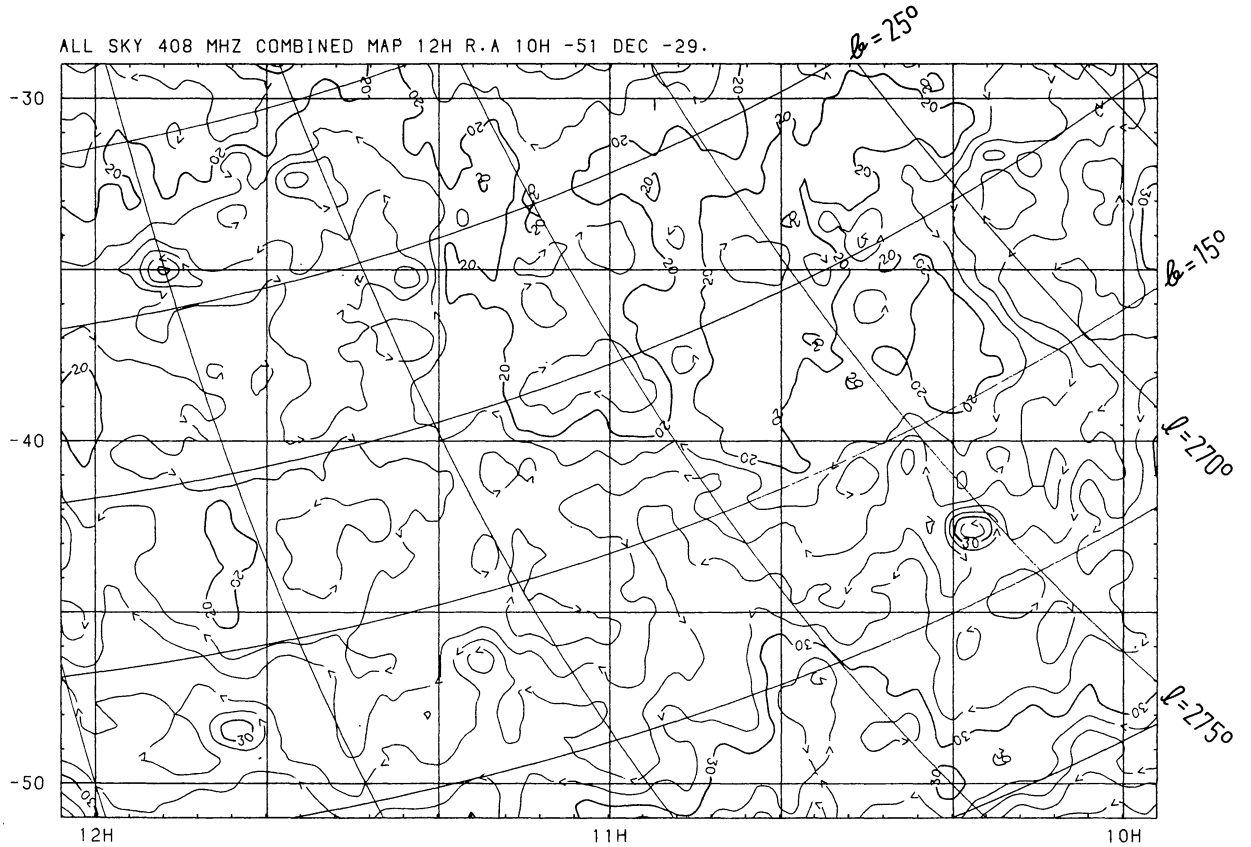

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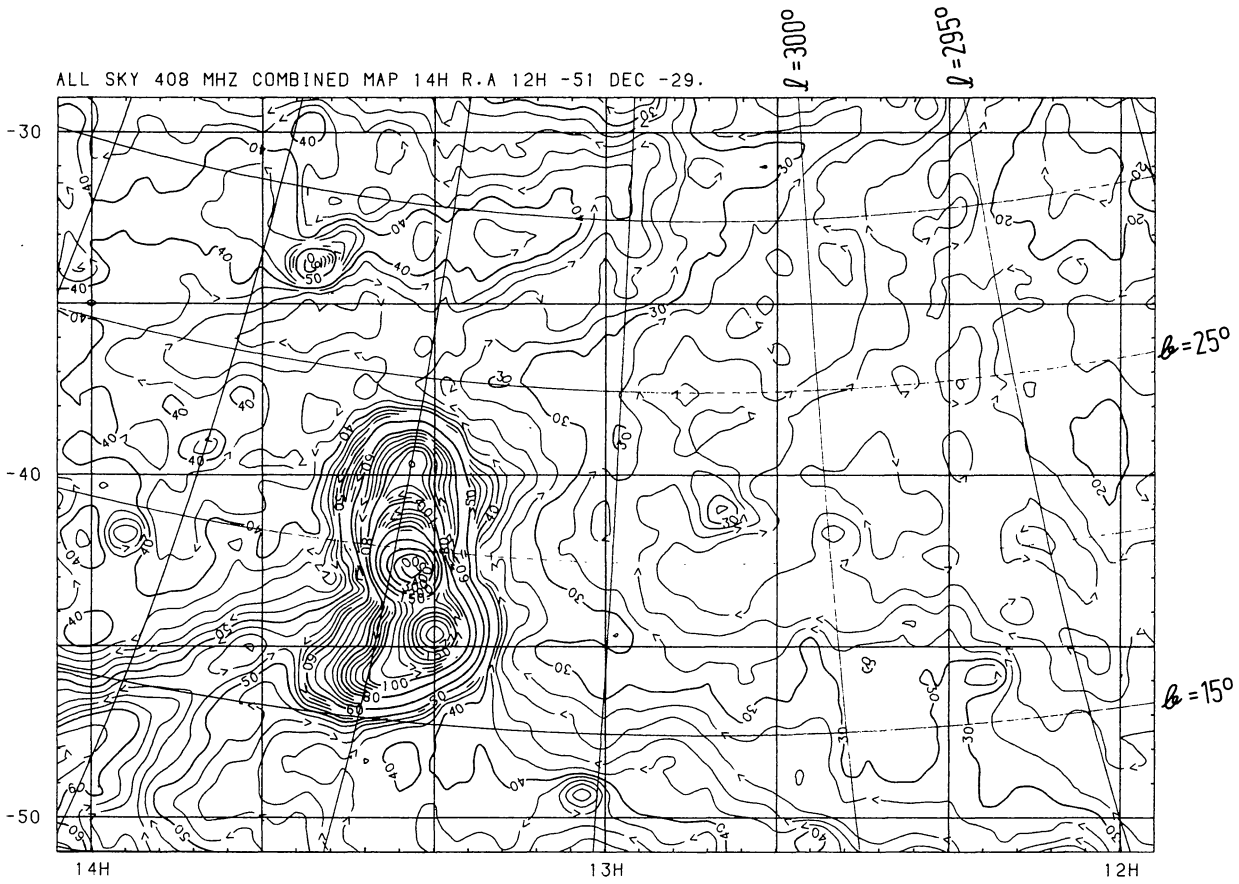

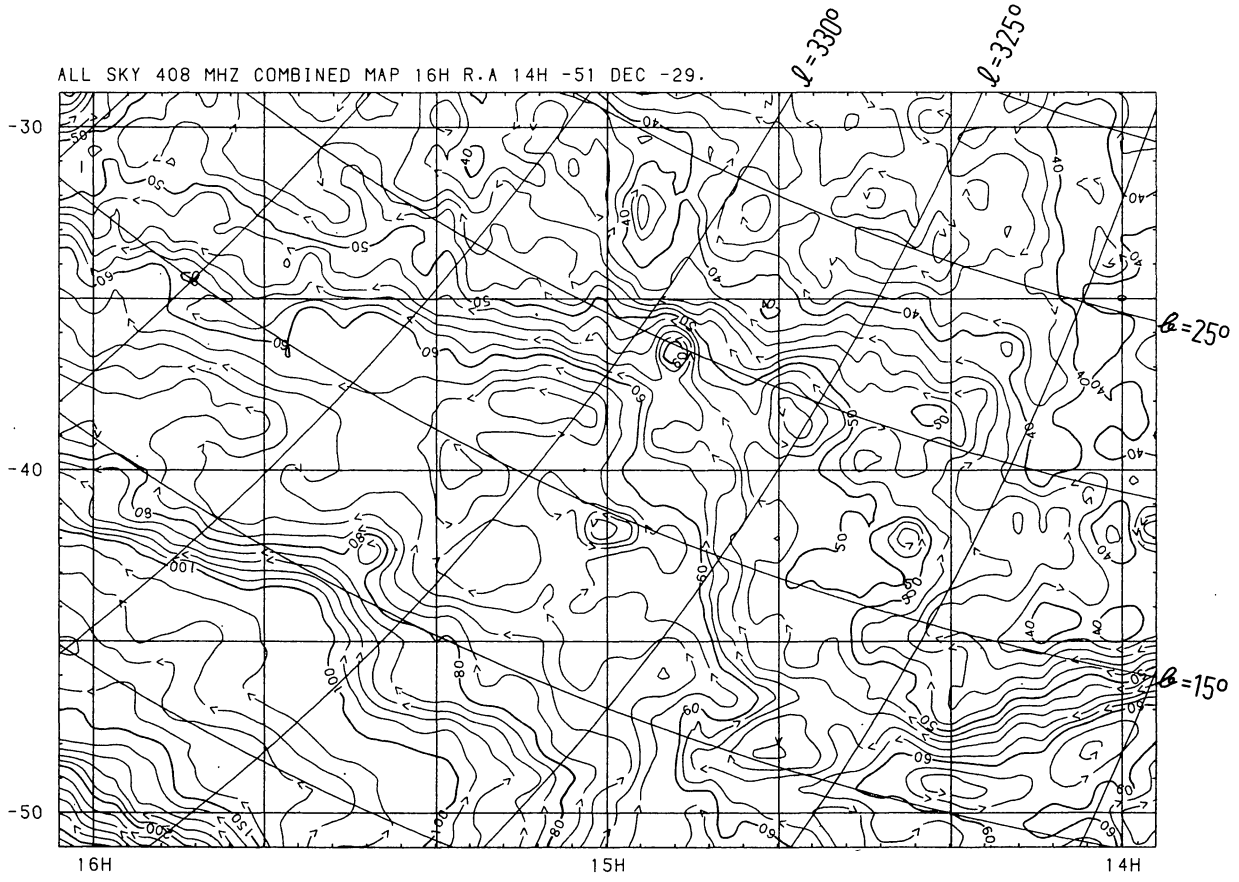

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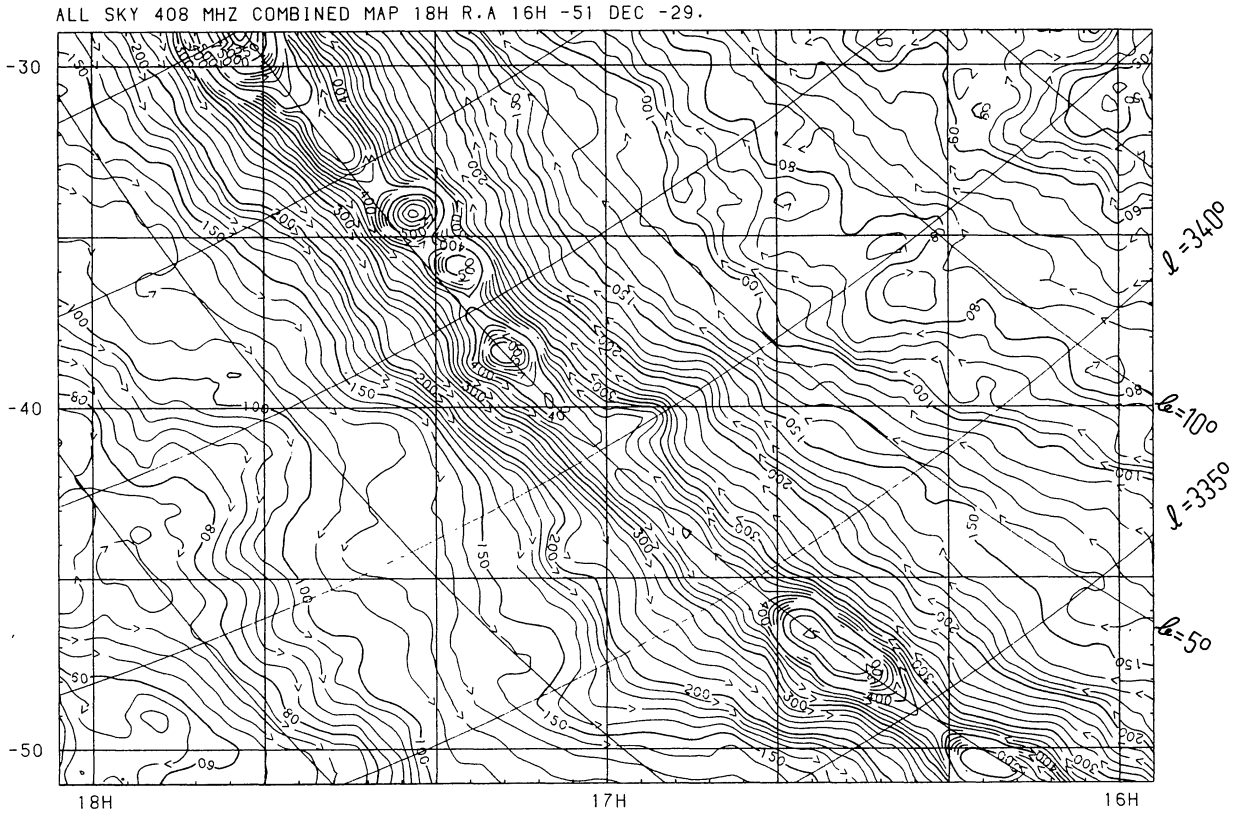

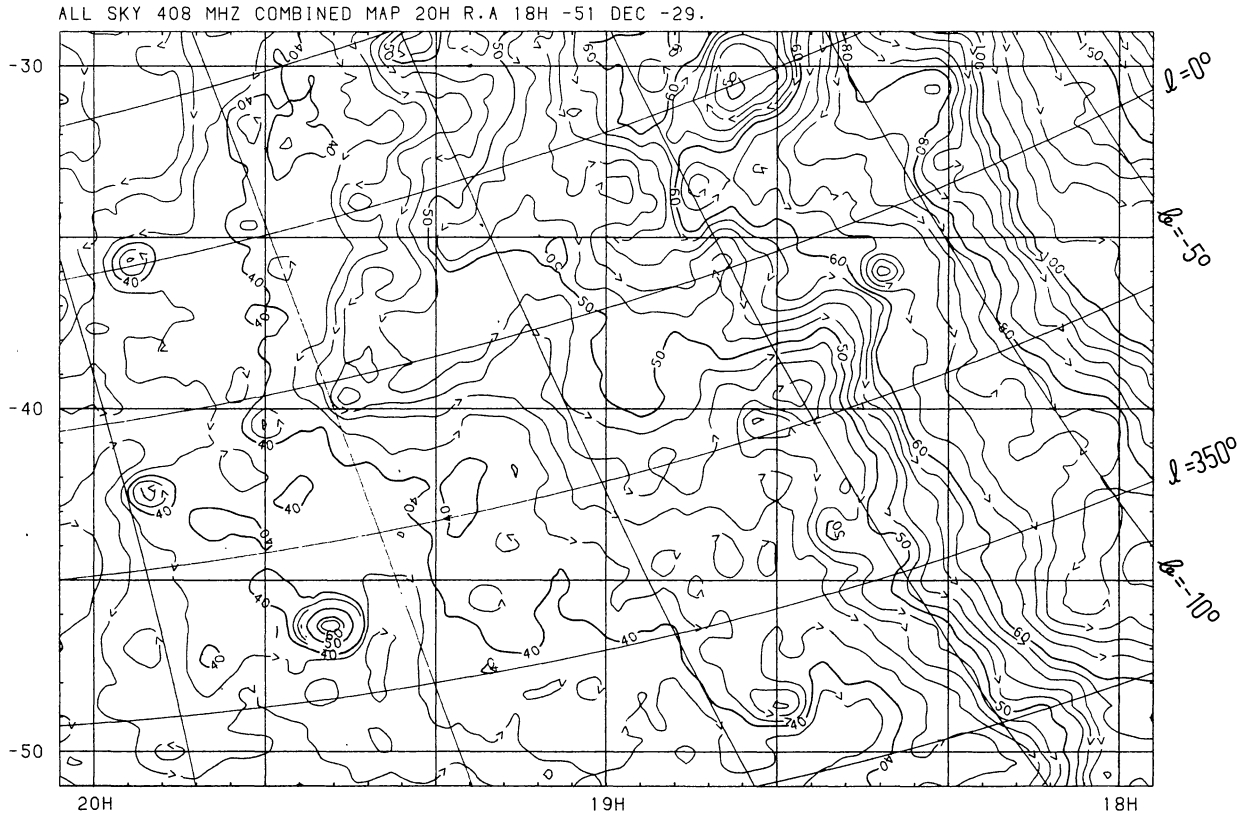

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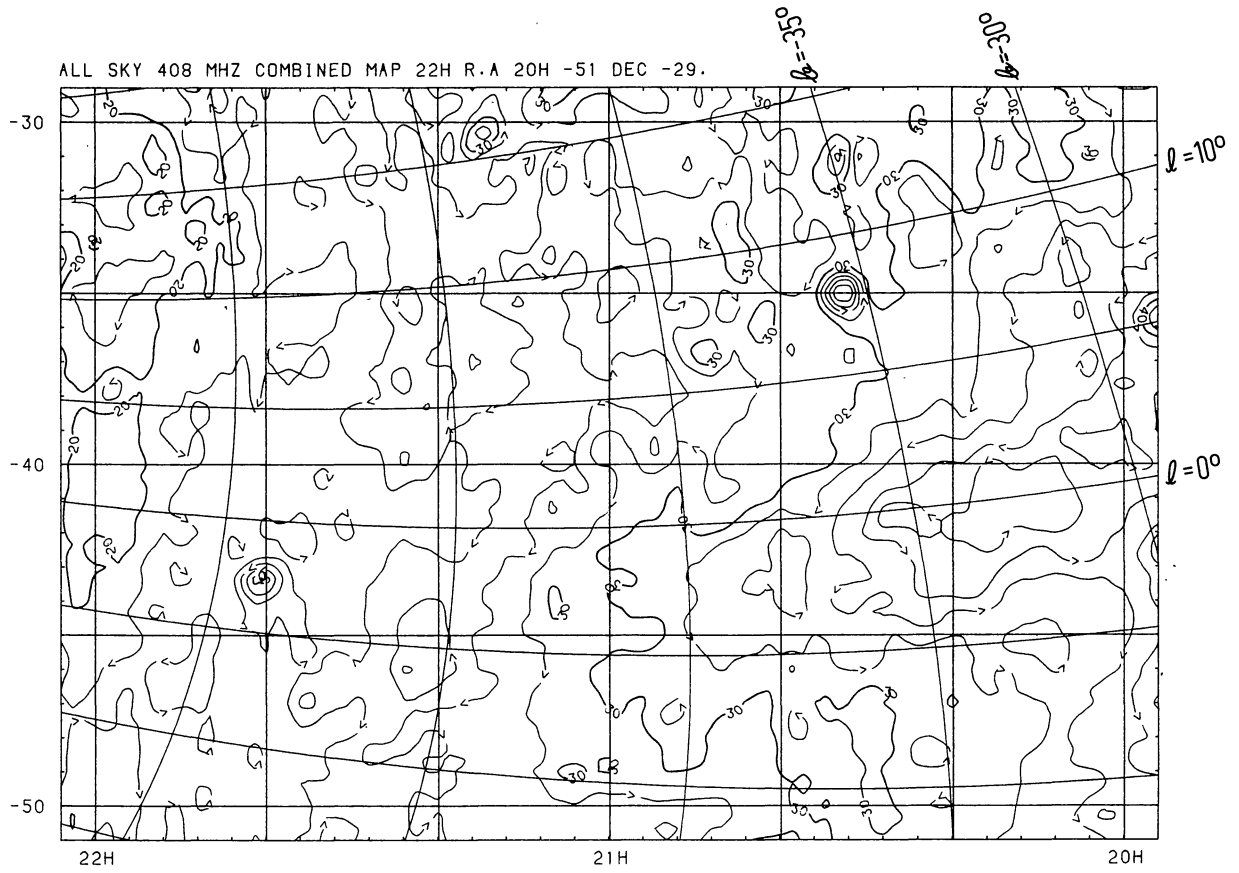

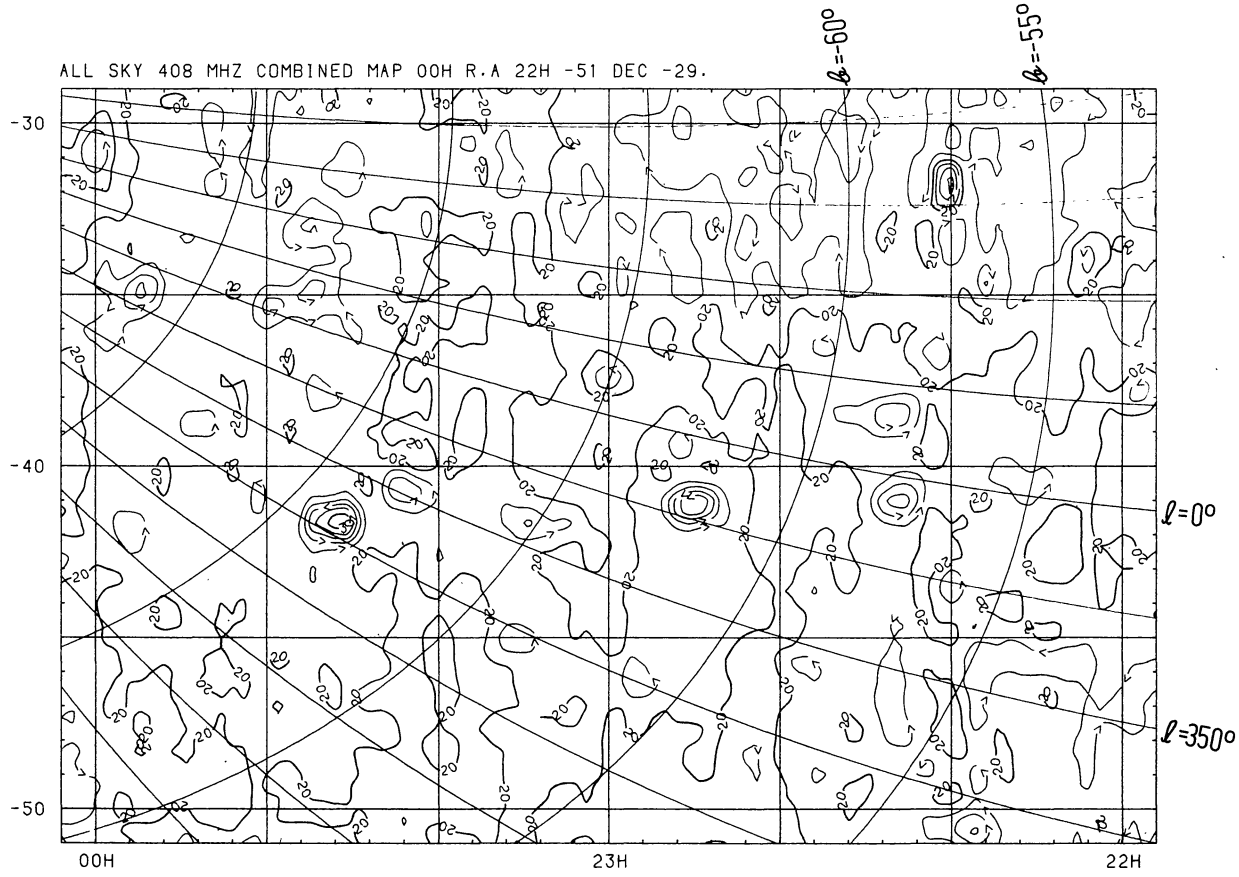

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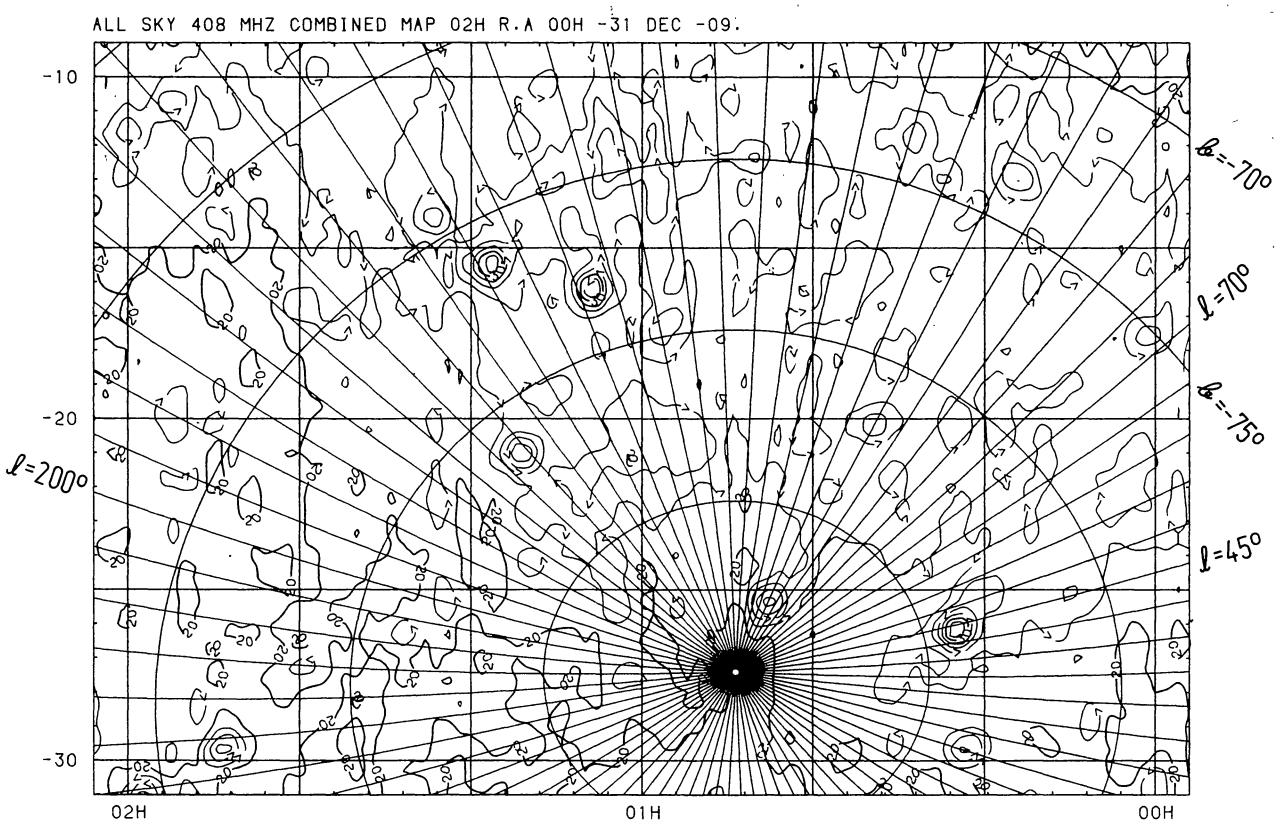

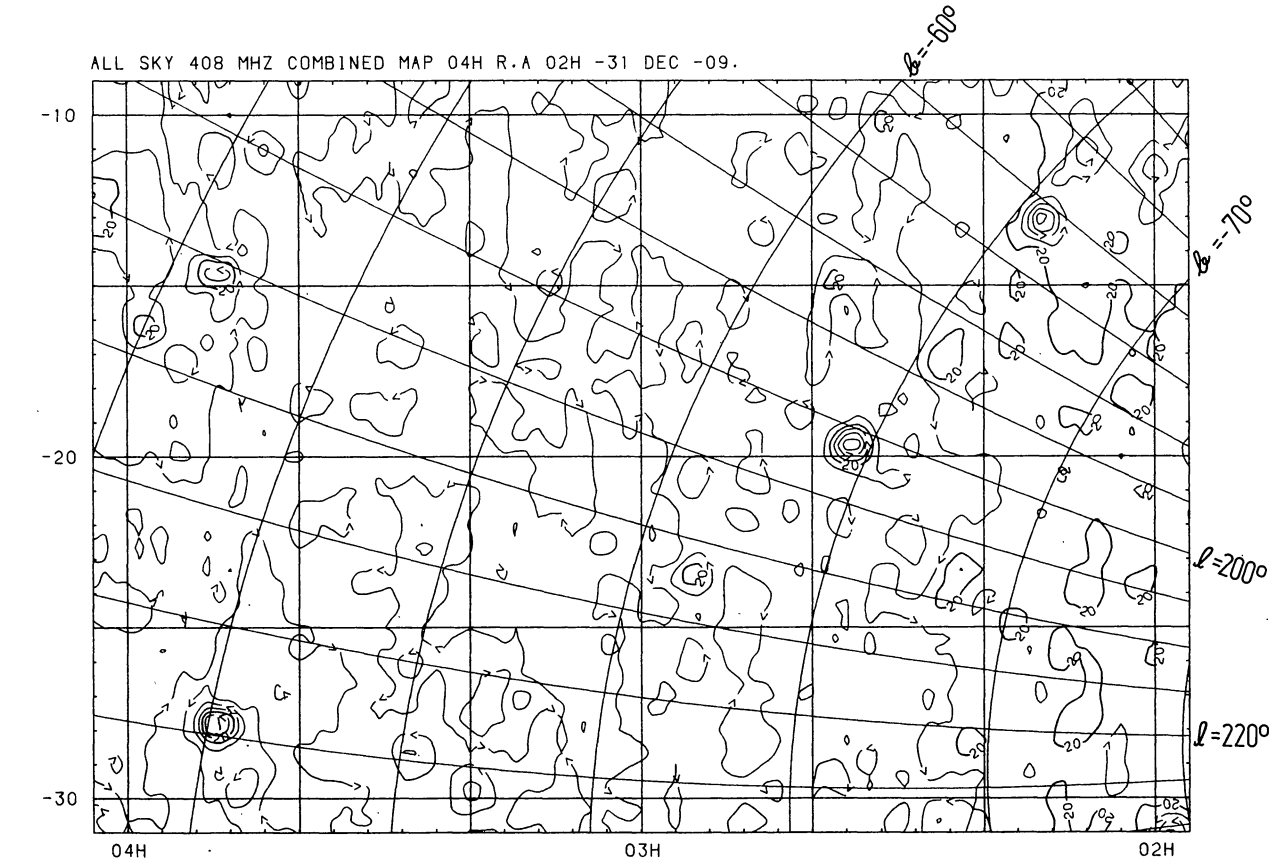

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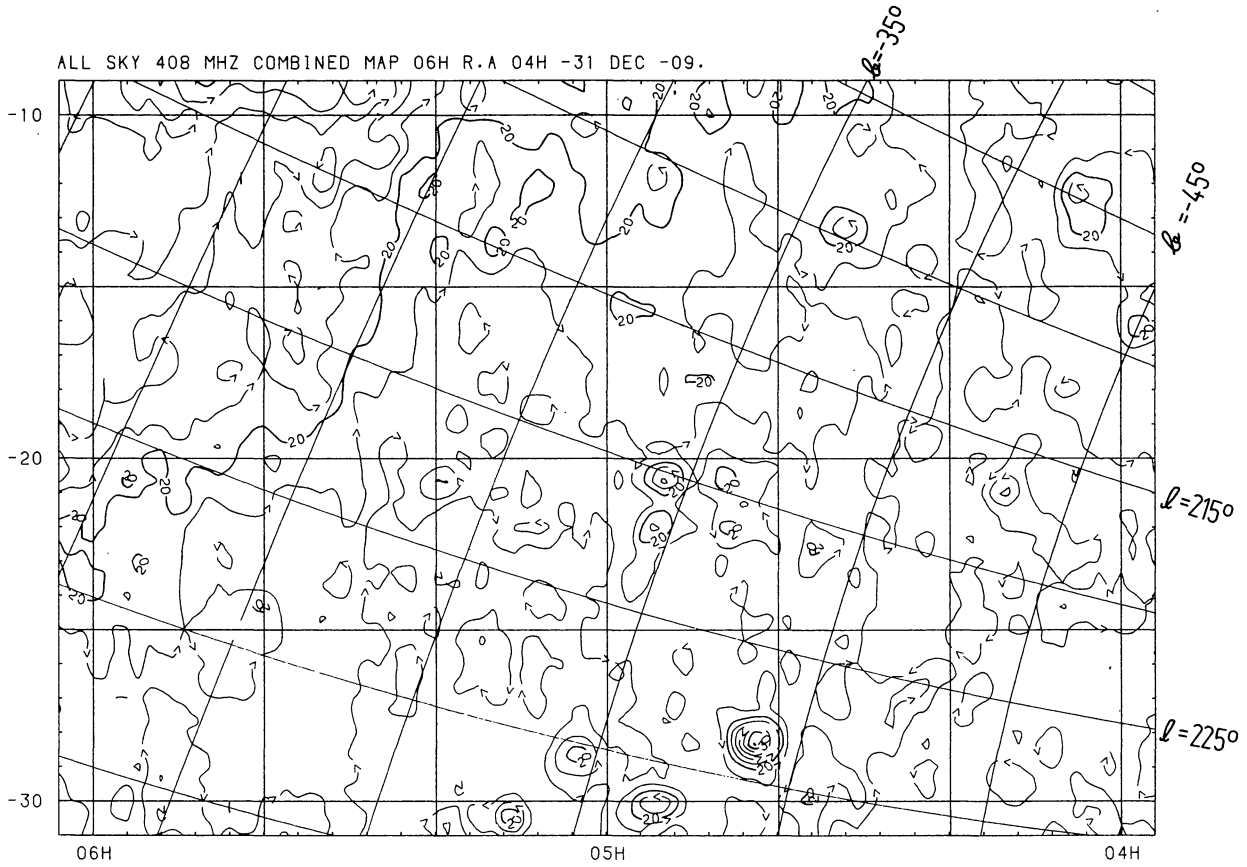

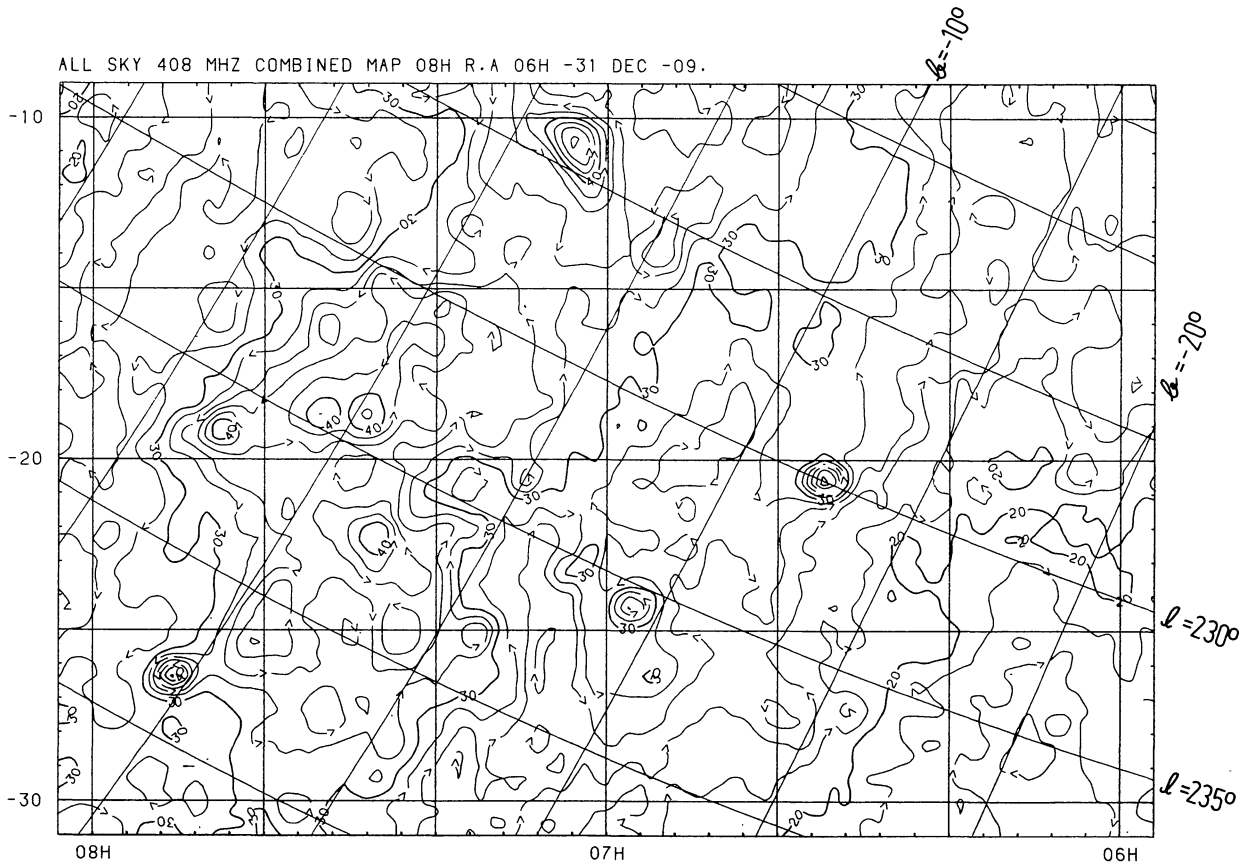

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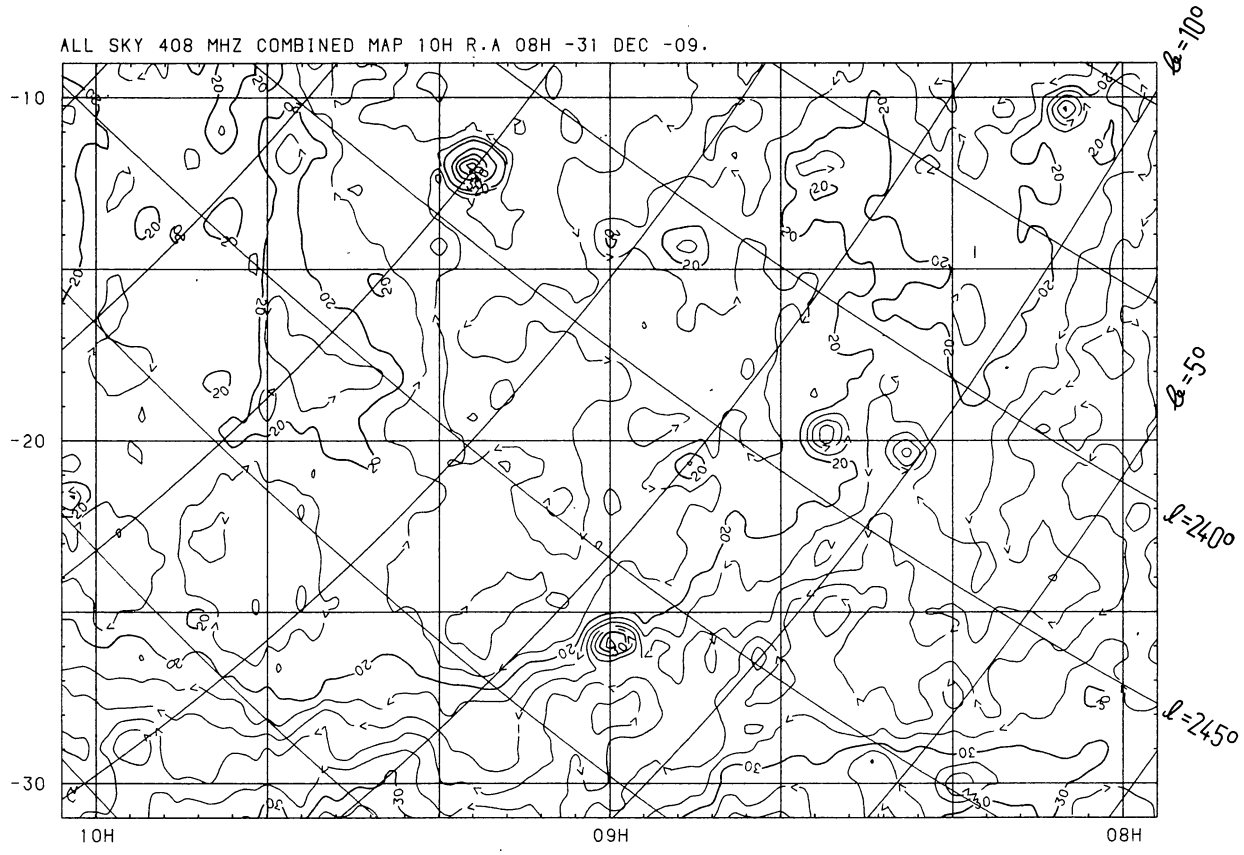

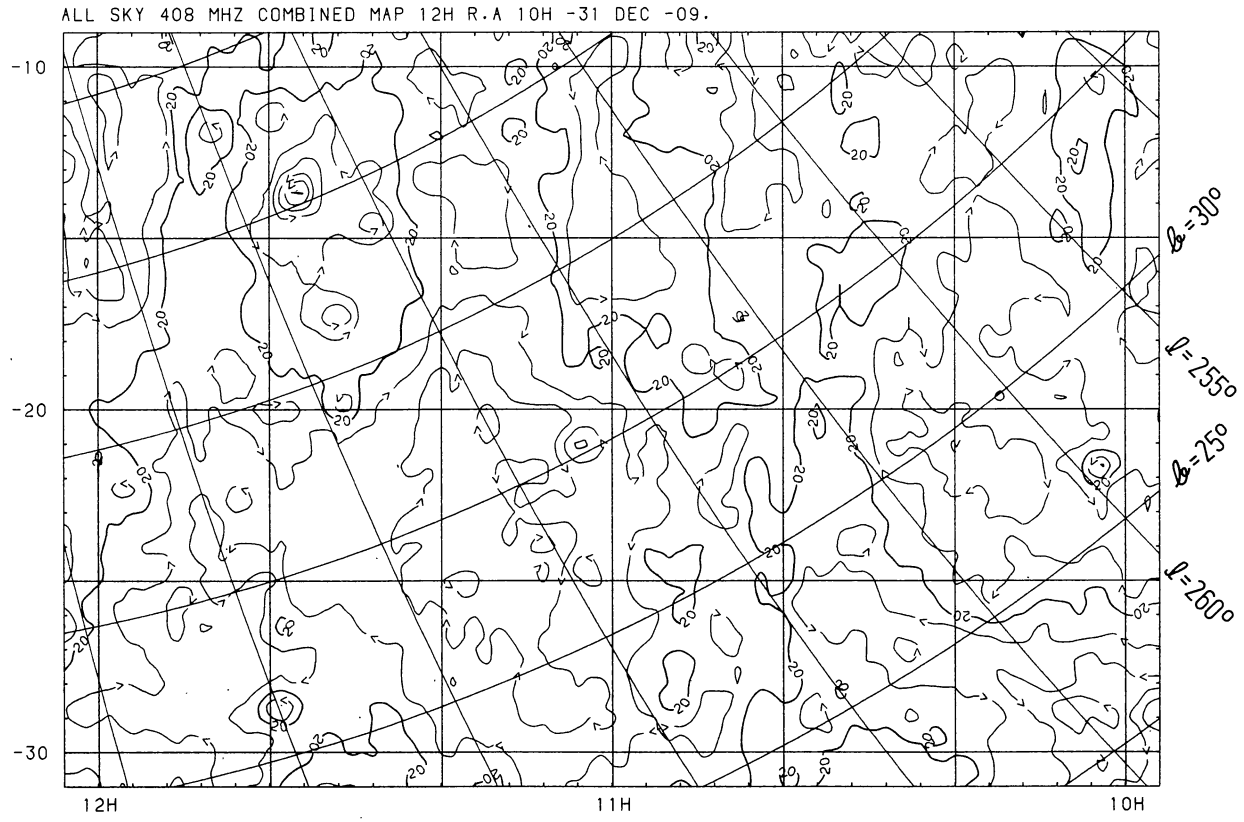

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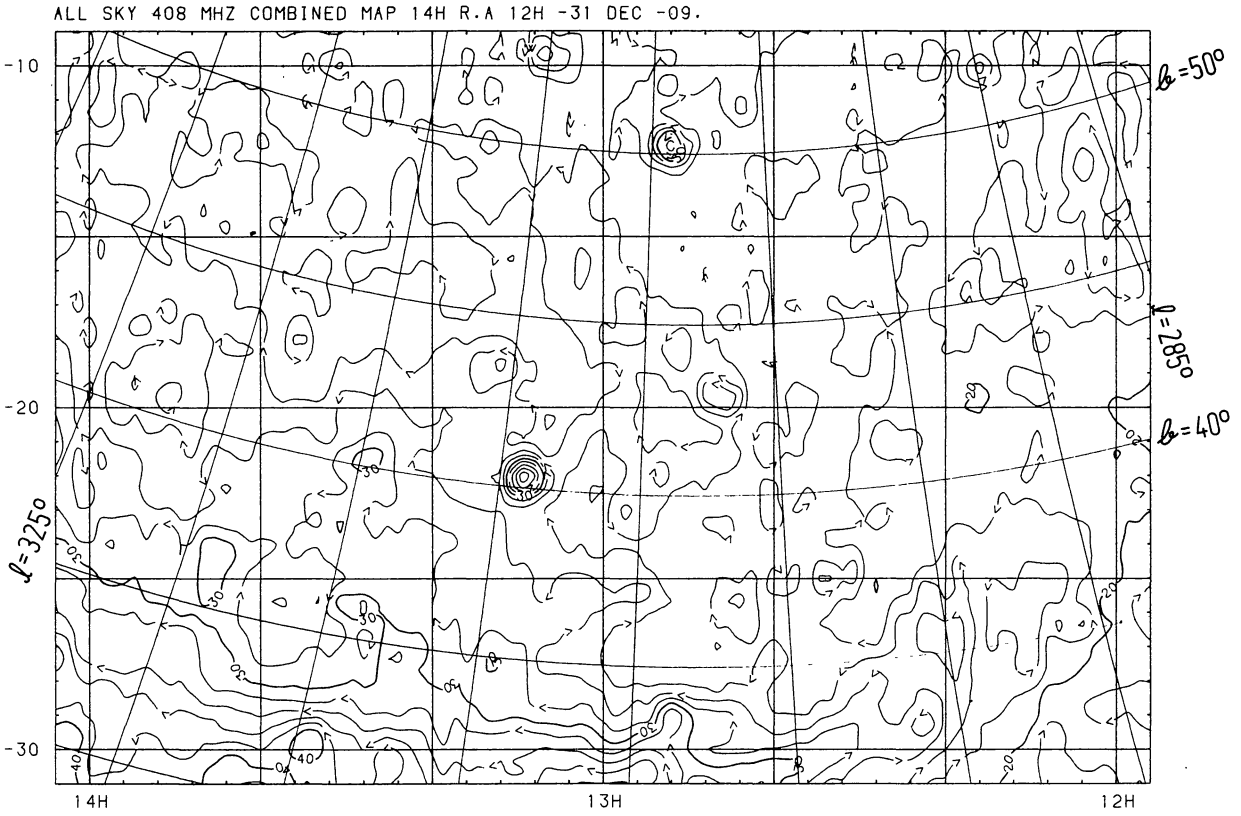

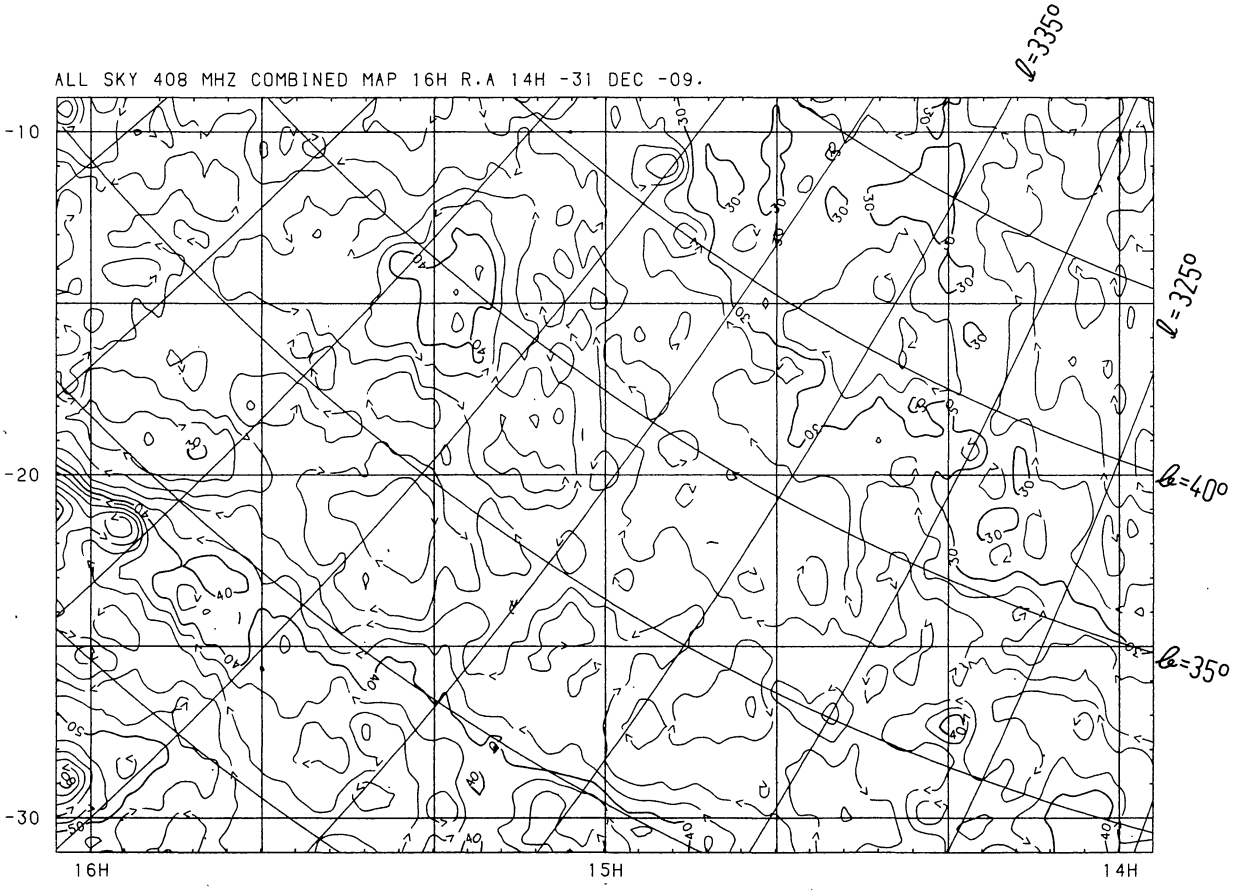

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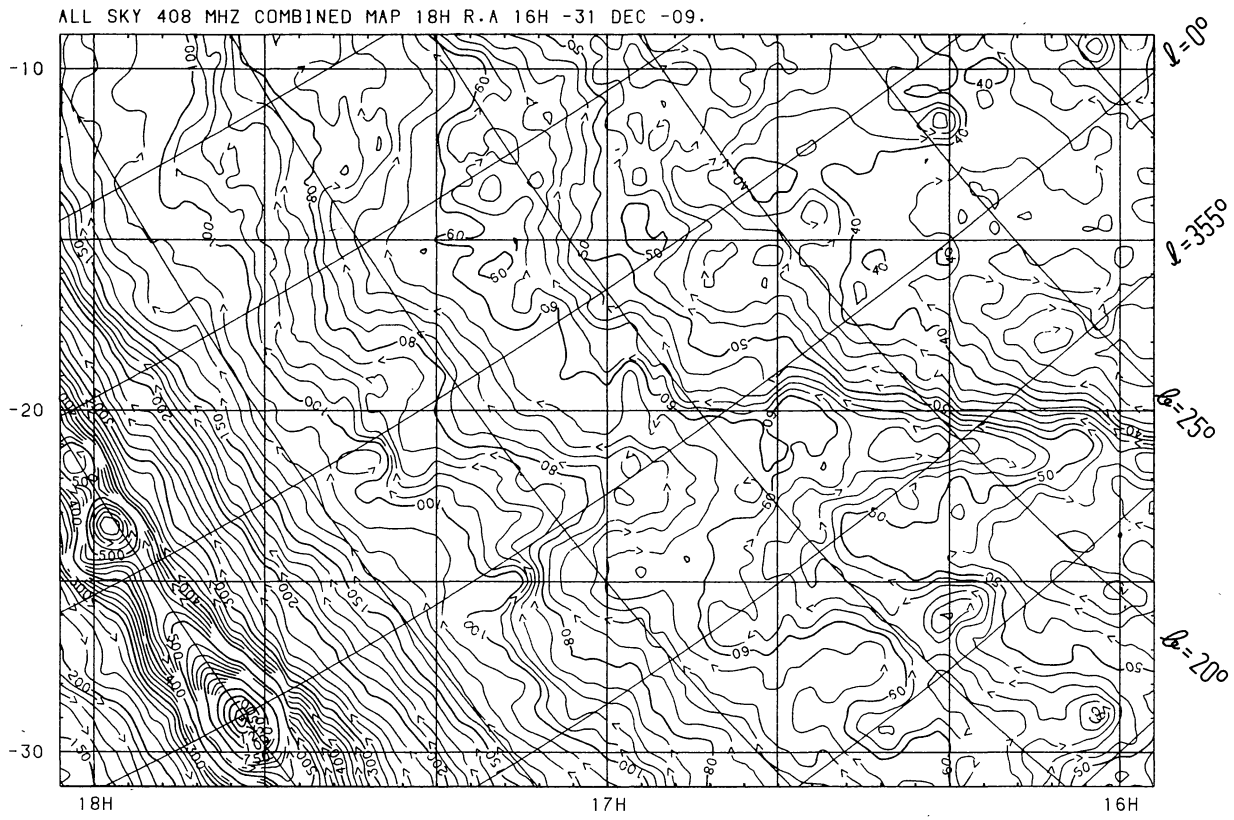

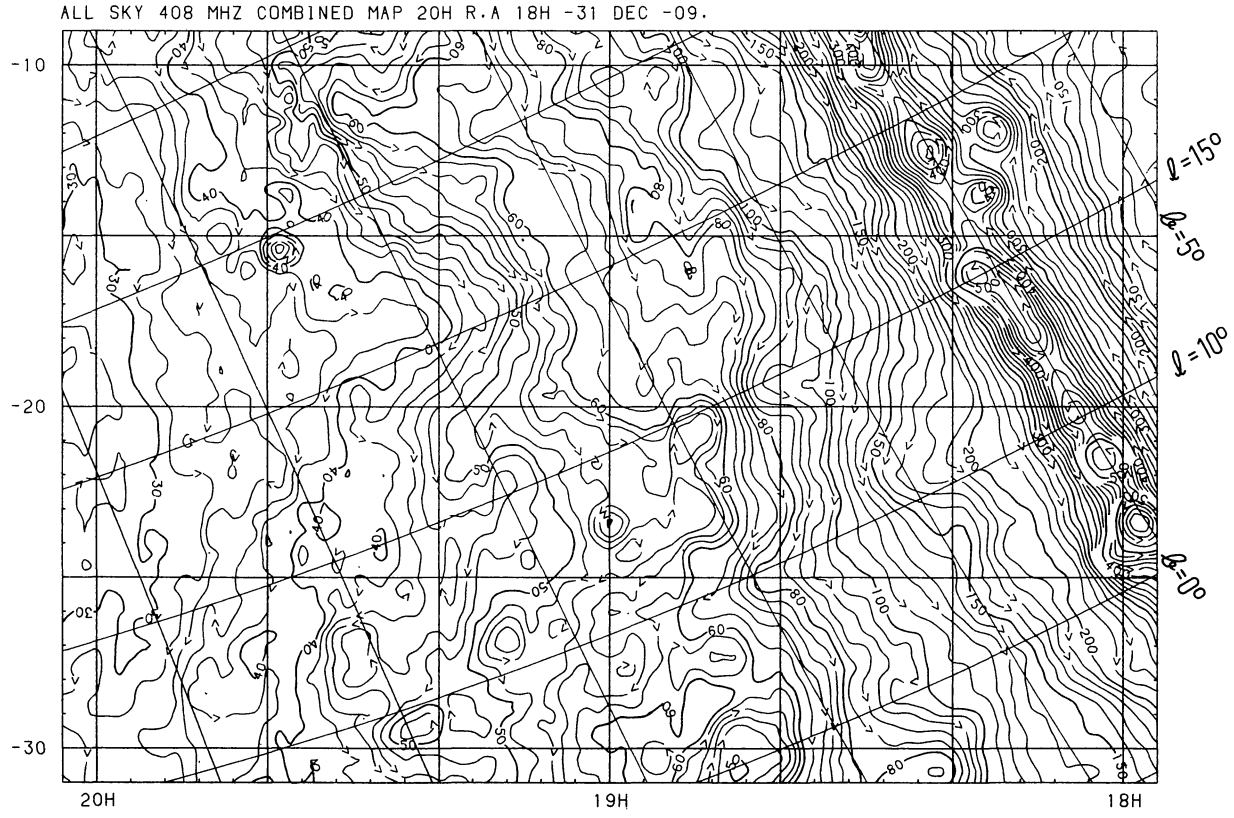

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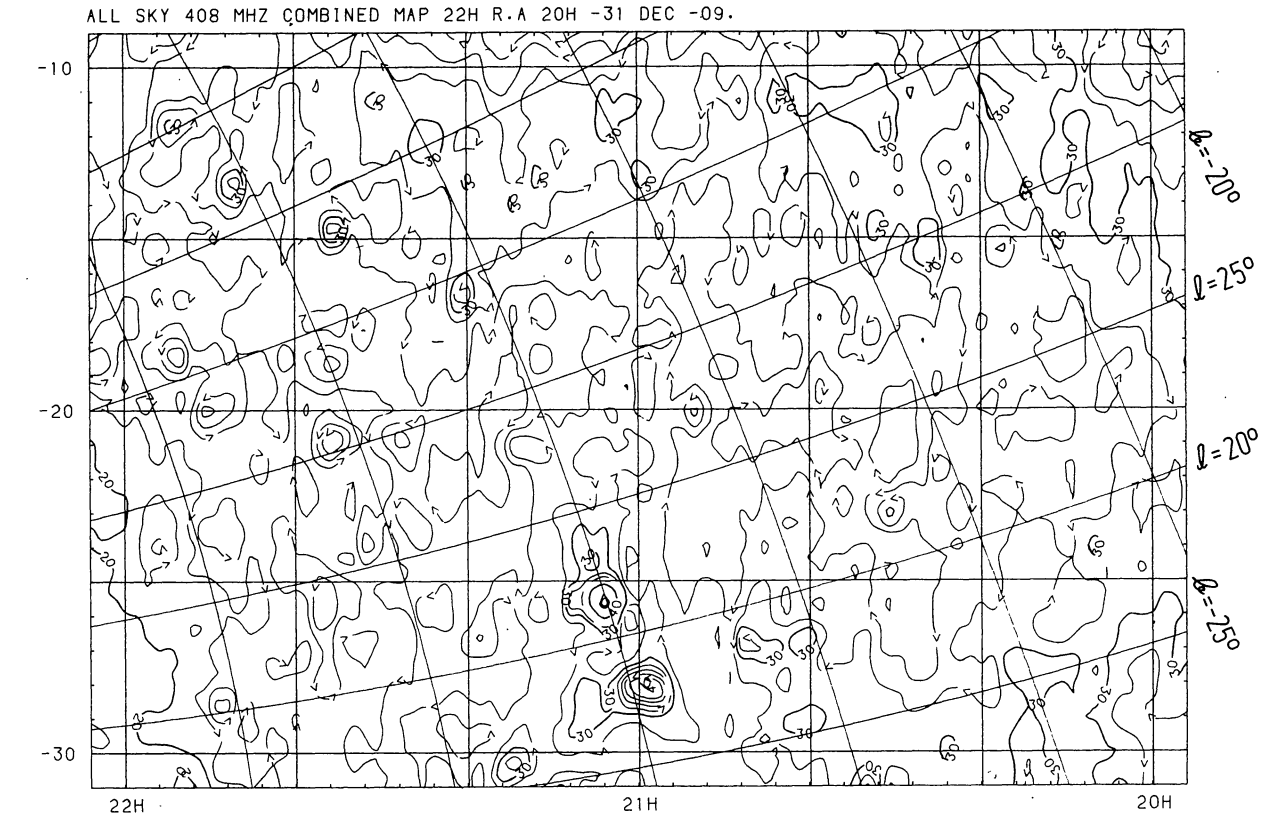

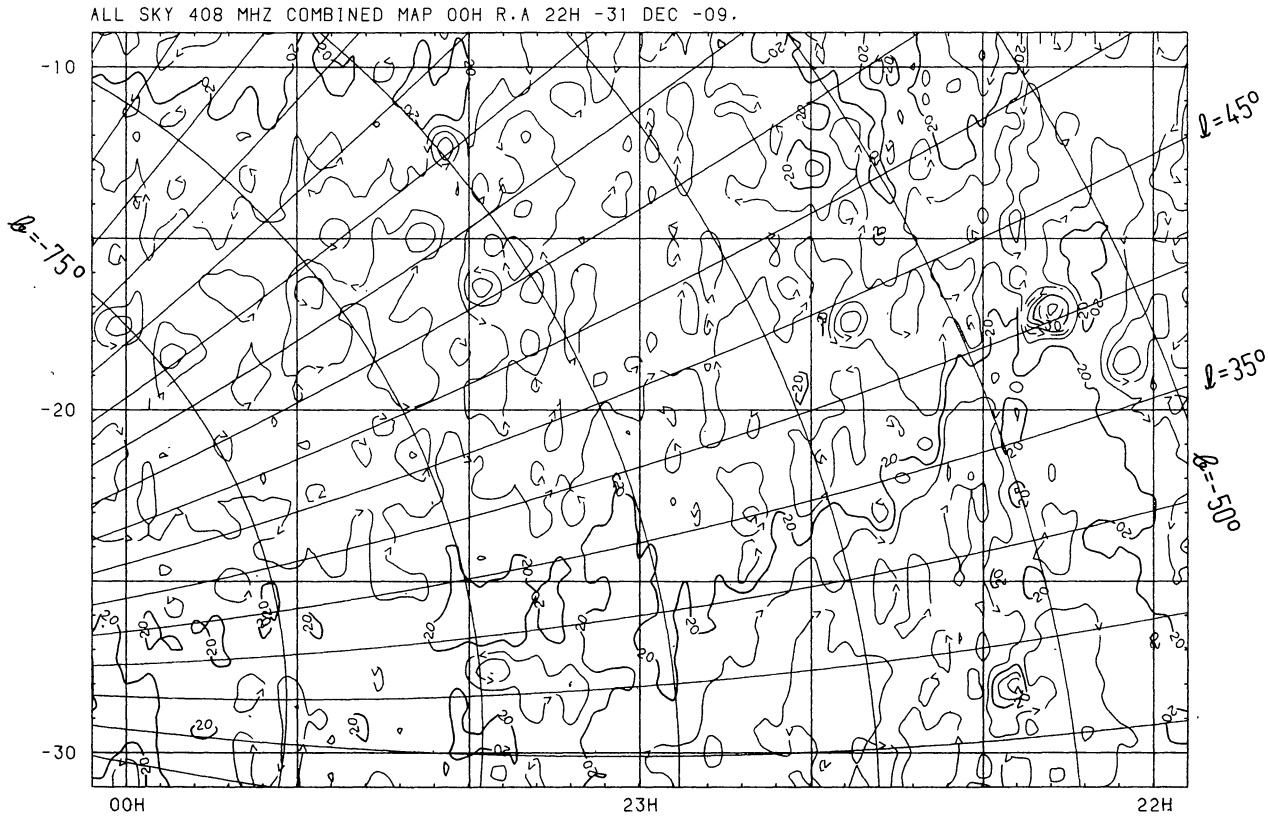

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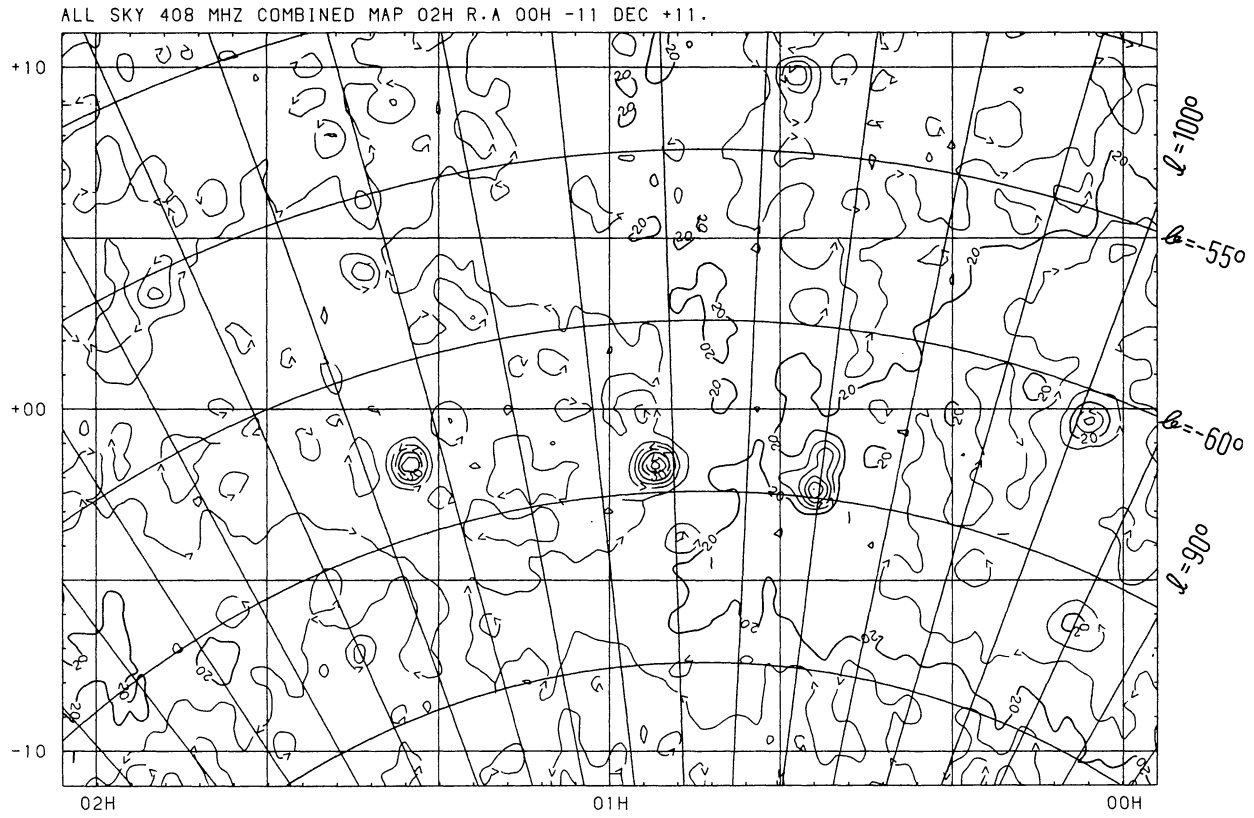

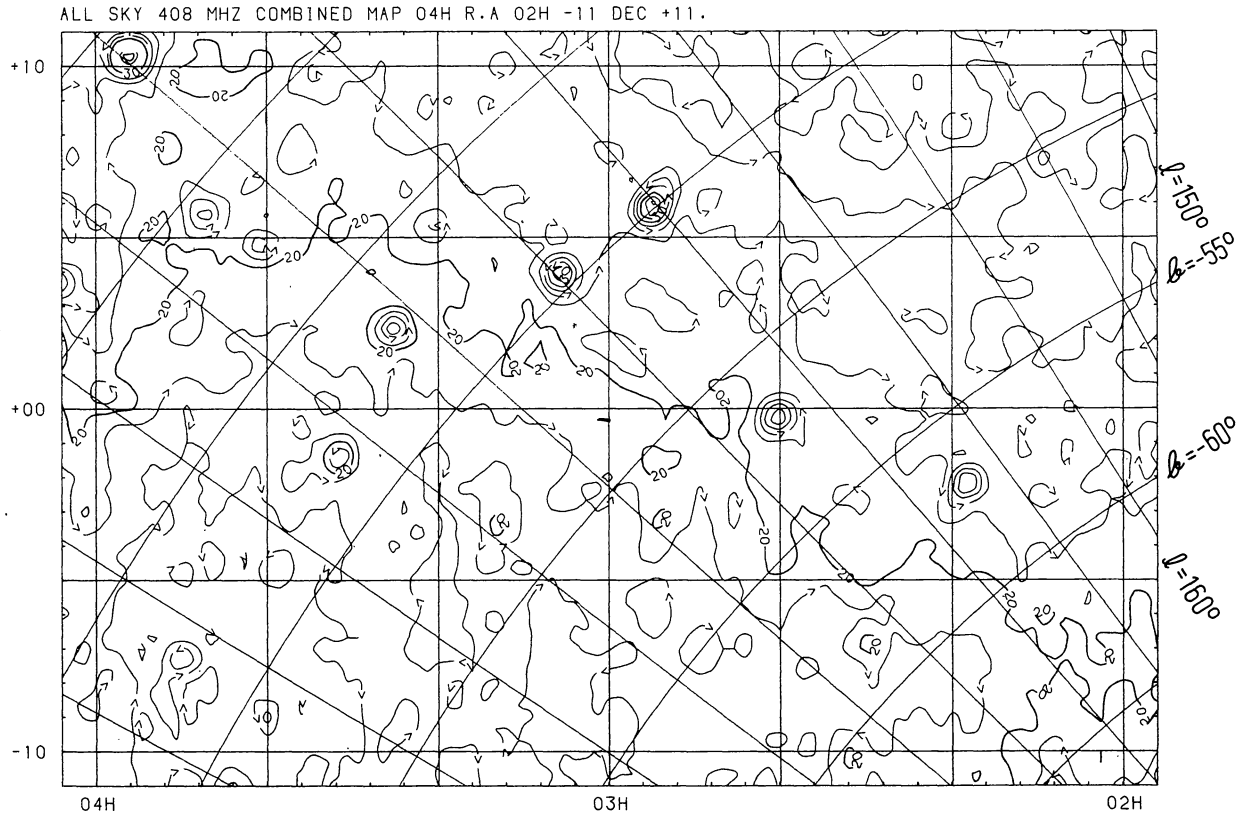

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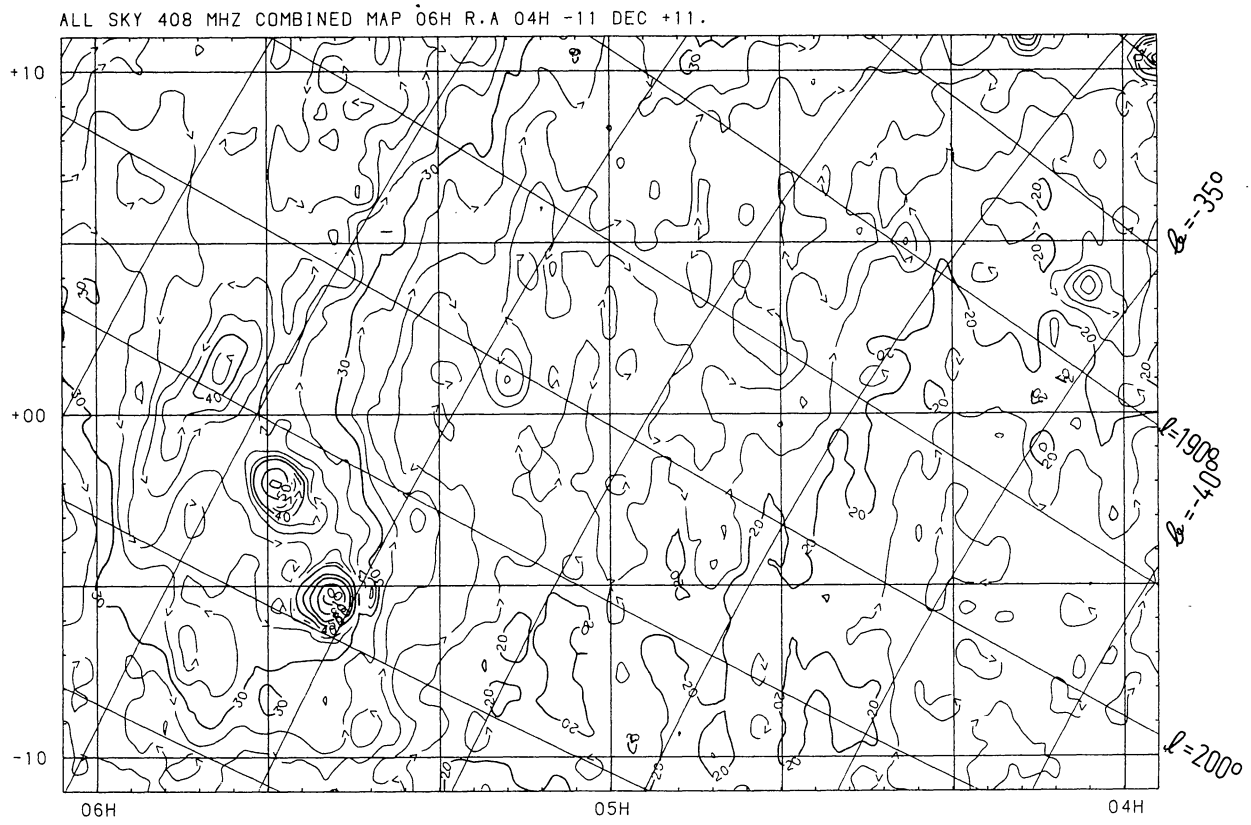

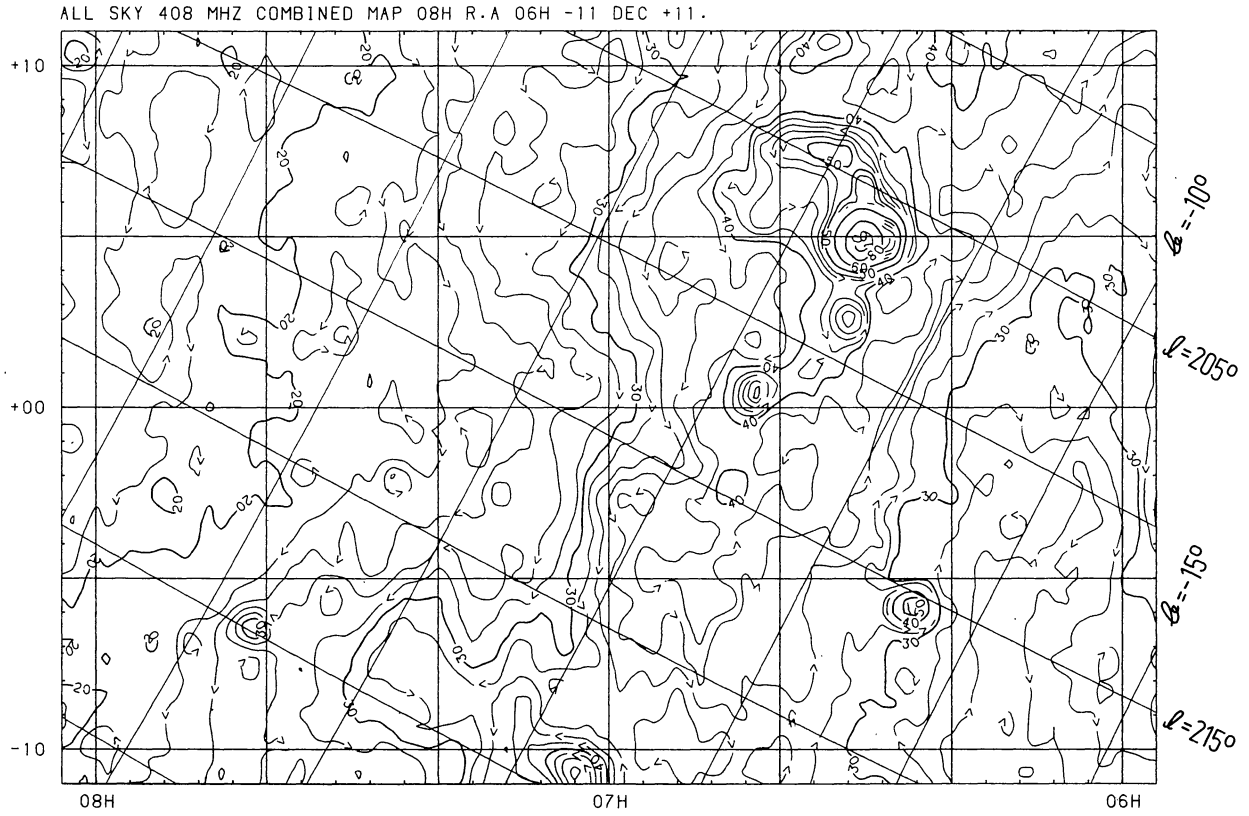

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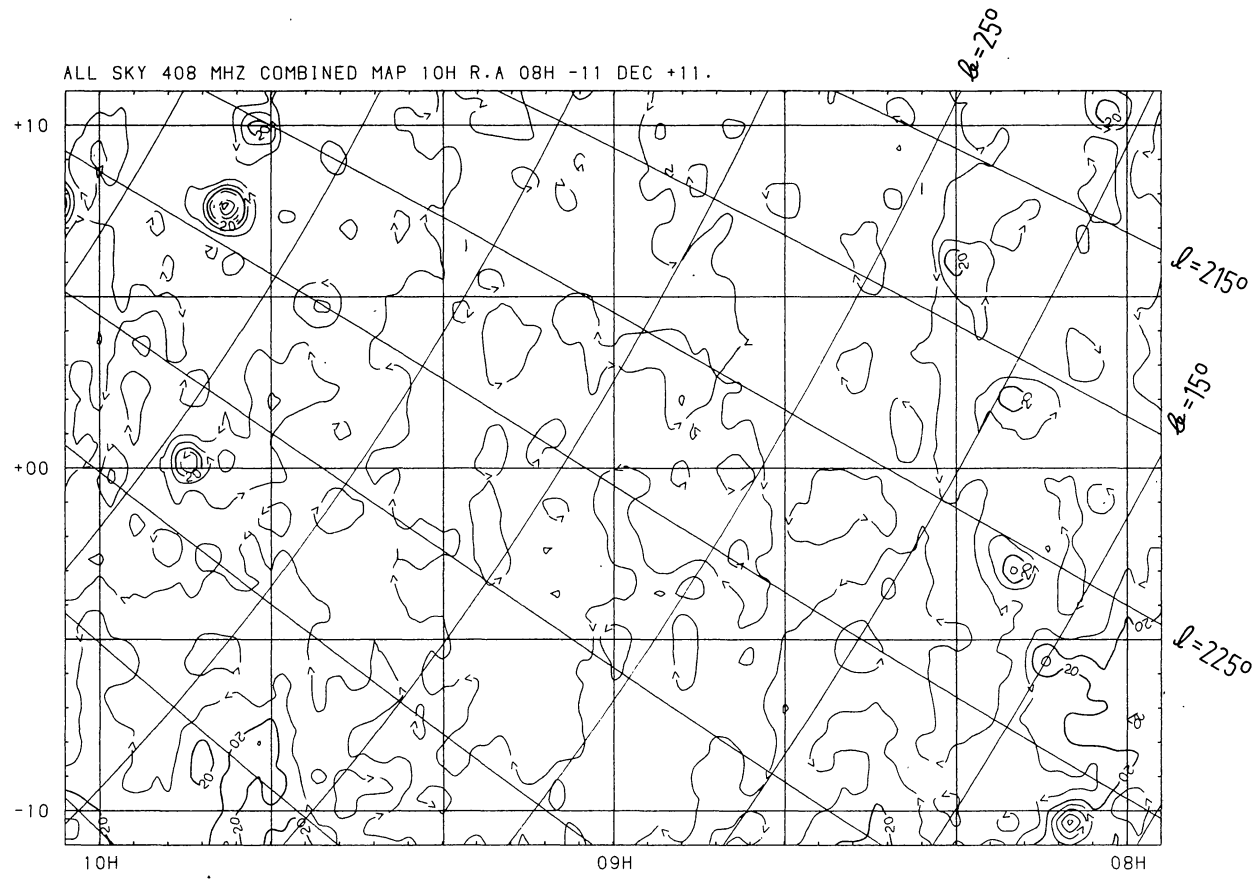

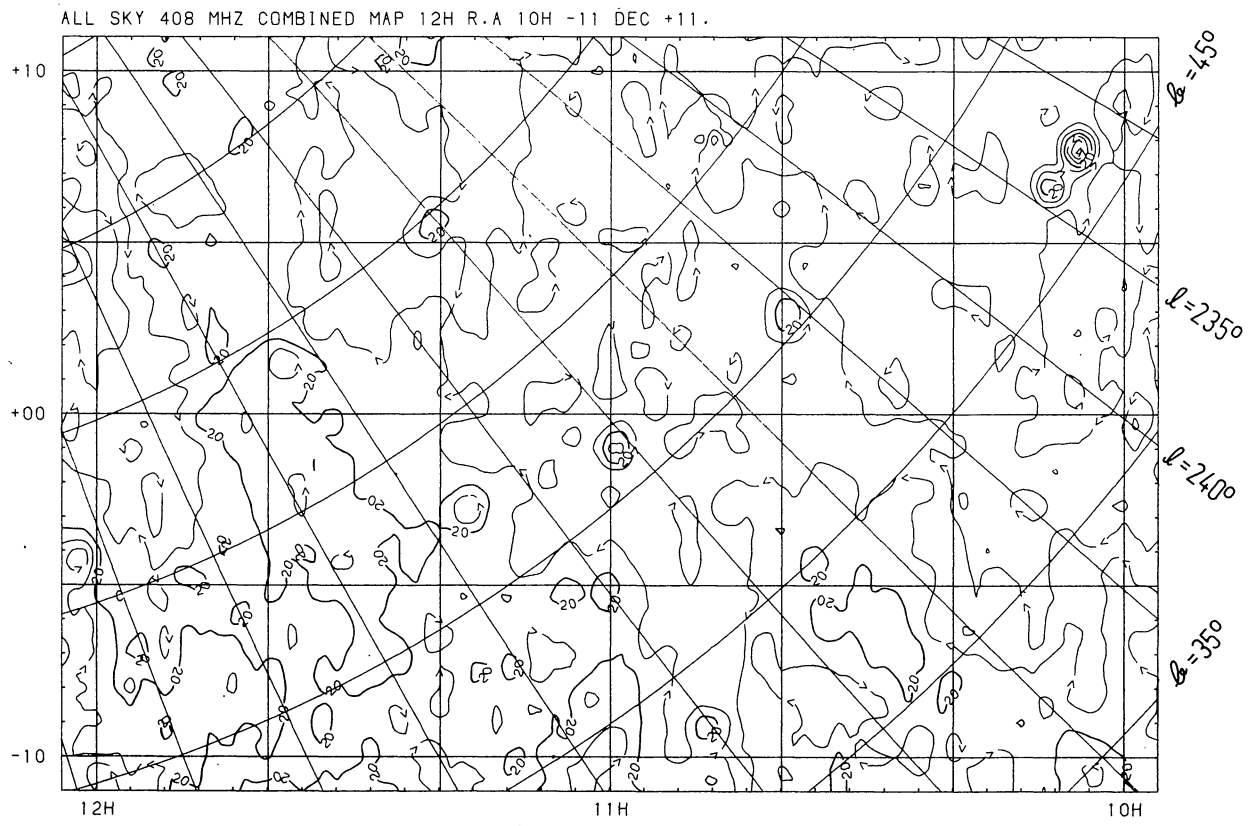

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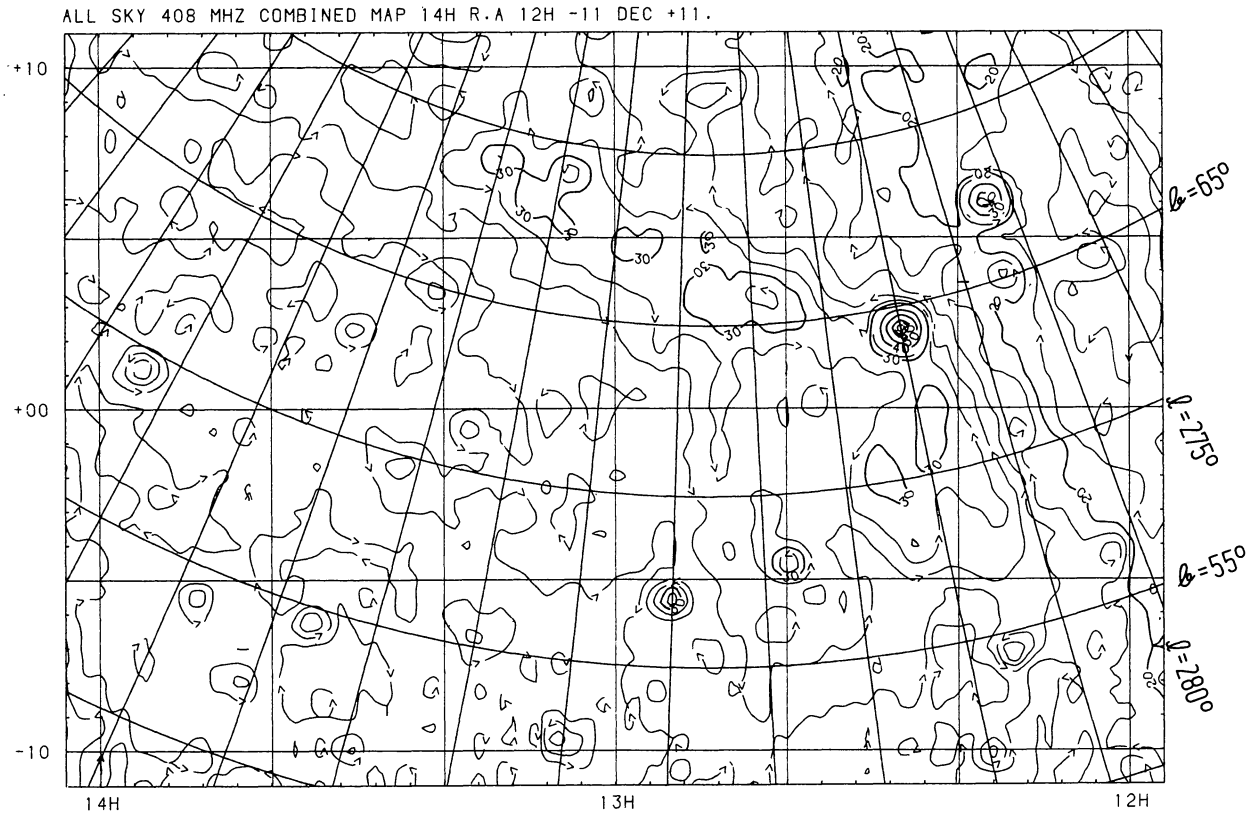

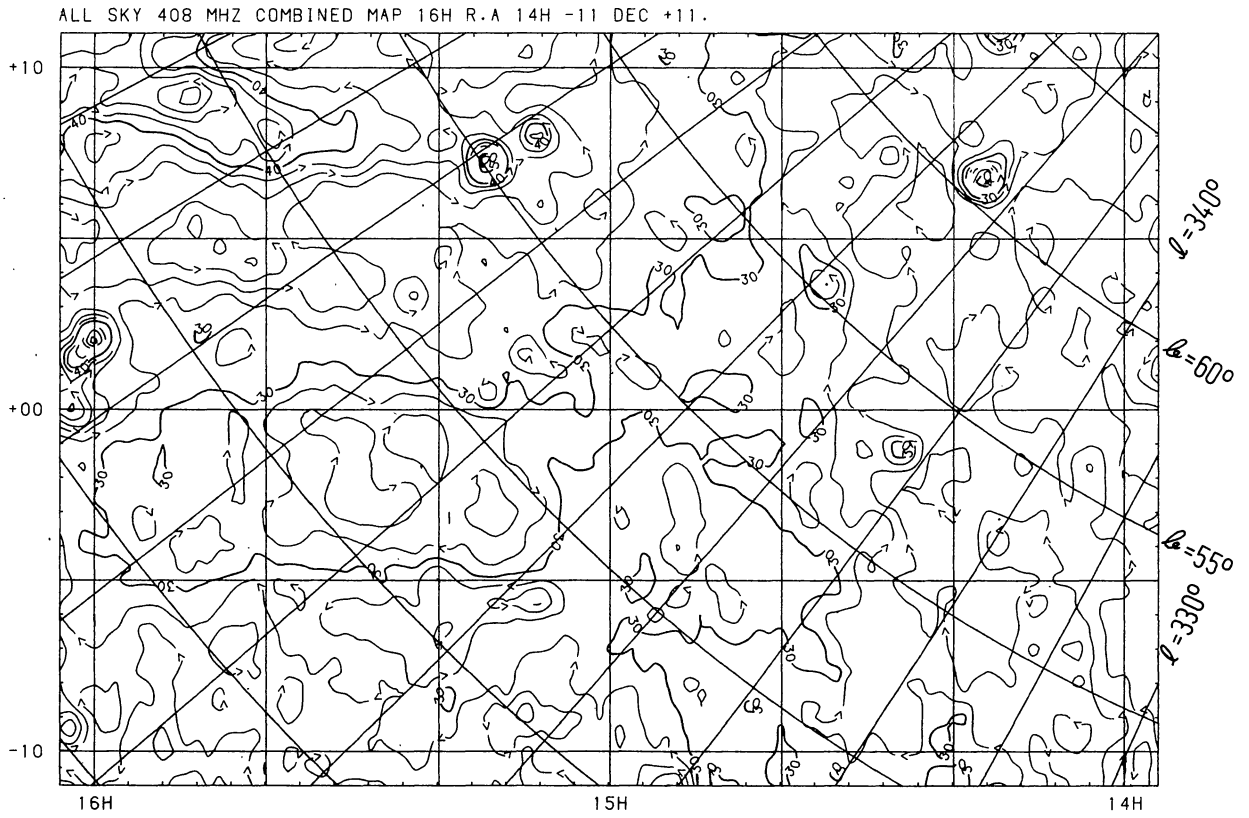

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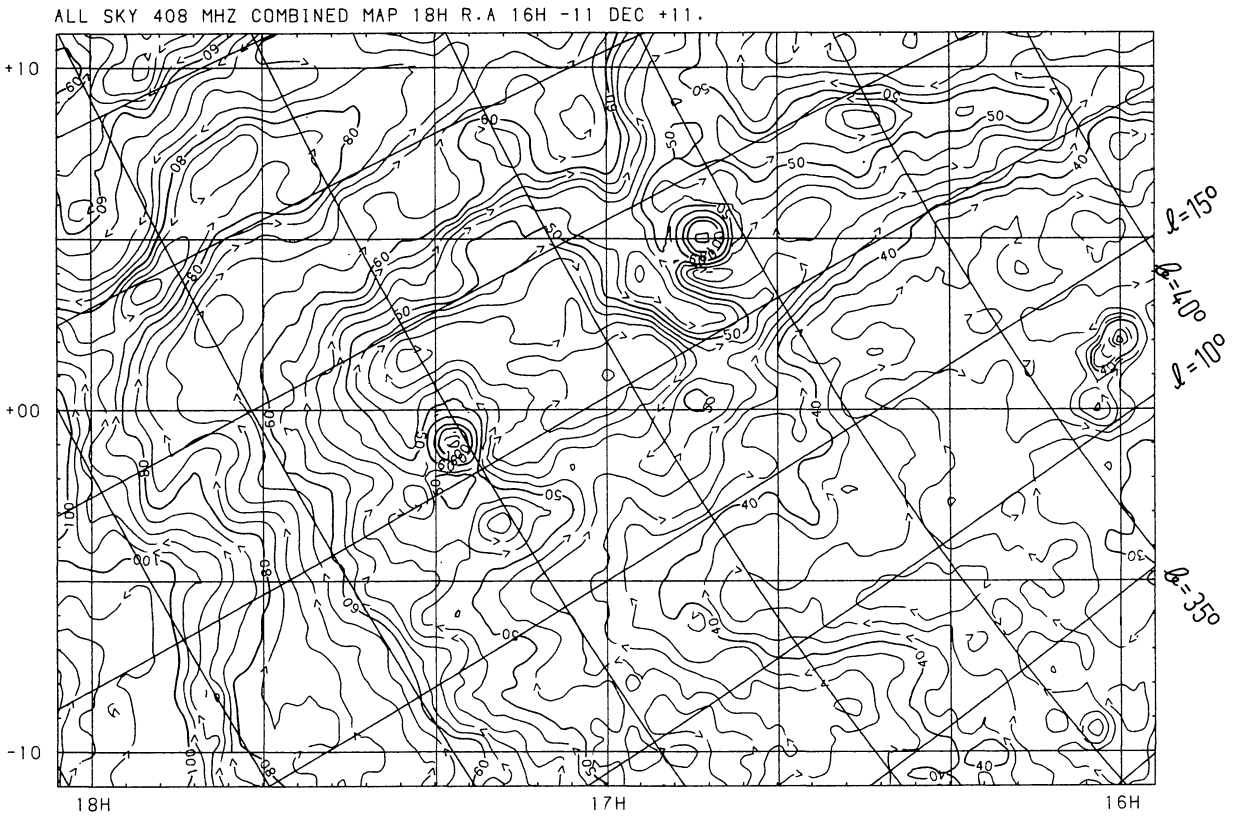

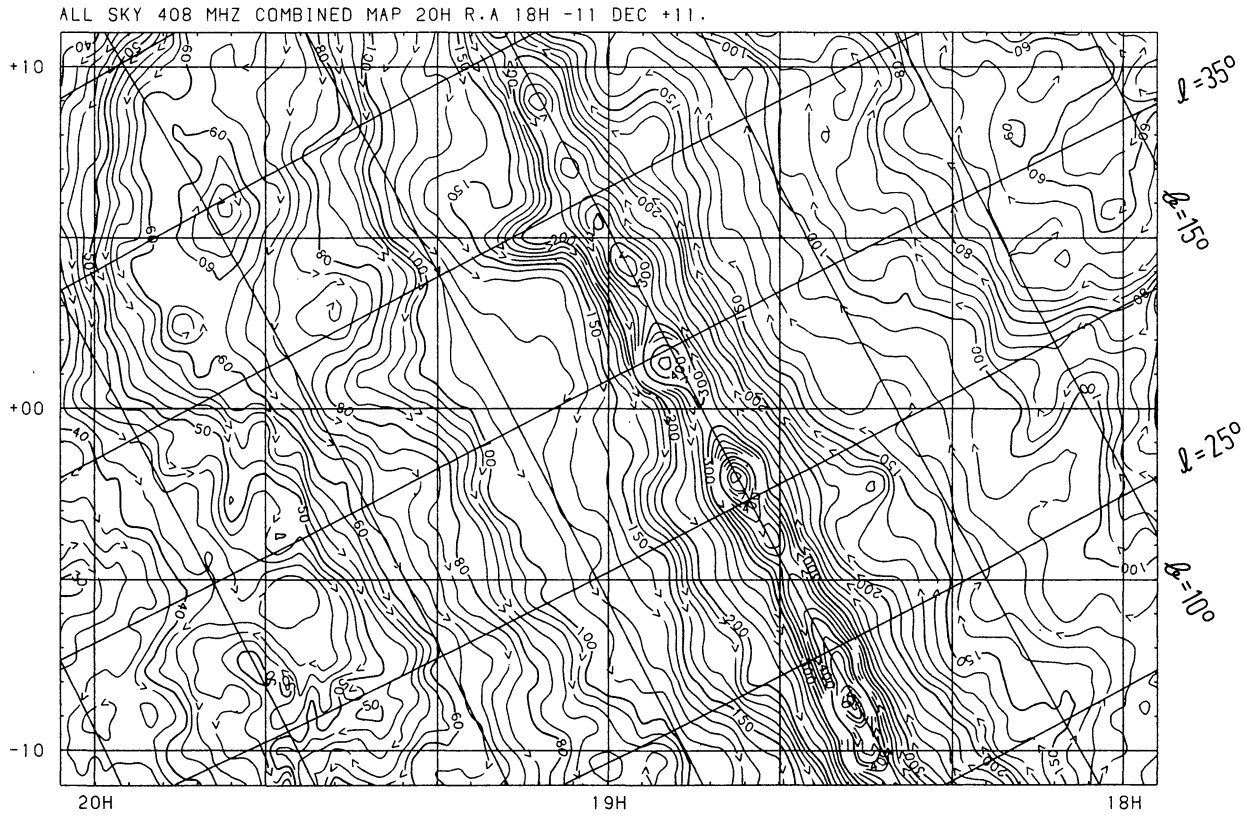

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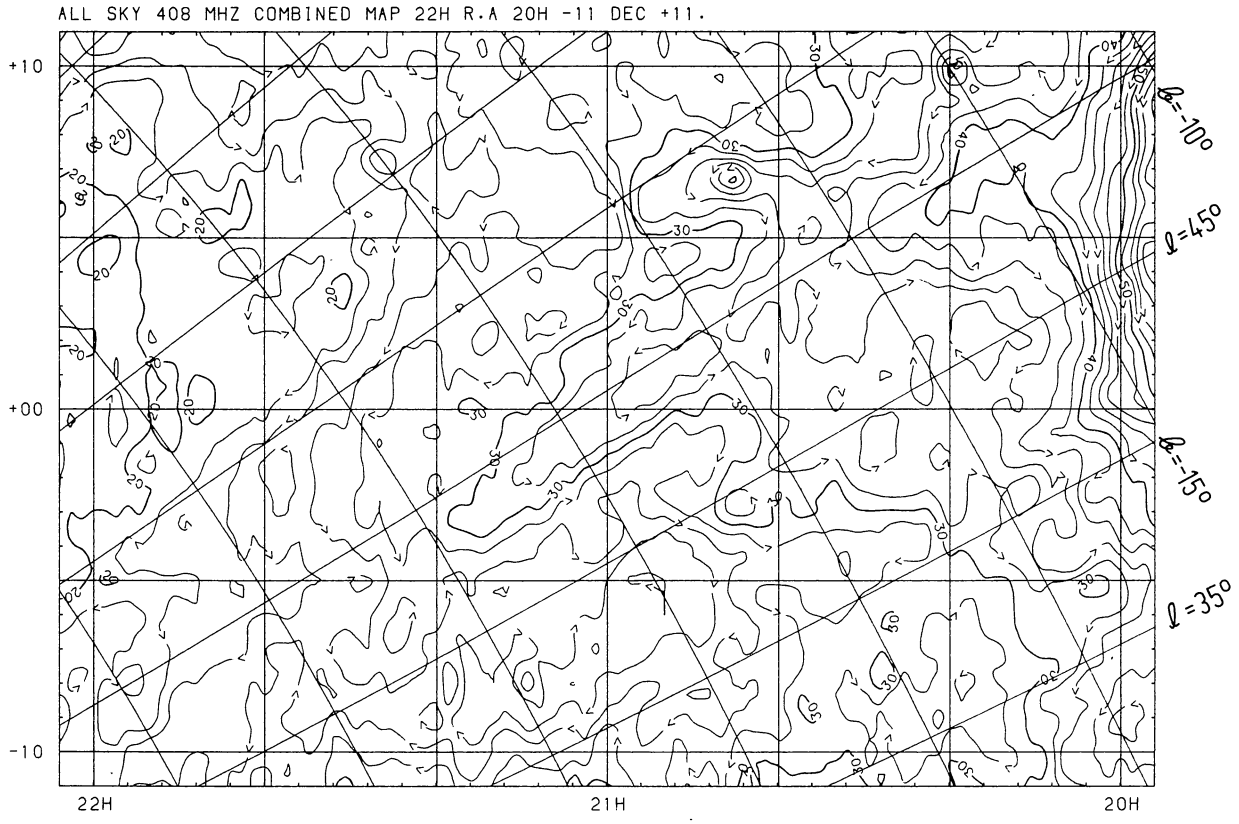

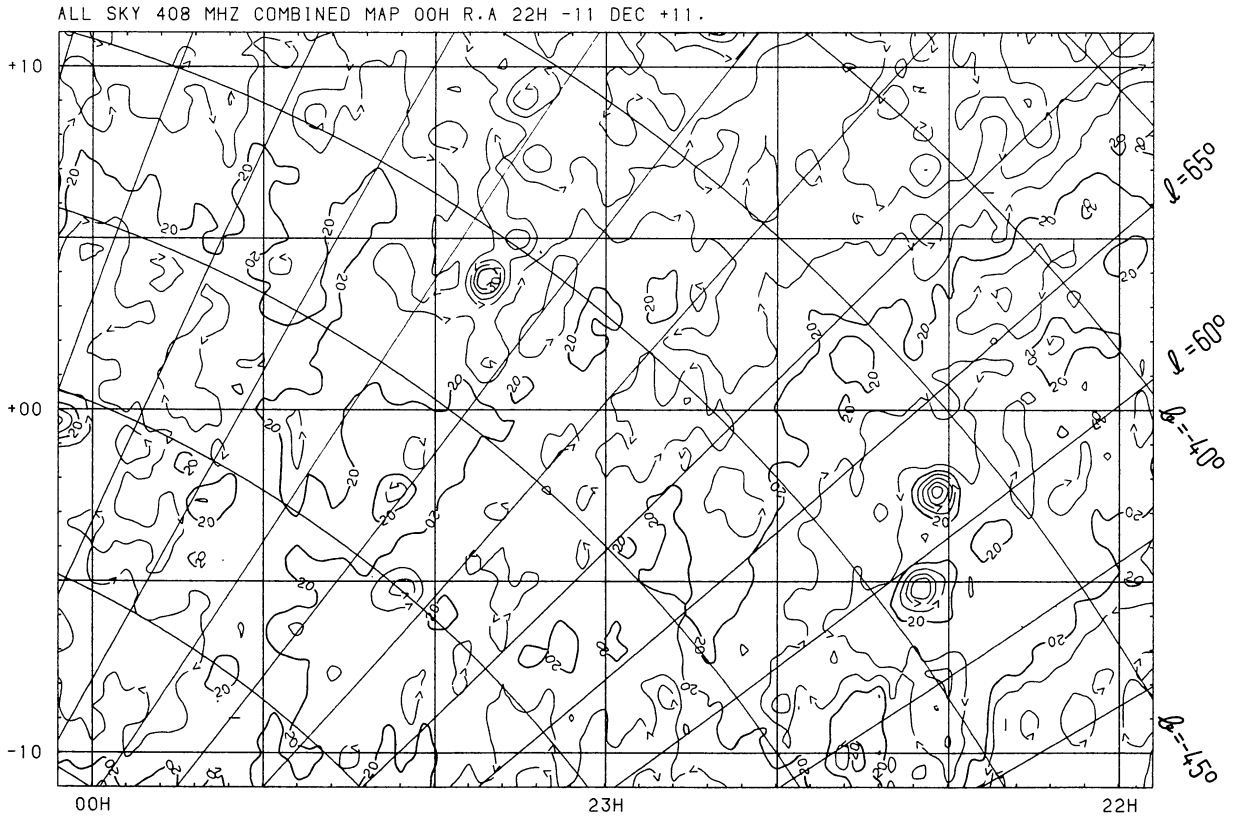

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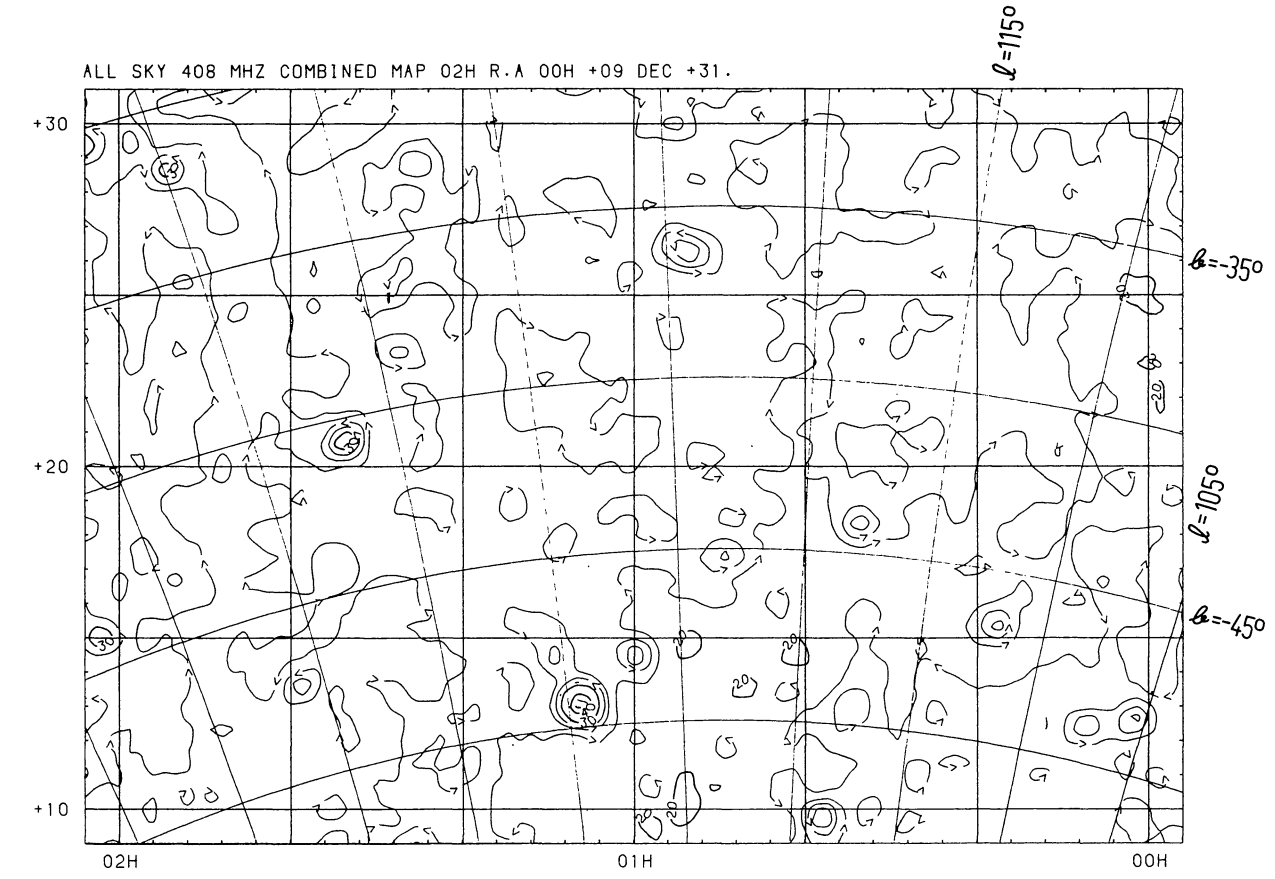

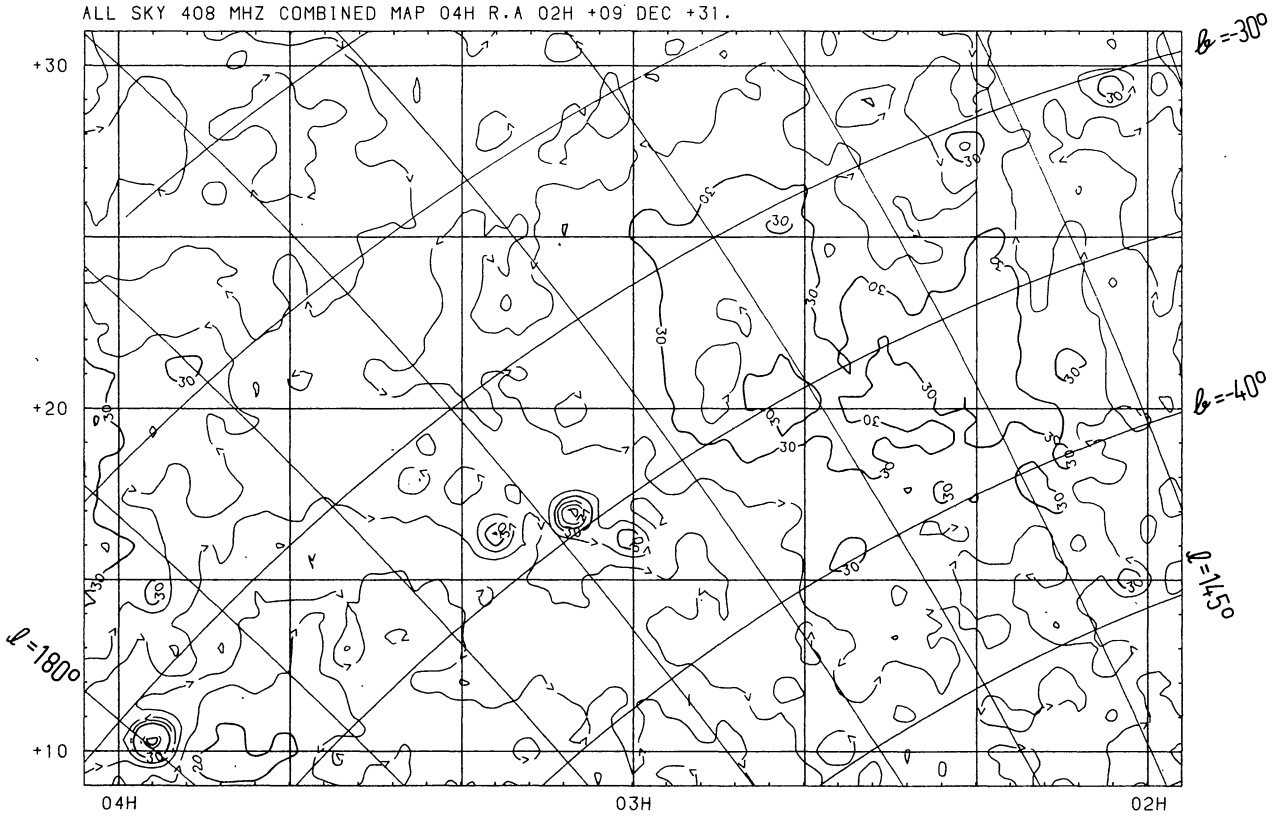

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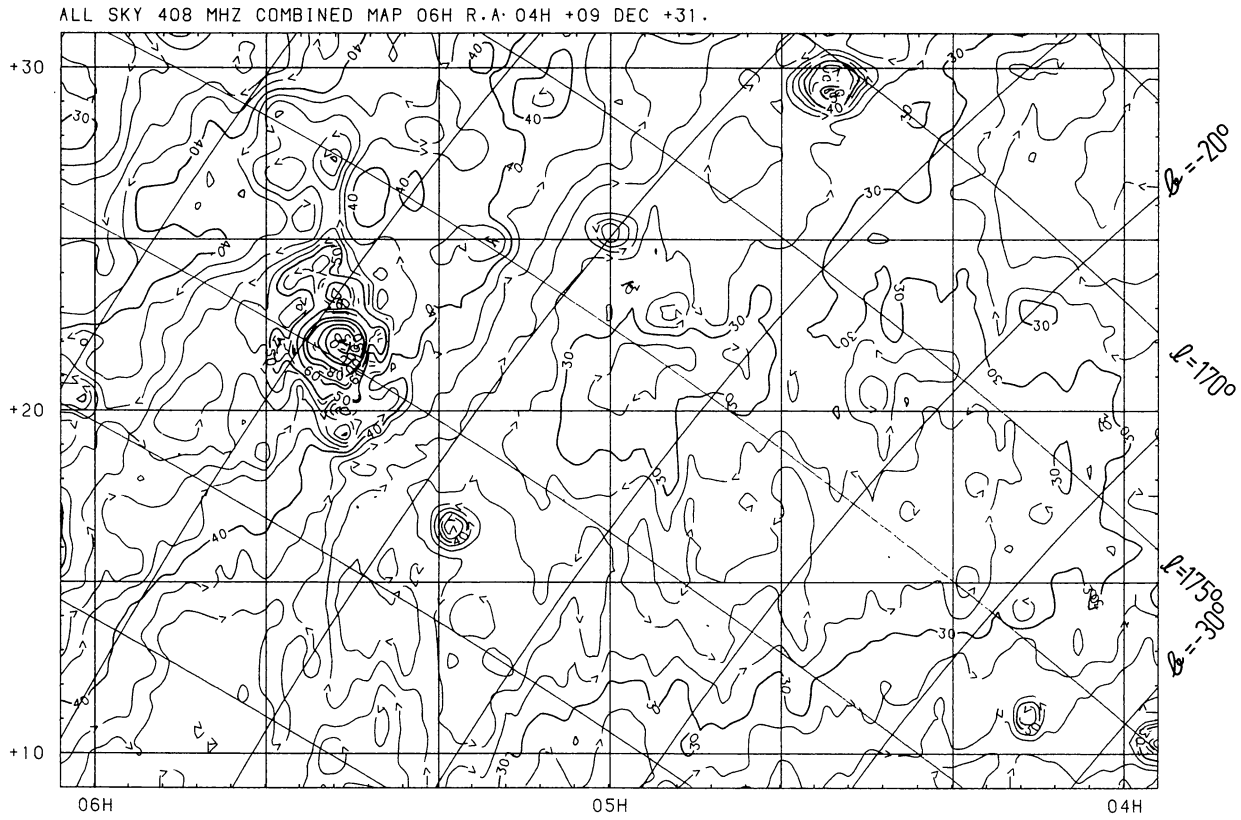

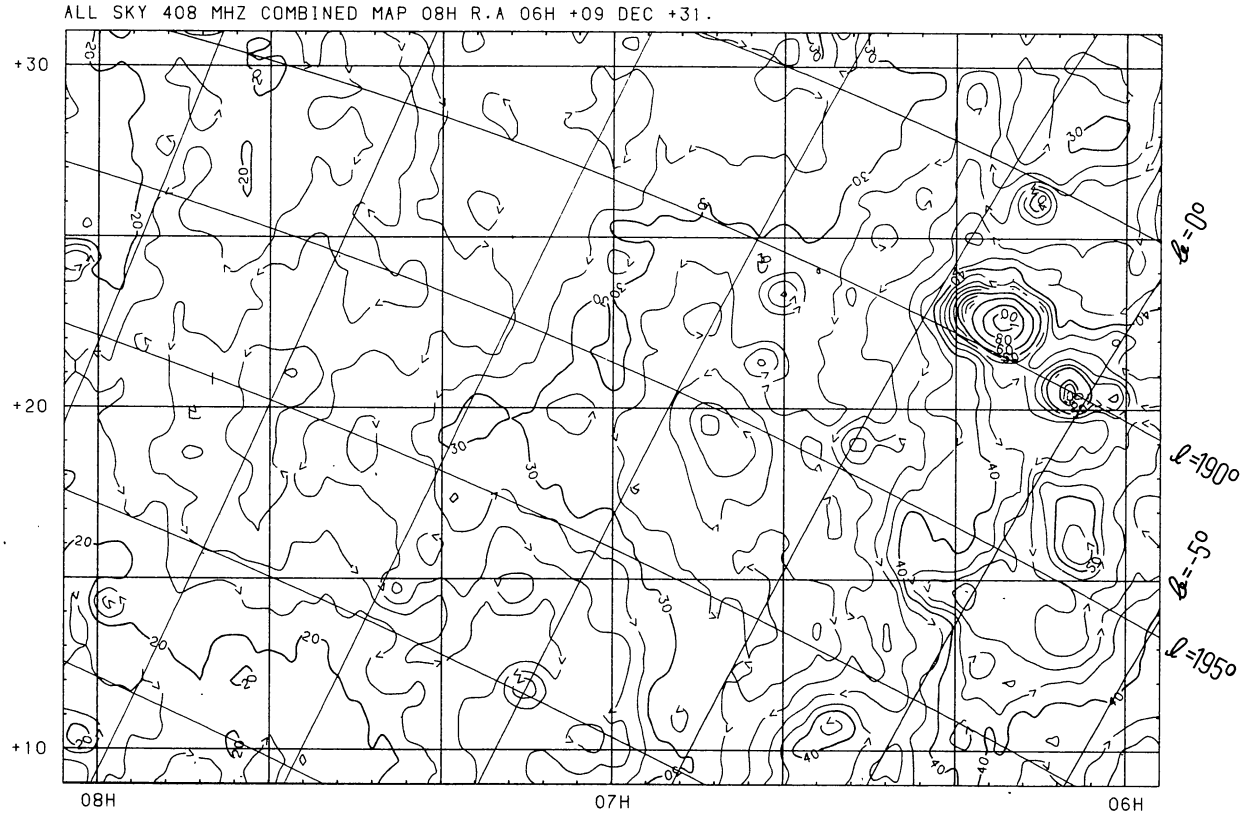

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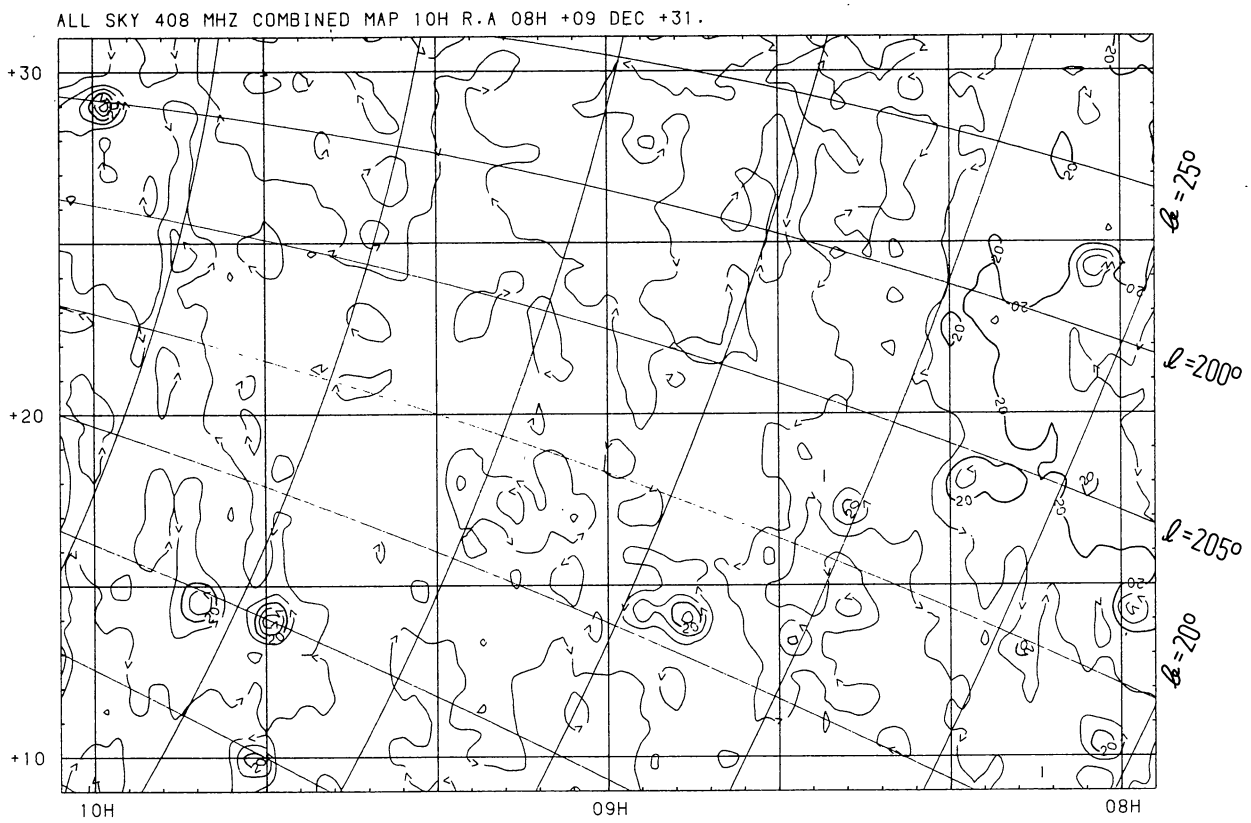

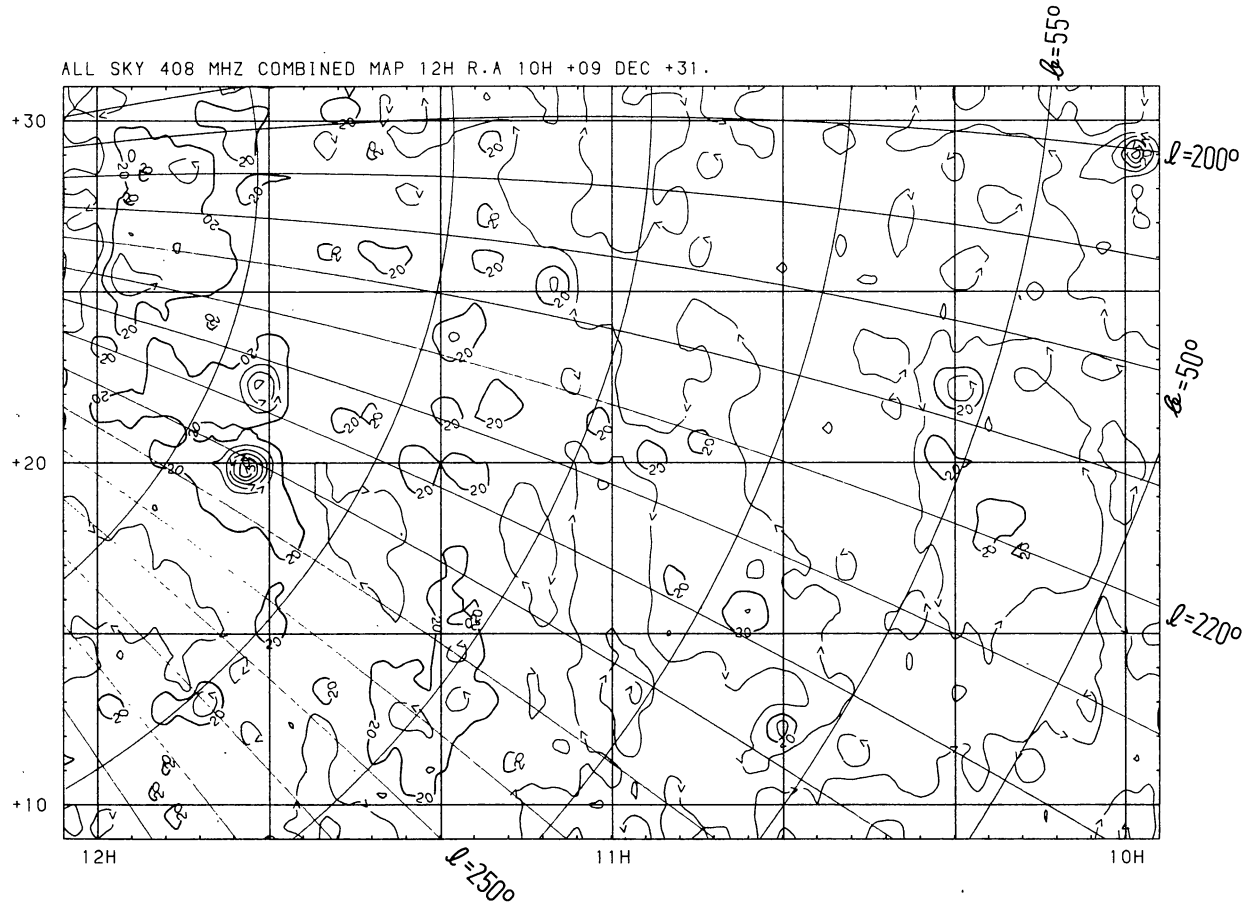

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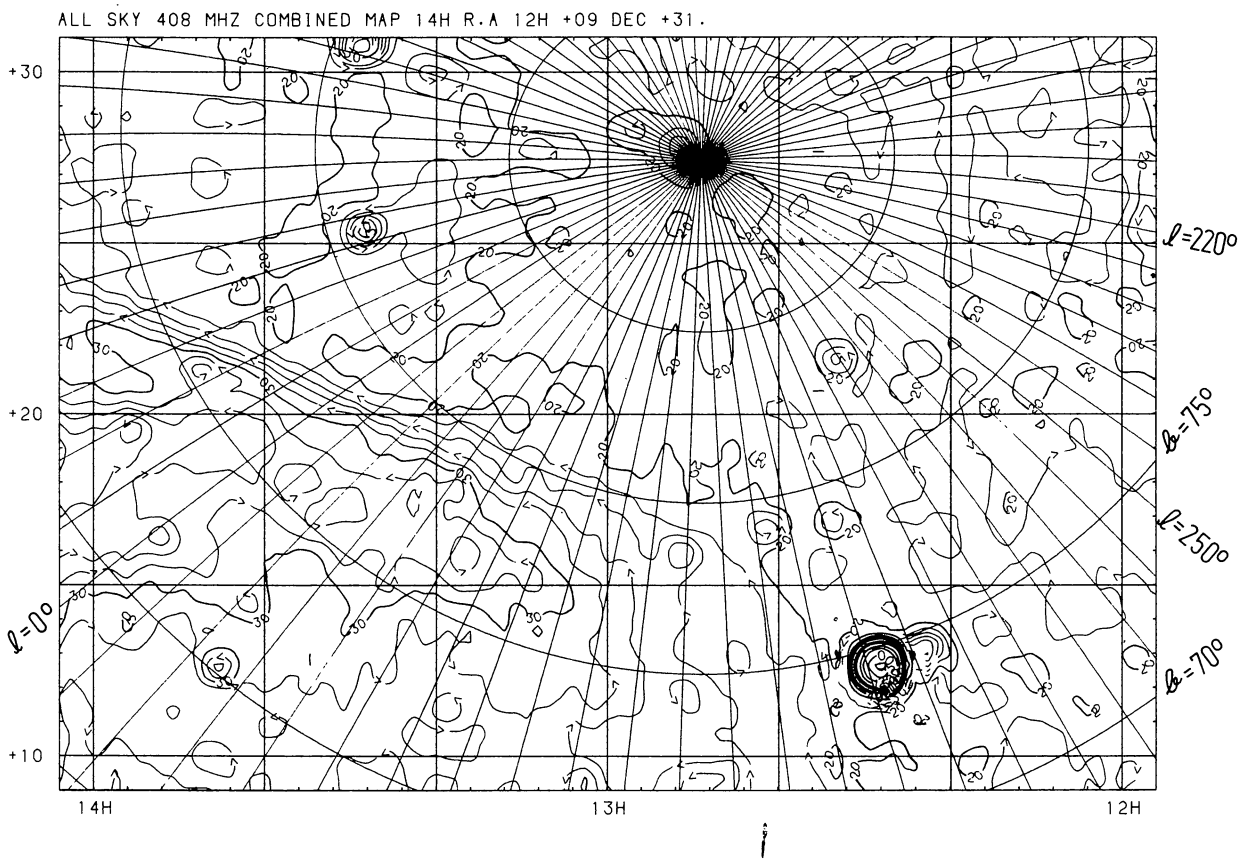

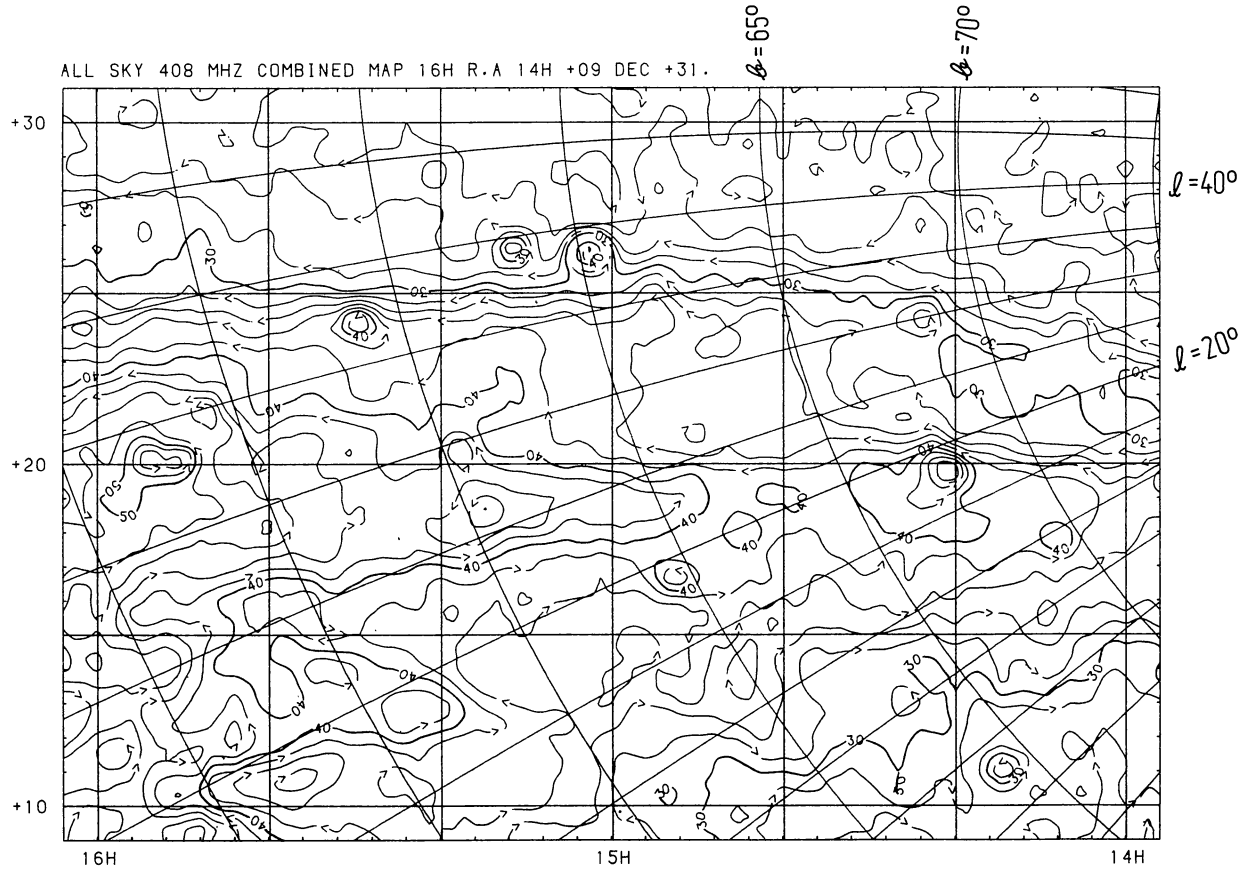

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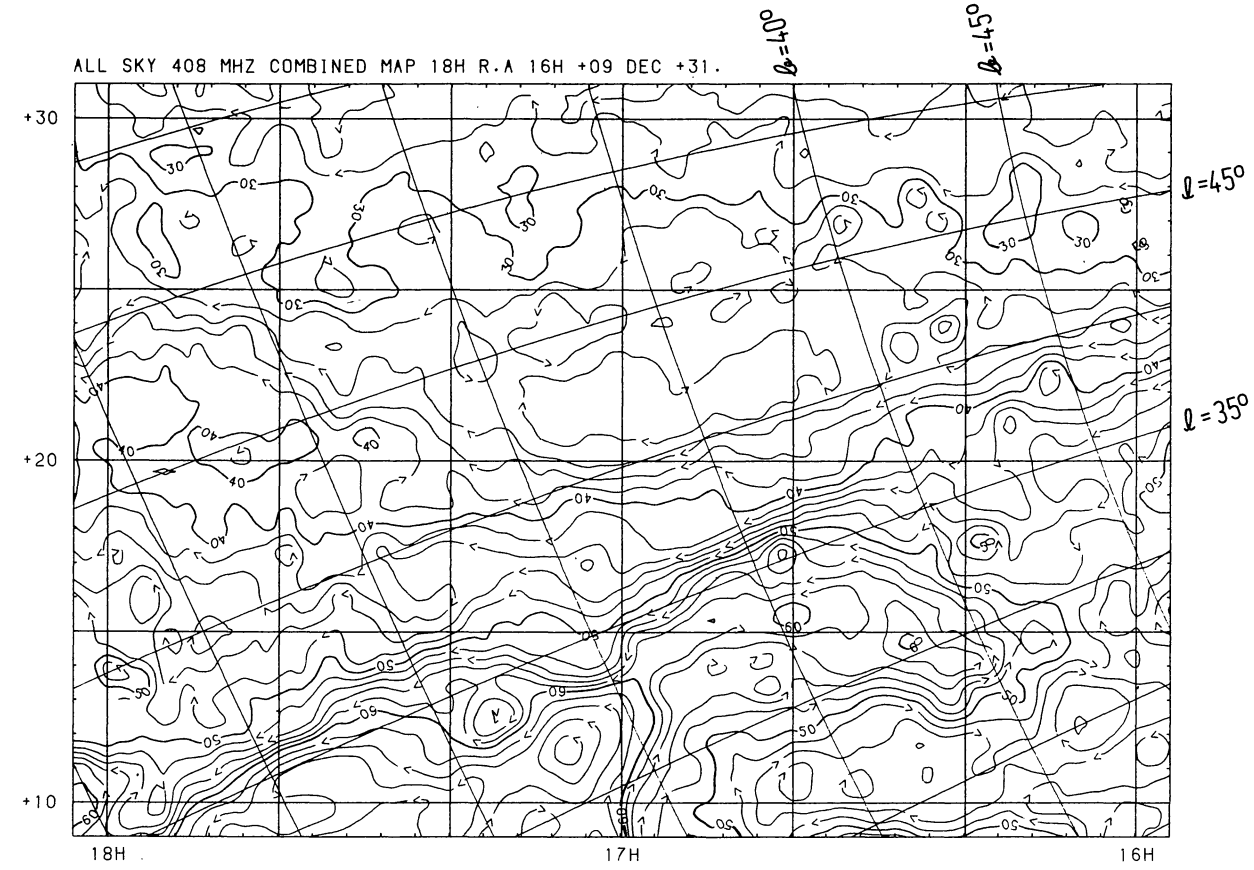

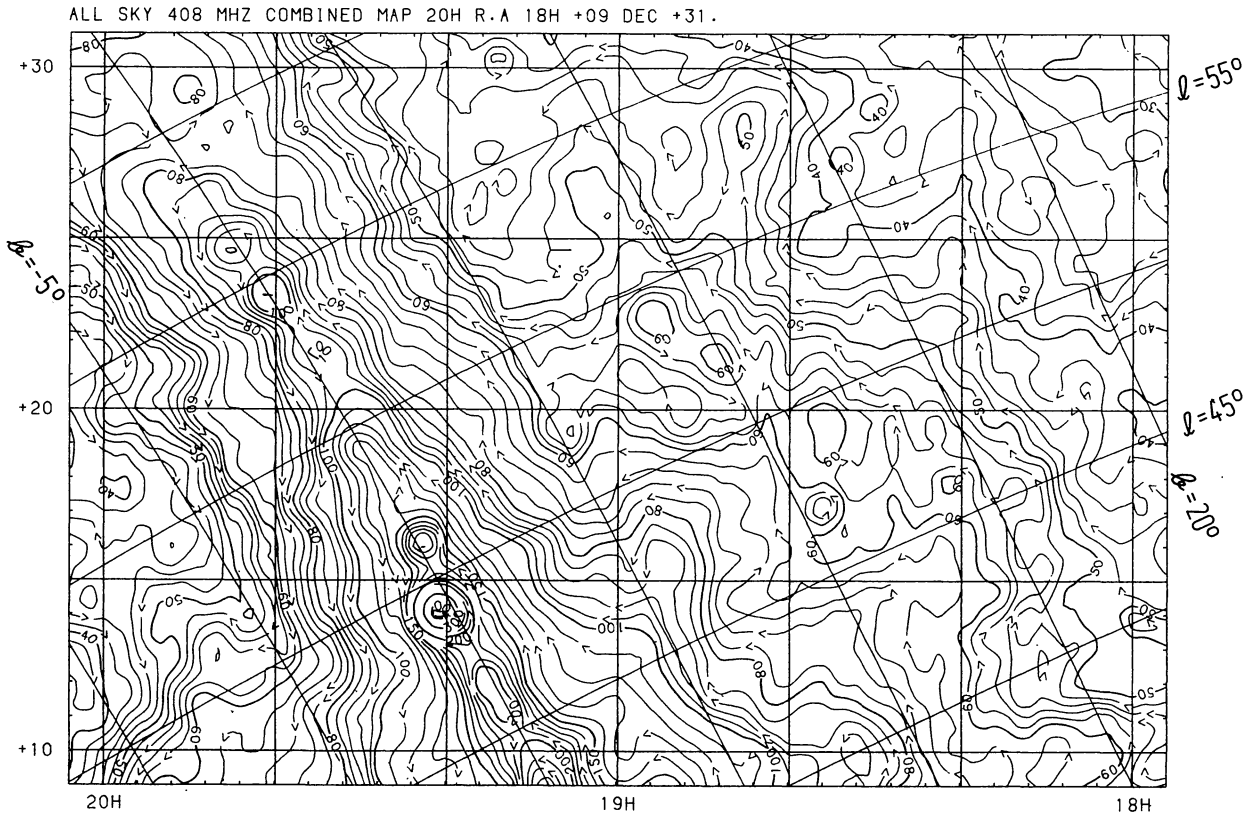

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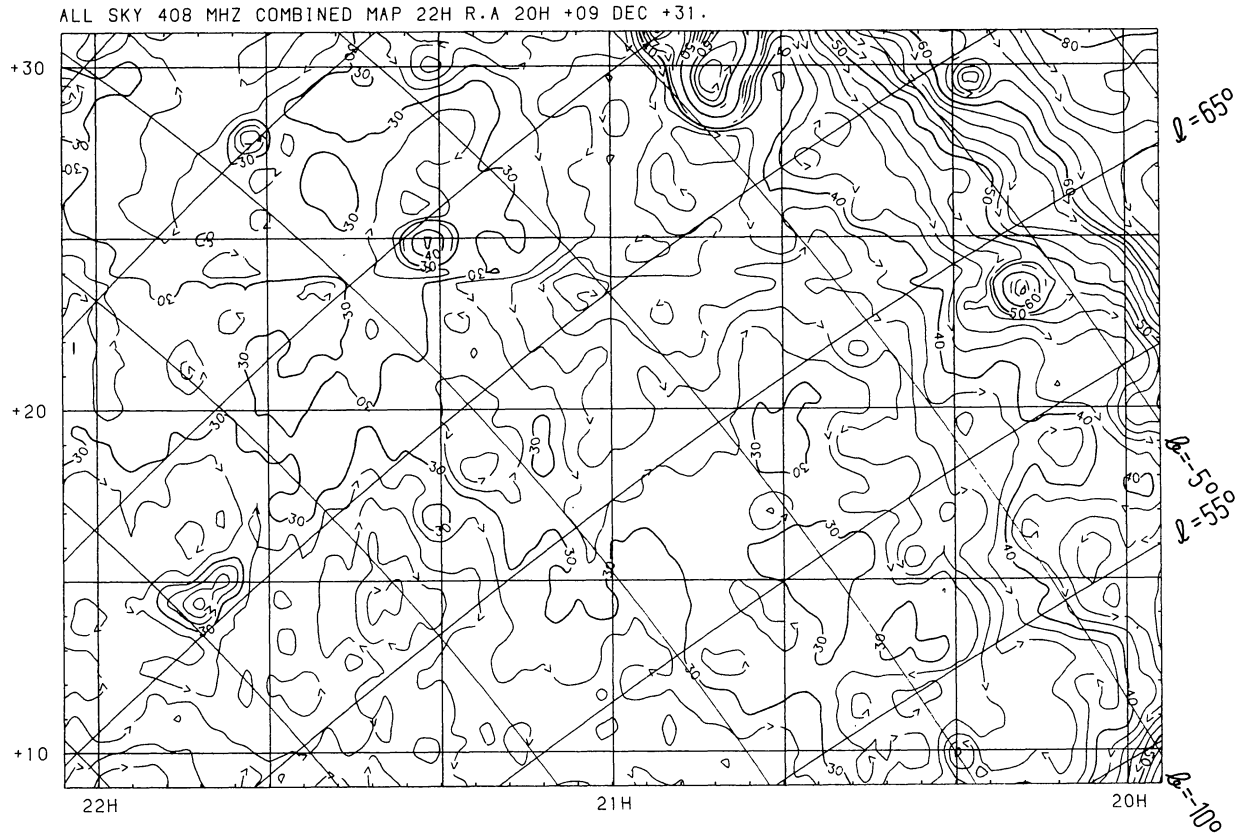

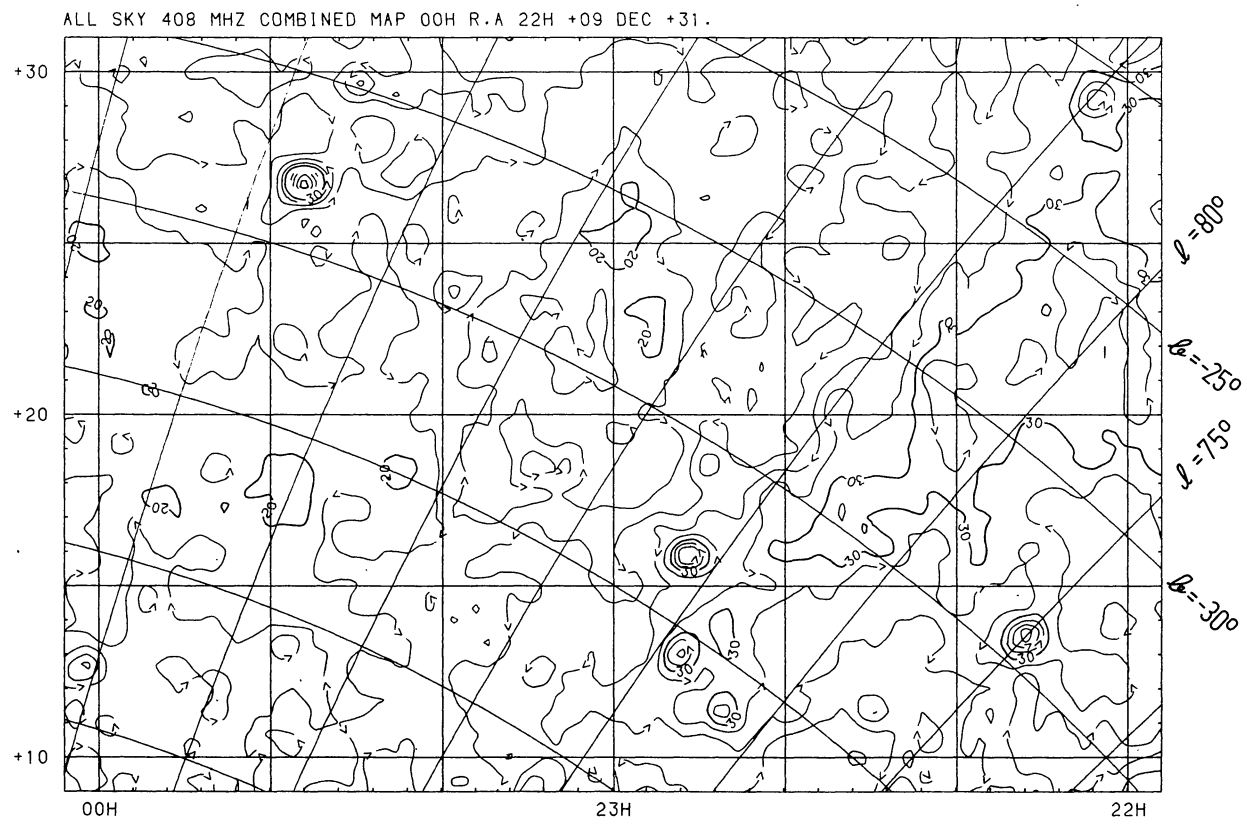

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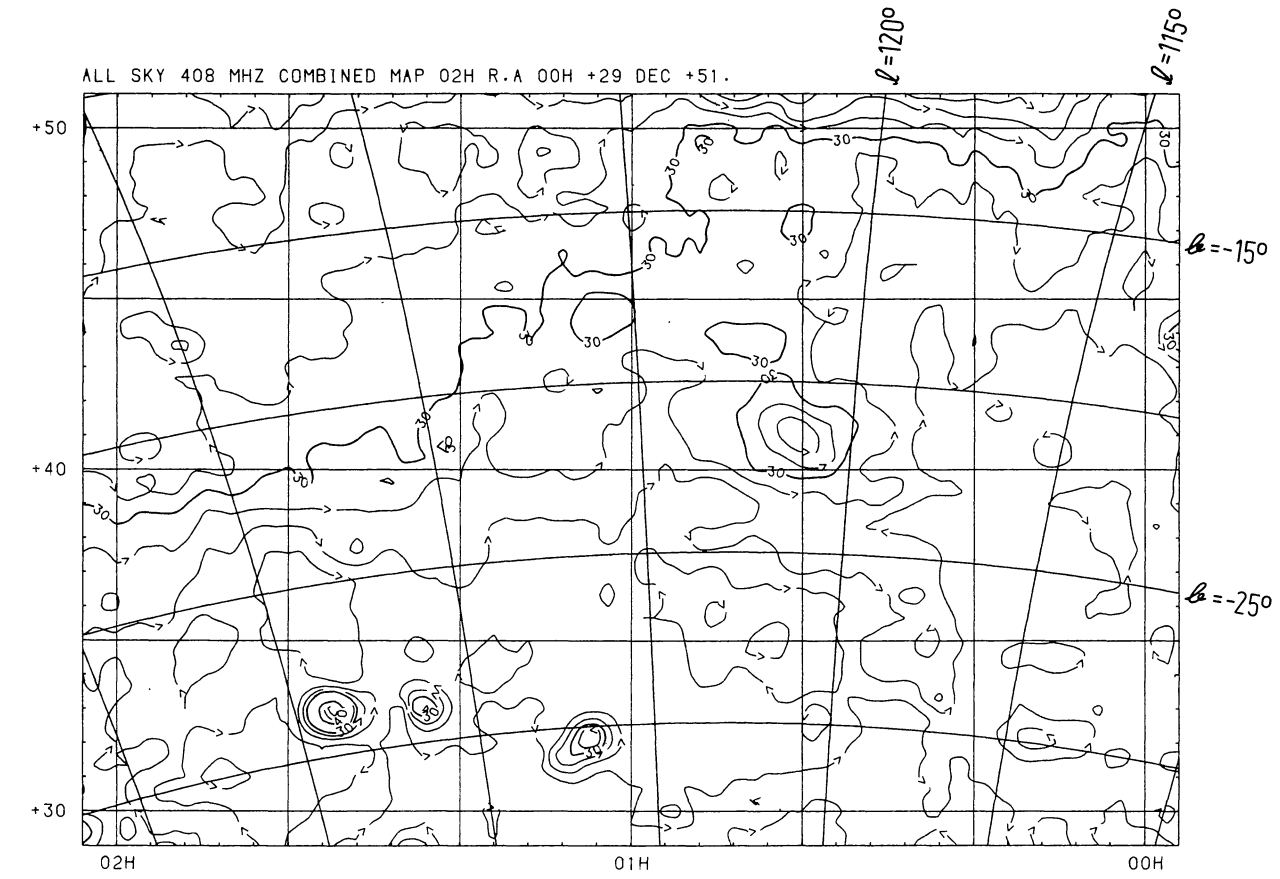

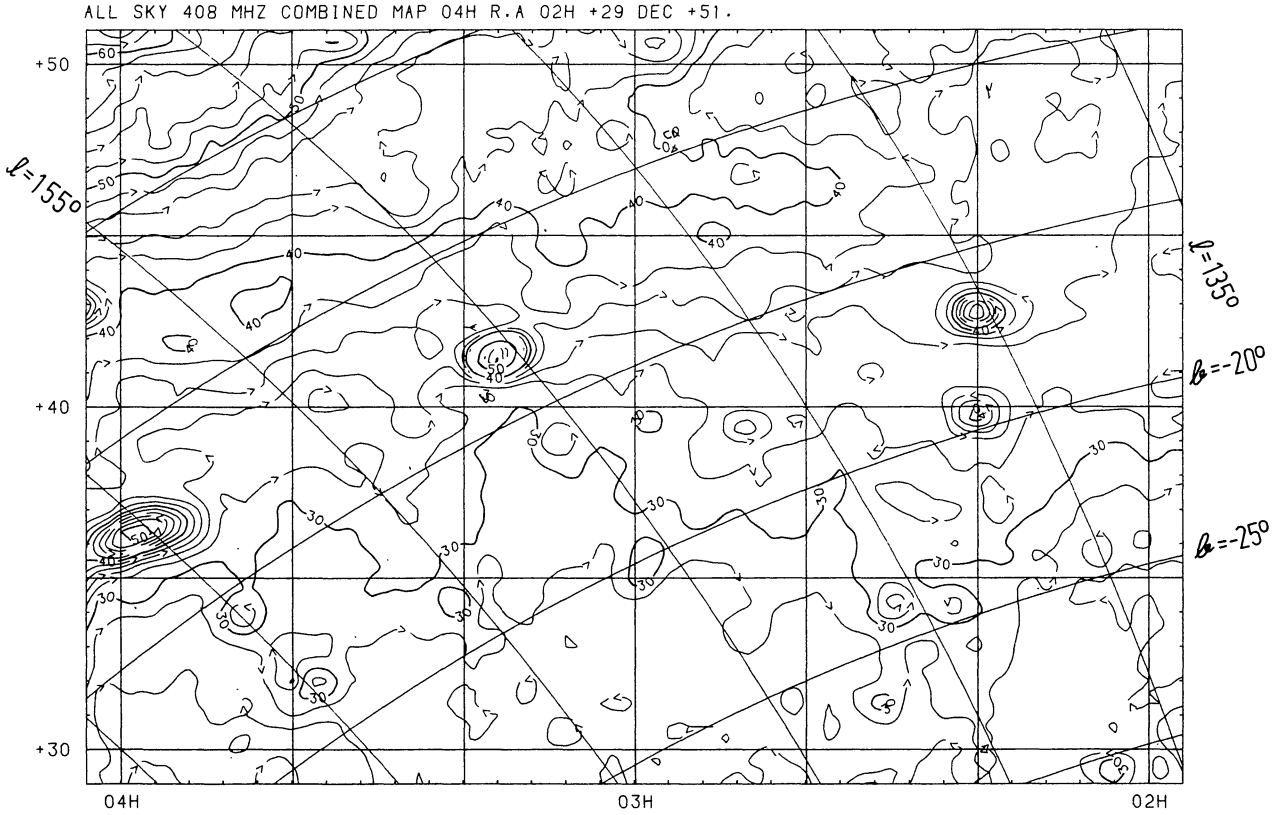

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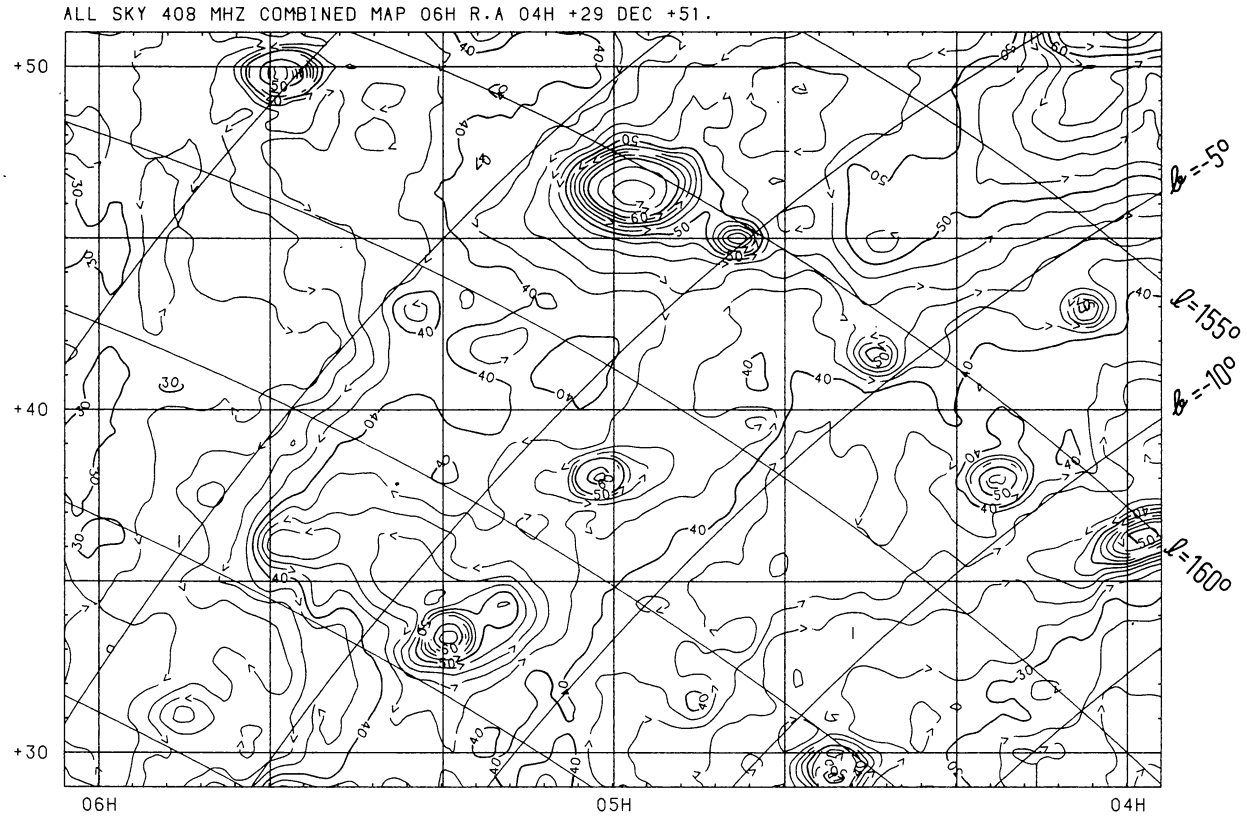

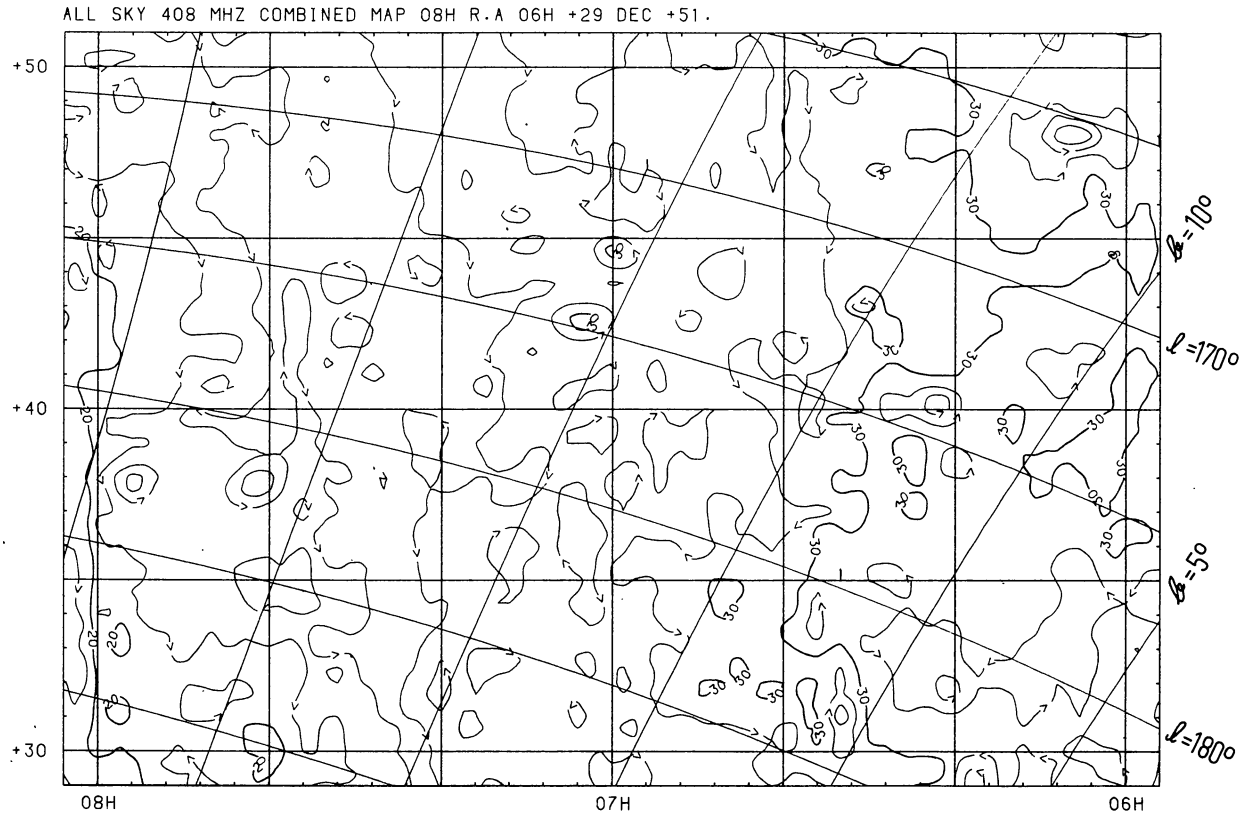

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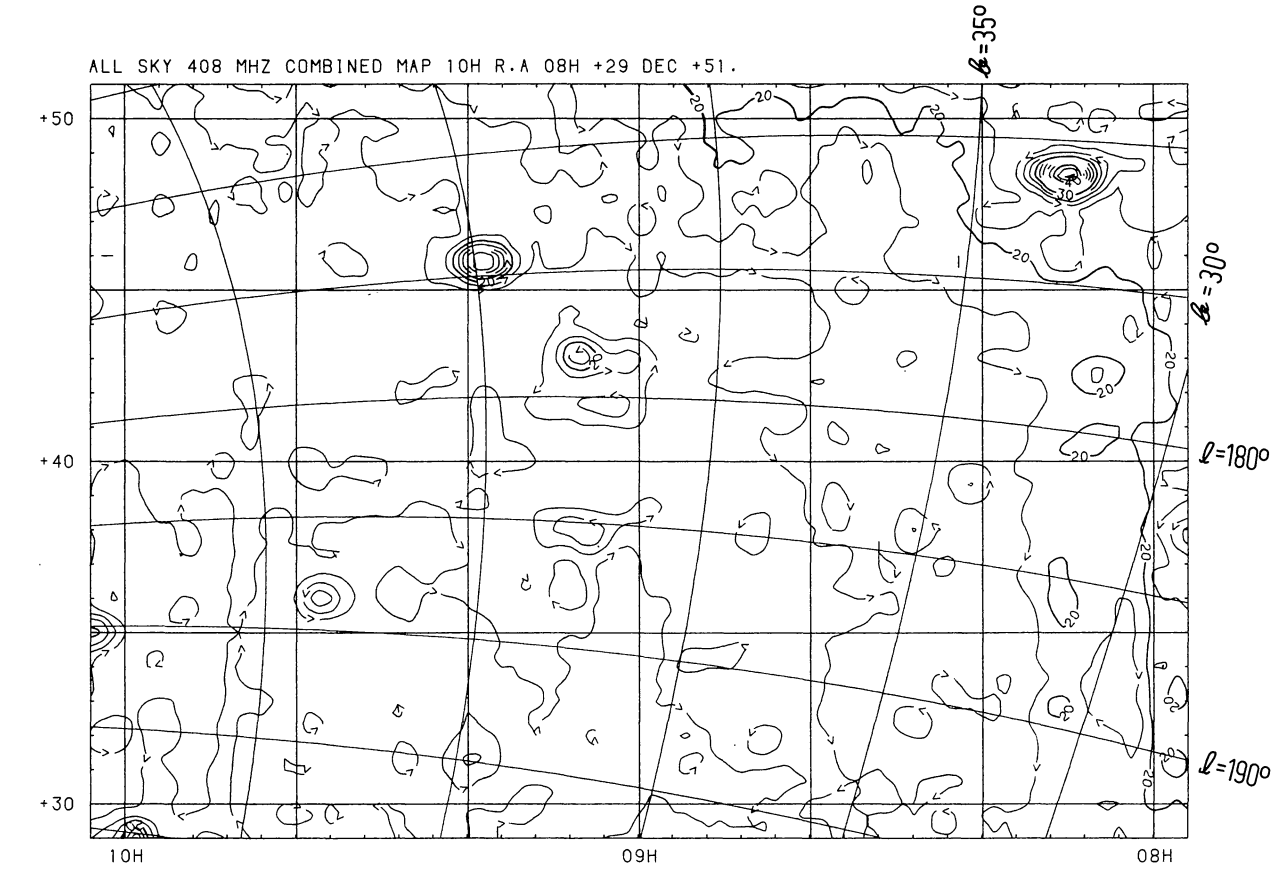

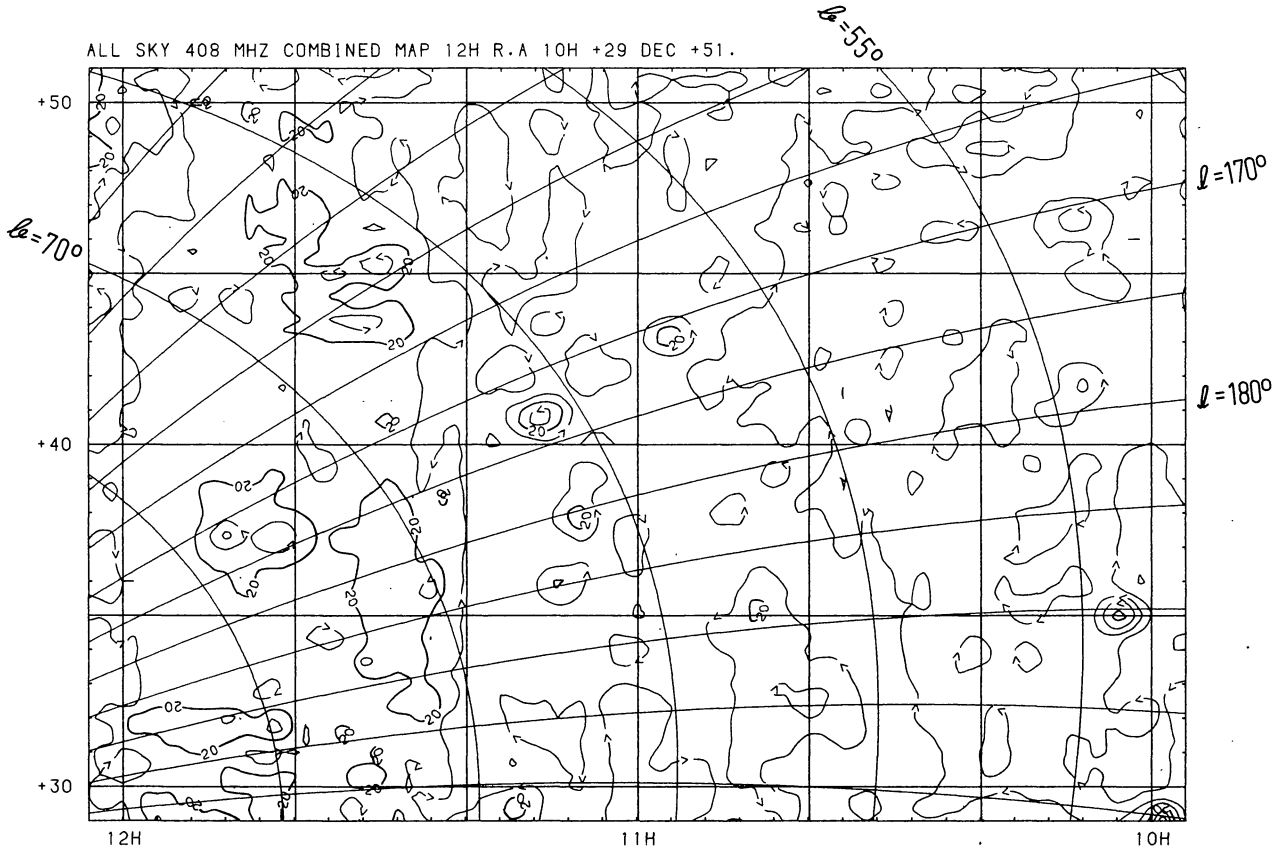

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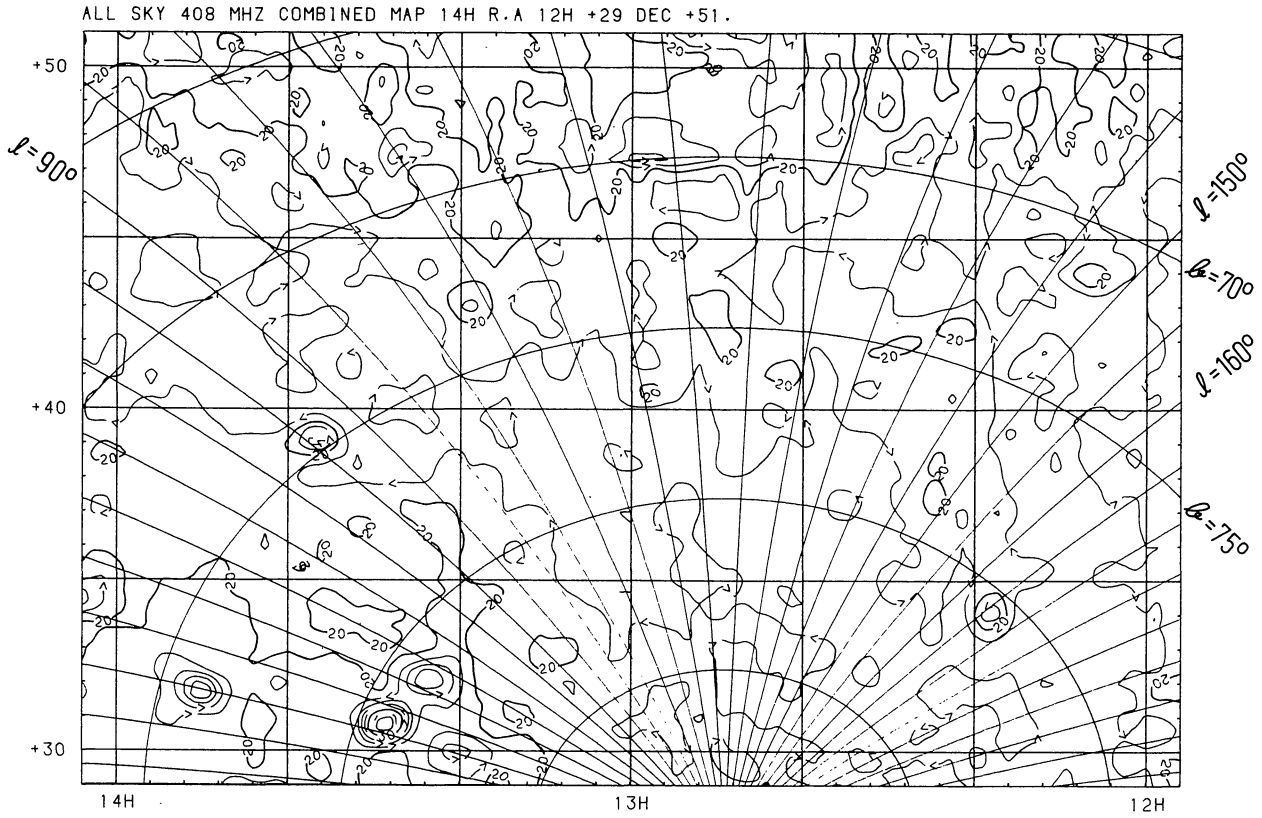

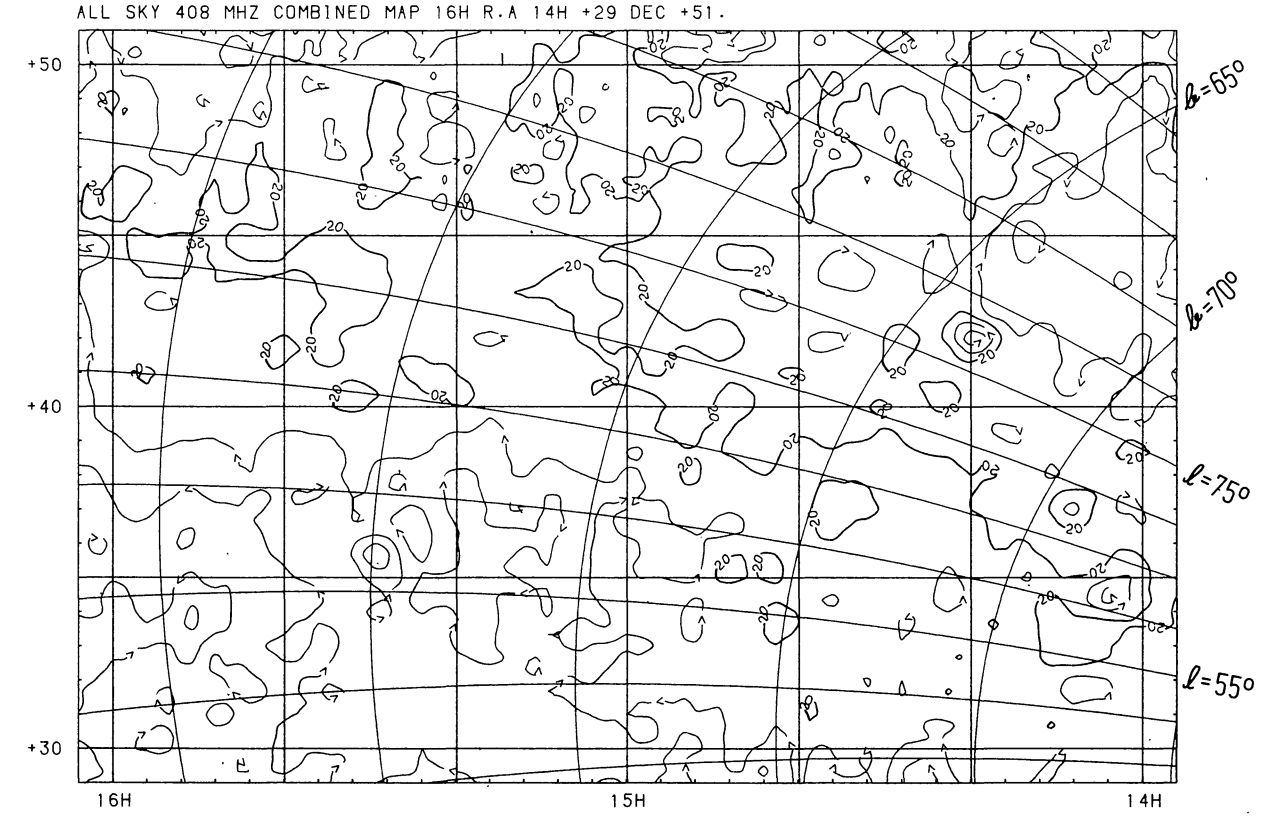

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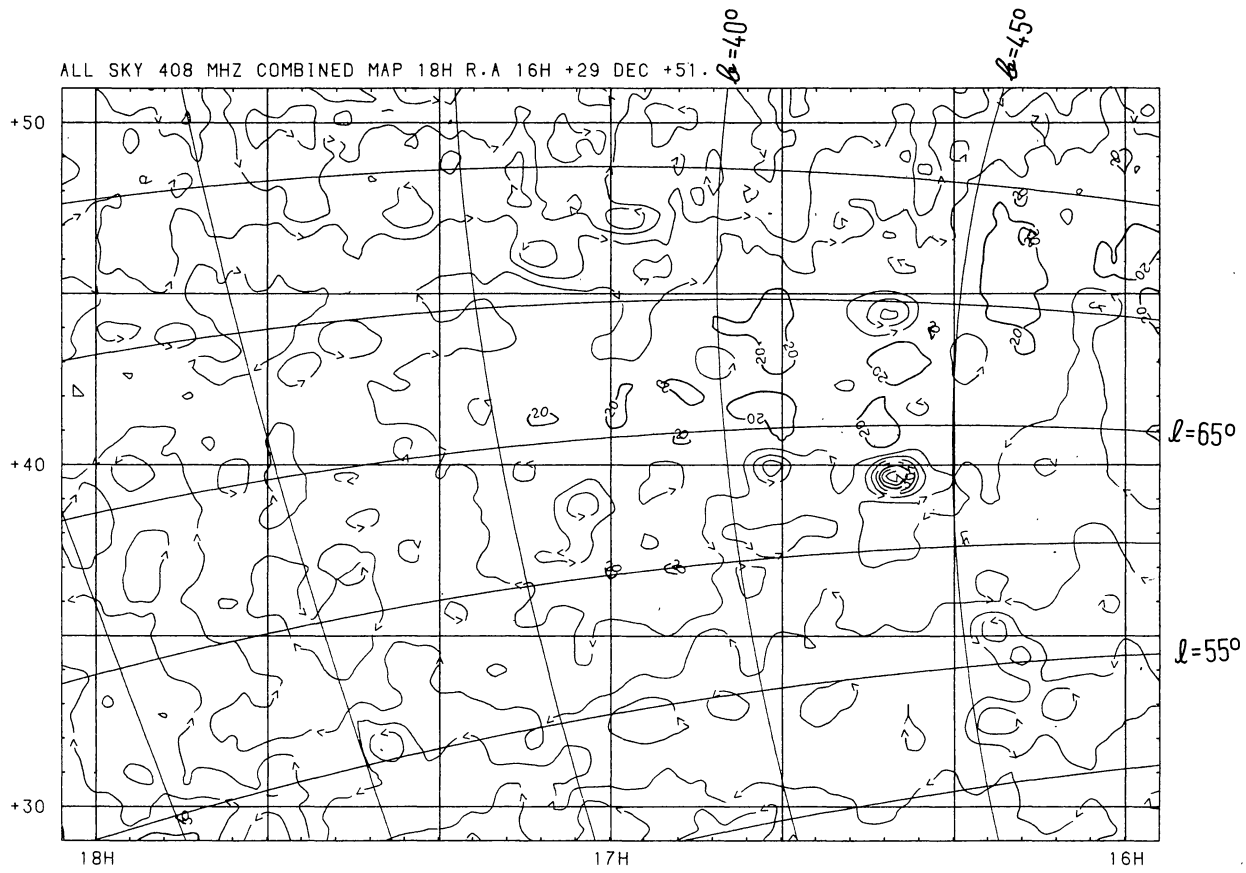

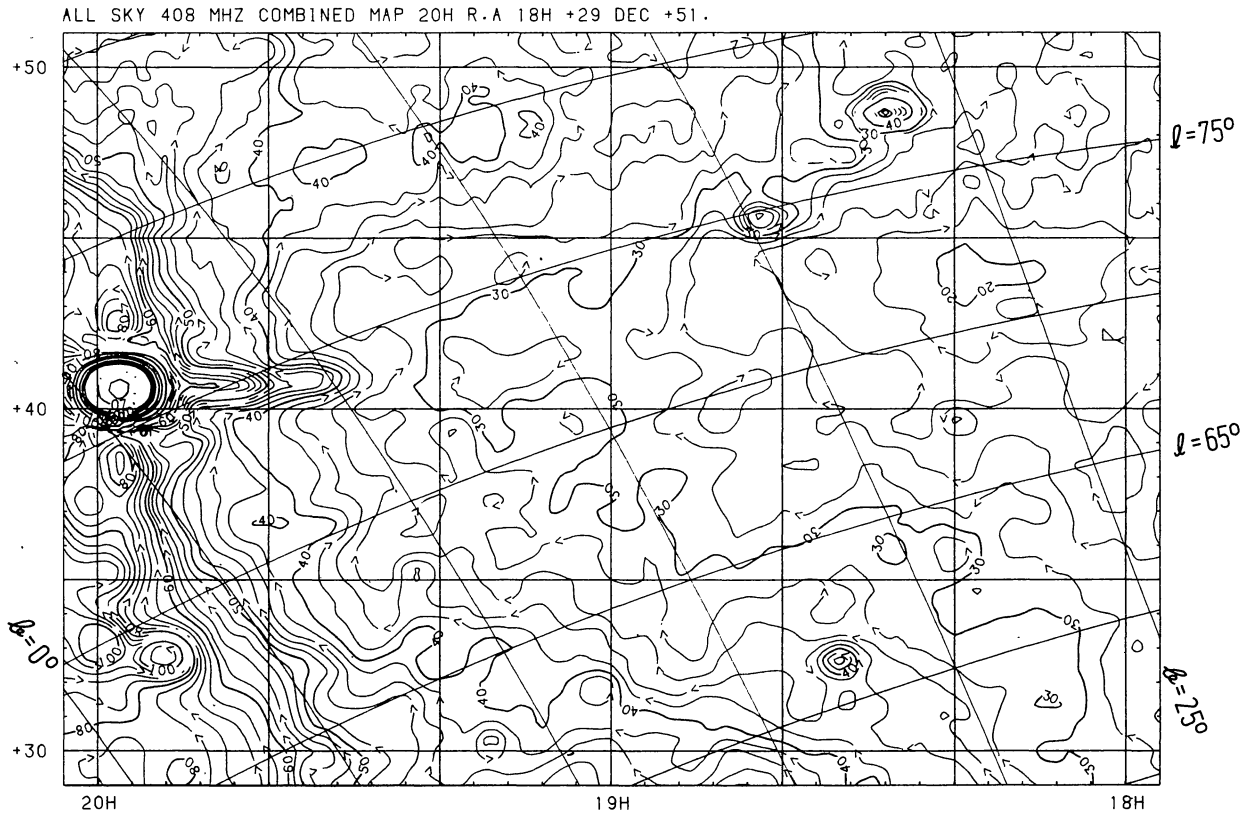

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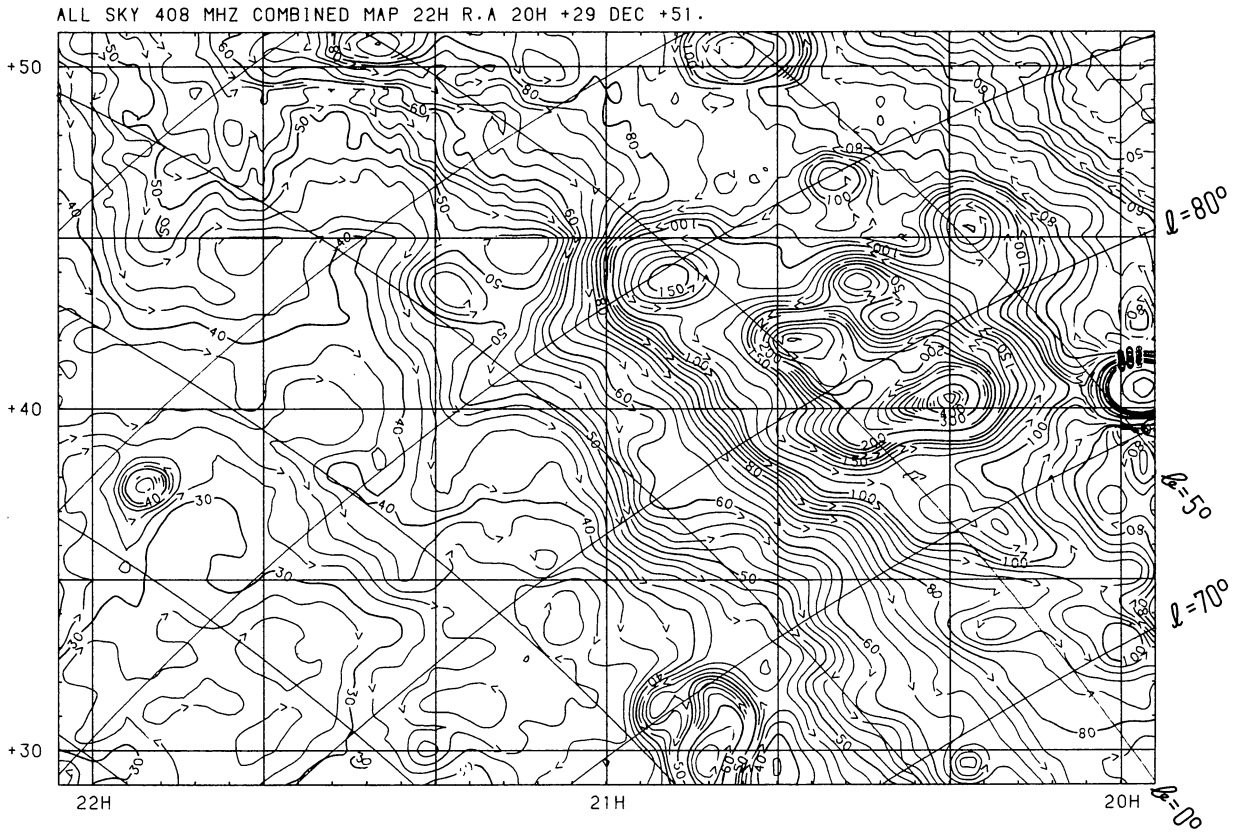

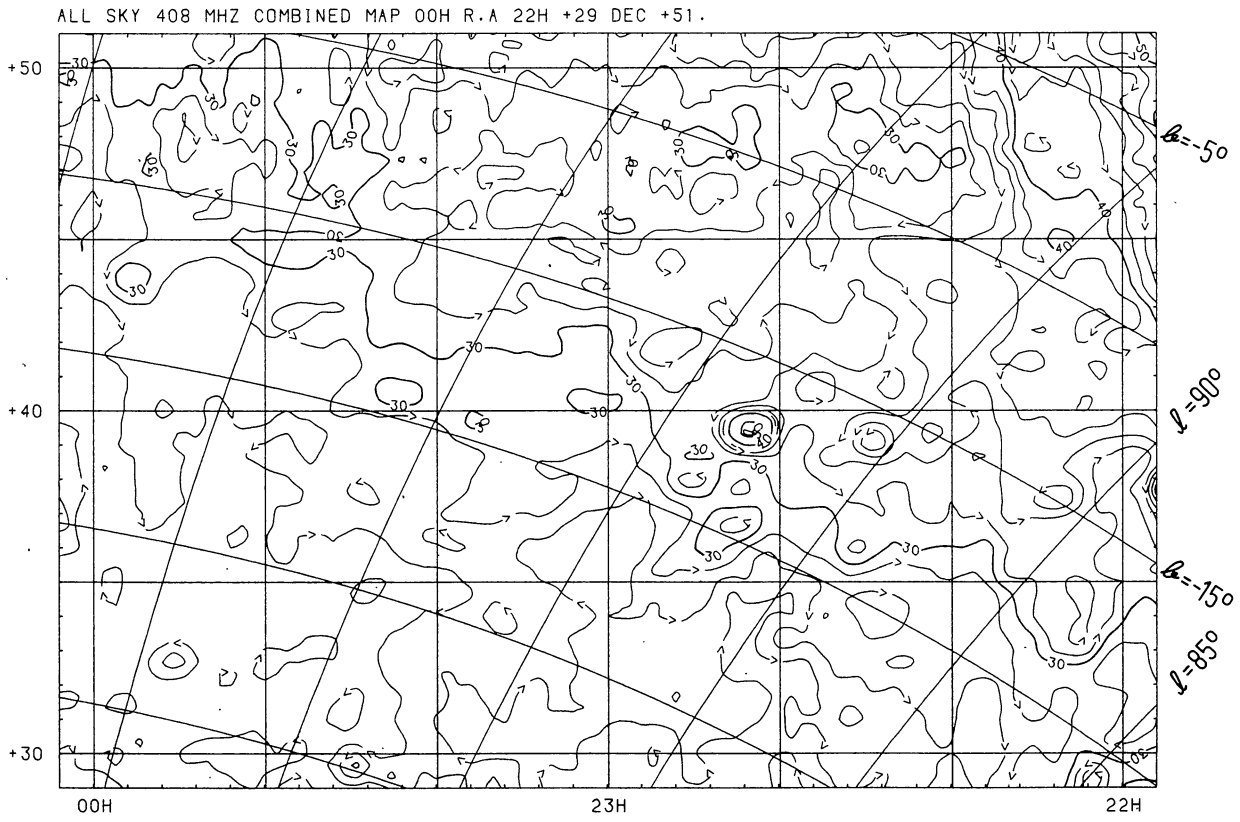

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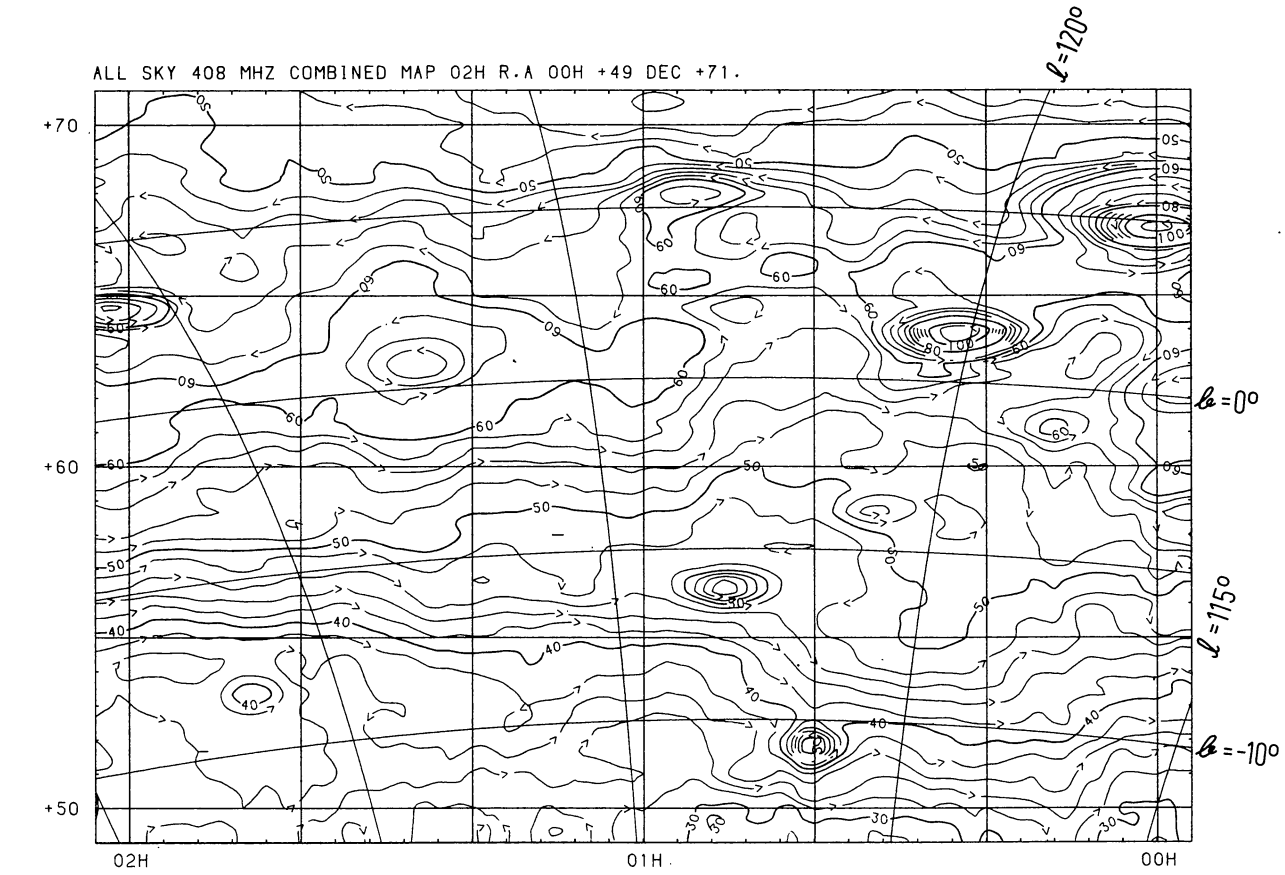

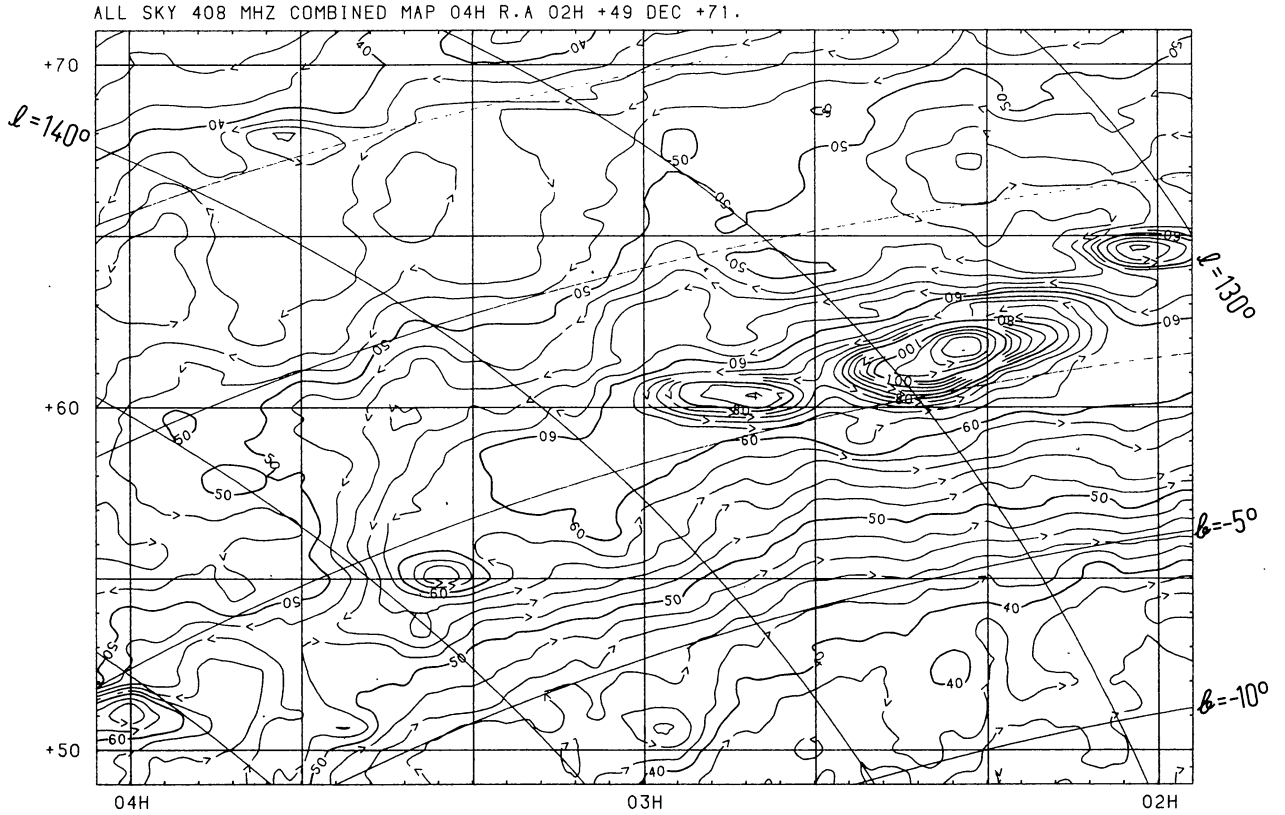

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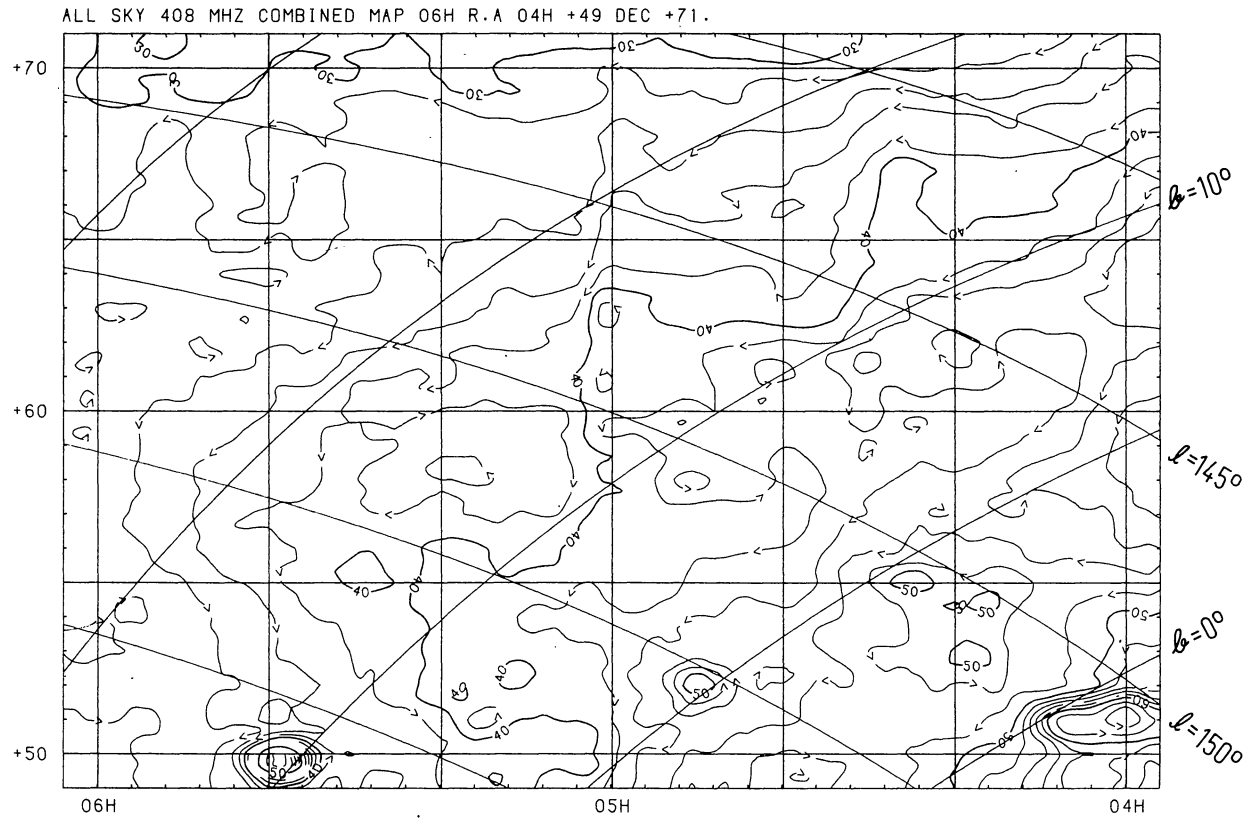

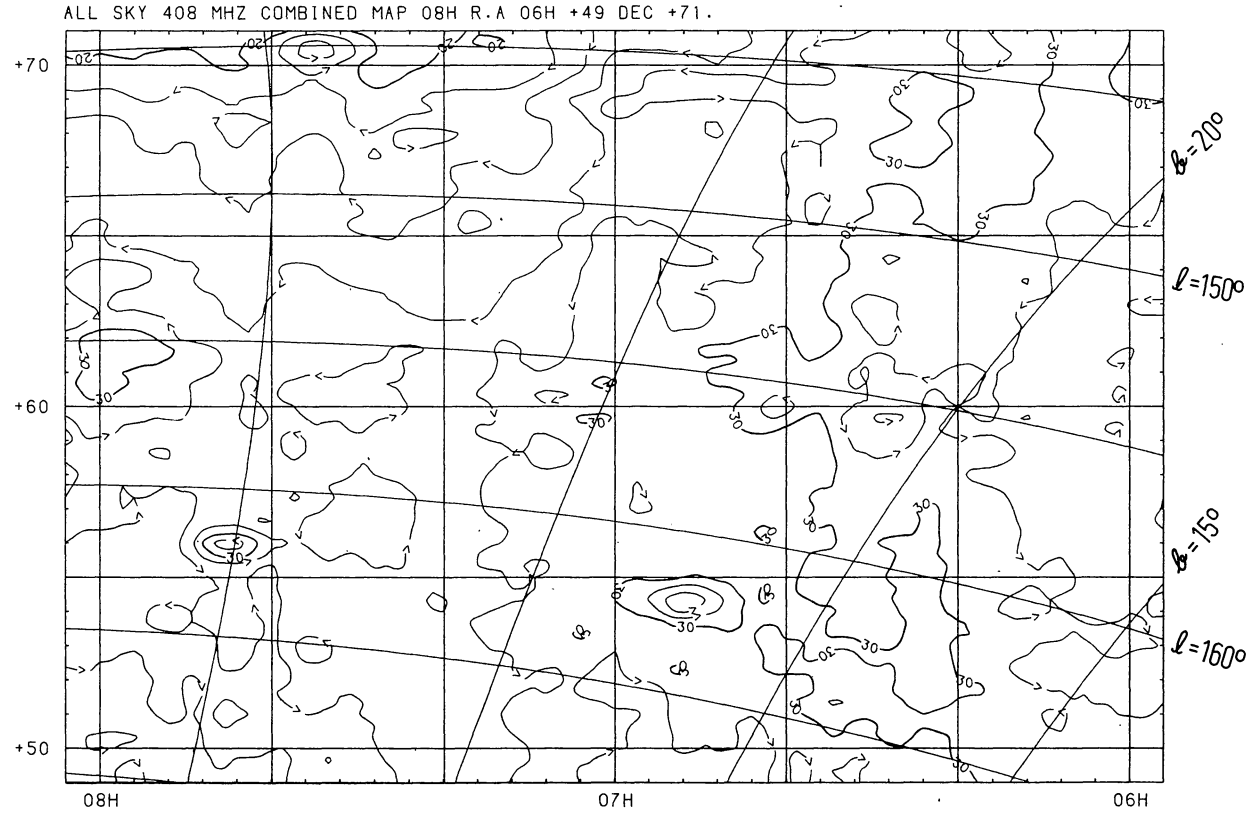

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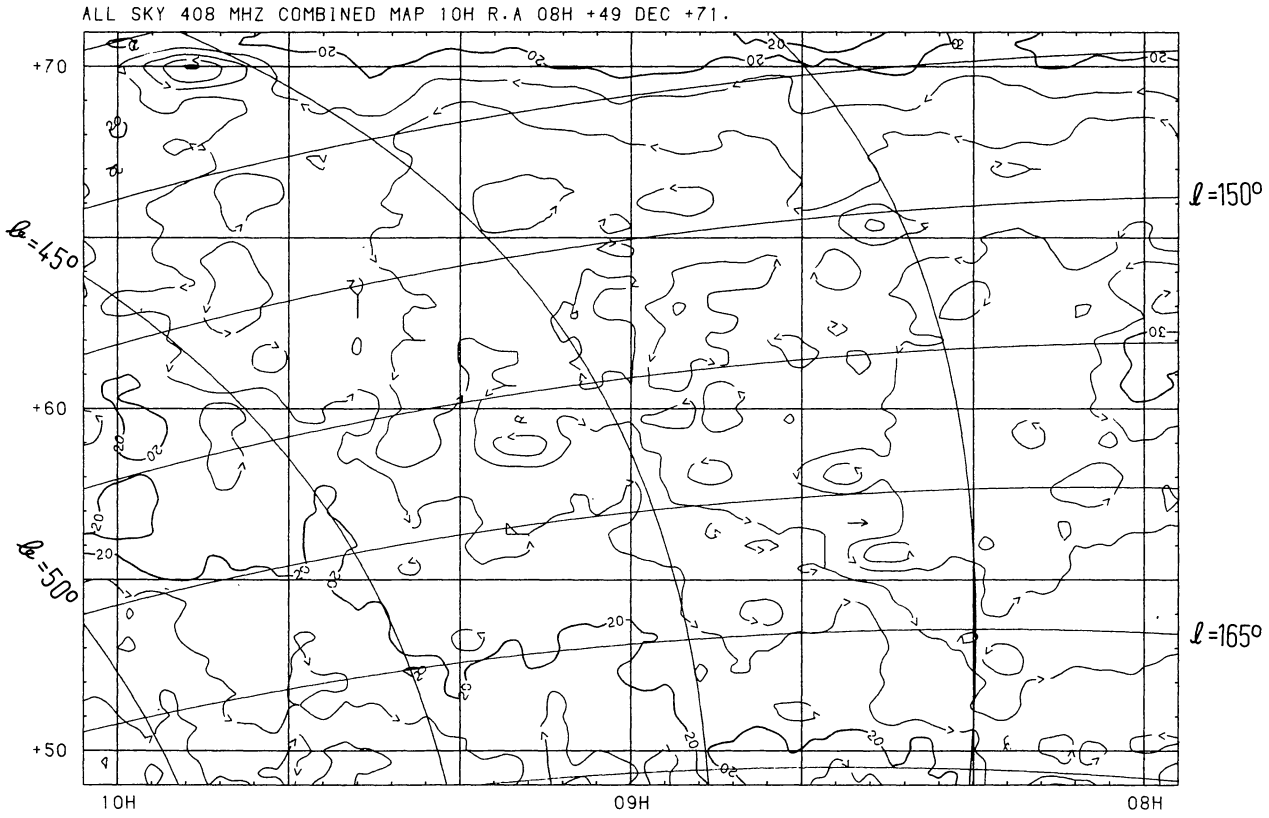

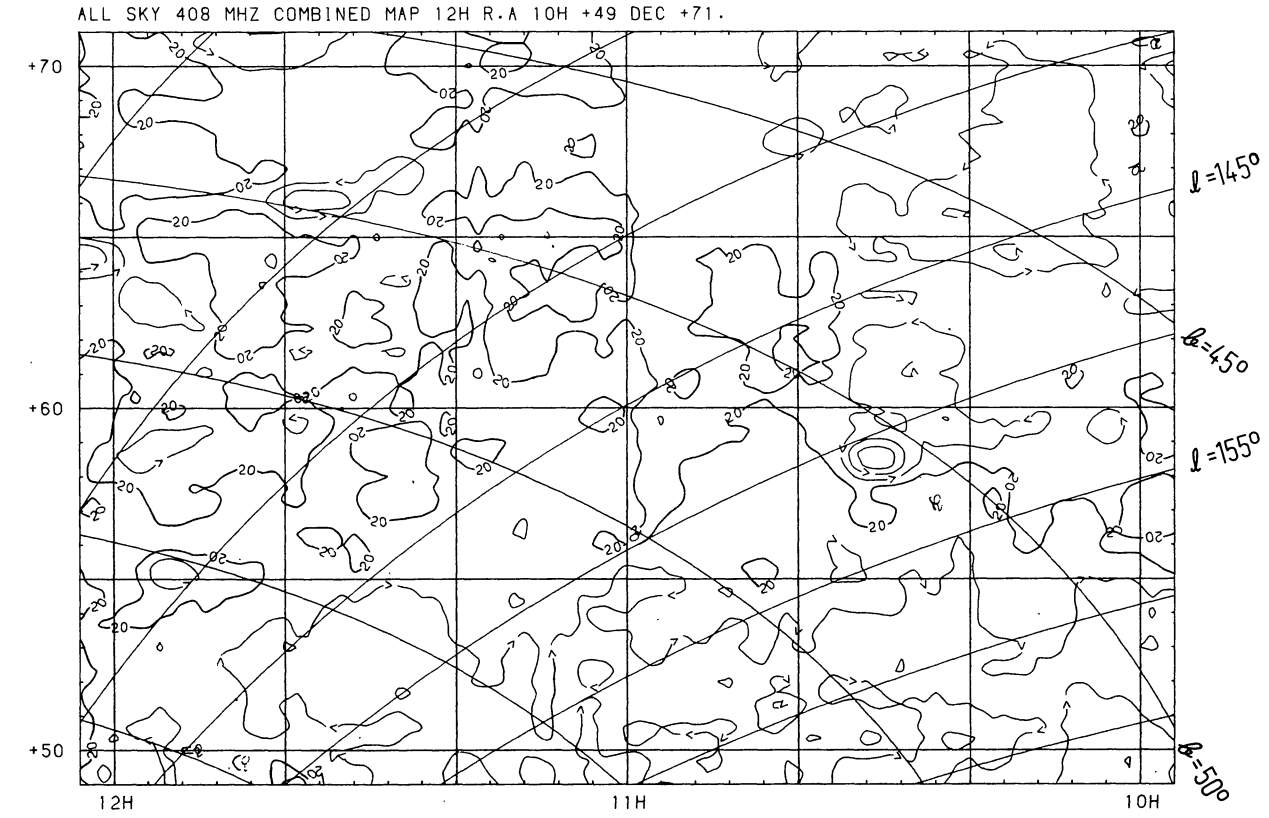

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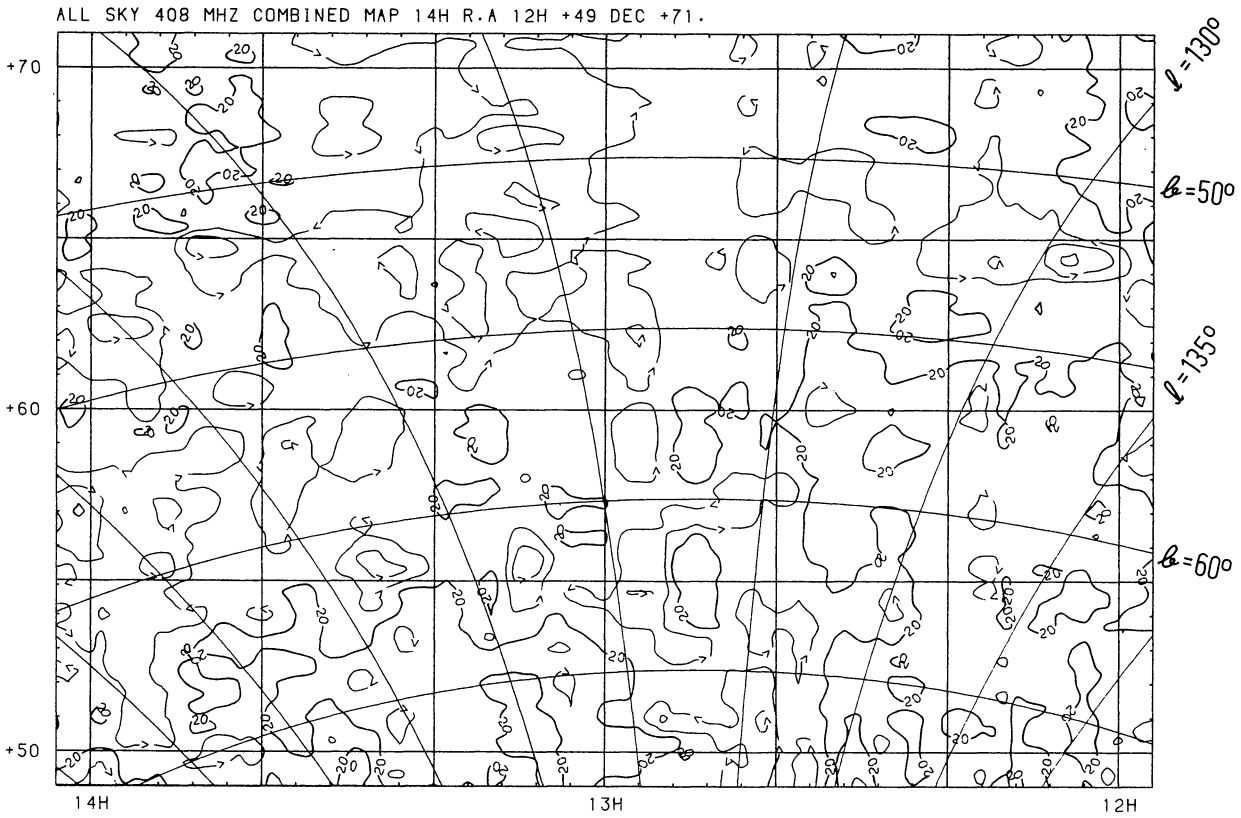

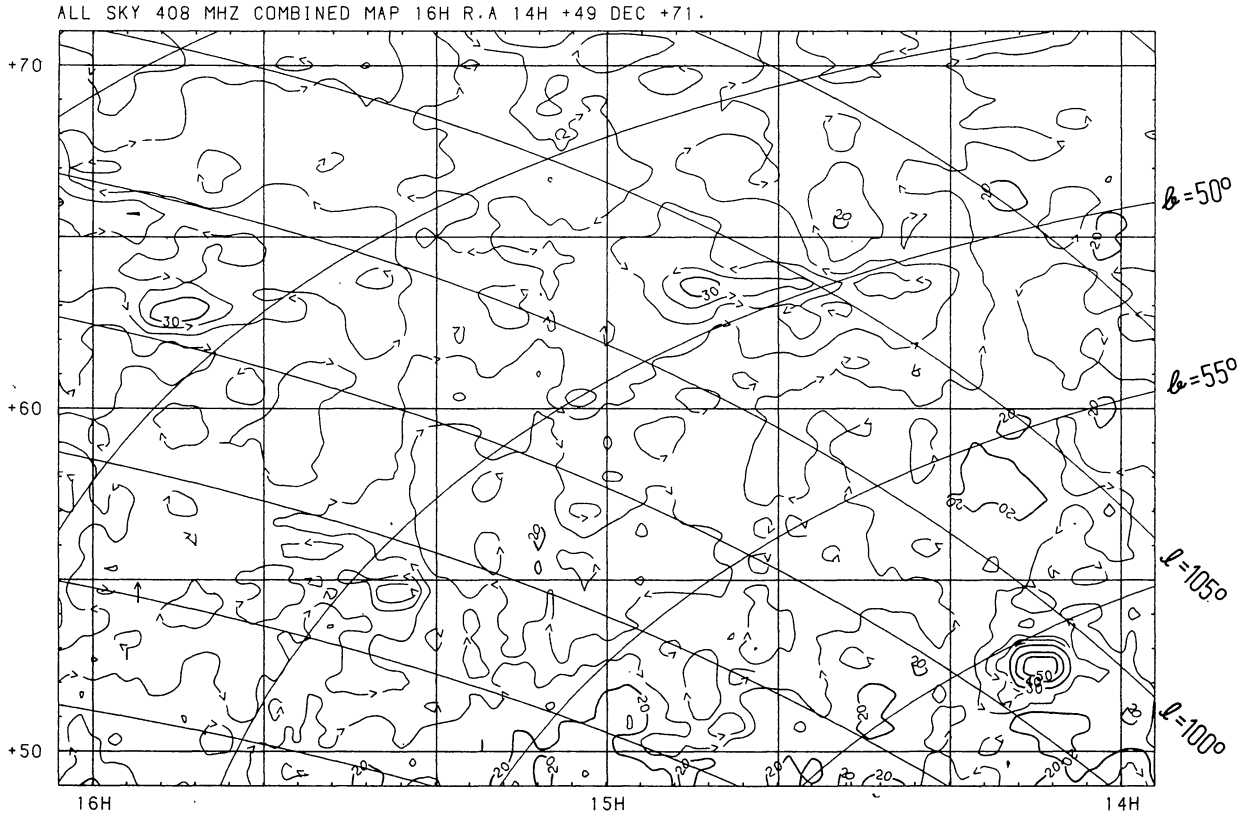

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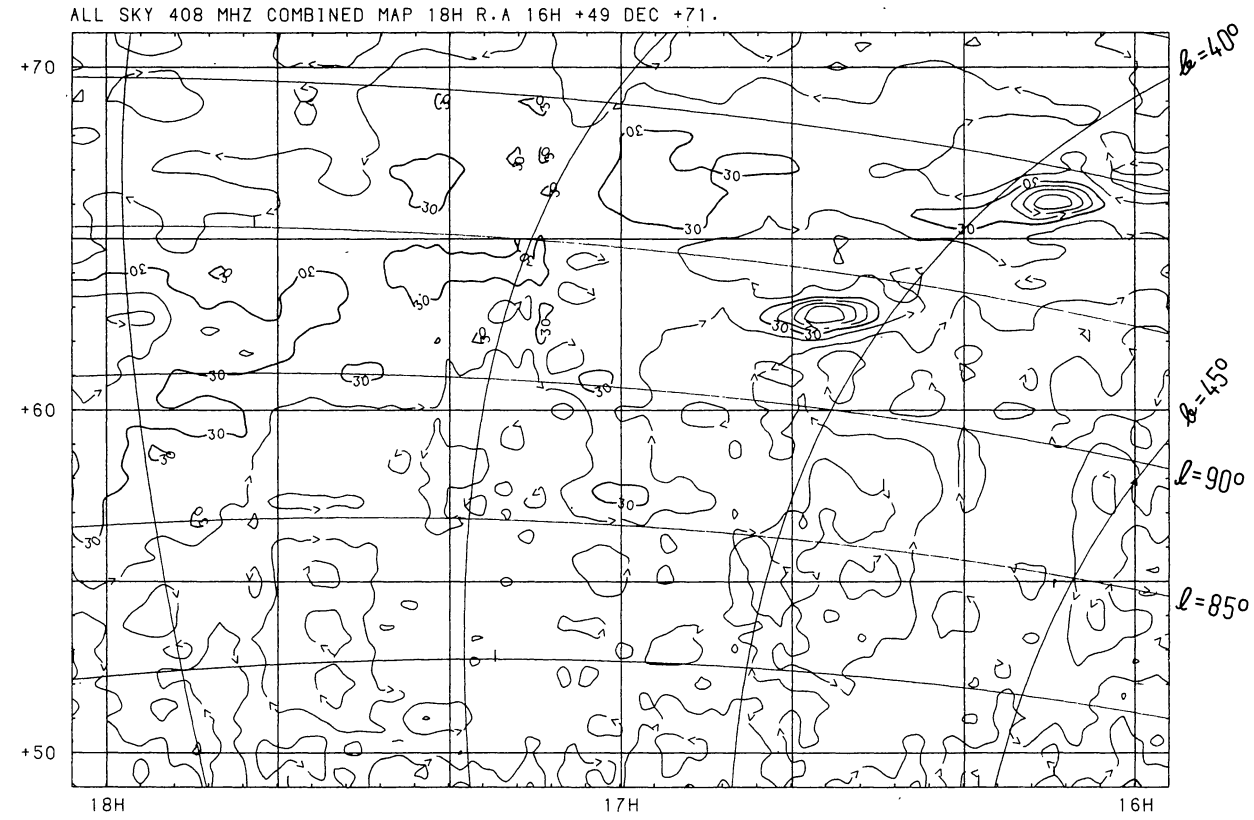

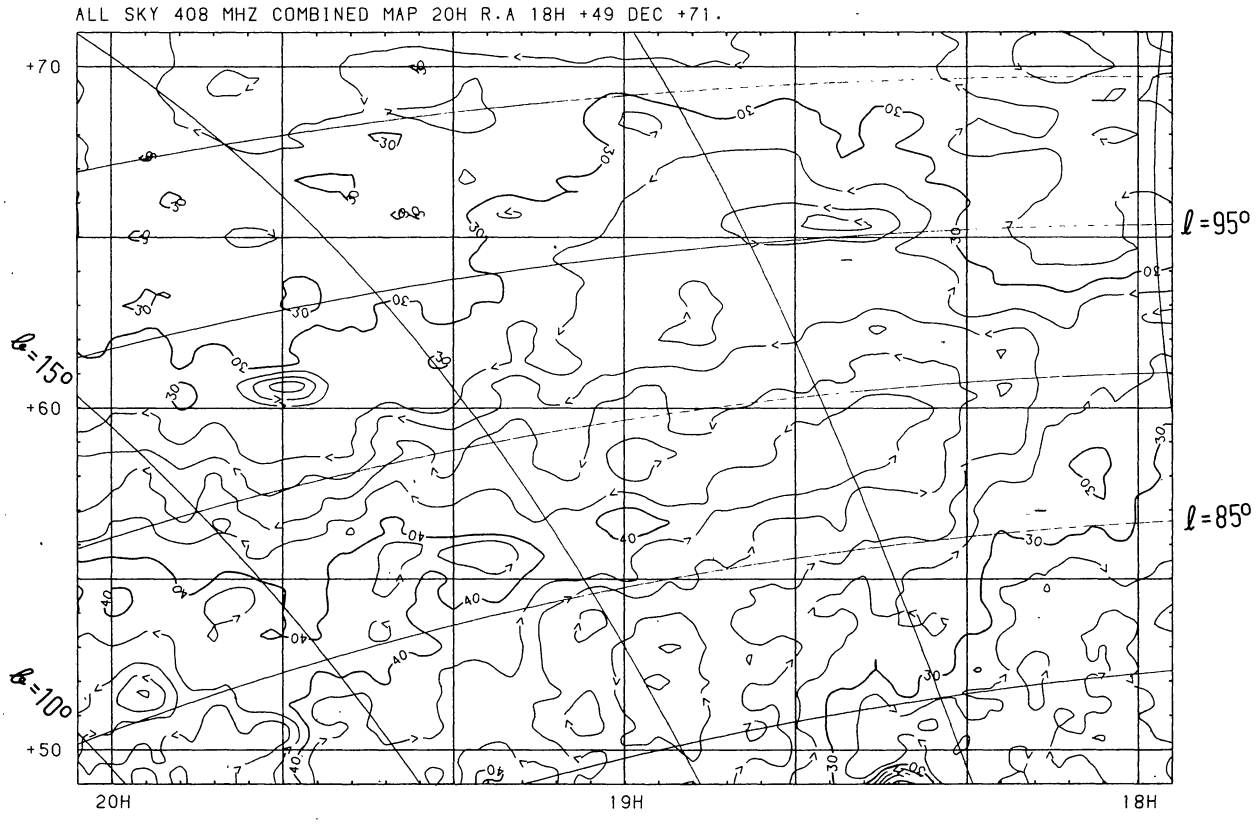

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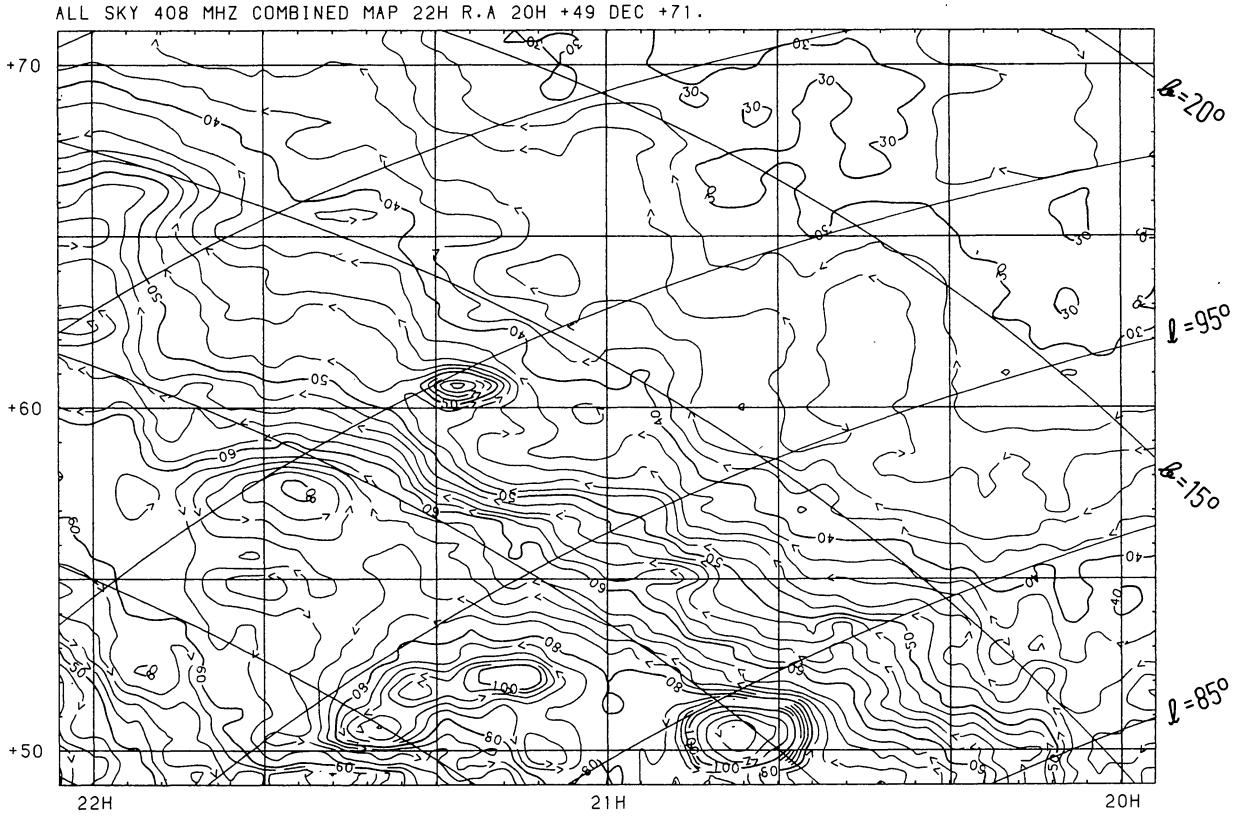

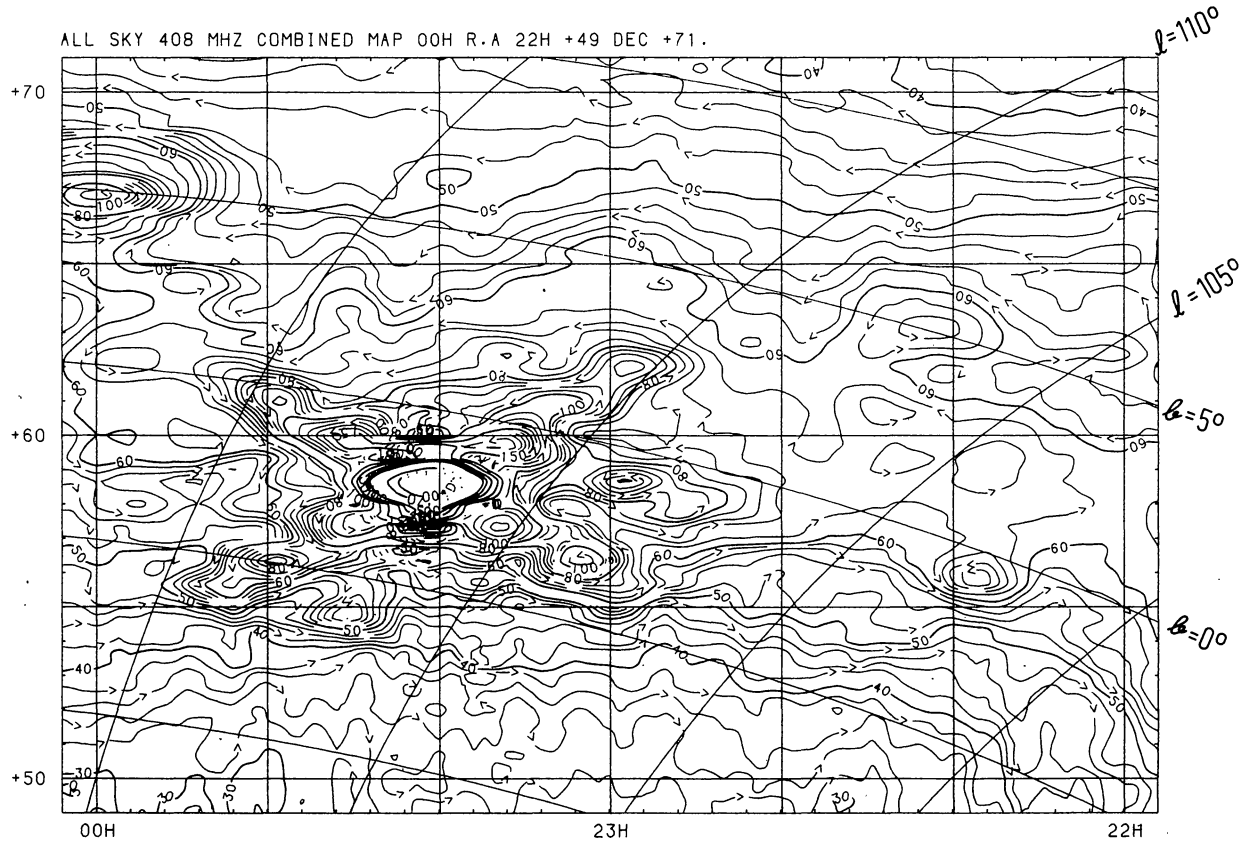

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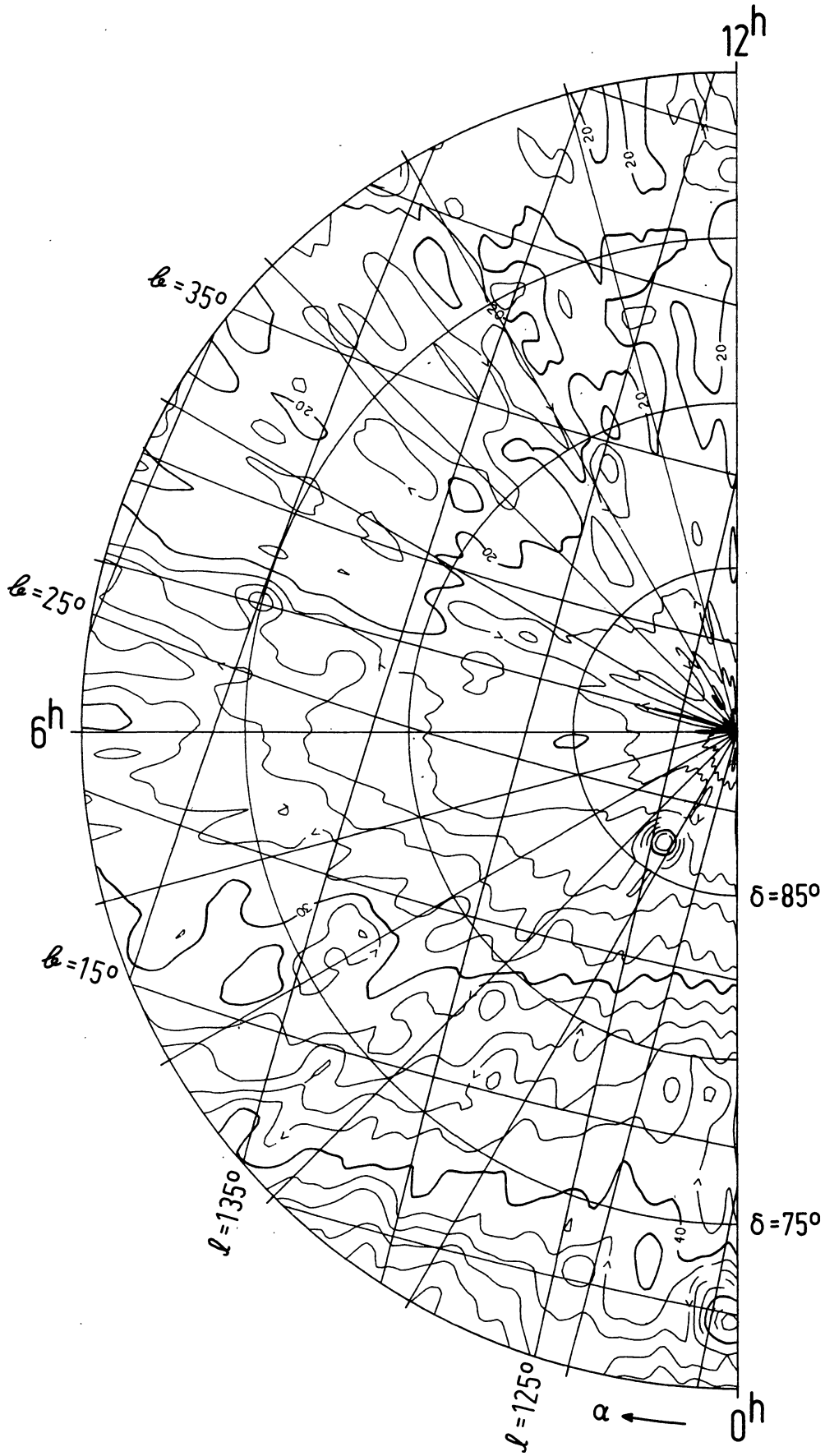
North celestial Pole.



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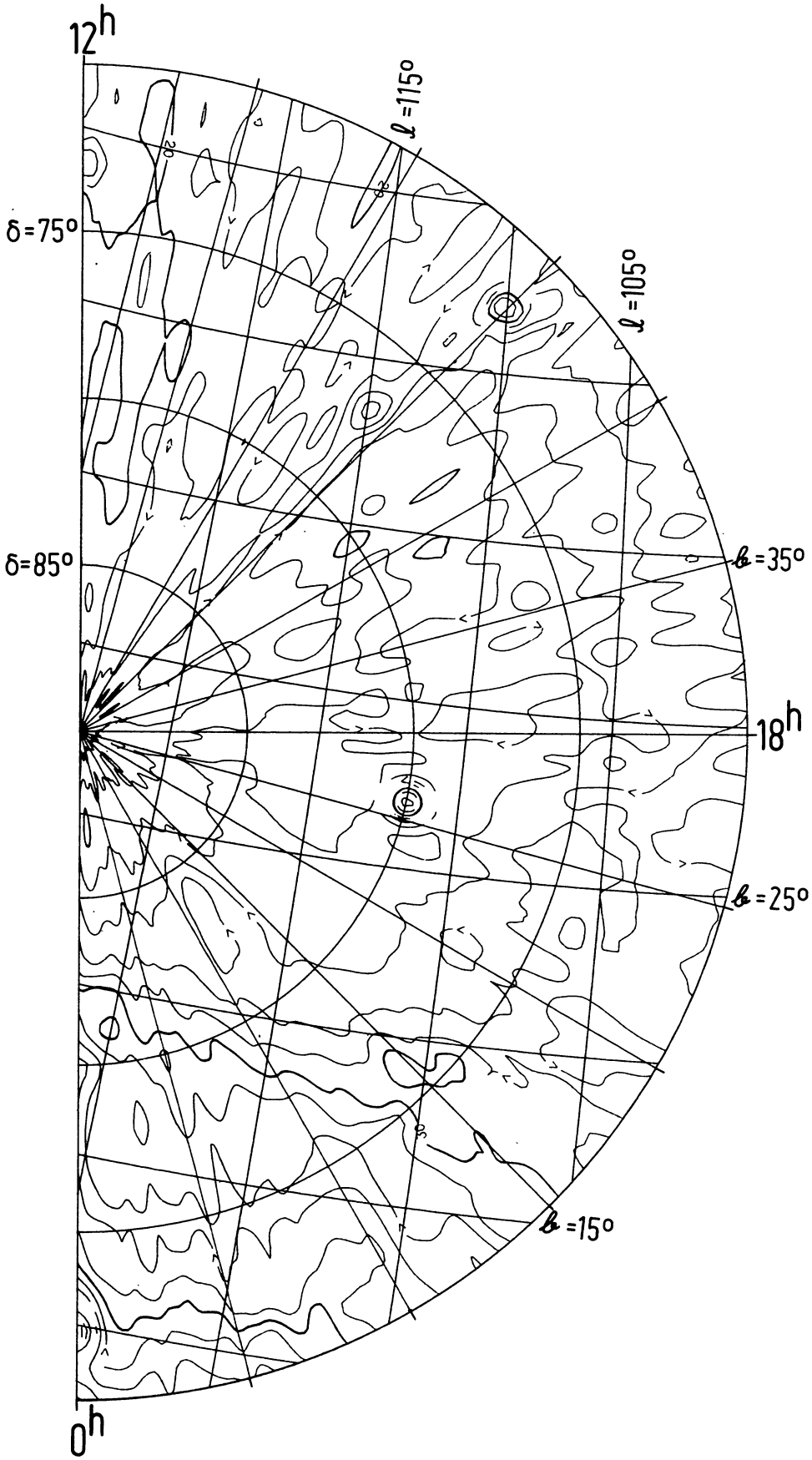

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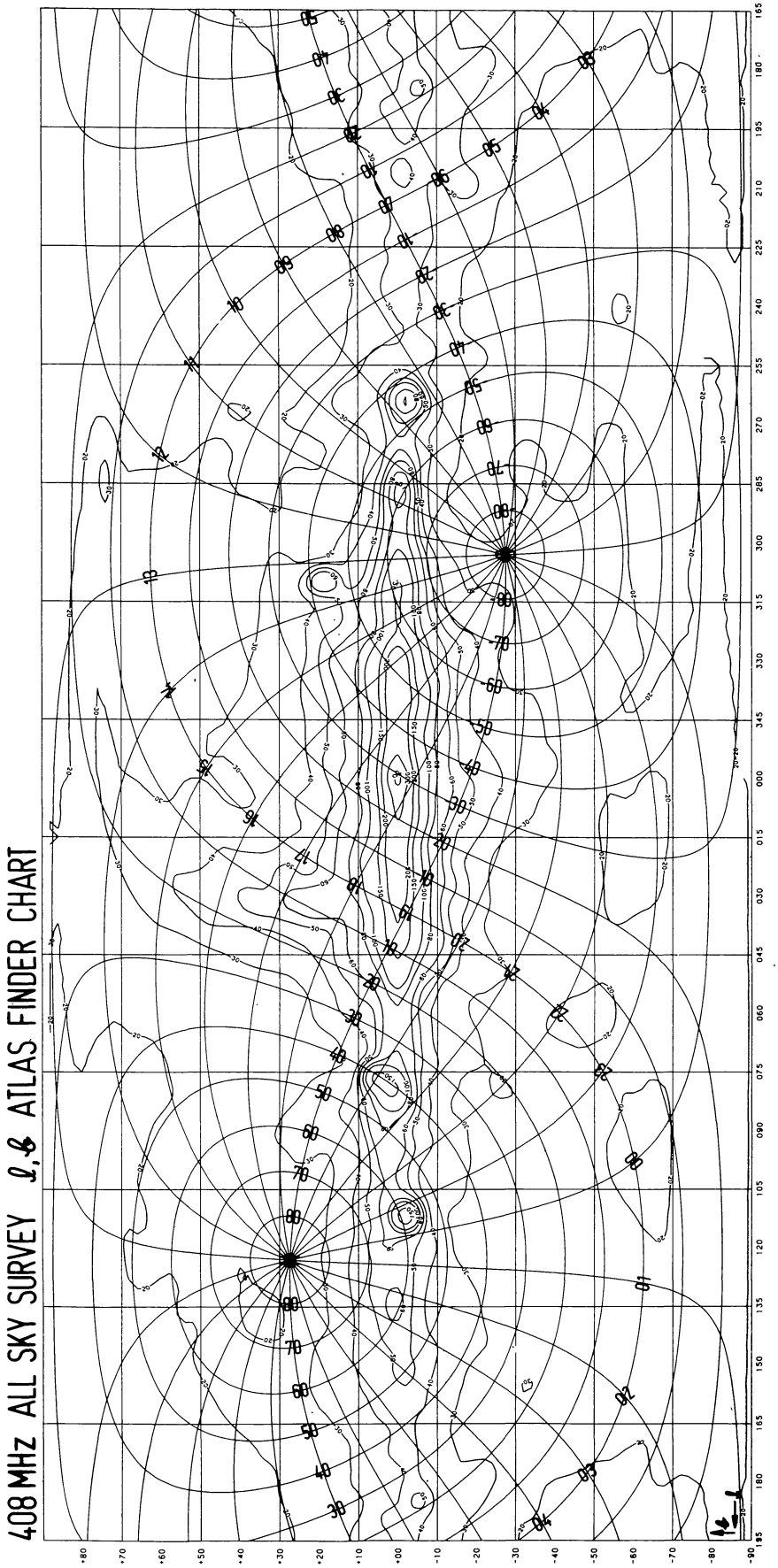

FIGURE 3. — The atlas of maps in Galactic coordinates. As with figure 2 a finder chart is provided with contours at 5° × 5° resolution, but with a 15° × 10° grid in celestial coordinates. Maps for $|b| \geqq 70°$ are presented as half segment polar plots. The other rows are ordered in increasing longitude with each subsequent row increasing in latitude.

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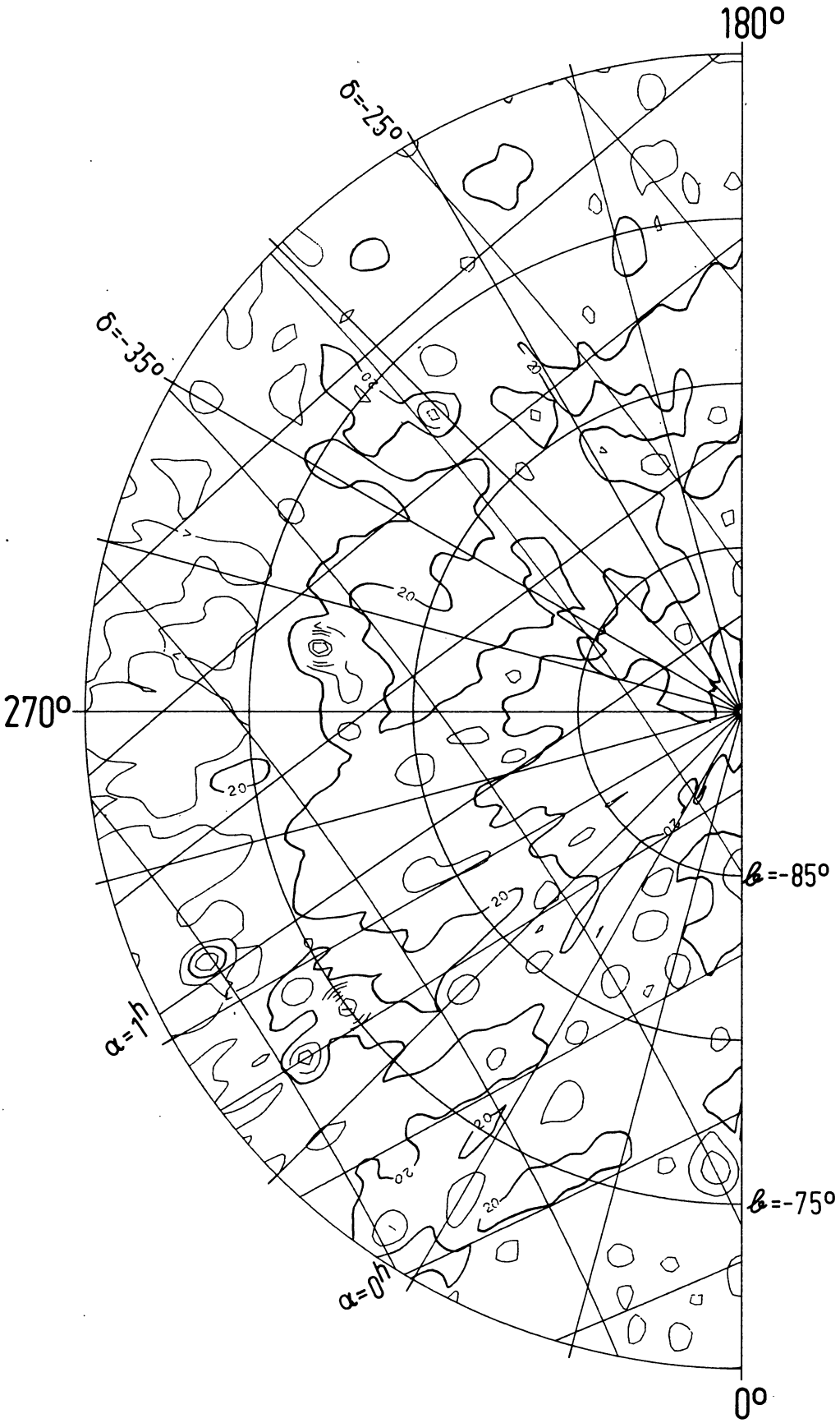
South galactic Pole.



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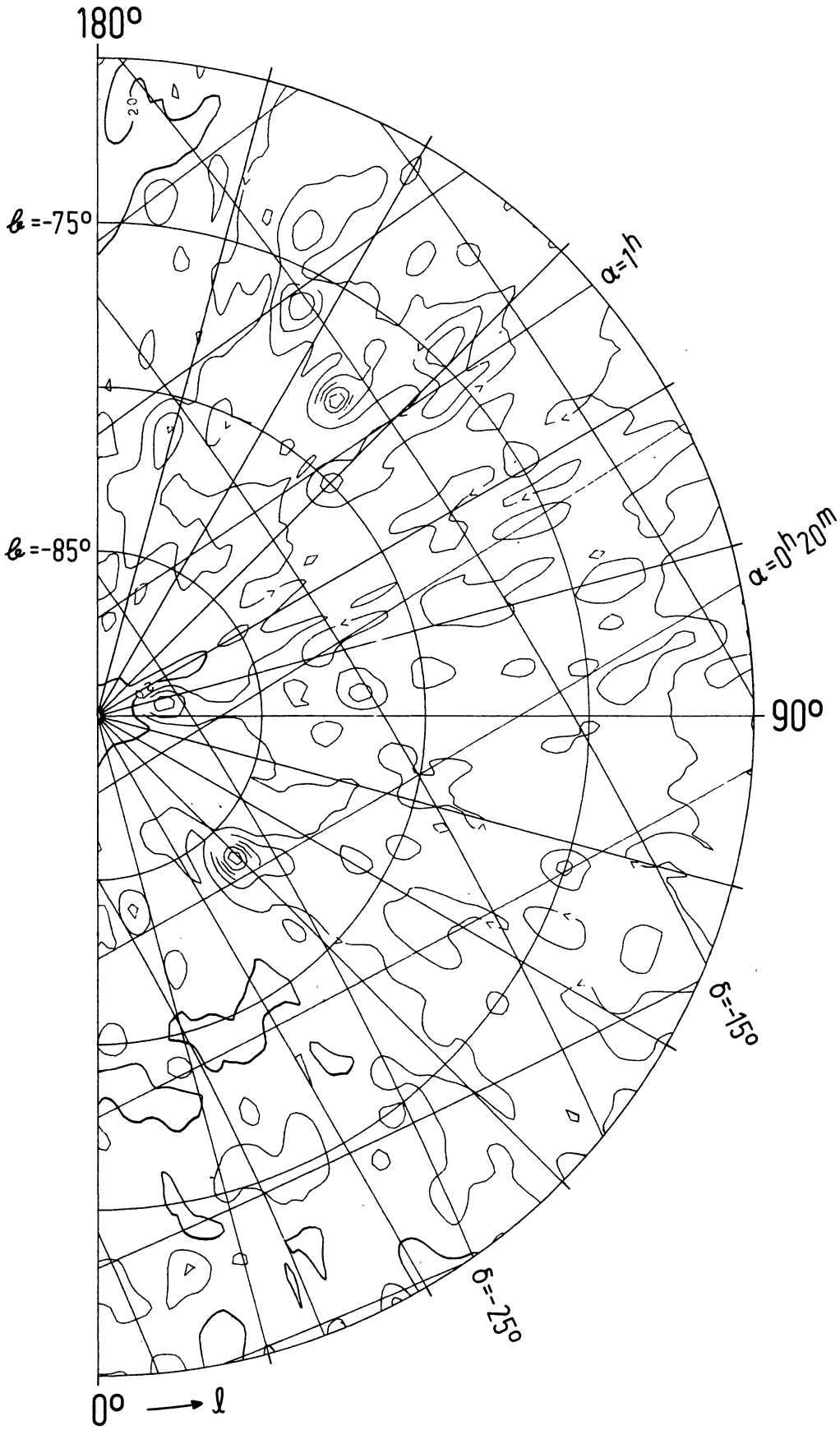

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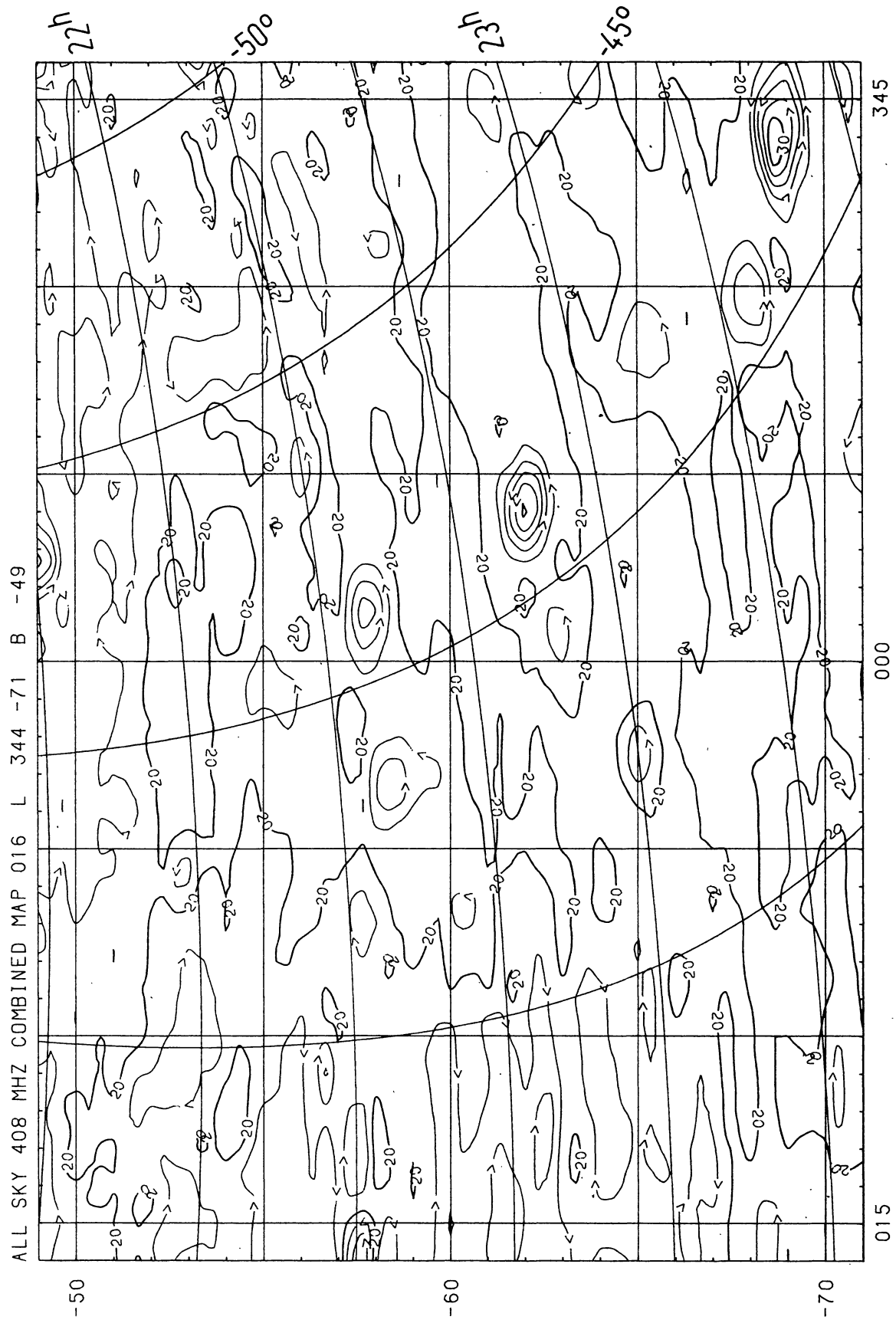

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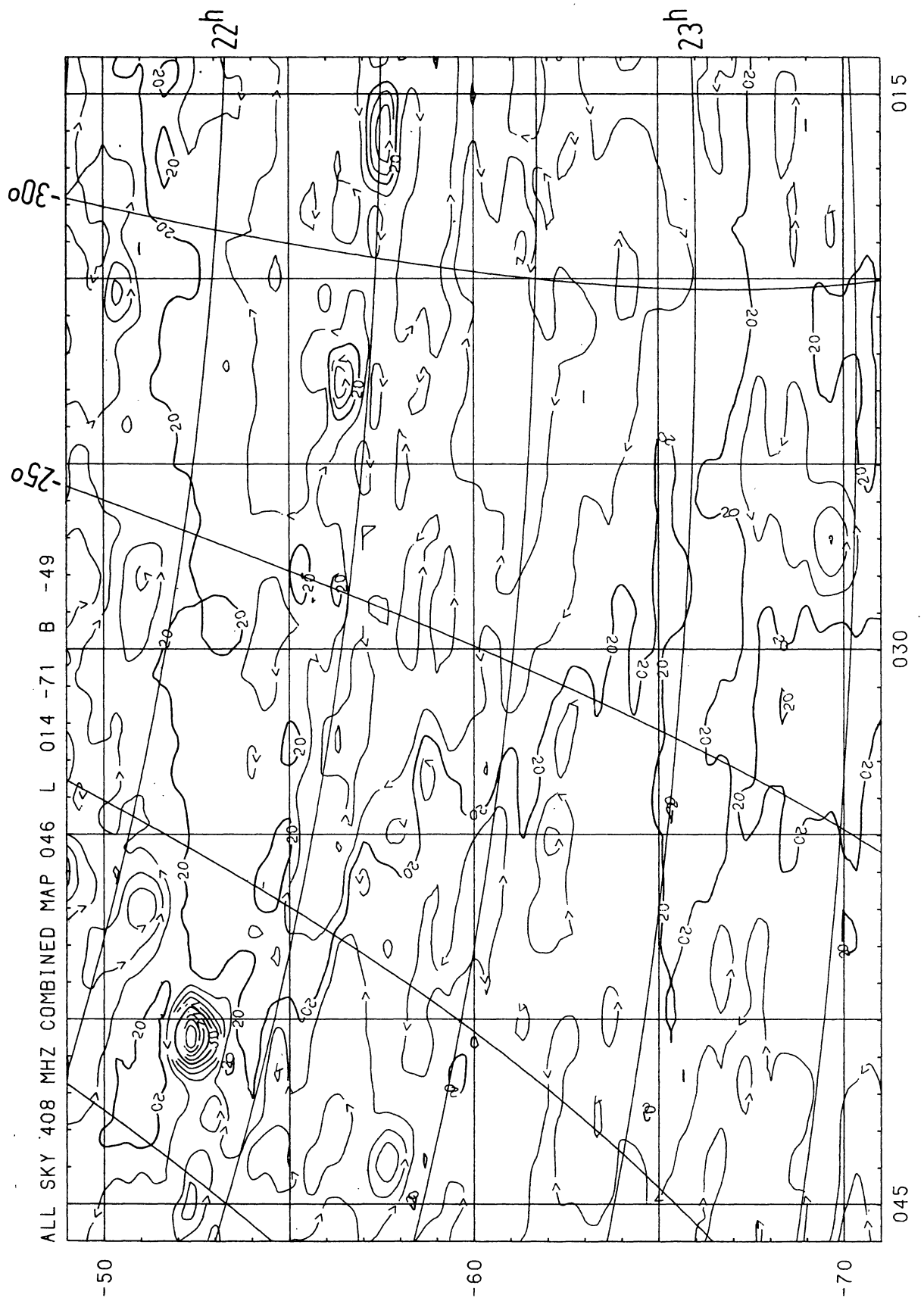

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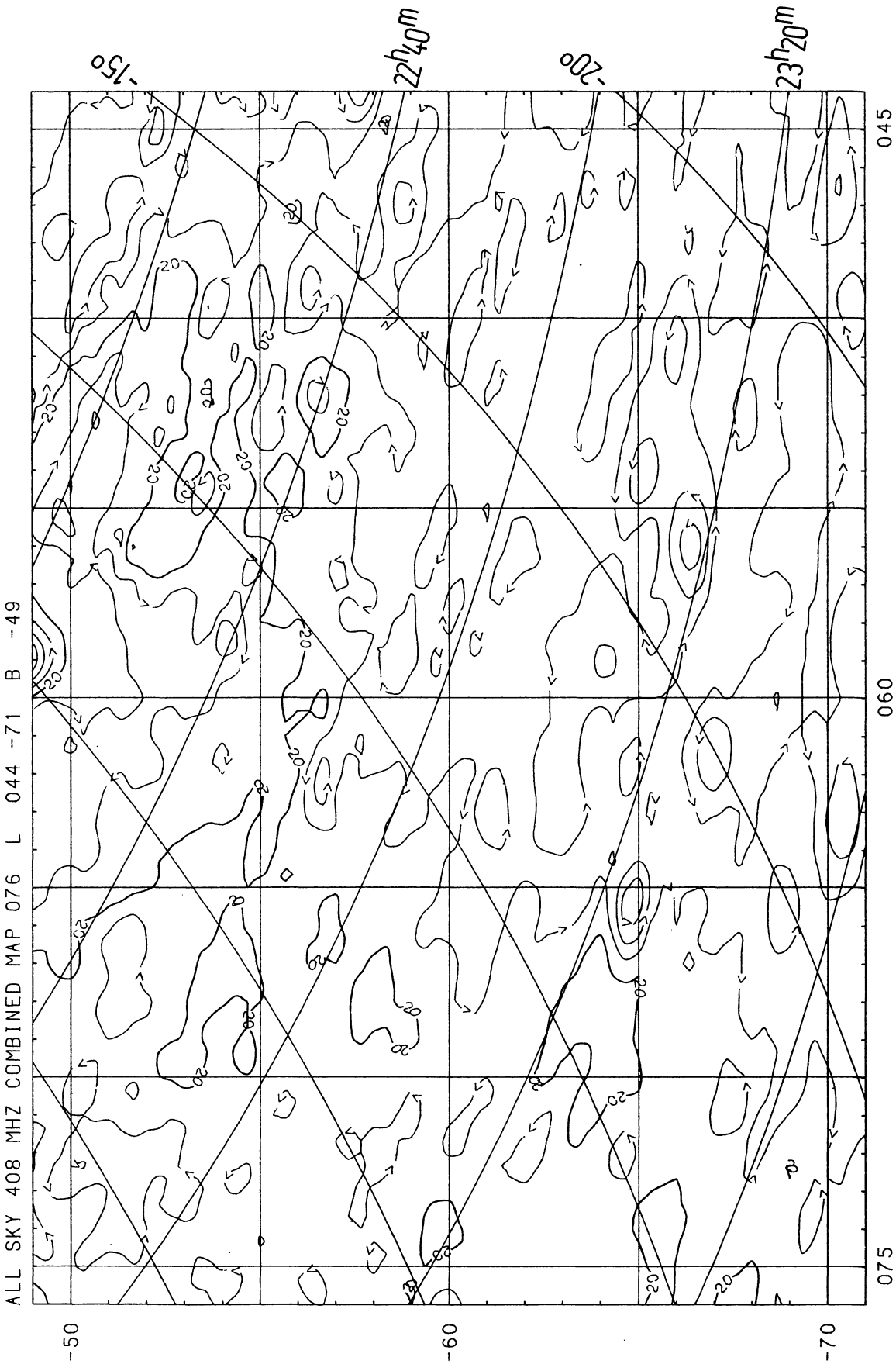

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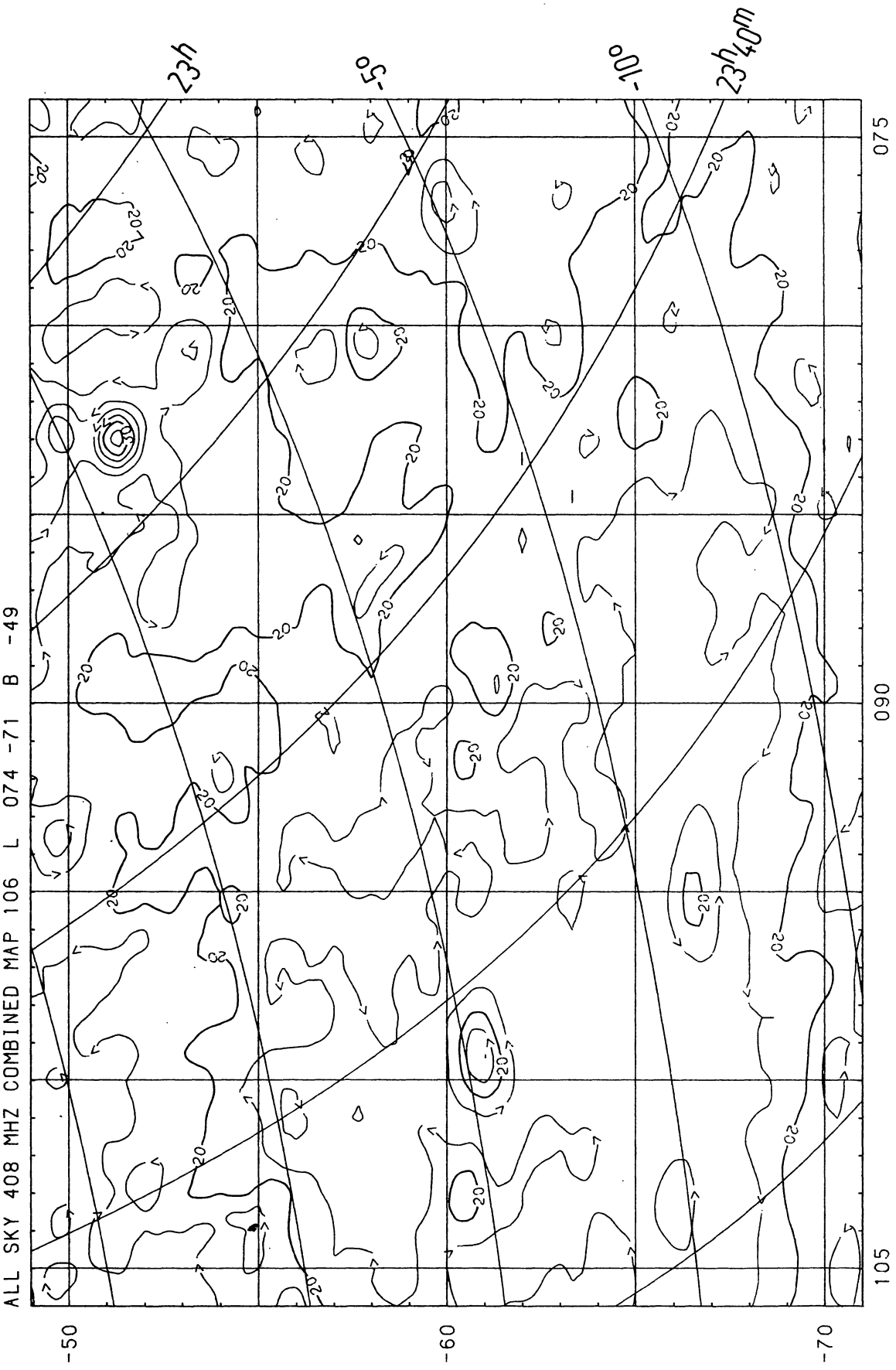

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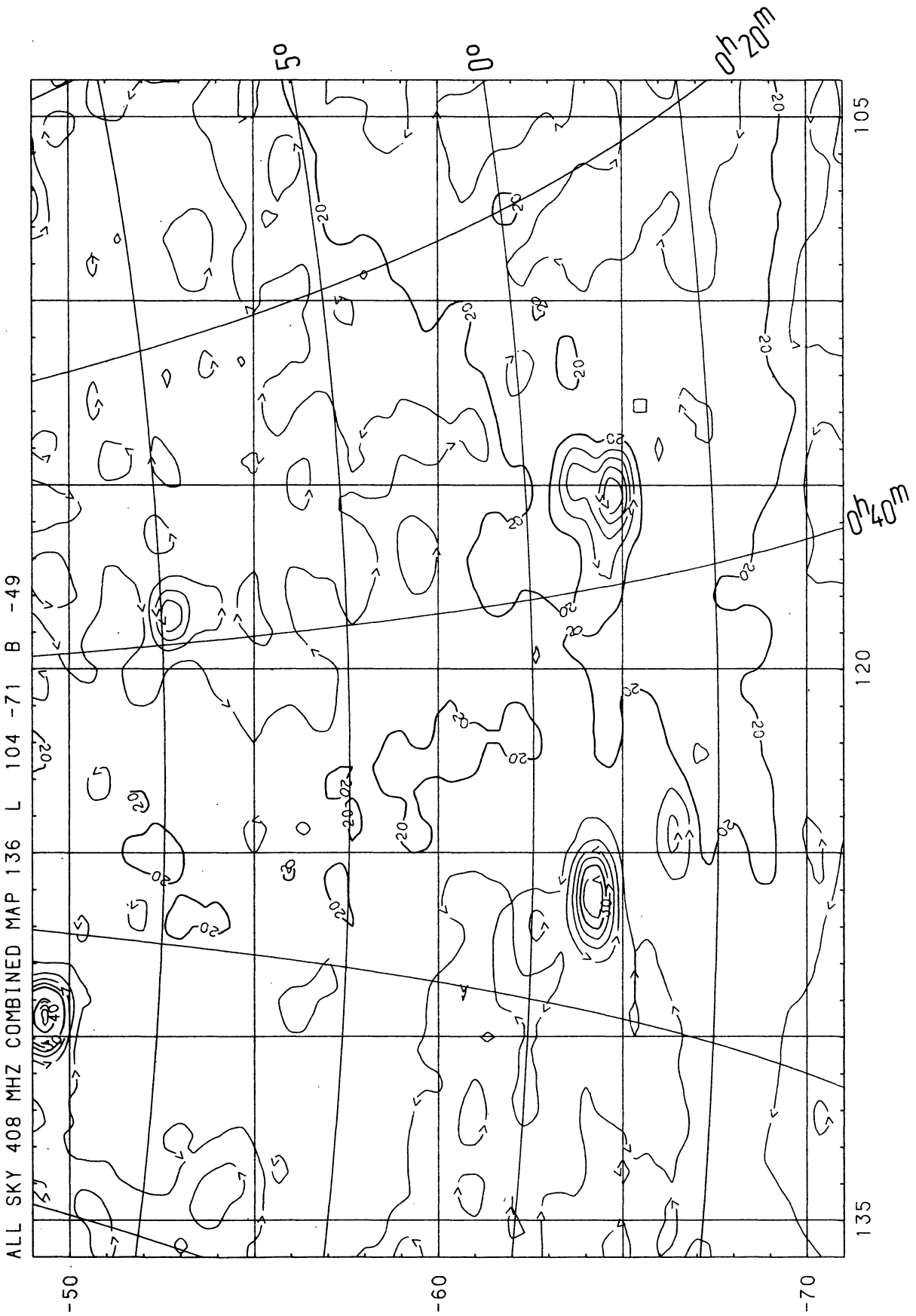

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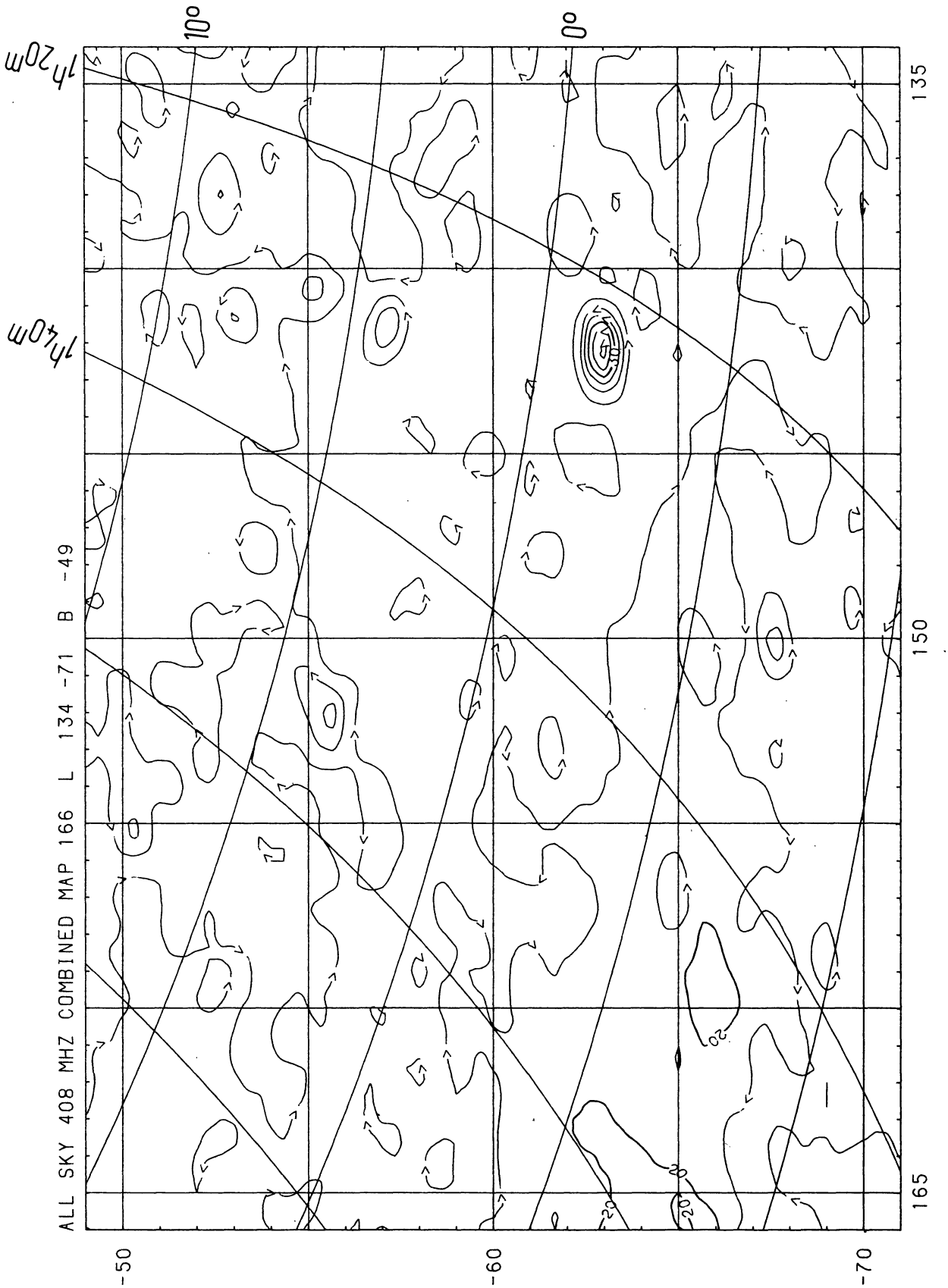

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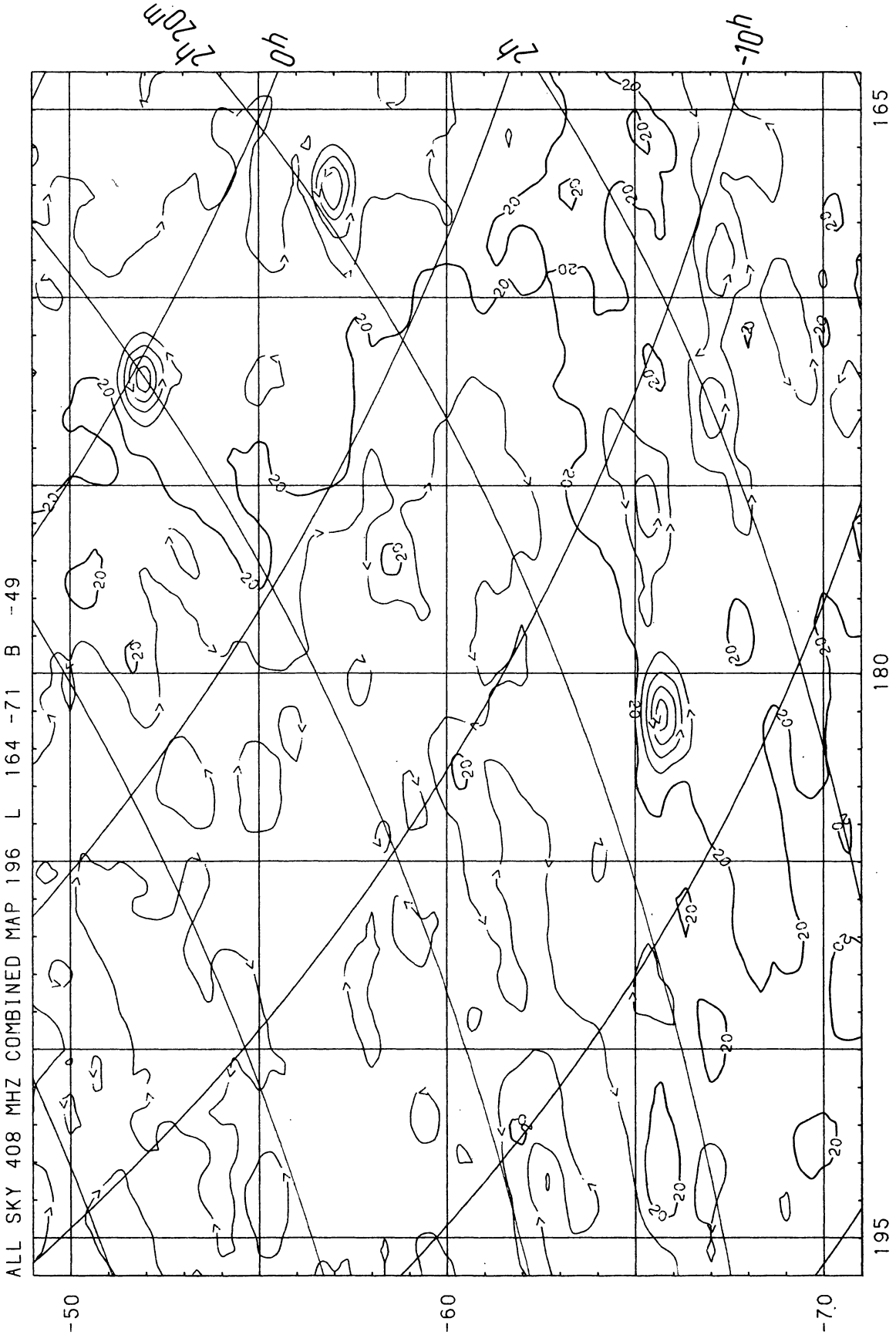

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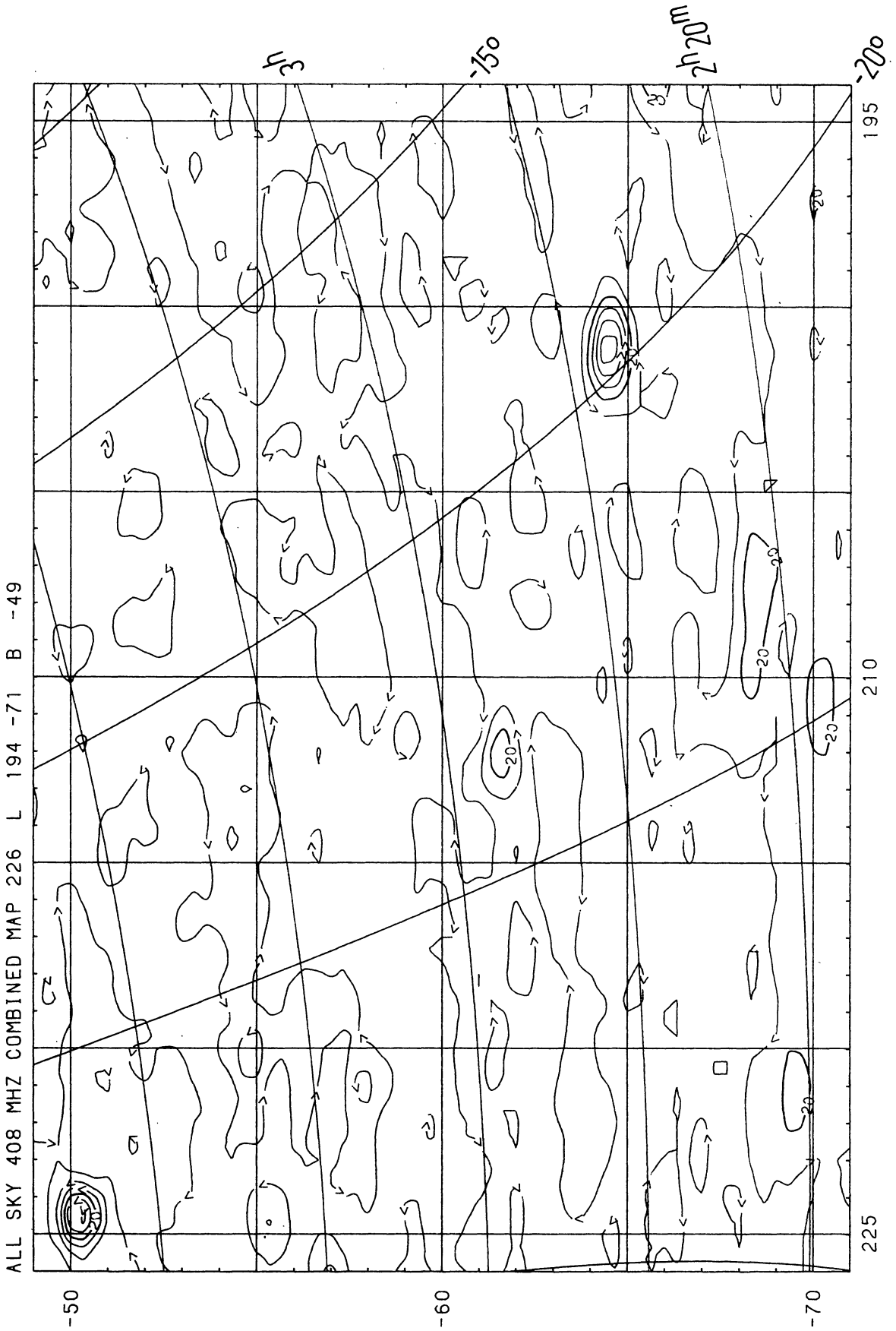

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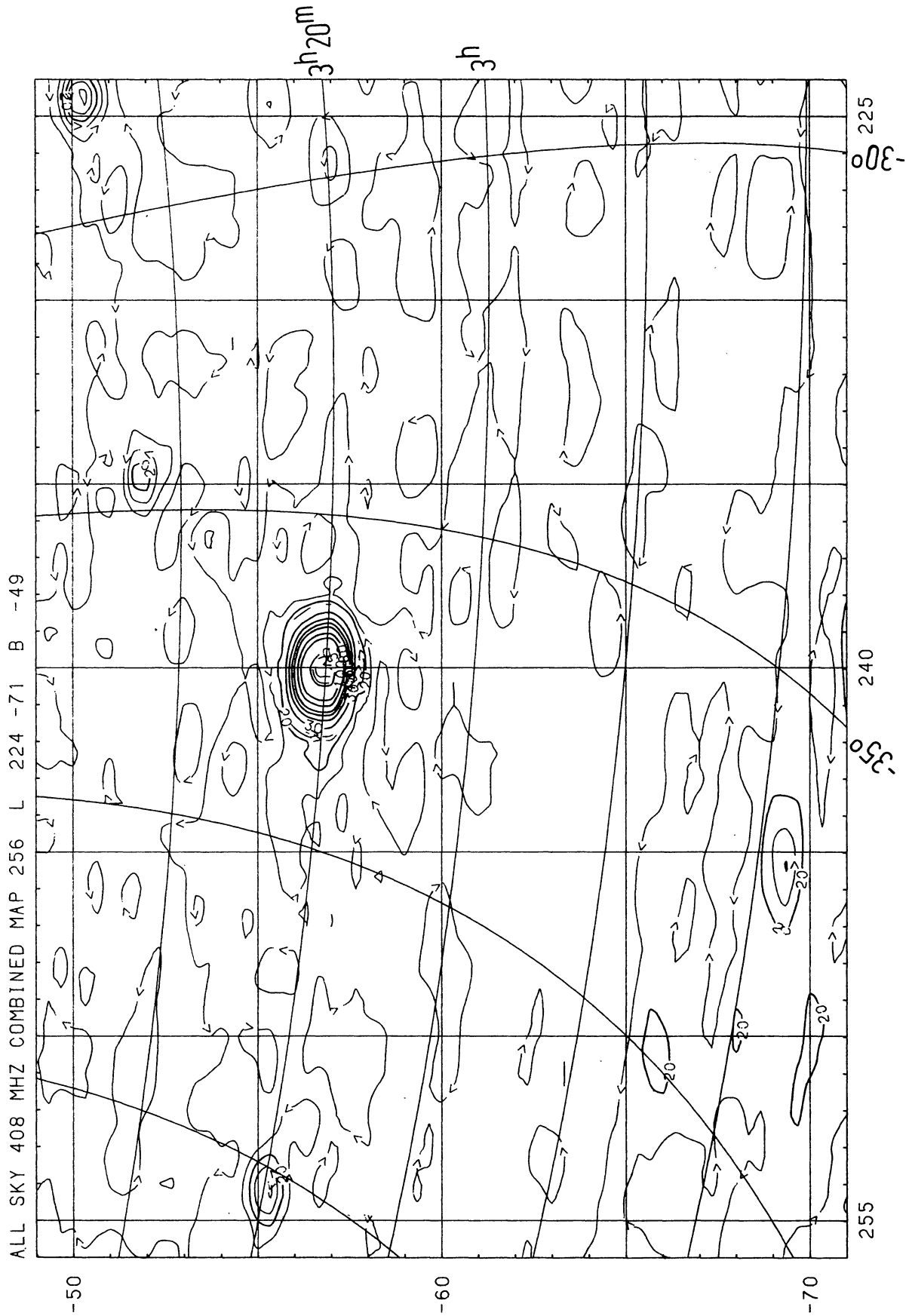

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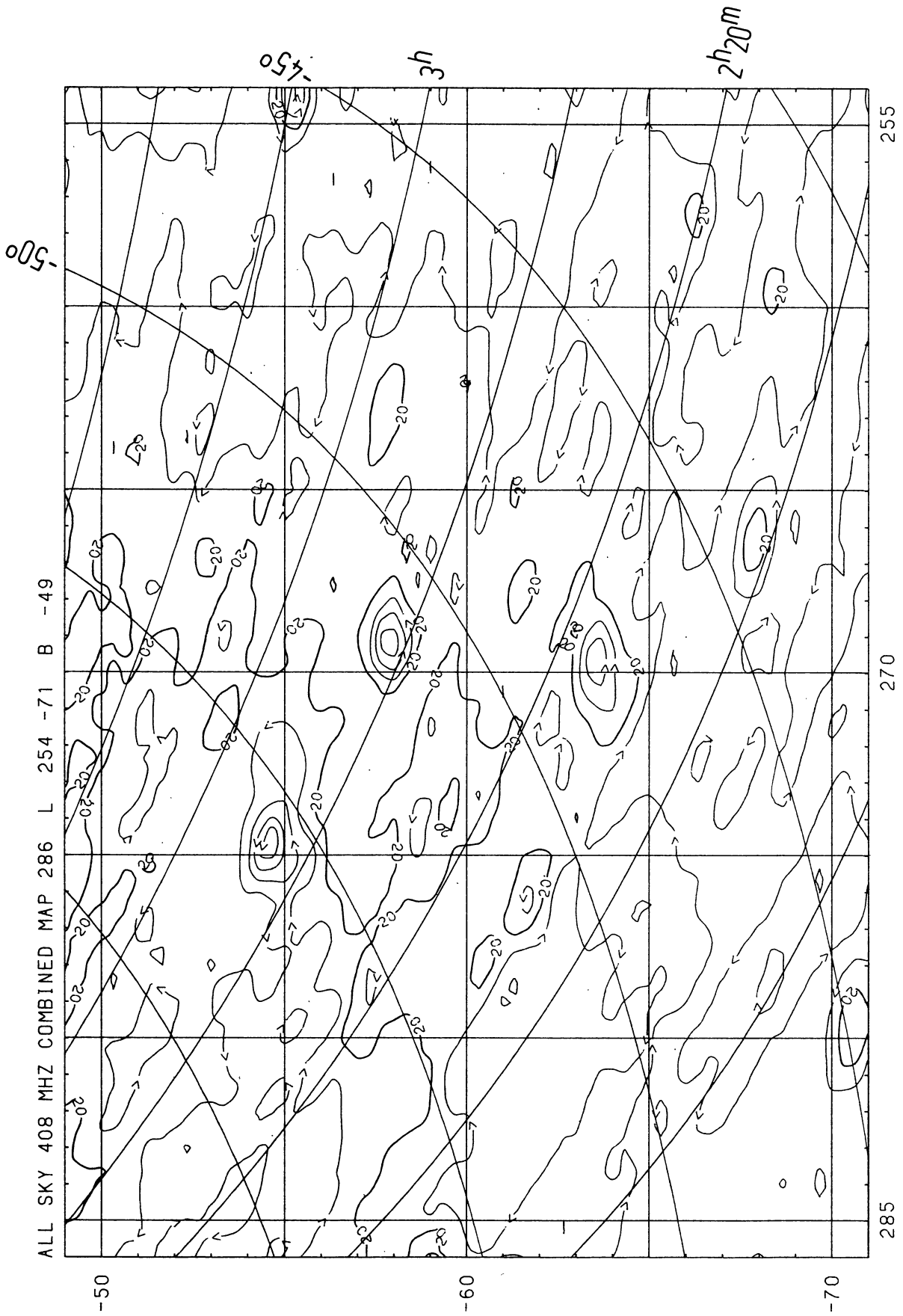

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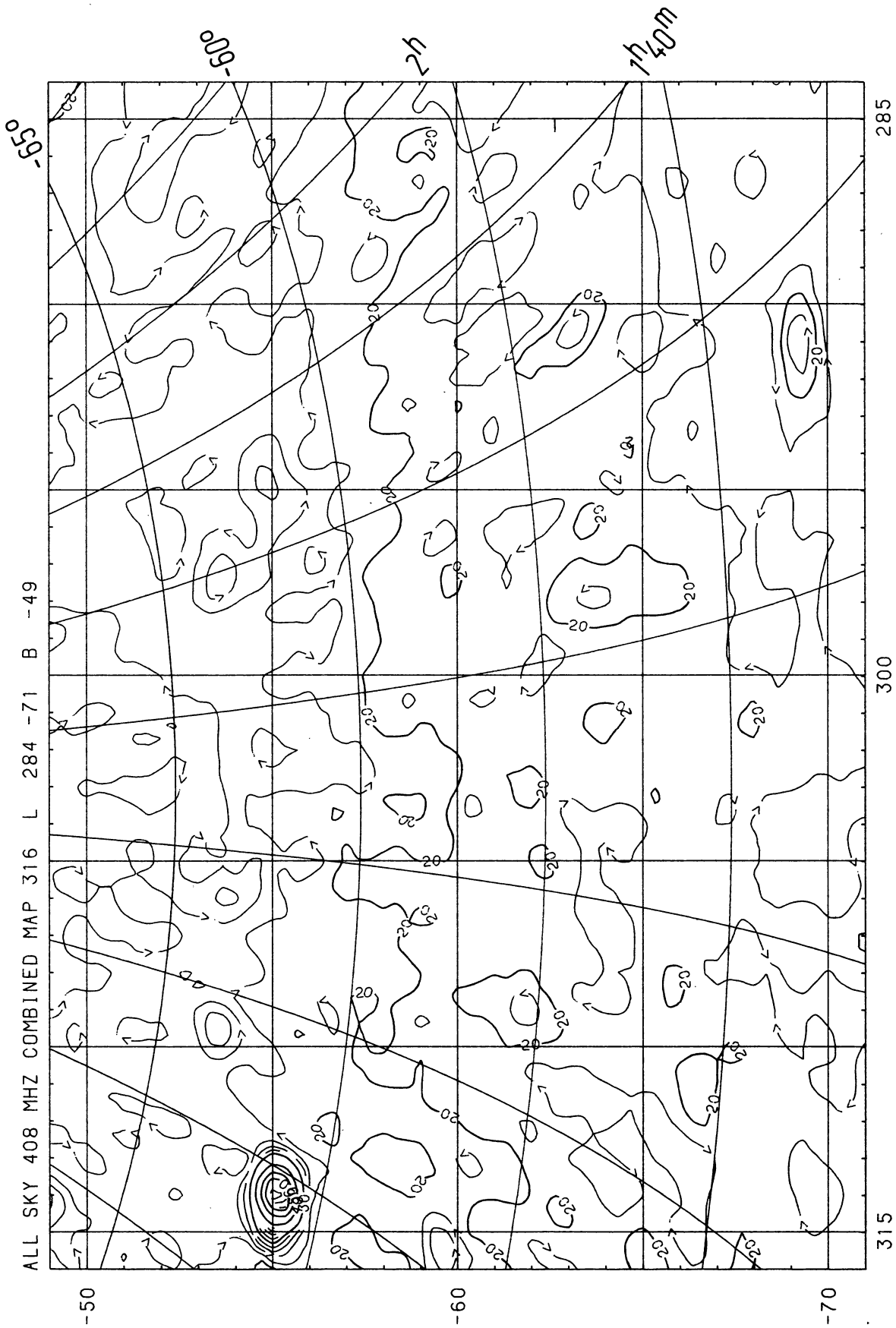

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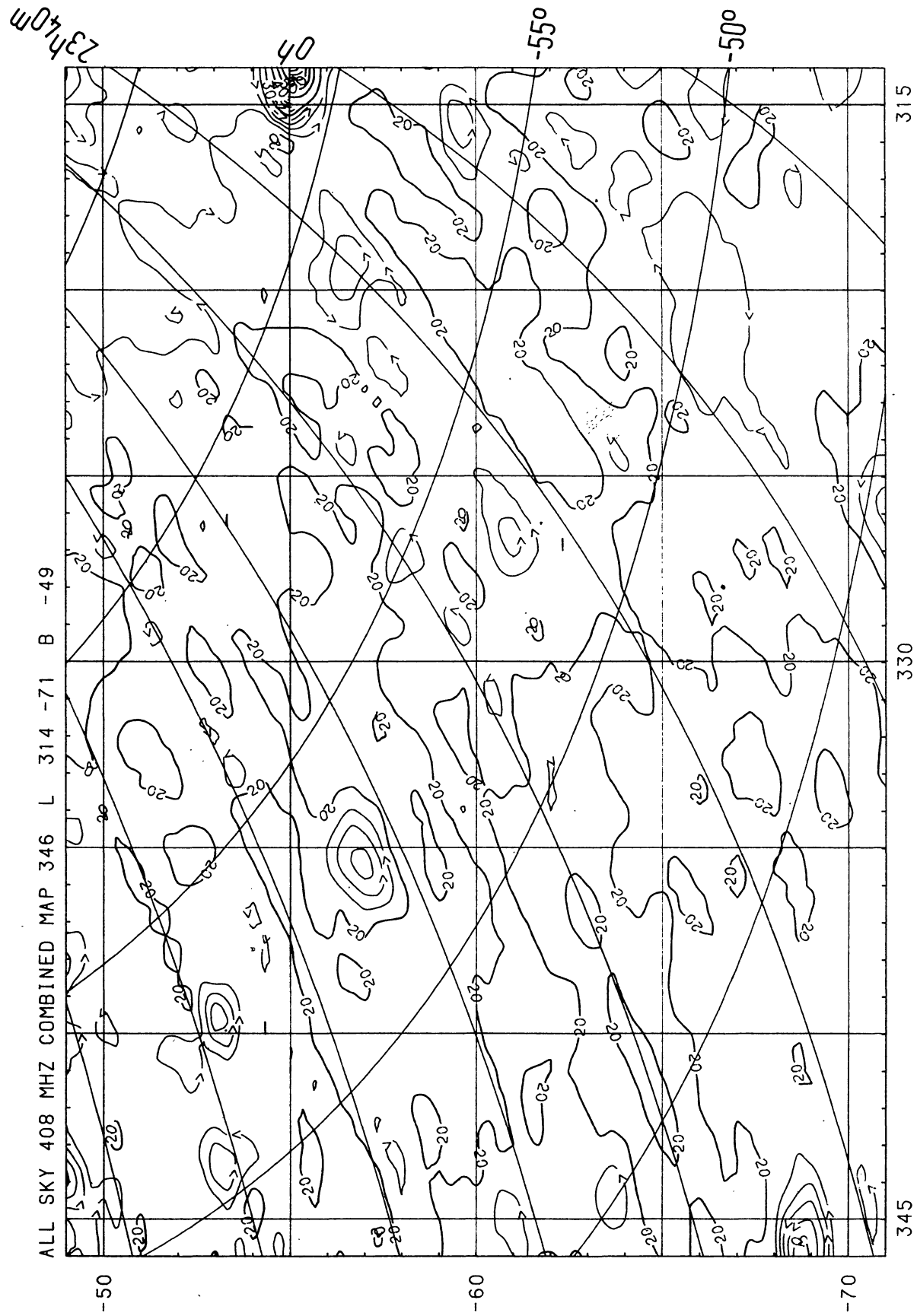

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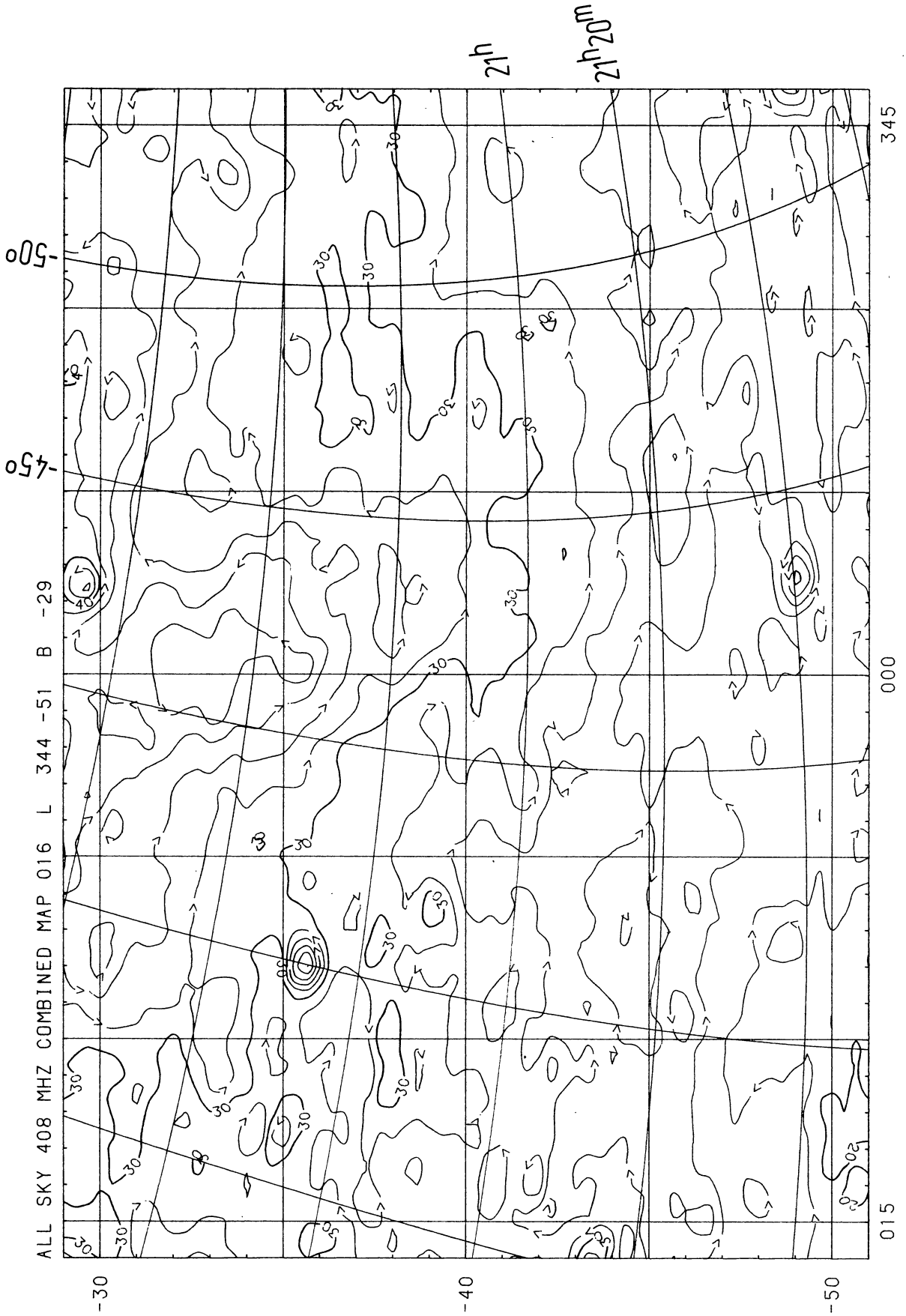

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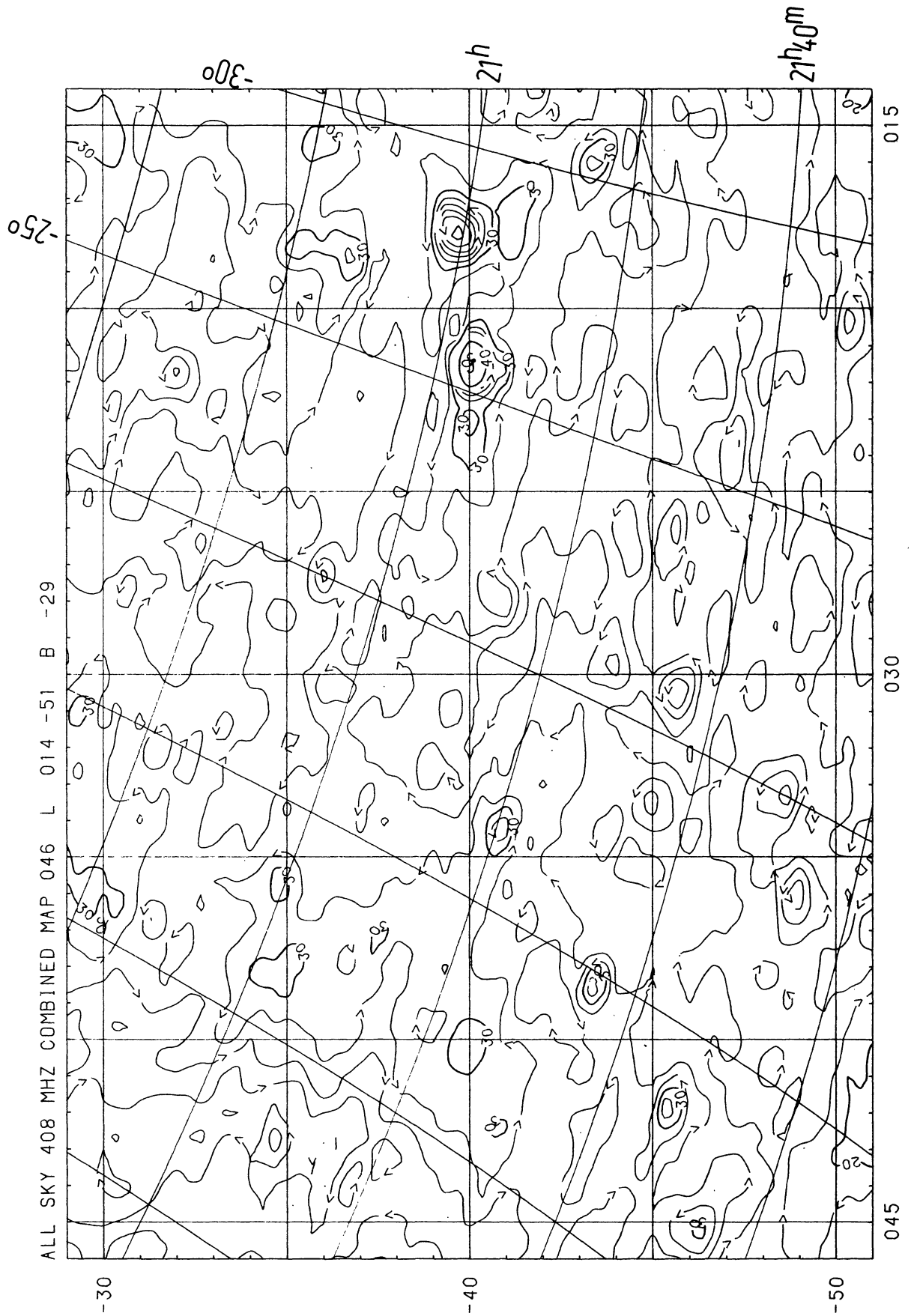

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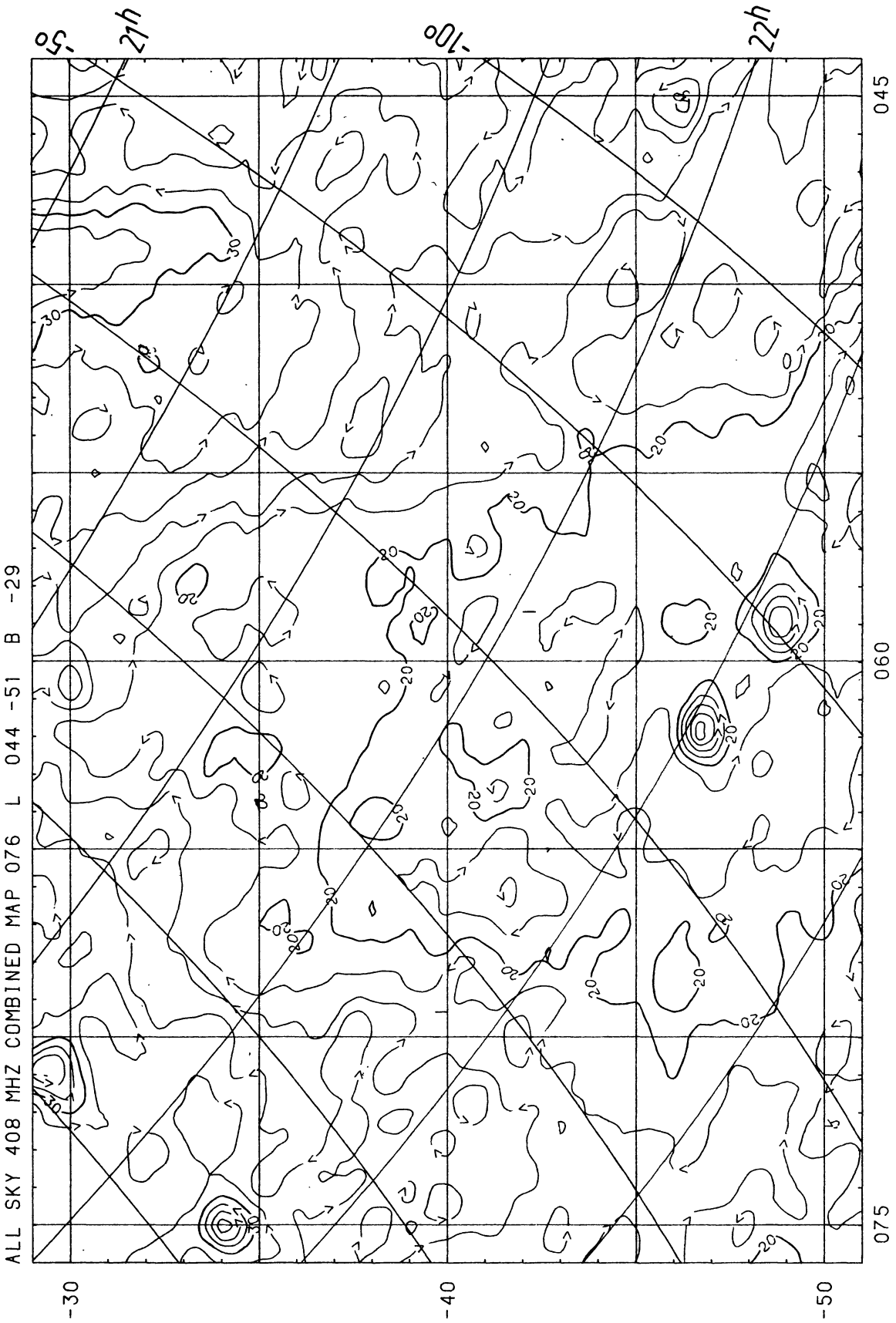

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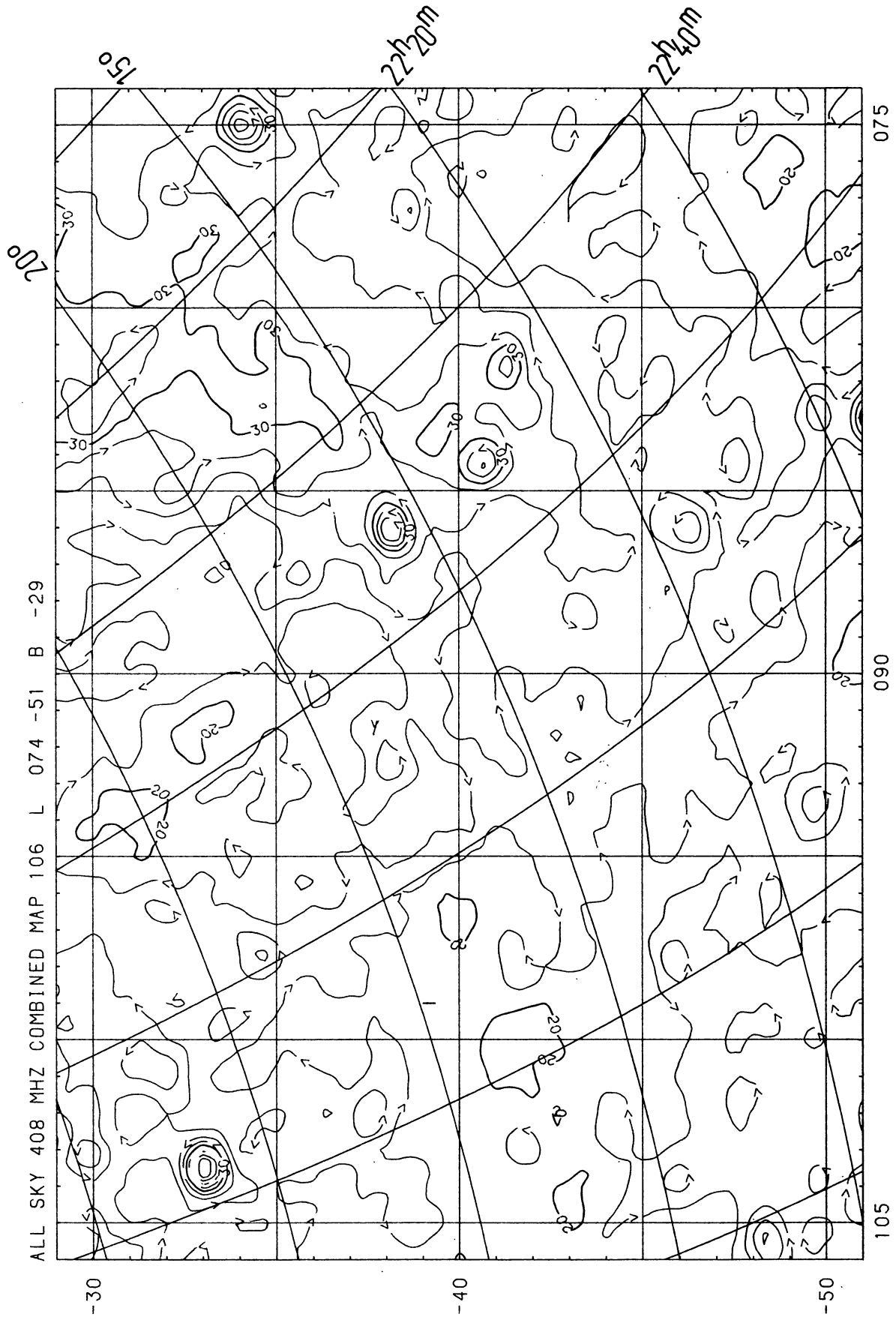

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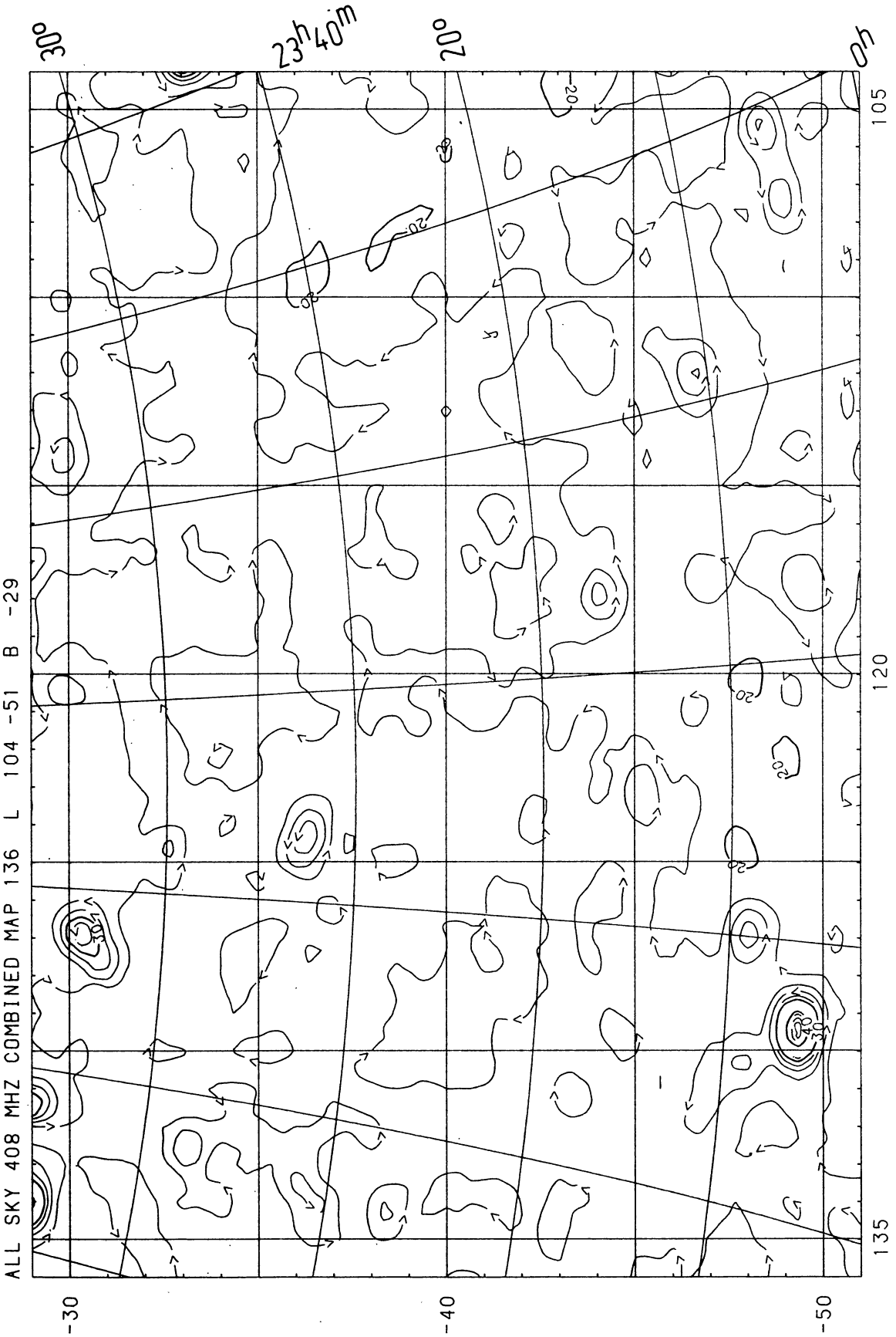

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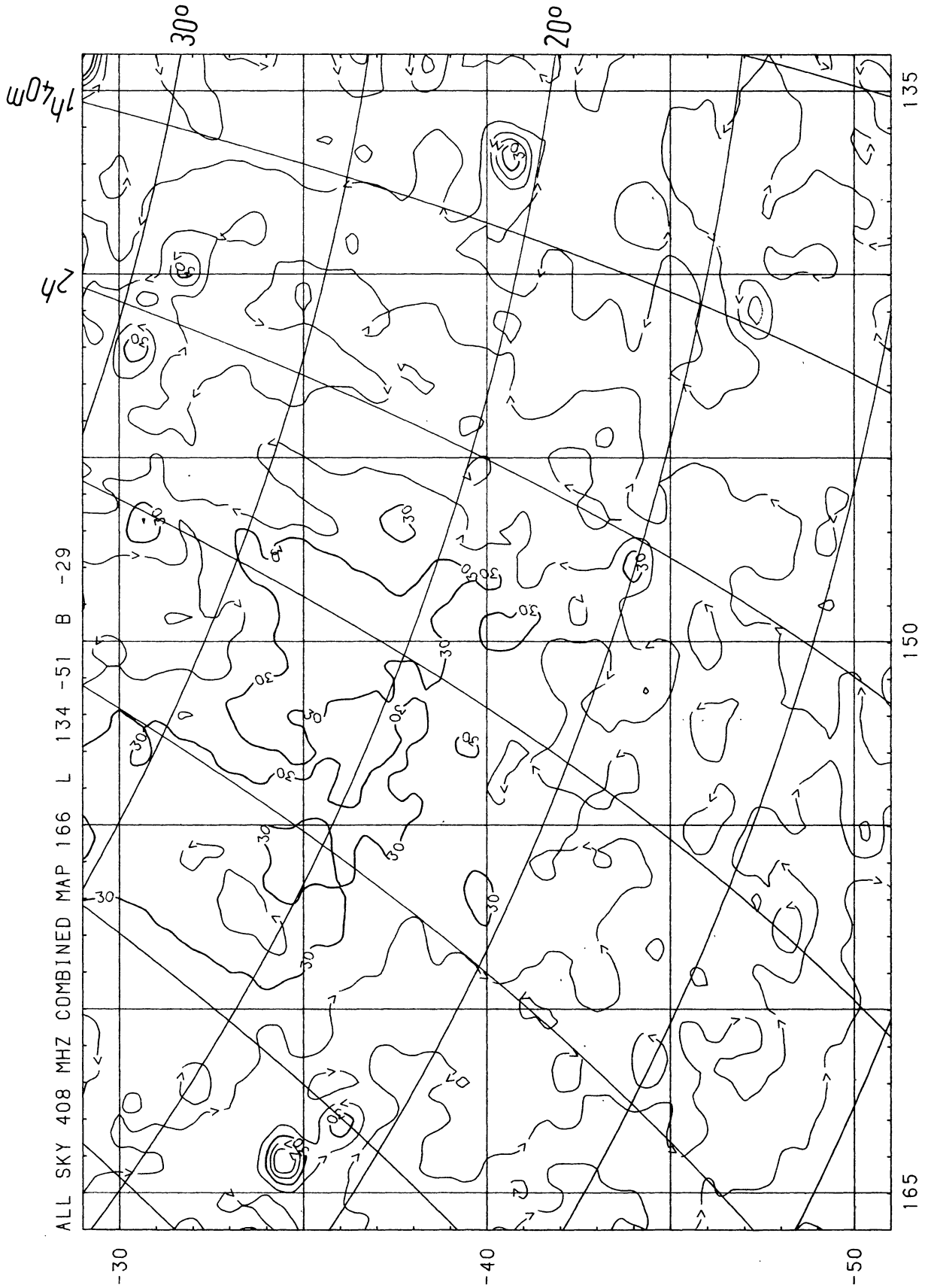

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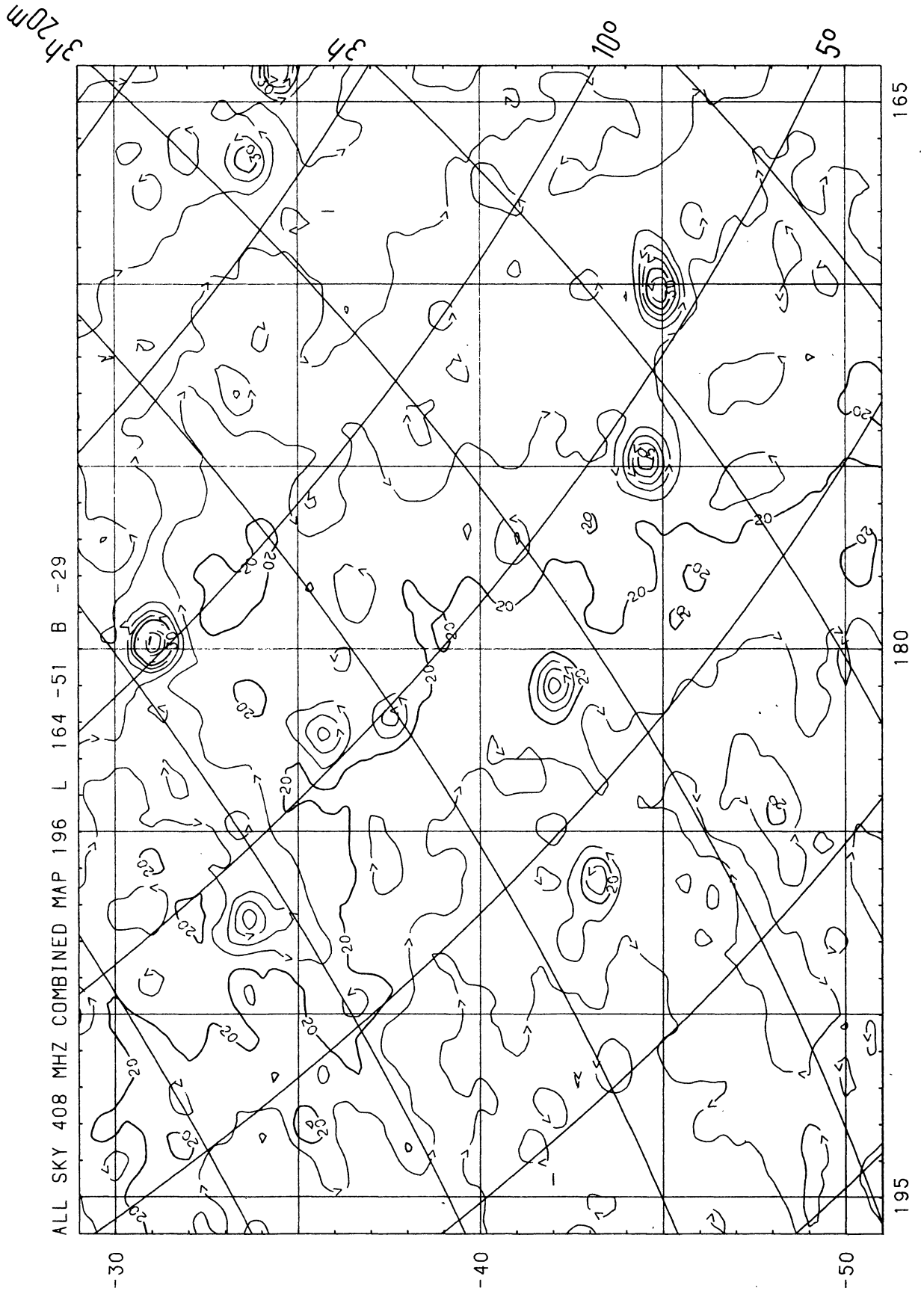

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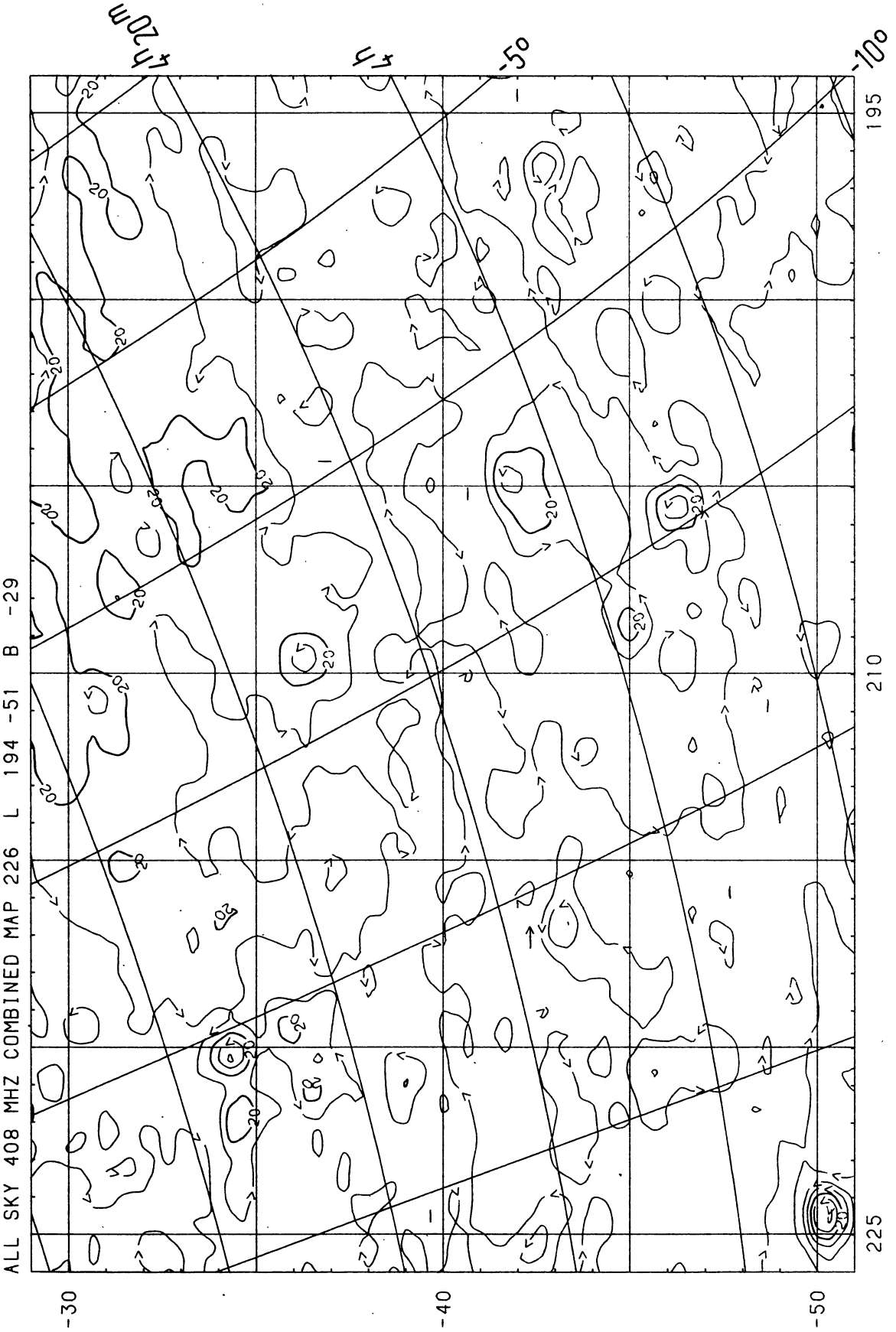

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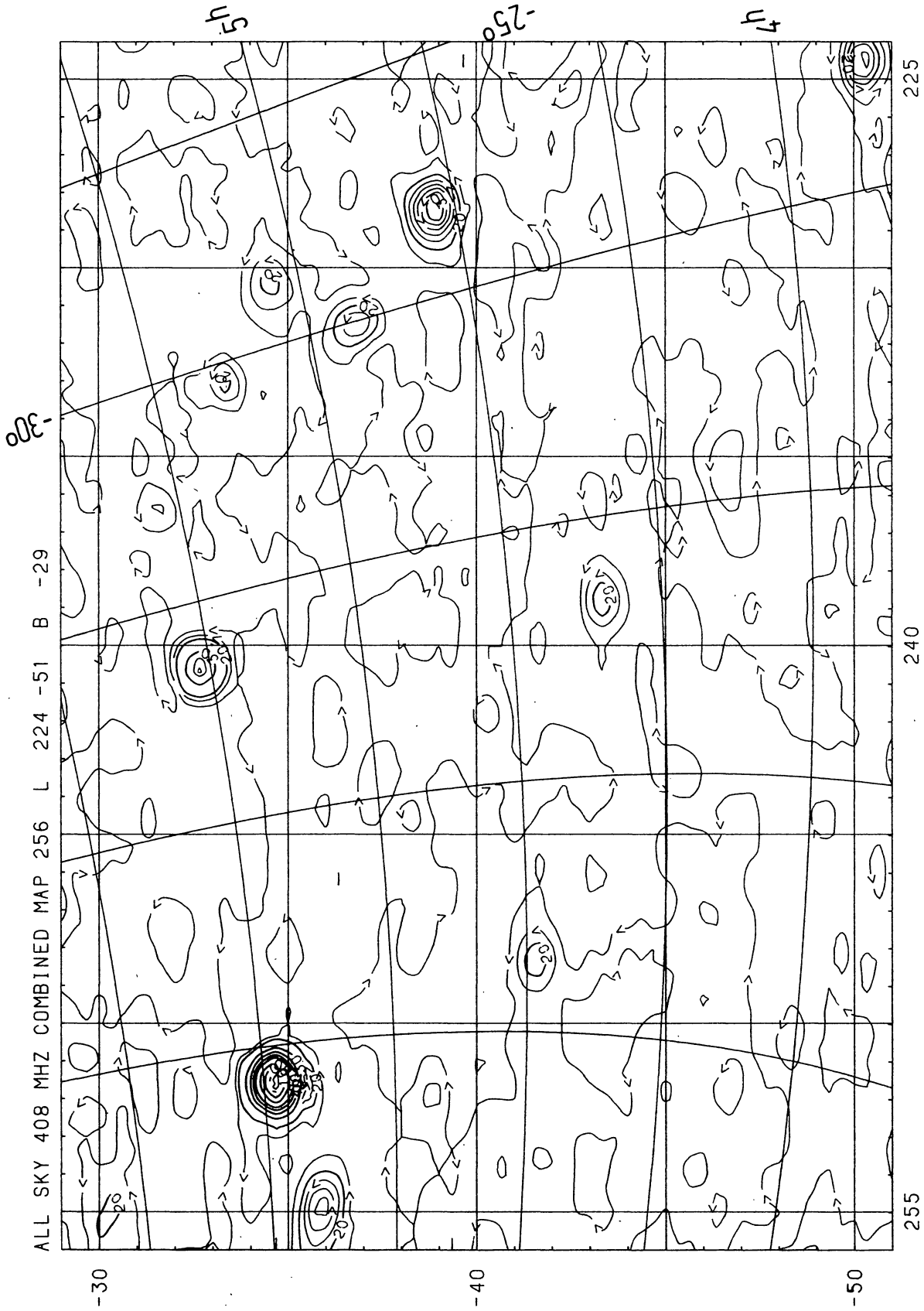

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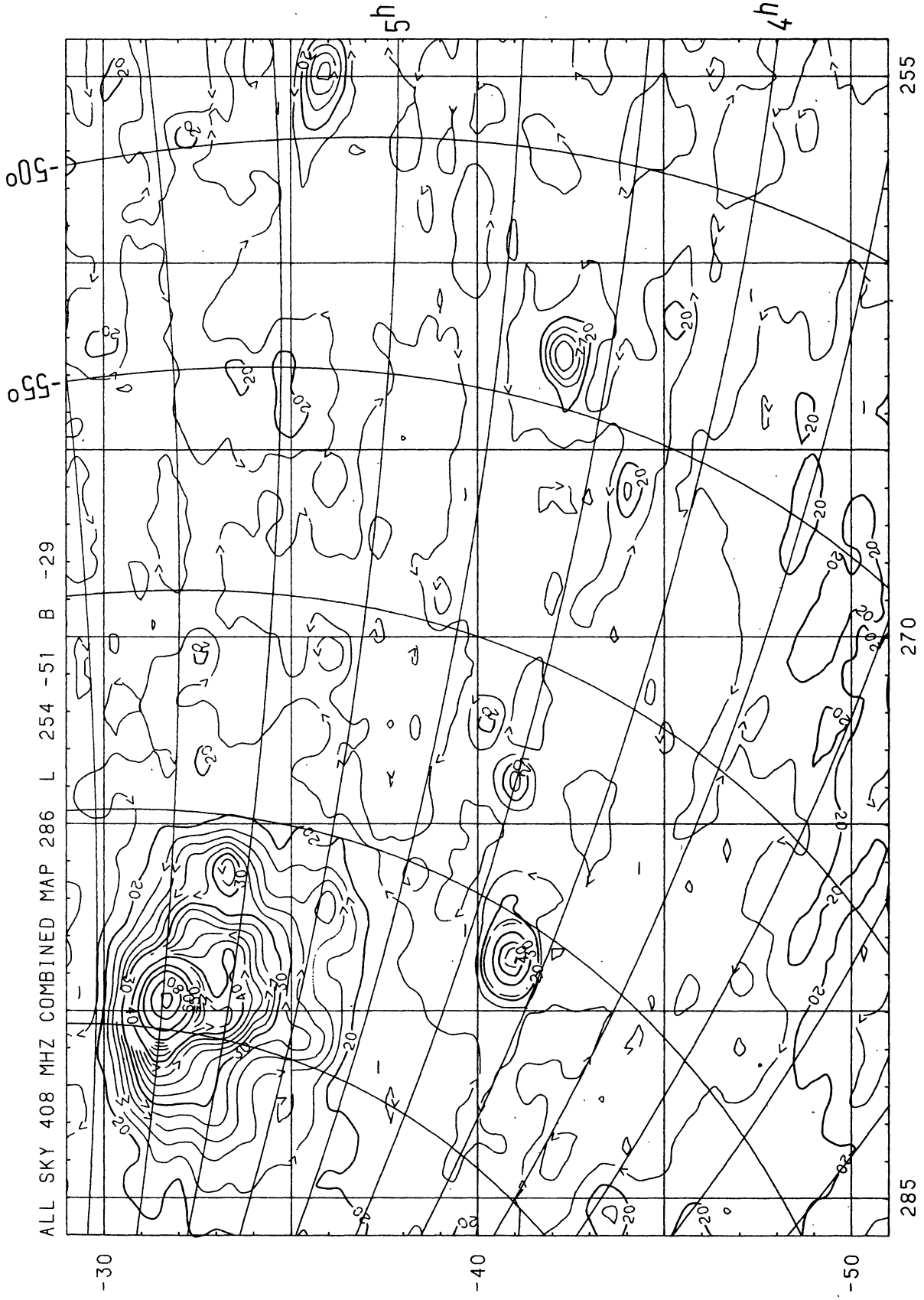

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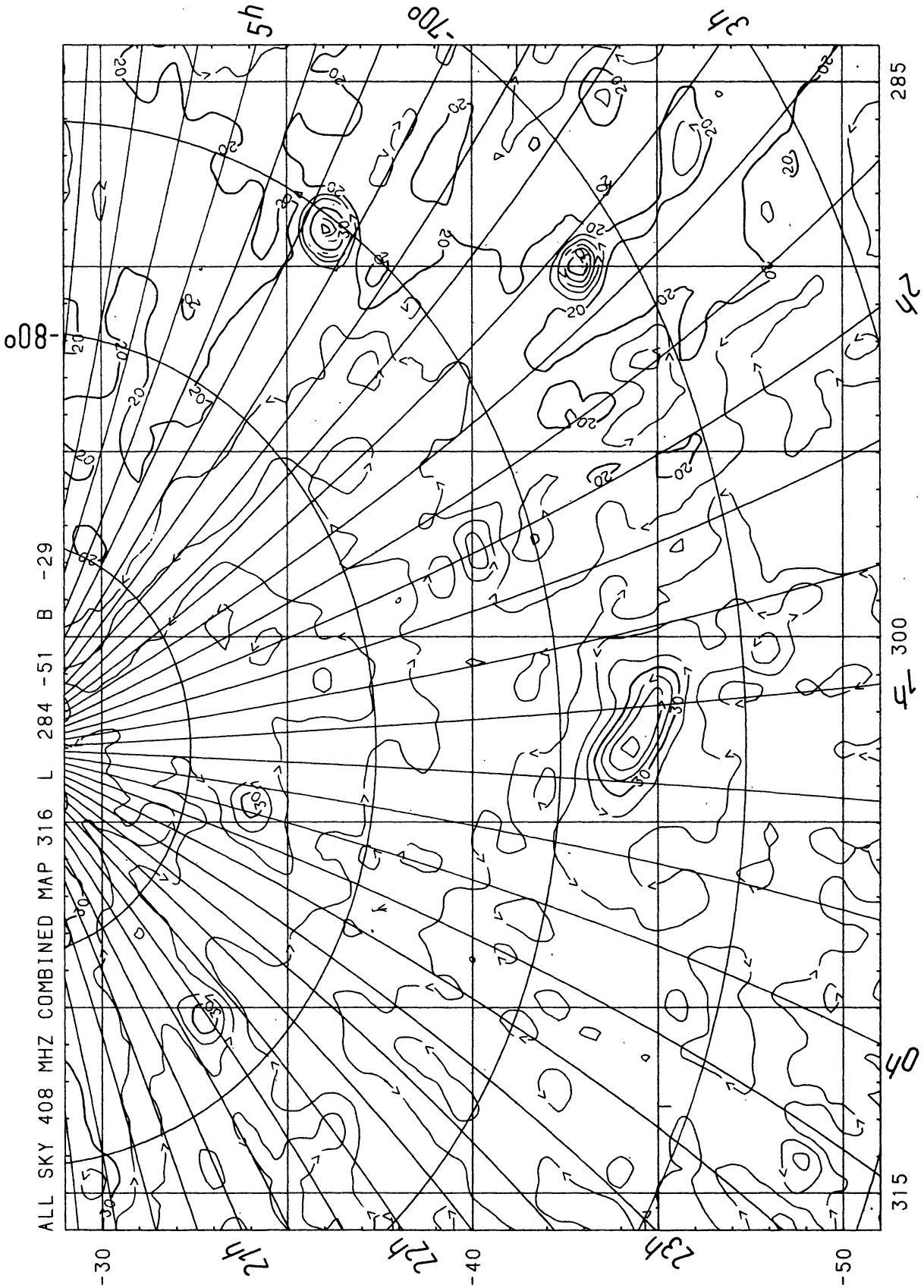

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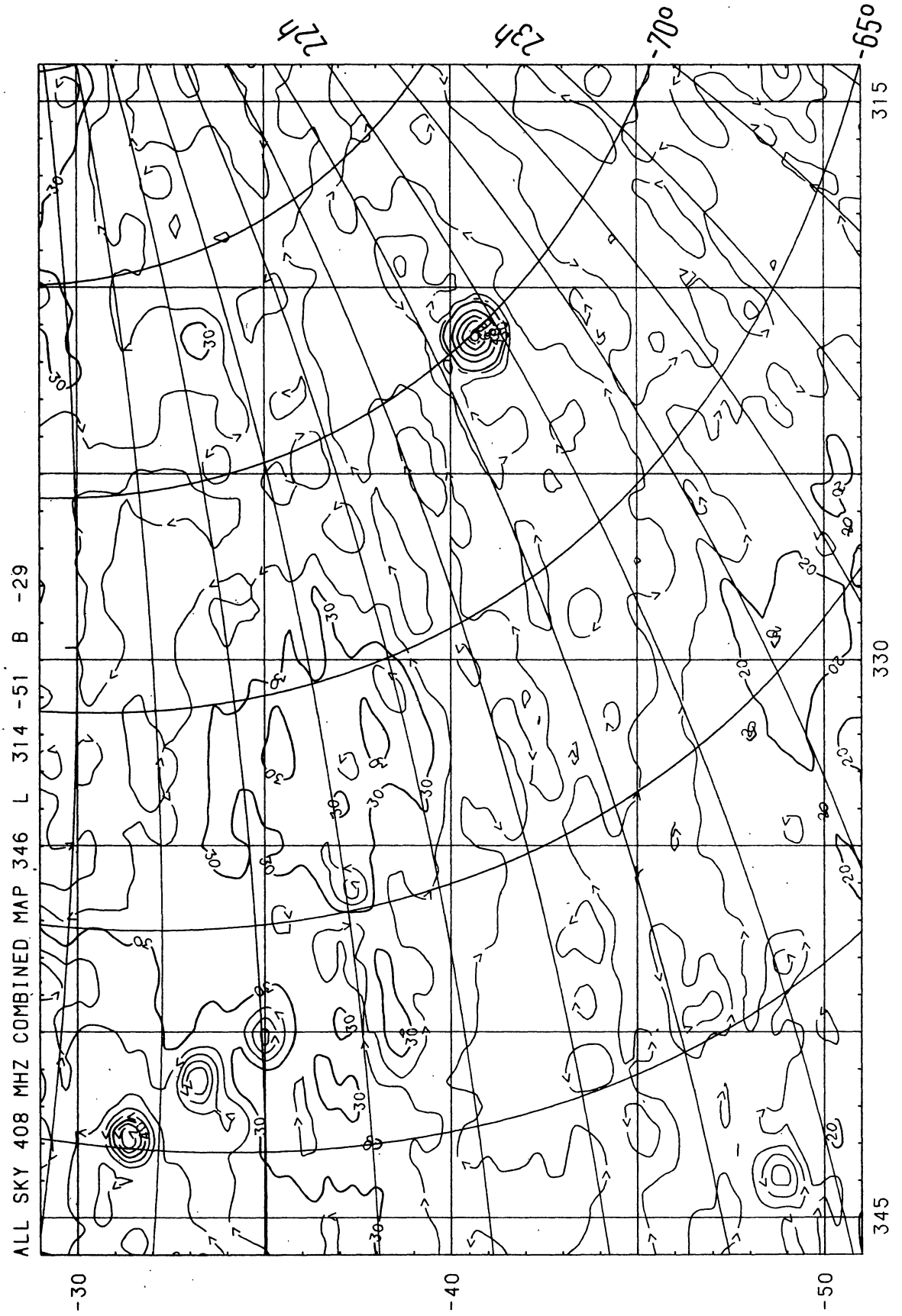

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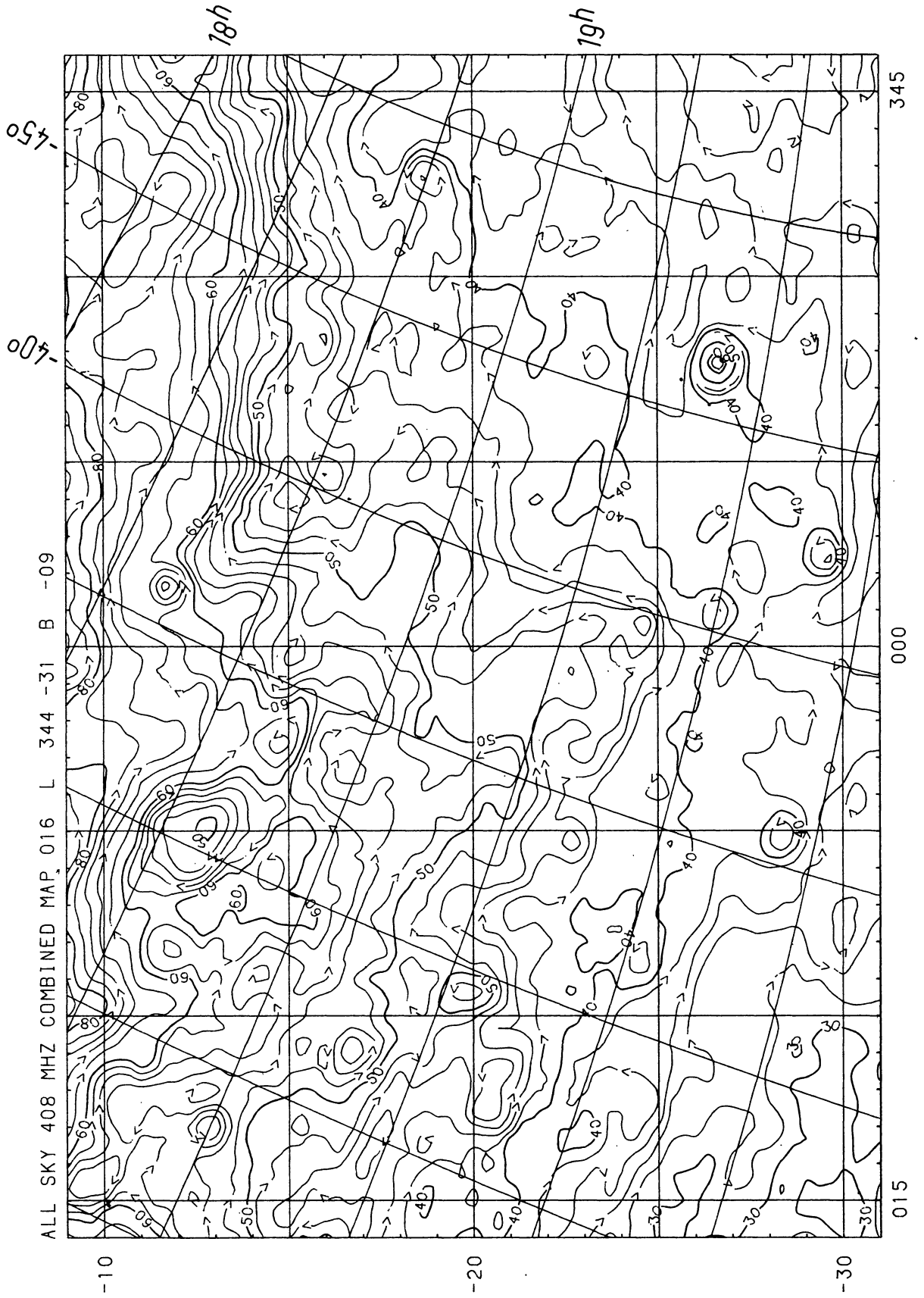

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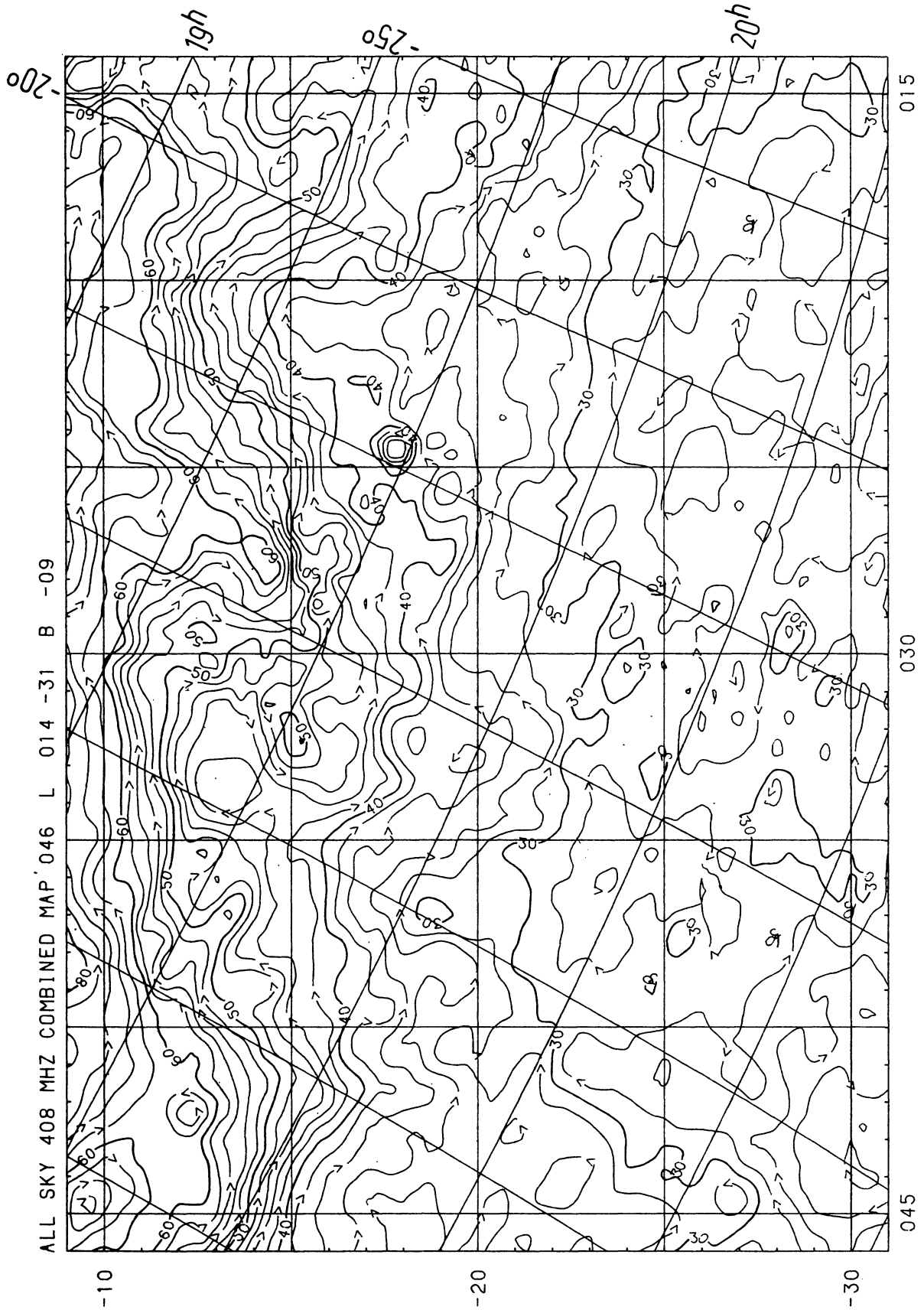

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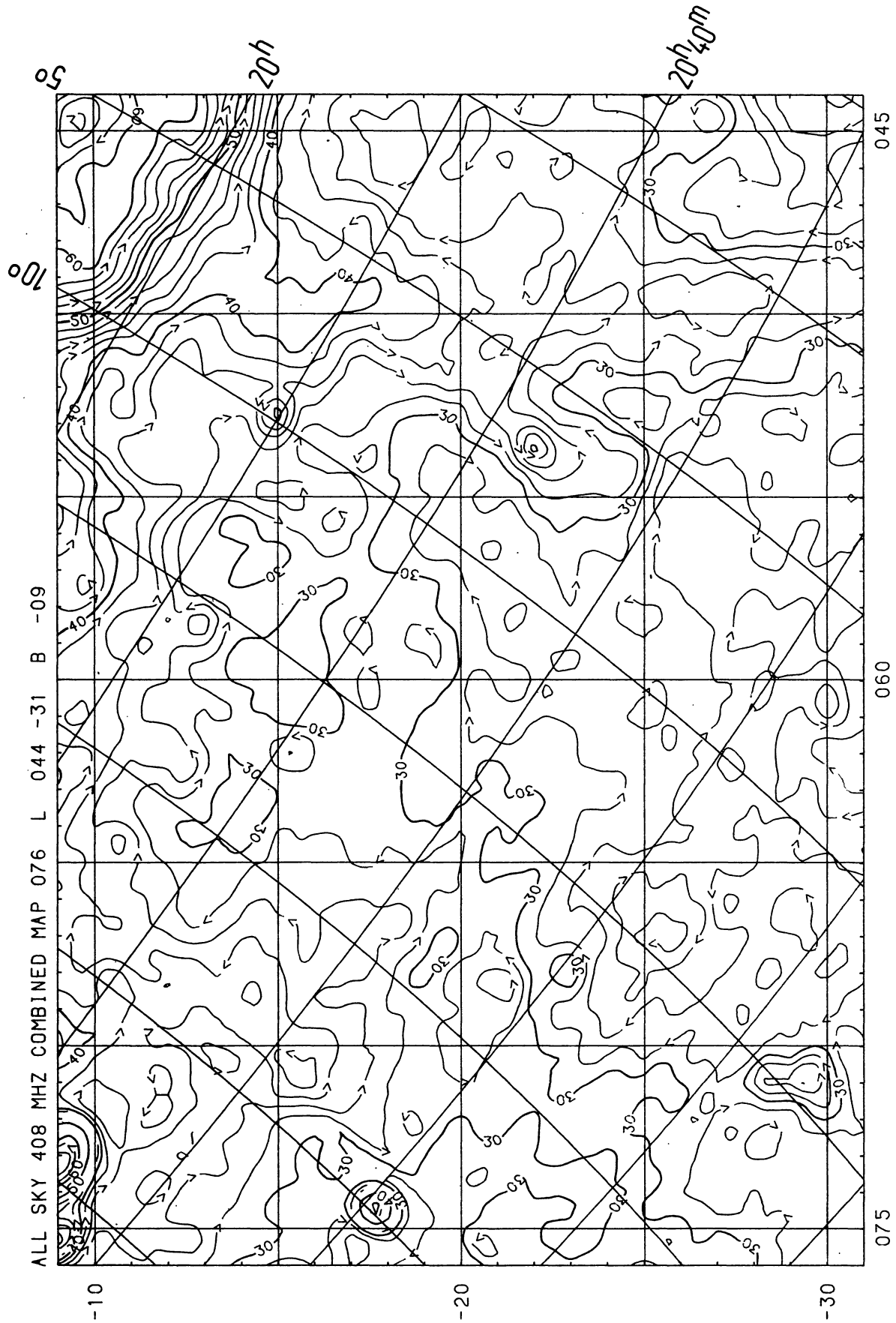

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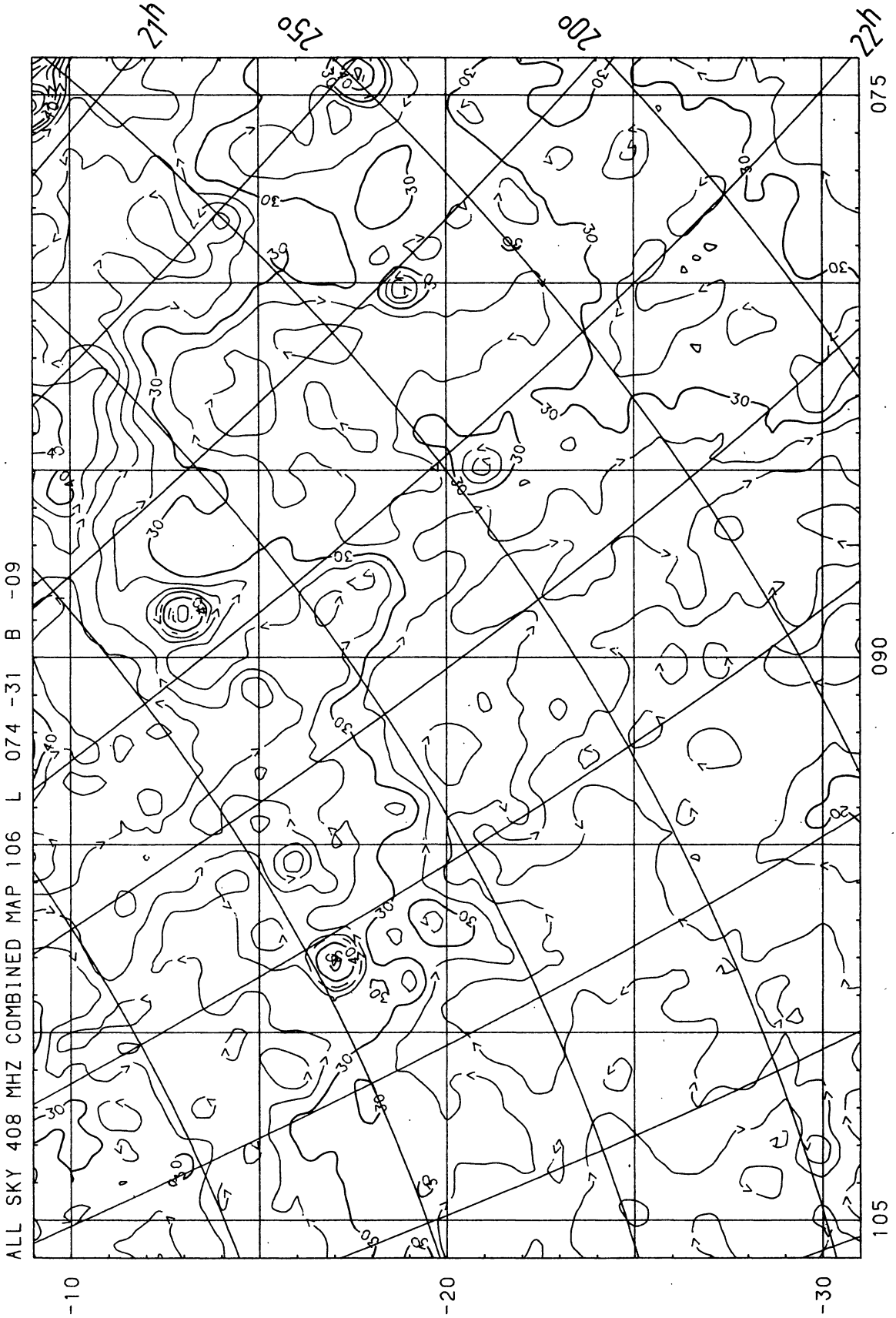

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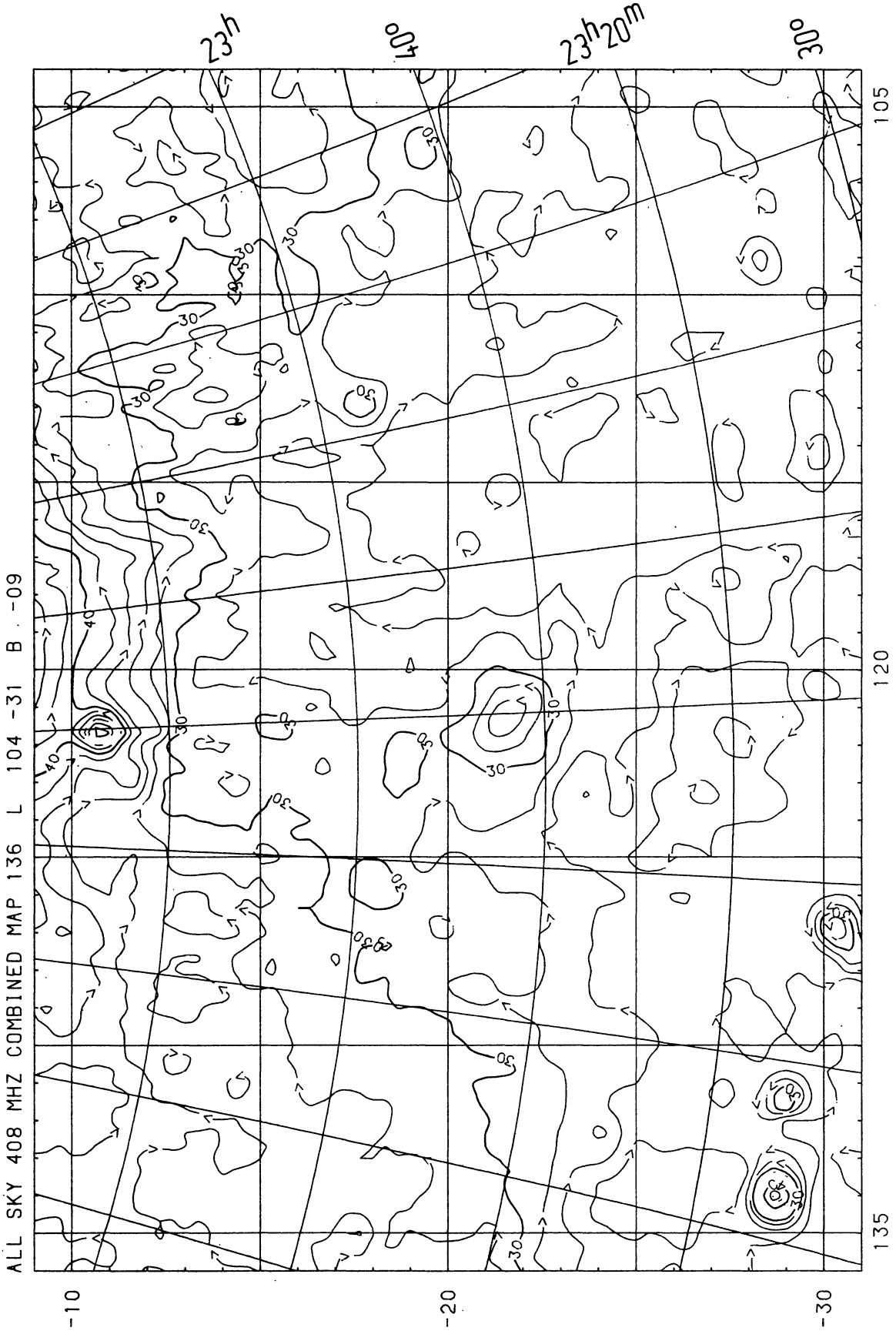

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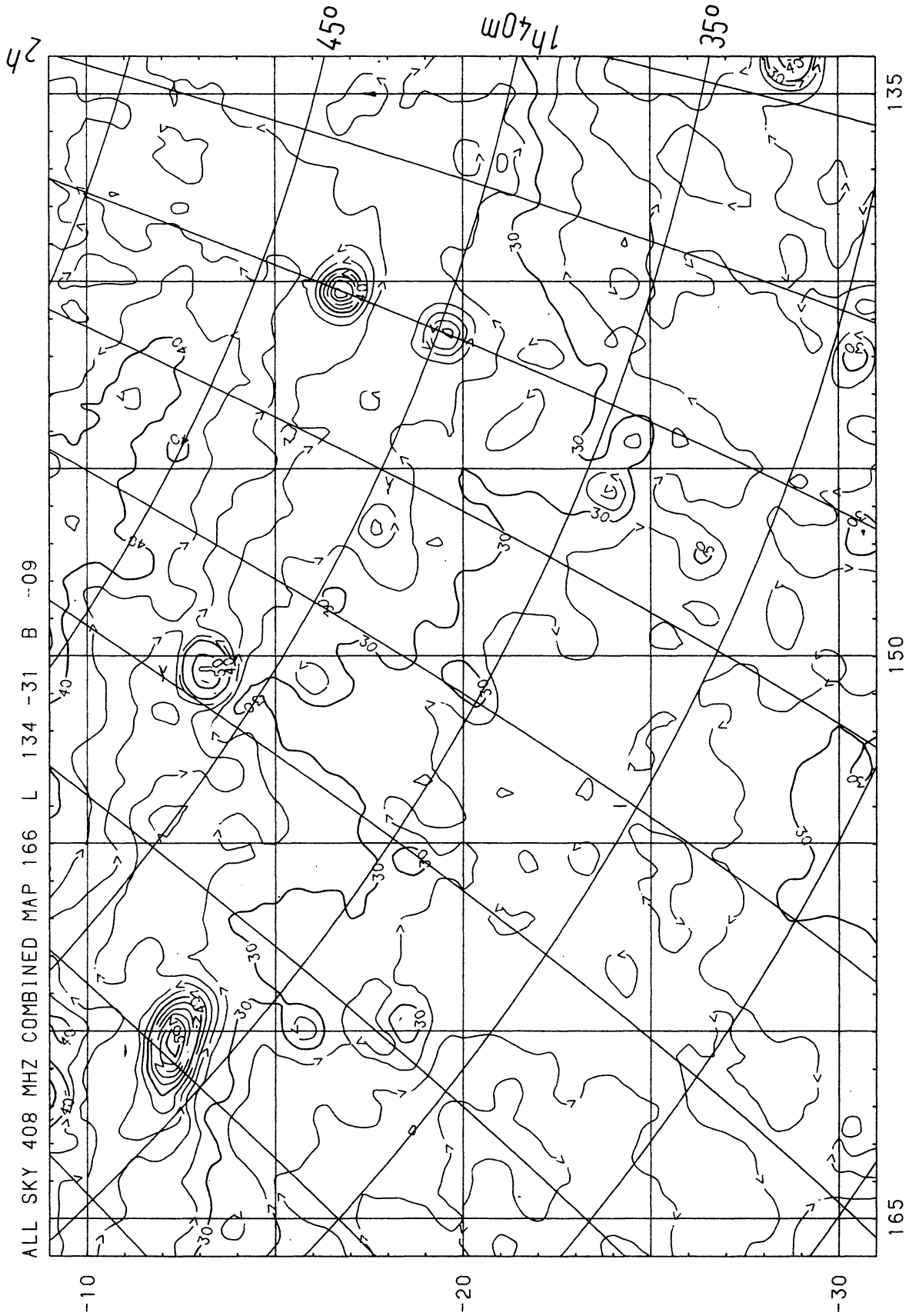

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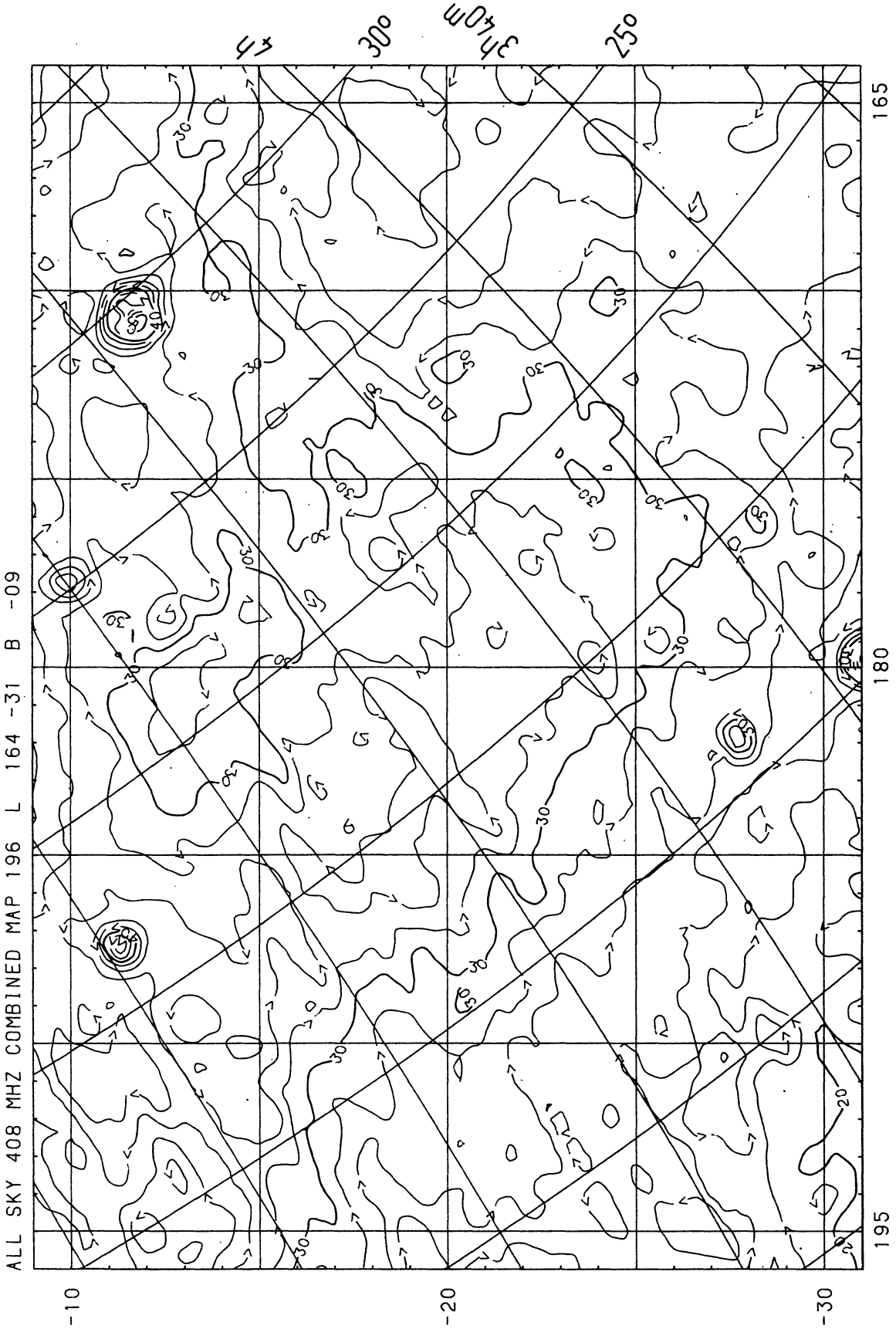
ALL SKY 408 MHZ COMBINED MAP 196 L 164 -31 B -09
165
180
195
-10
-20
-30
30
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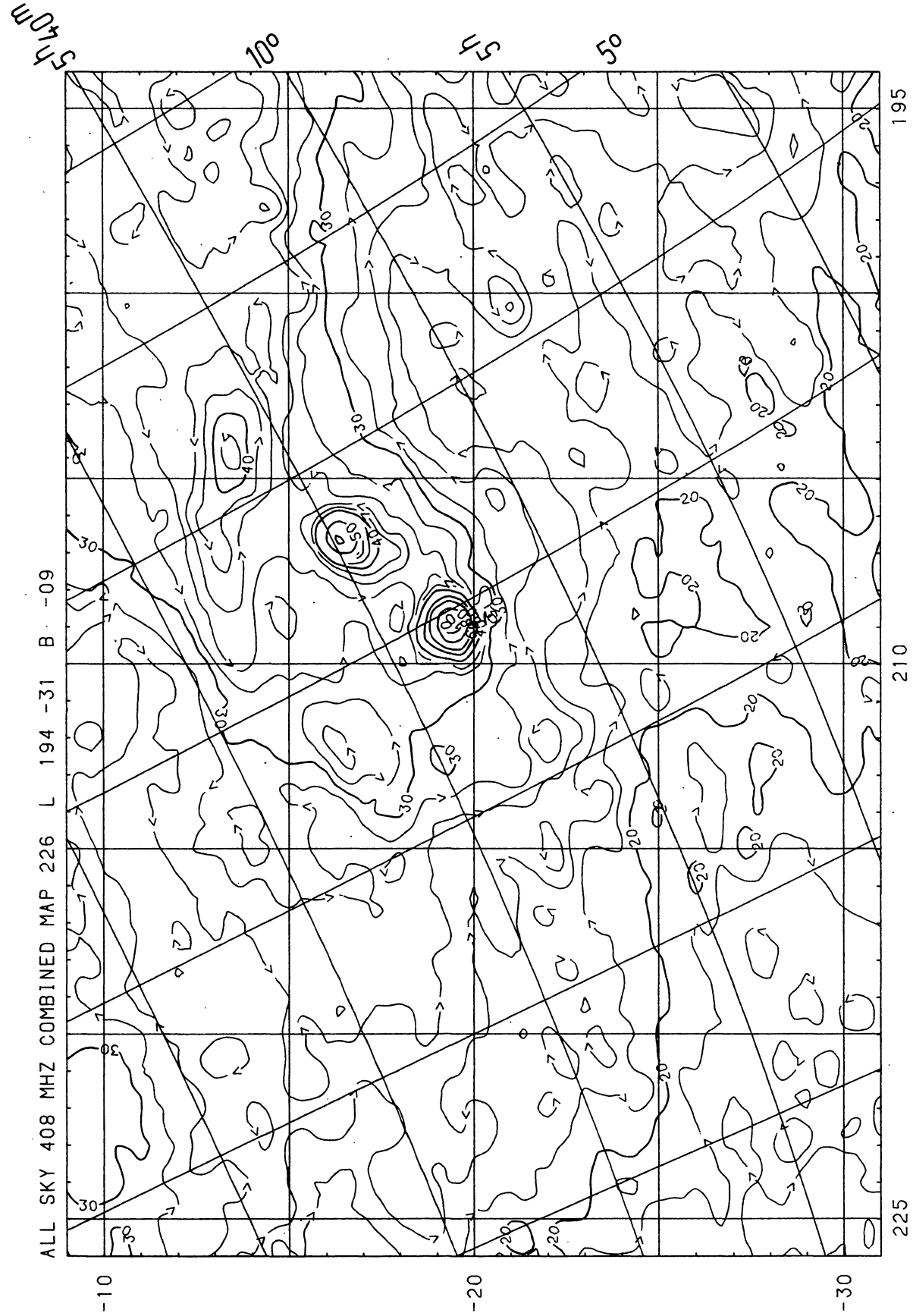

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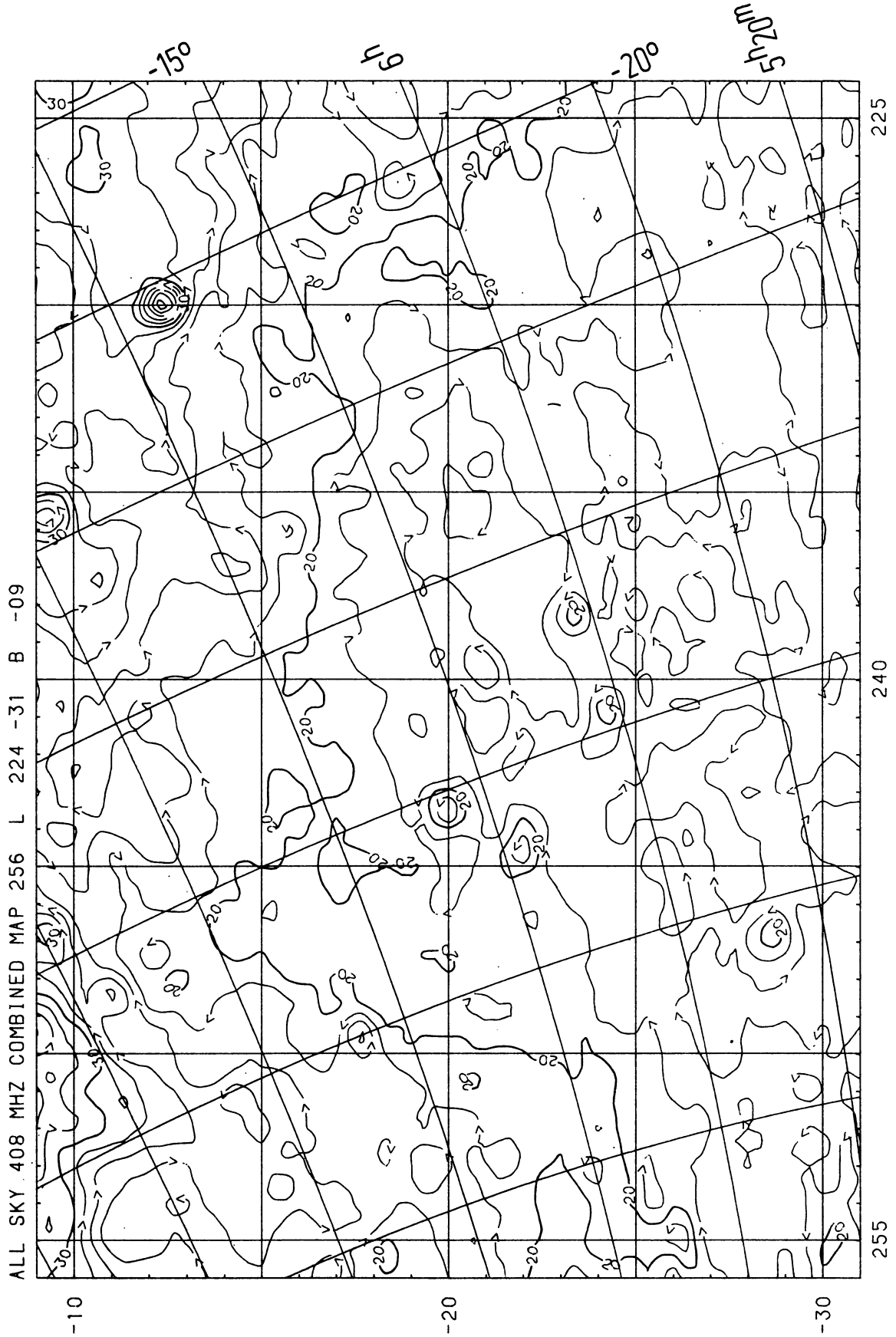

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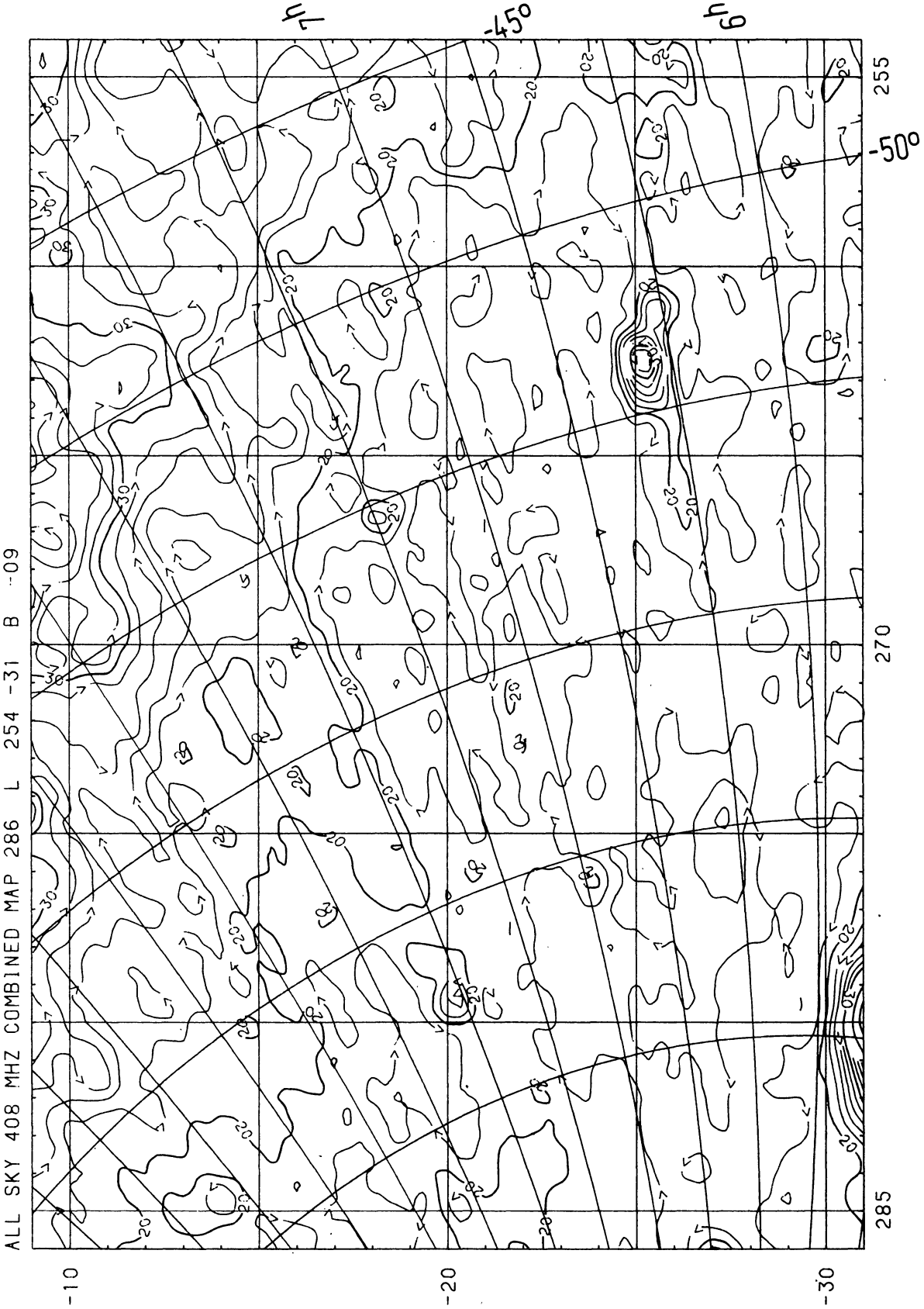

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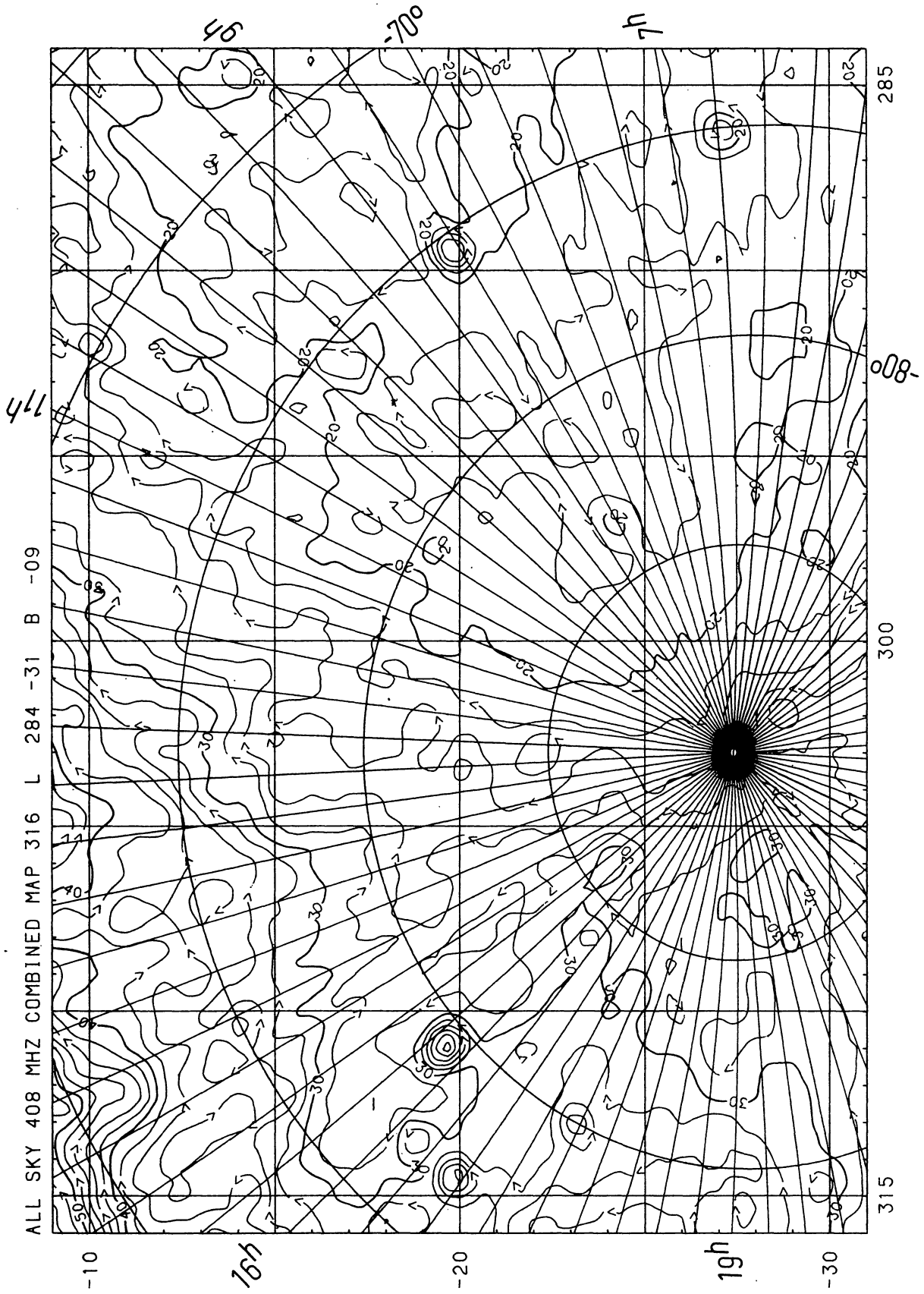

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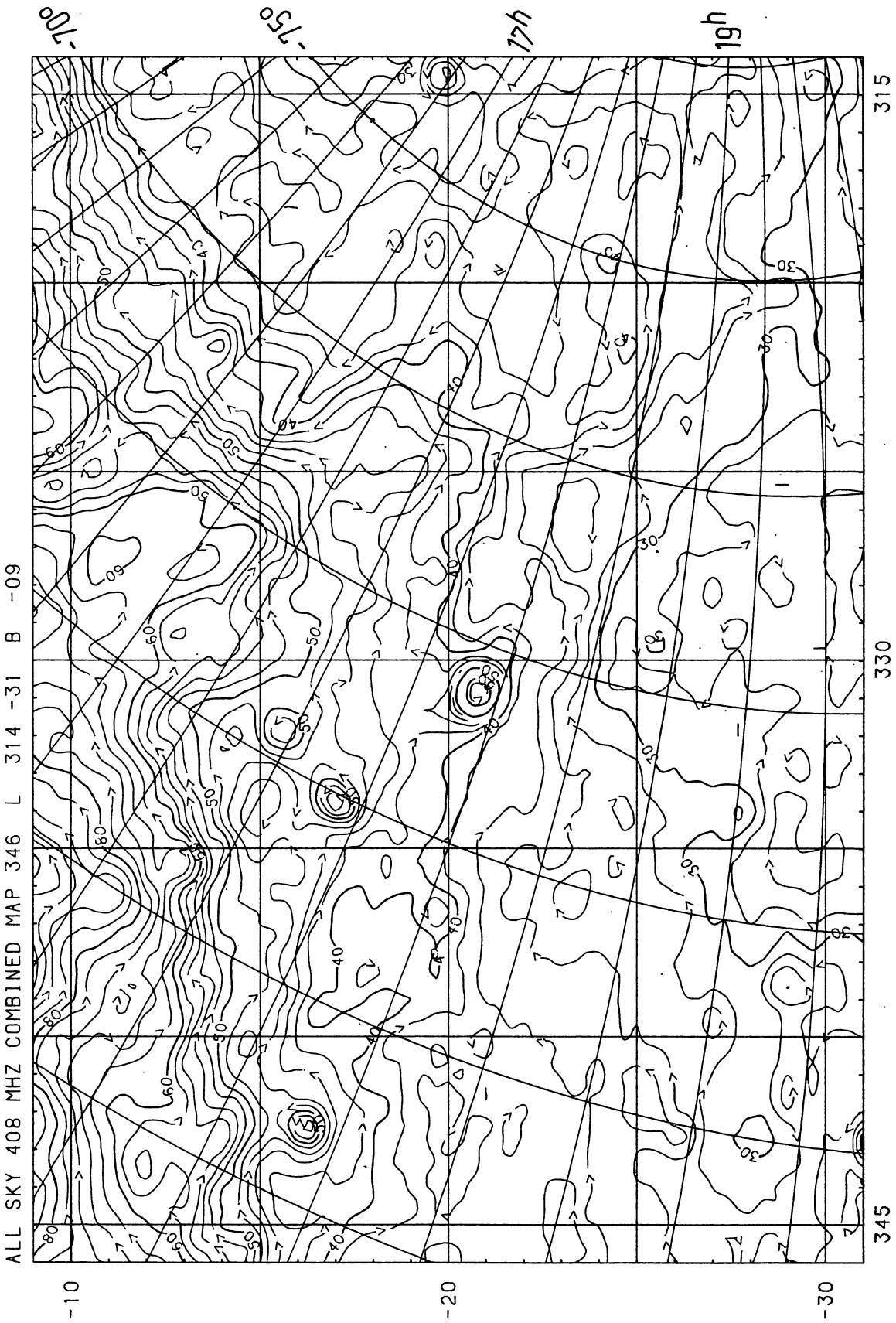

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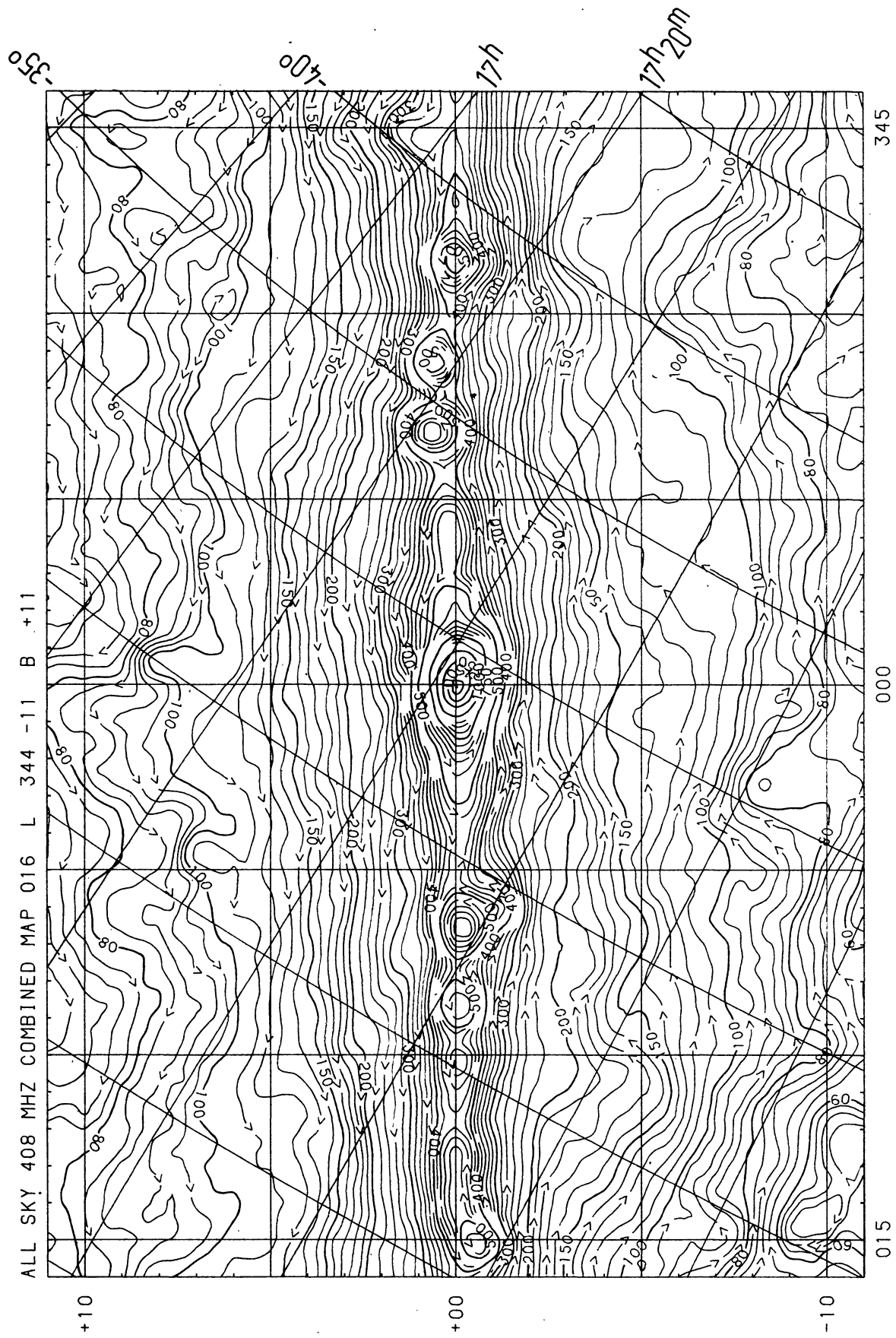

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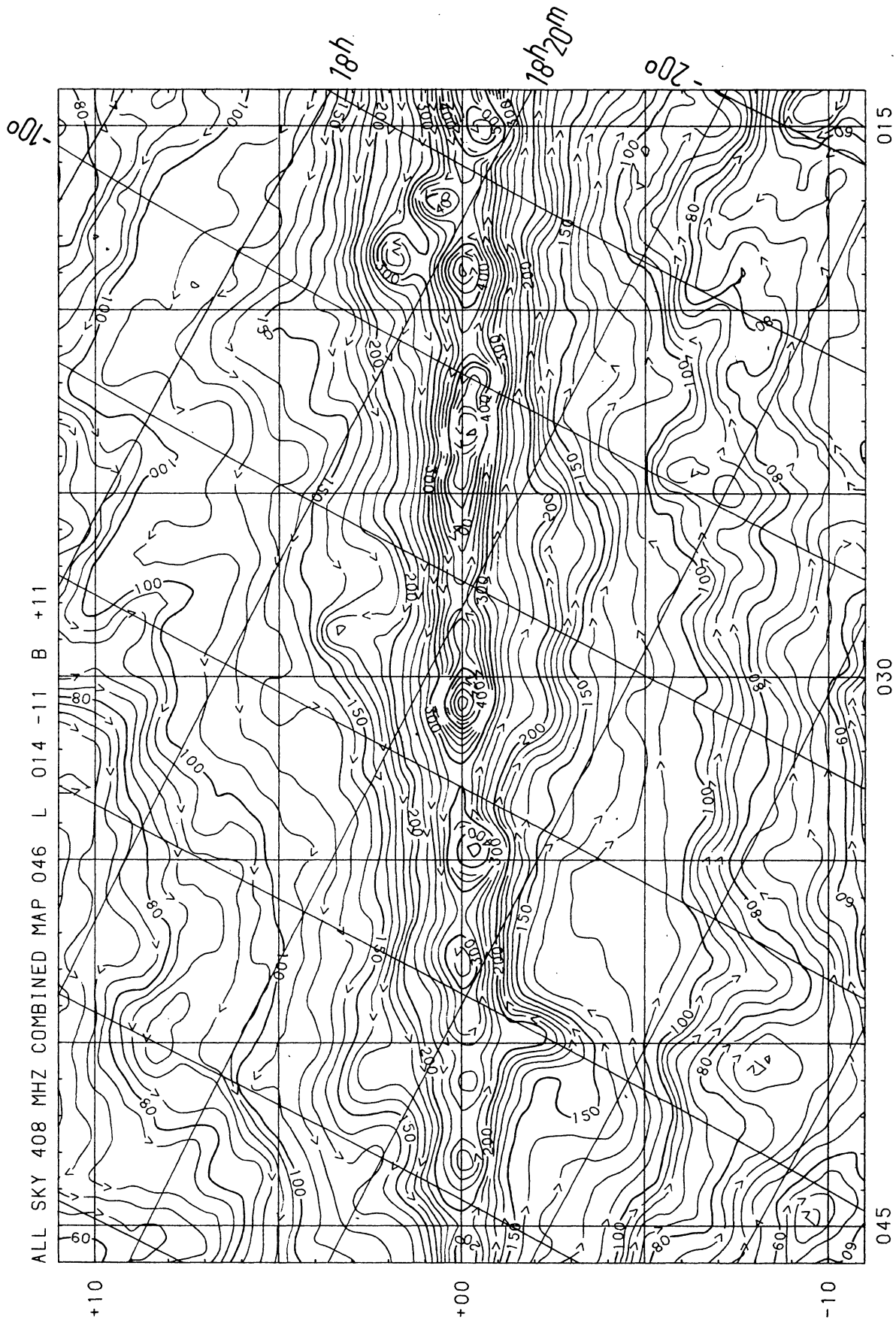

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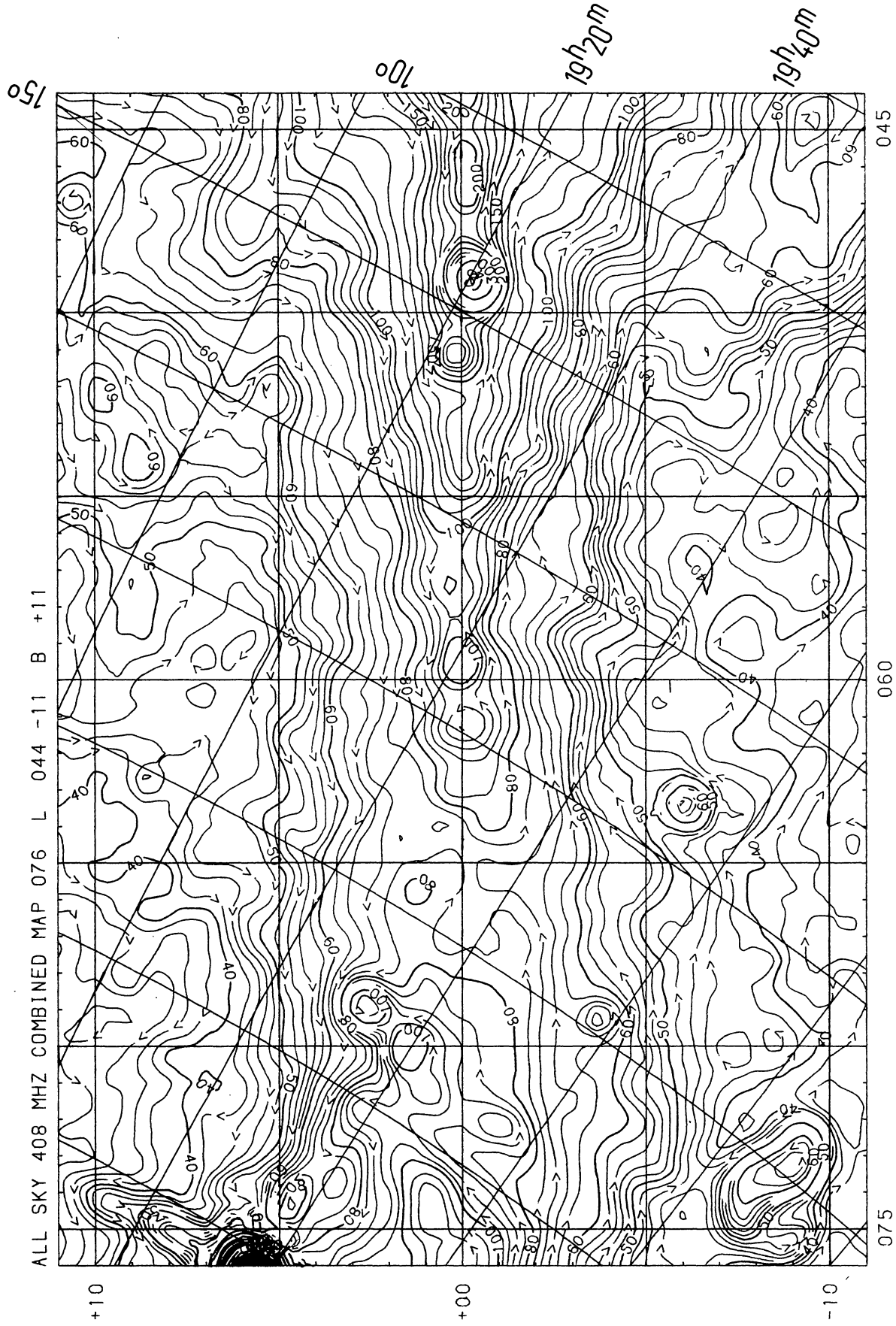

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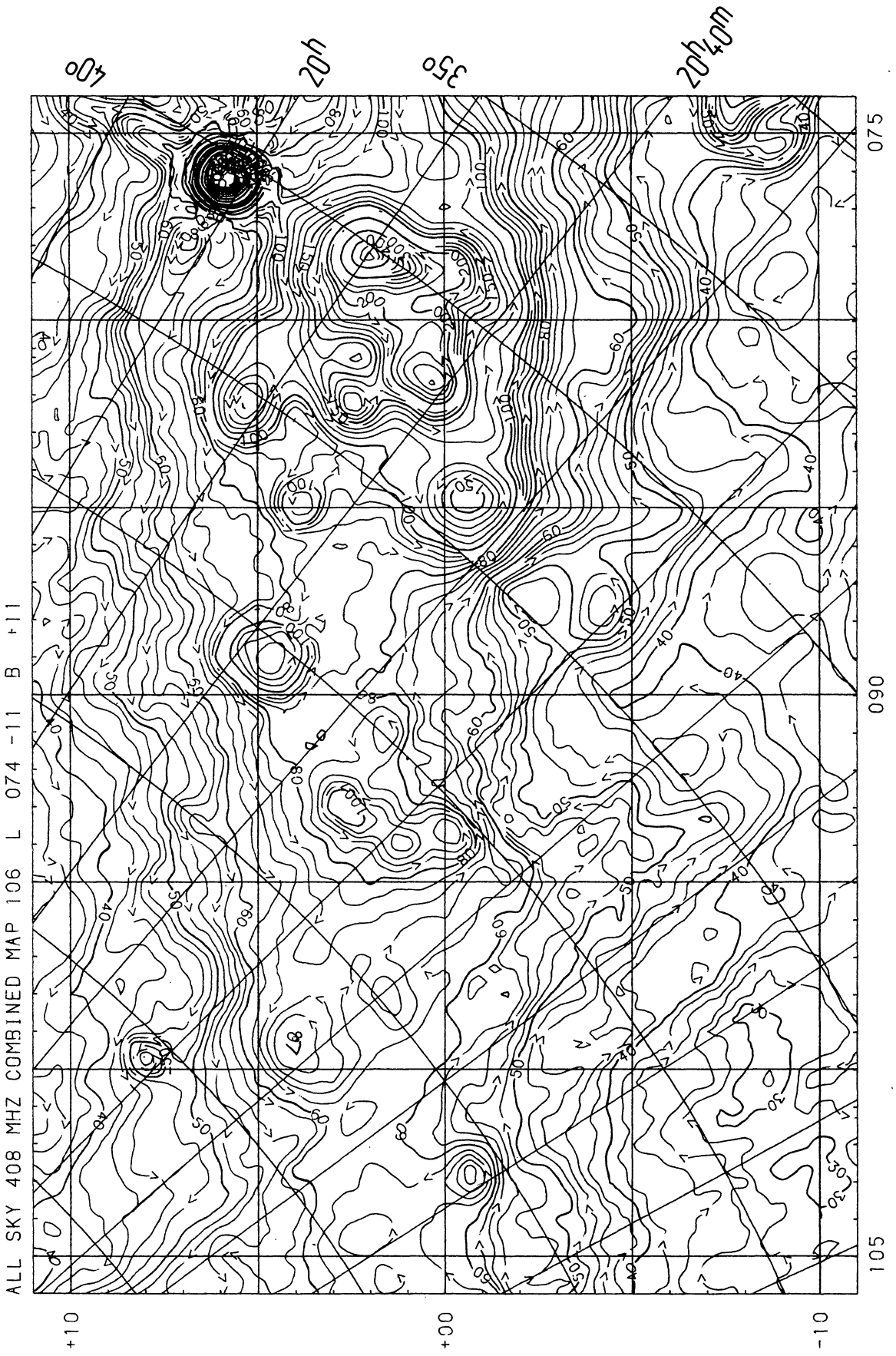

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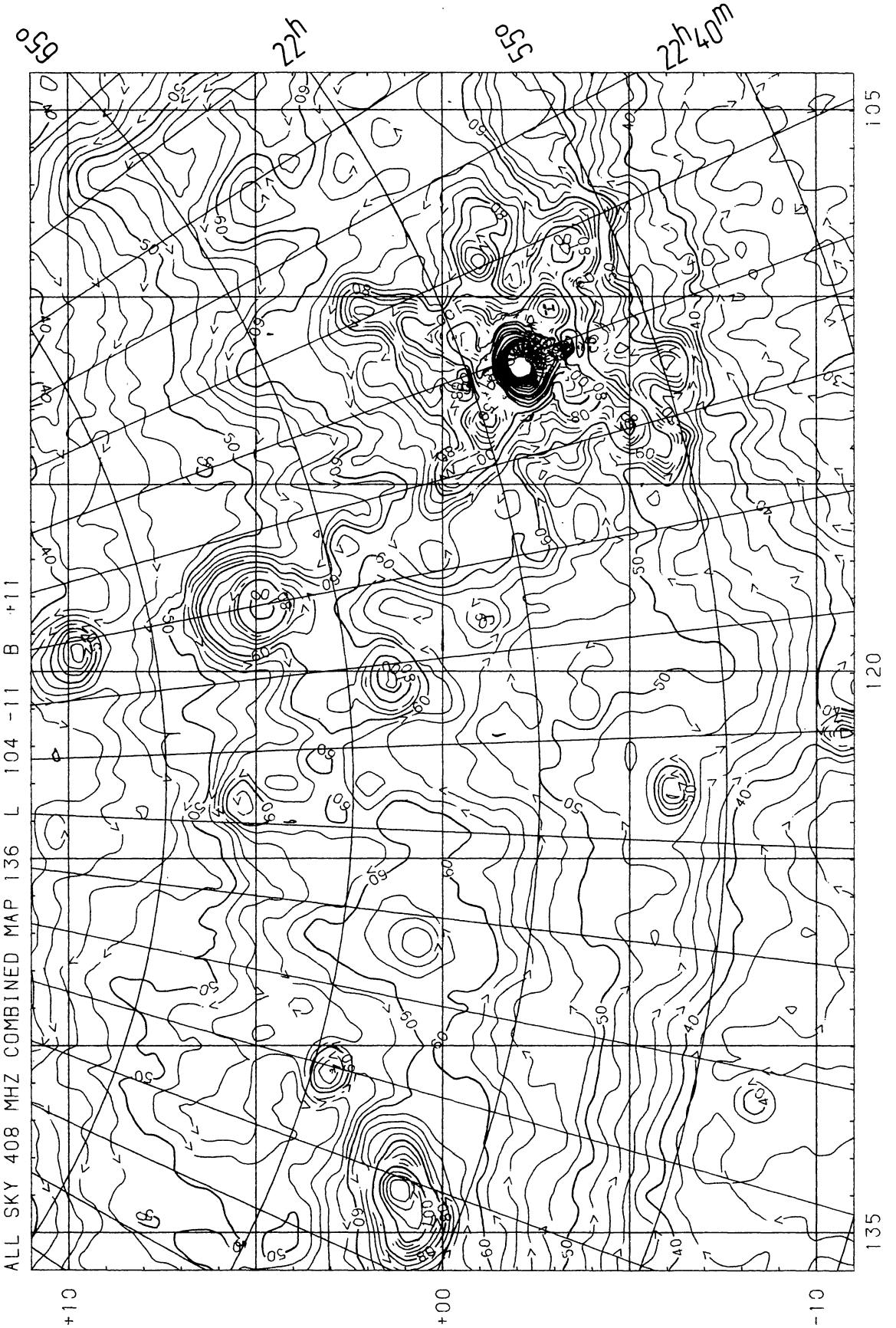

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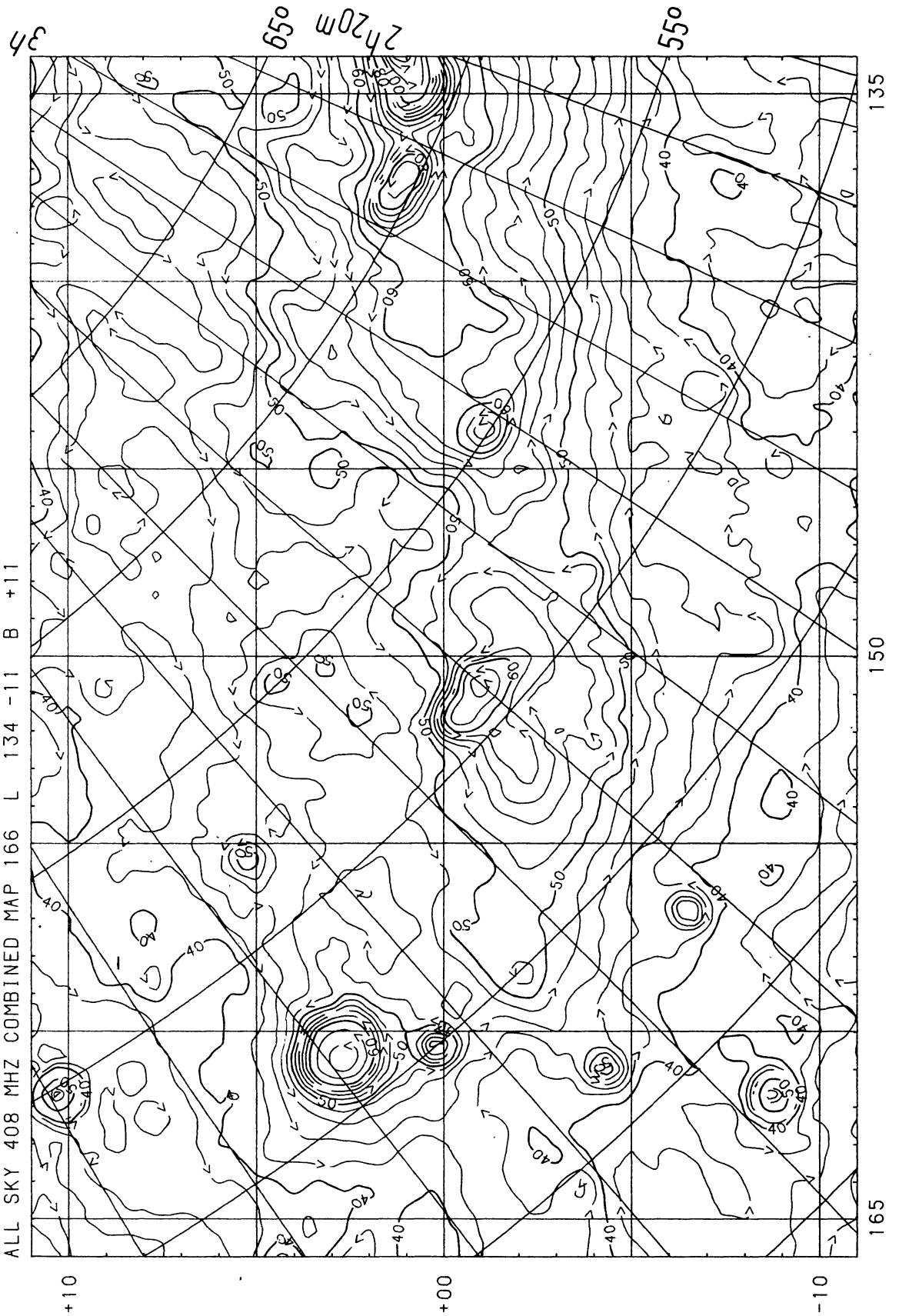

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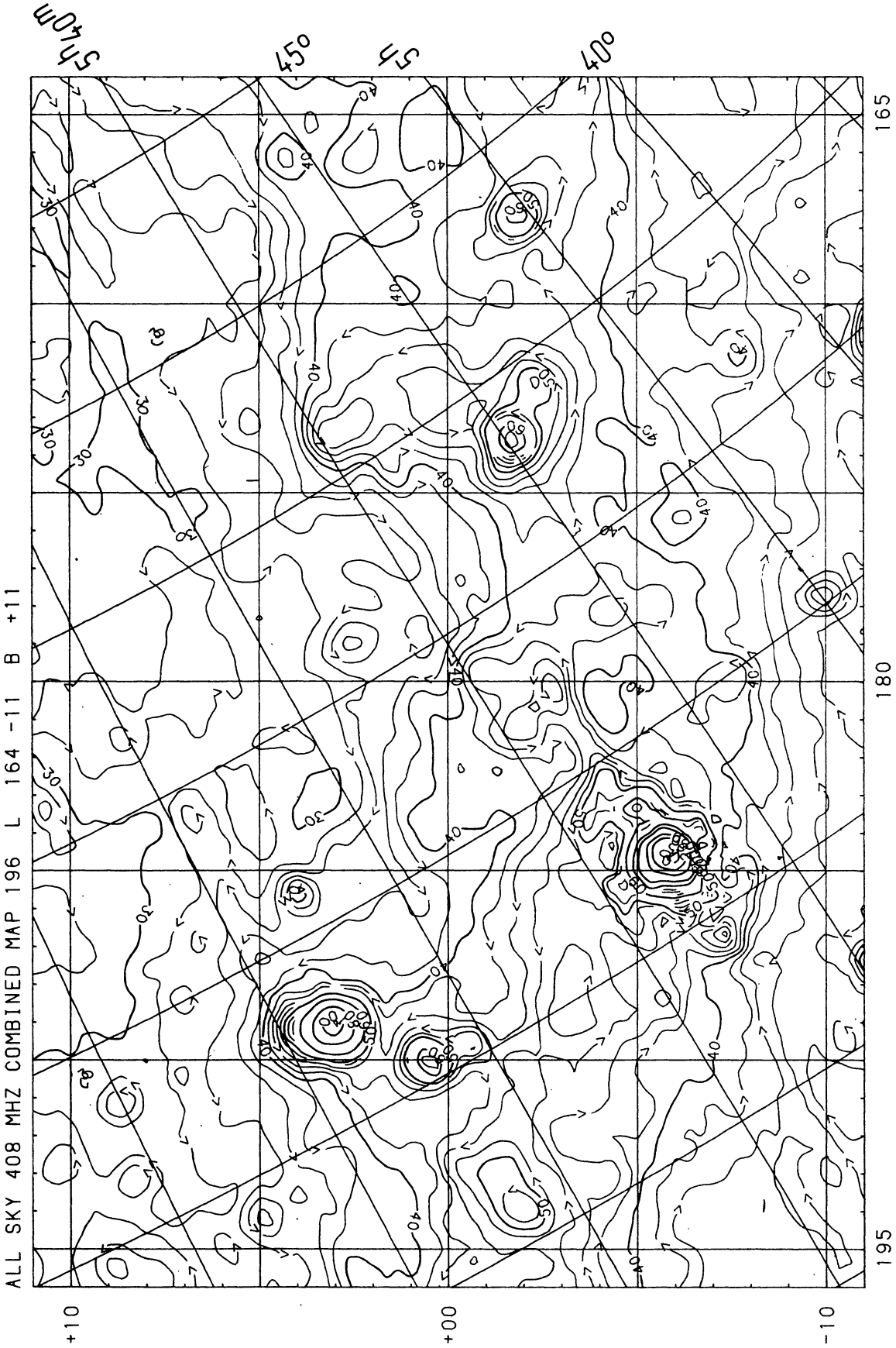

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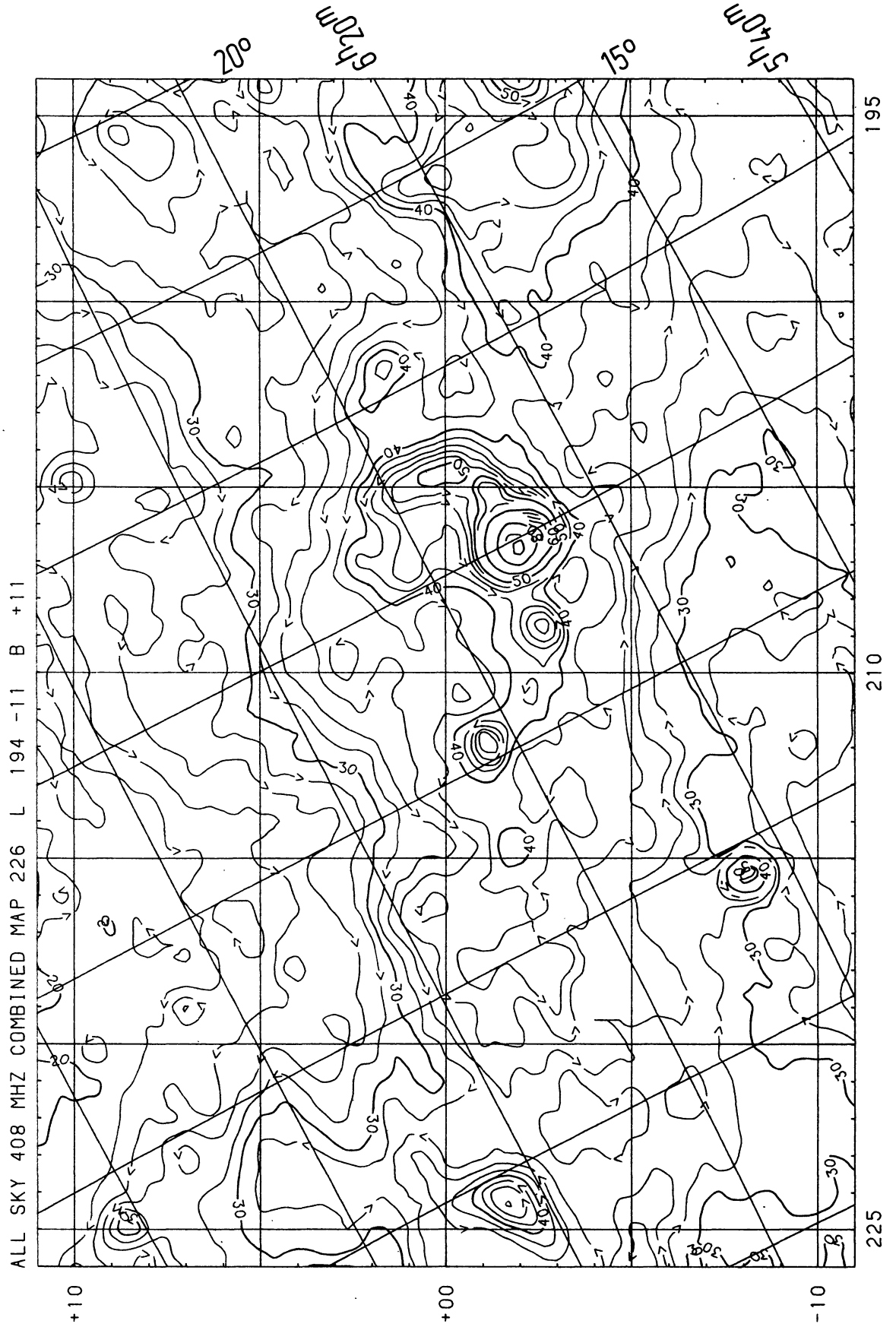

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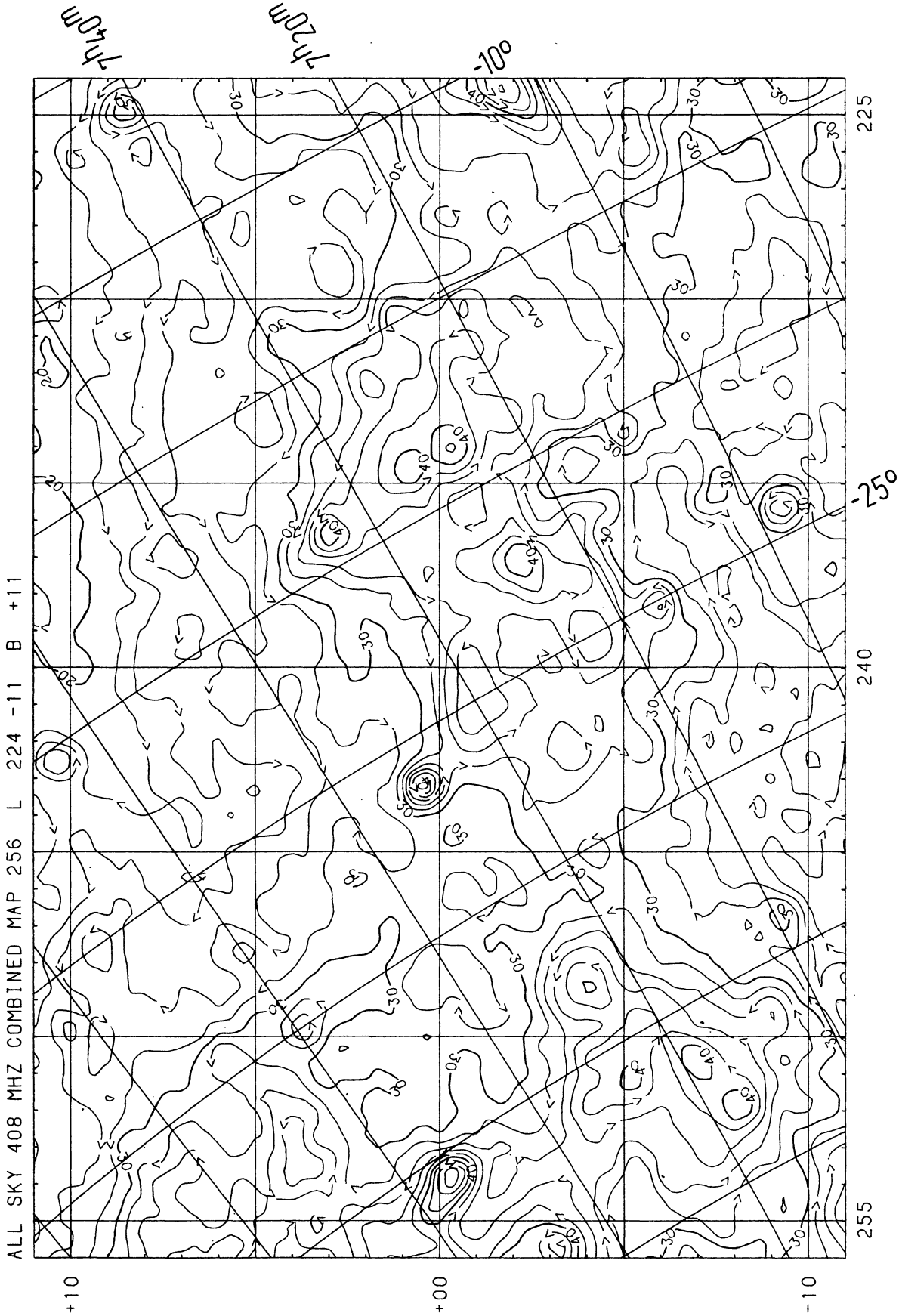

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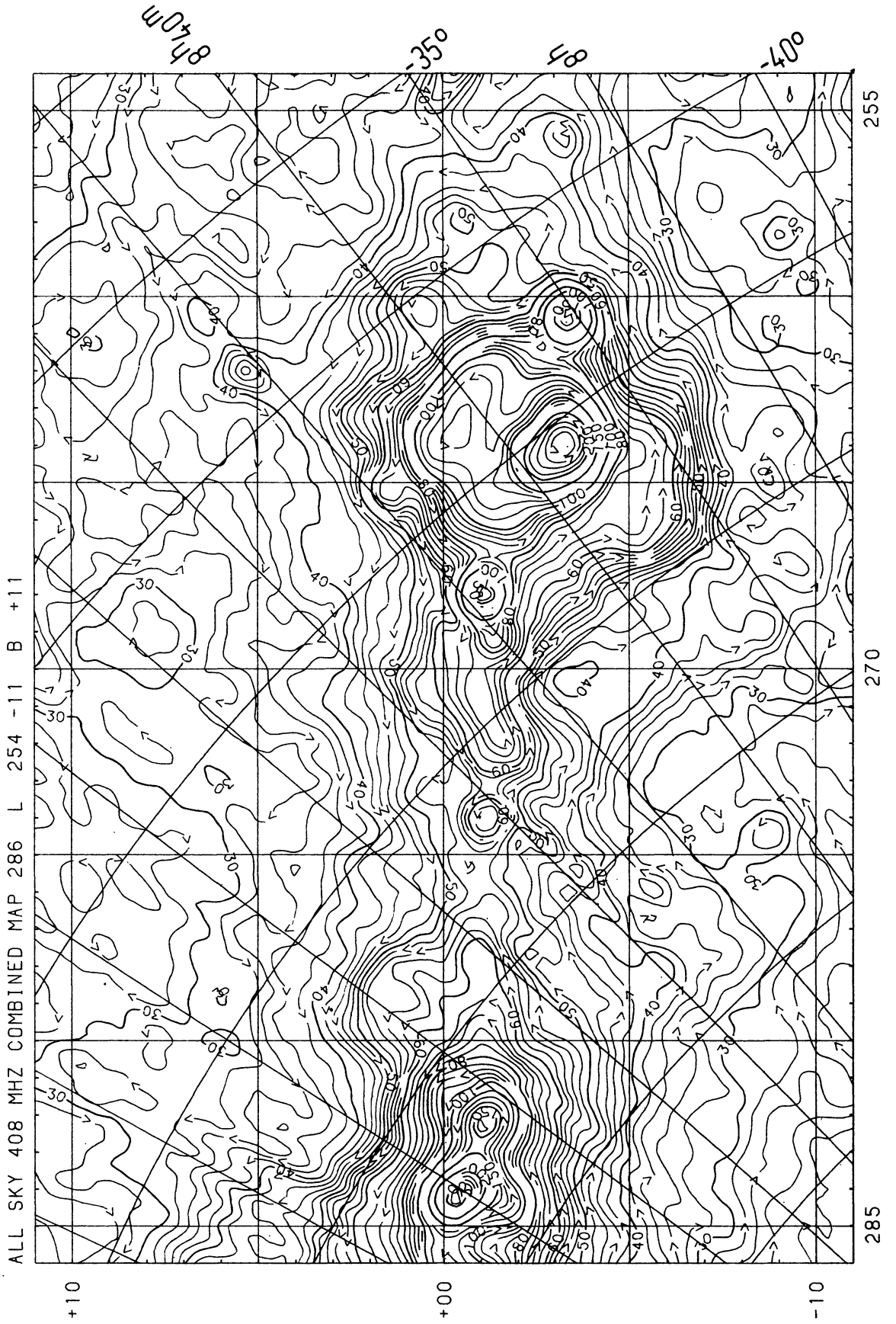

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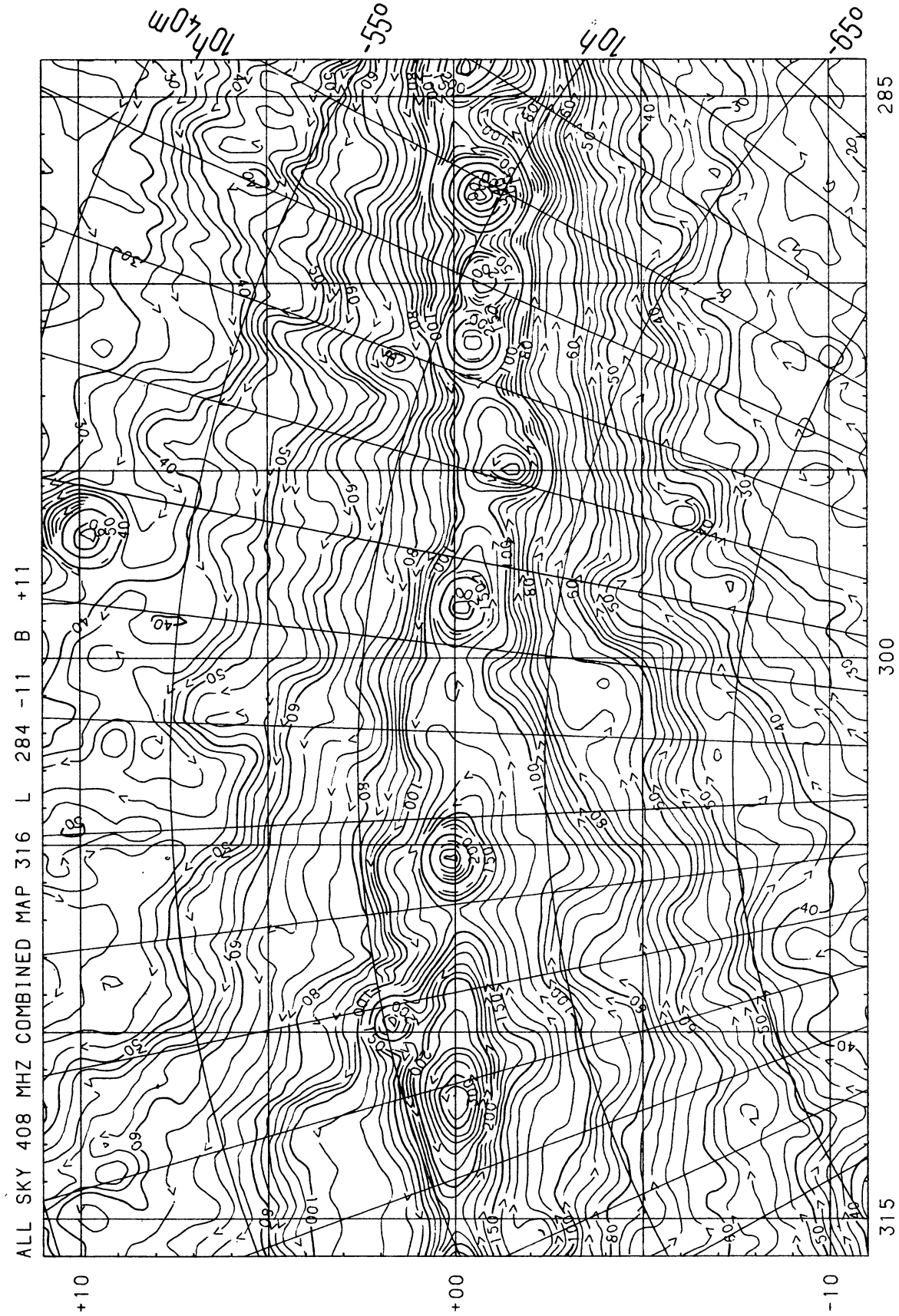

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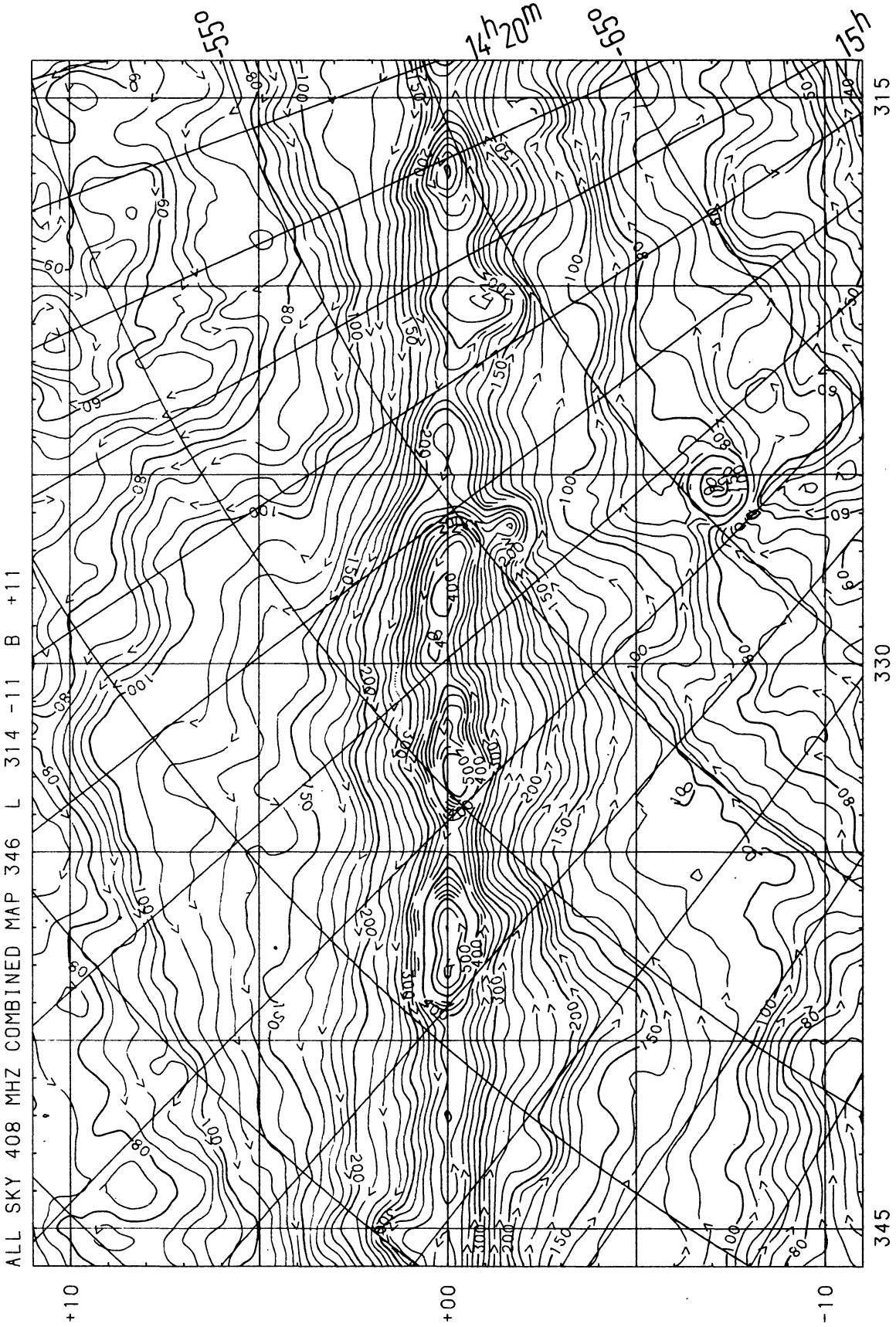

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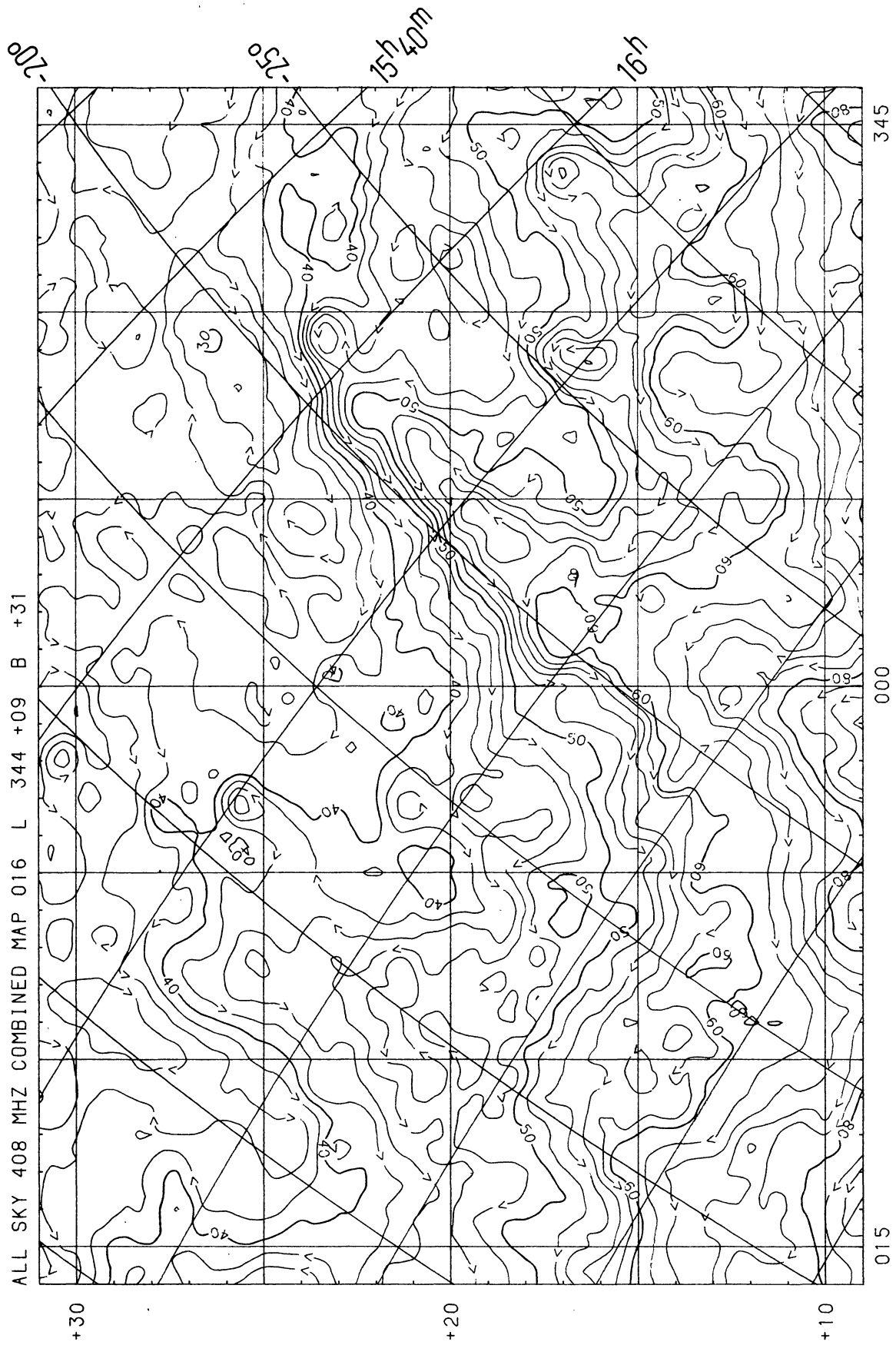

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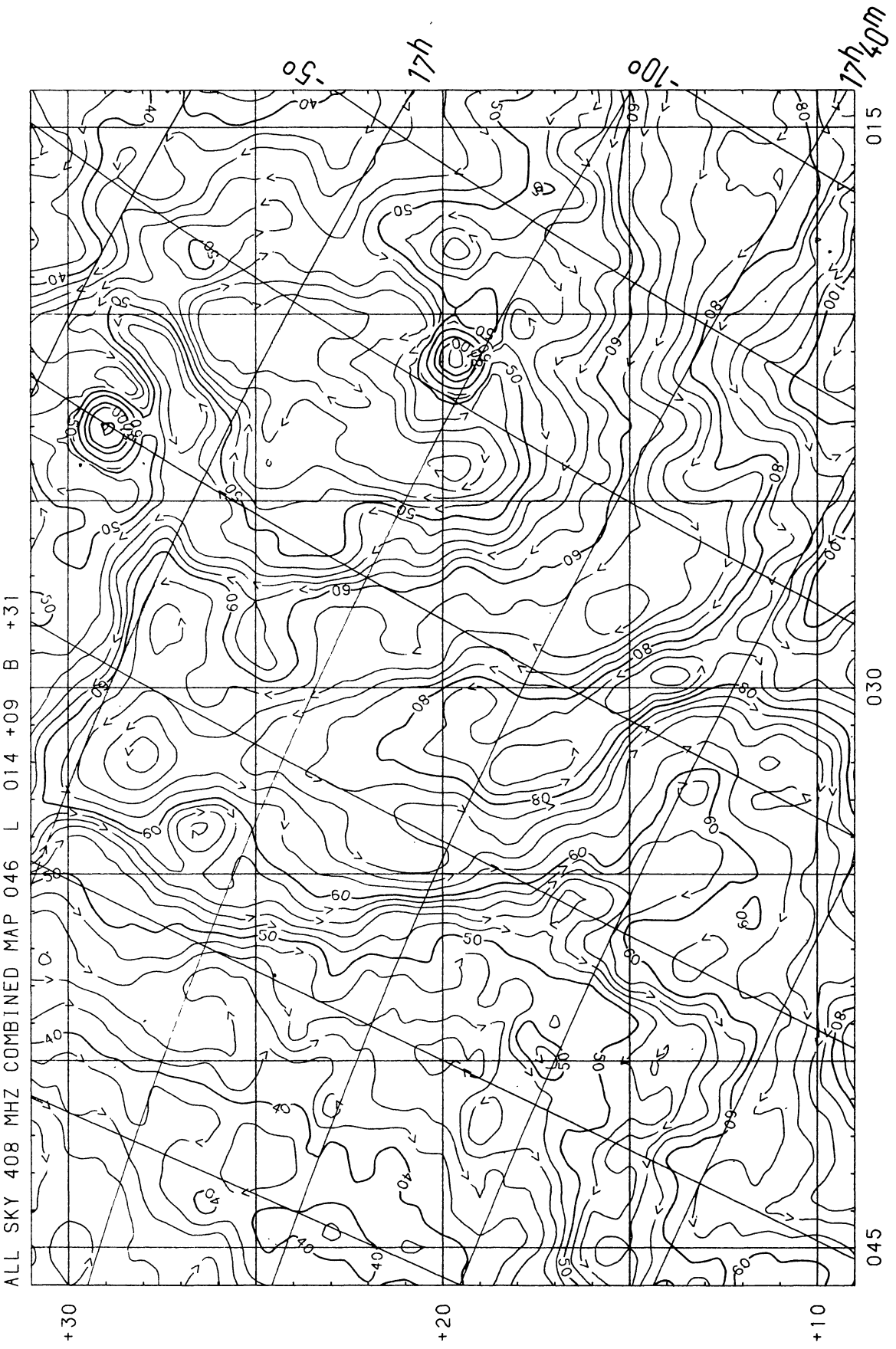

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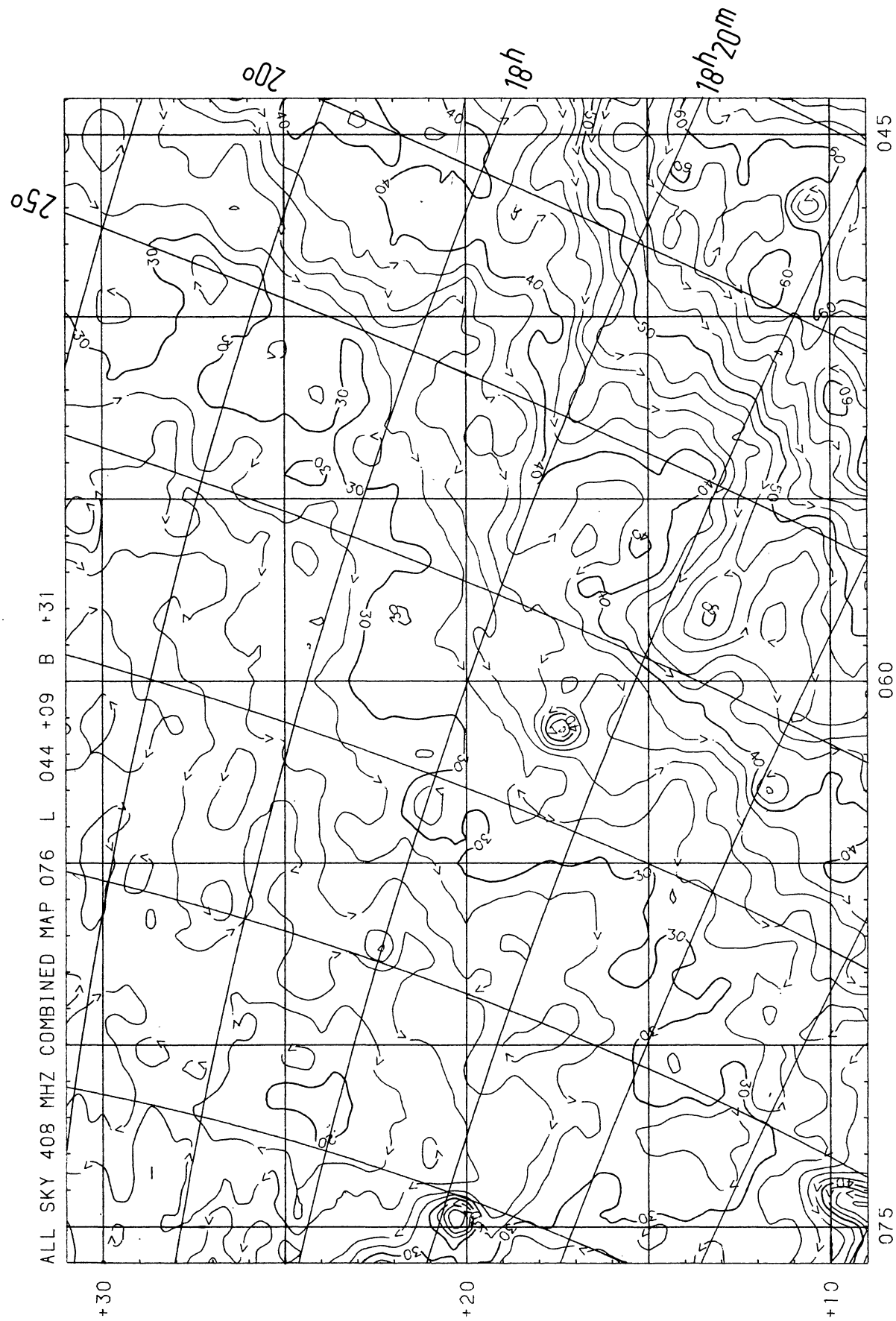

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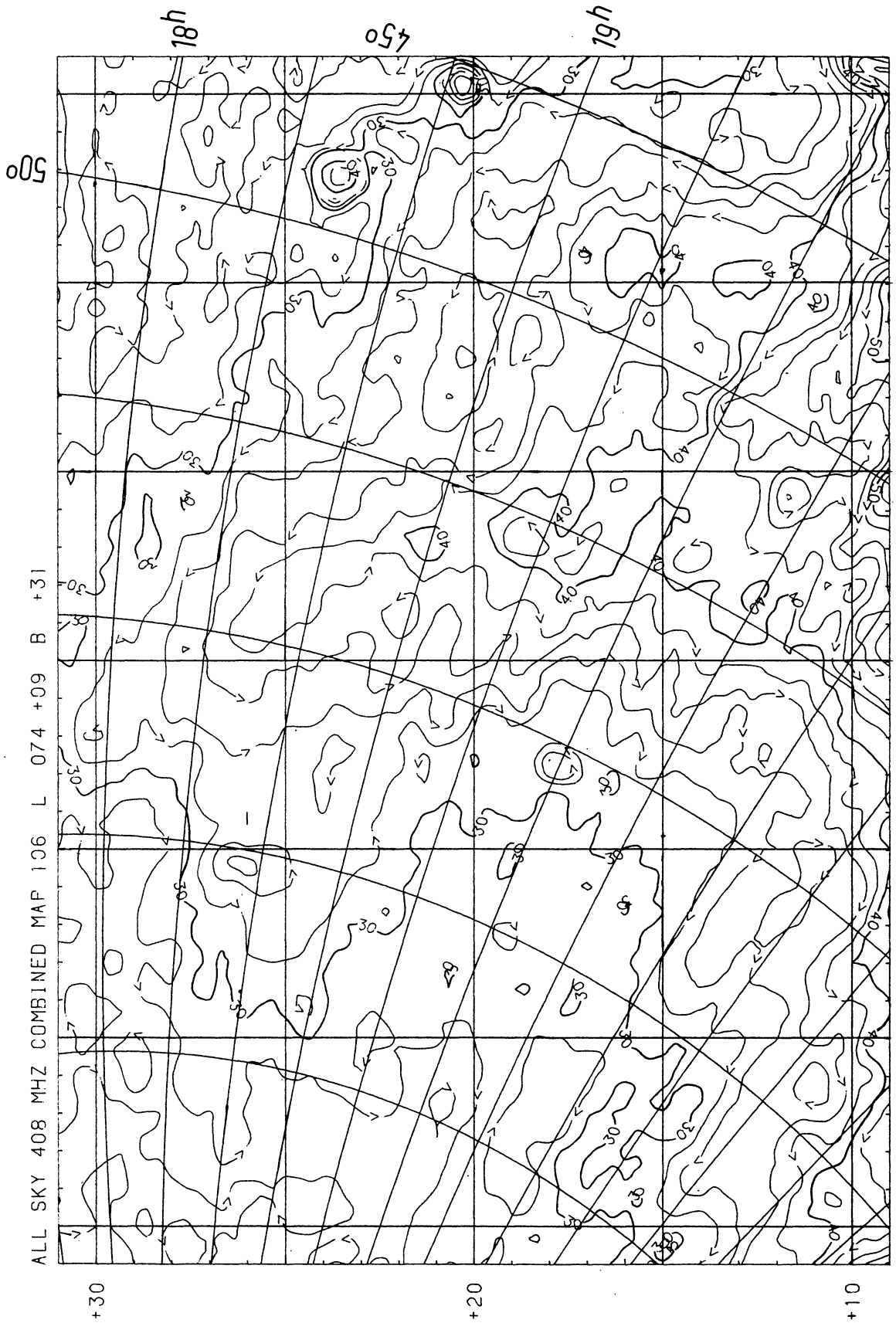

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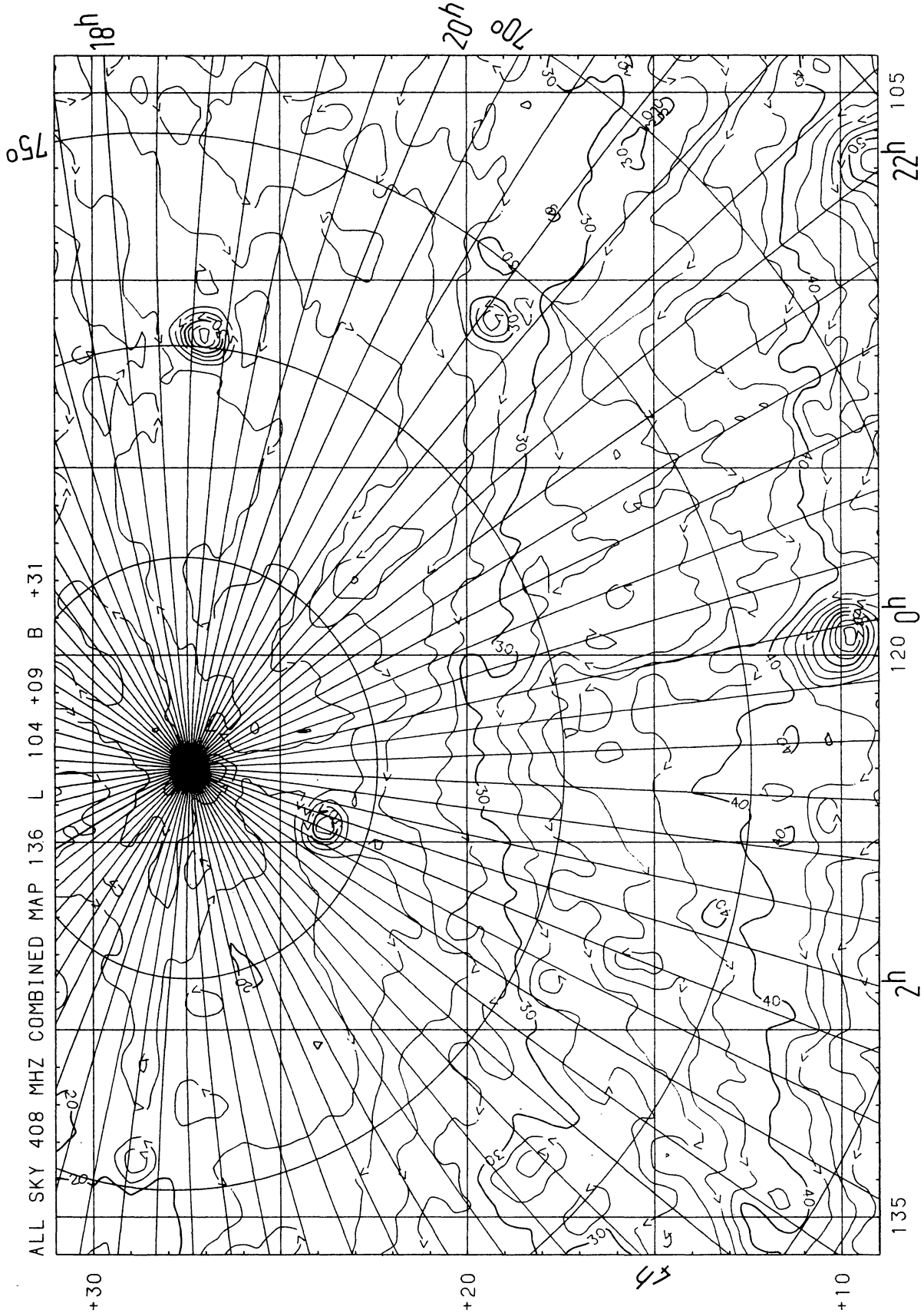

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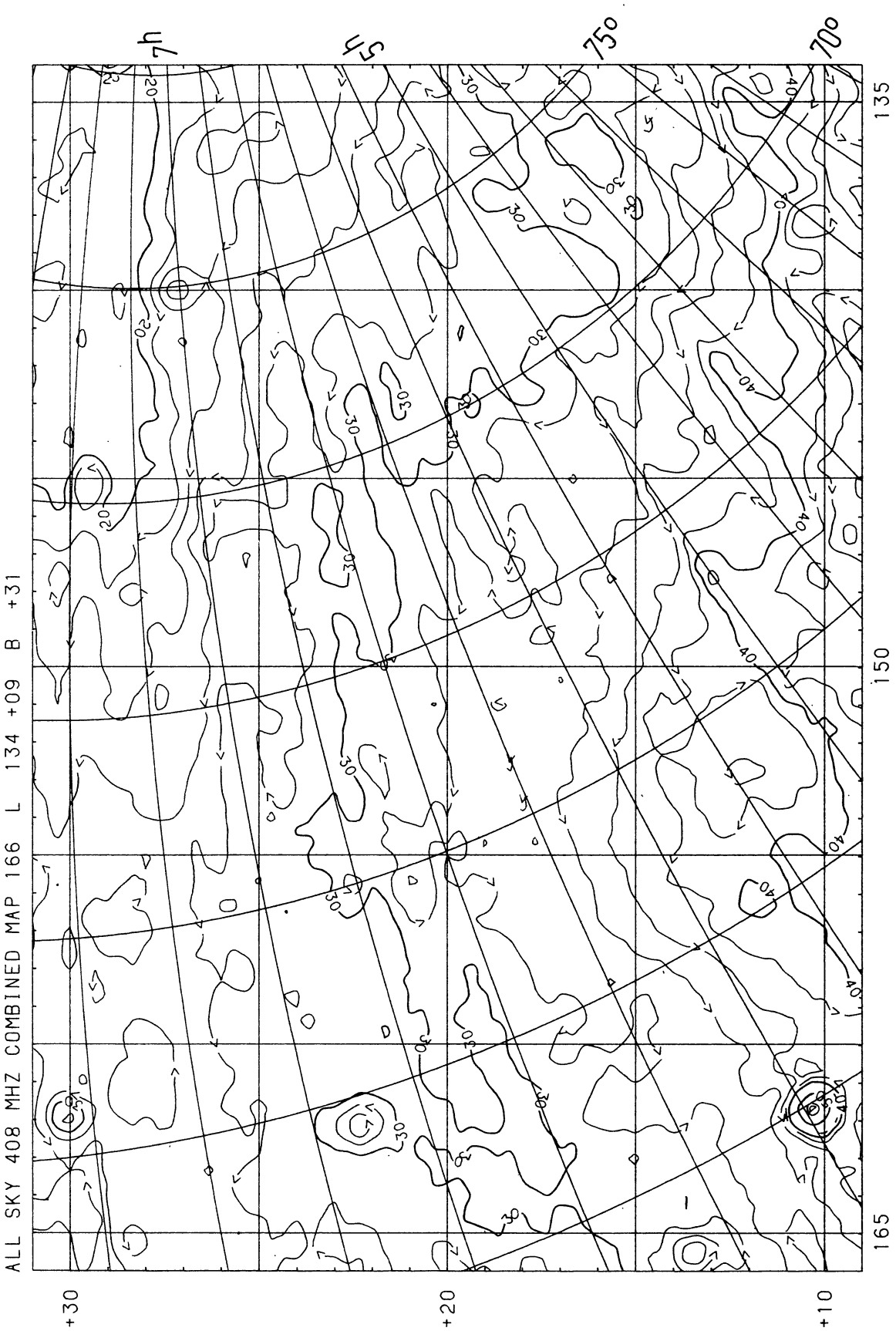

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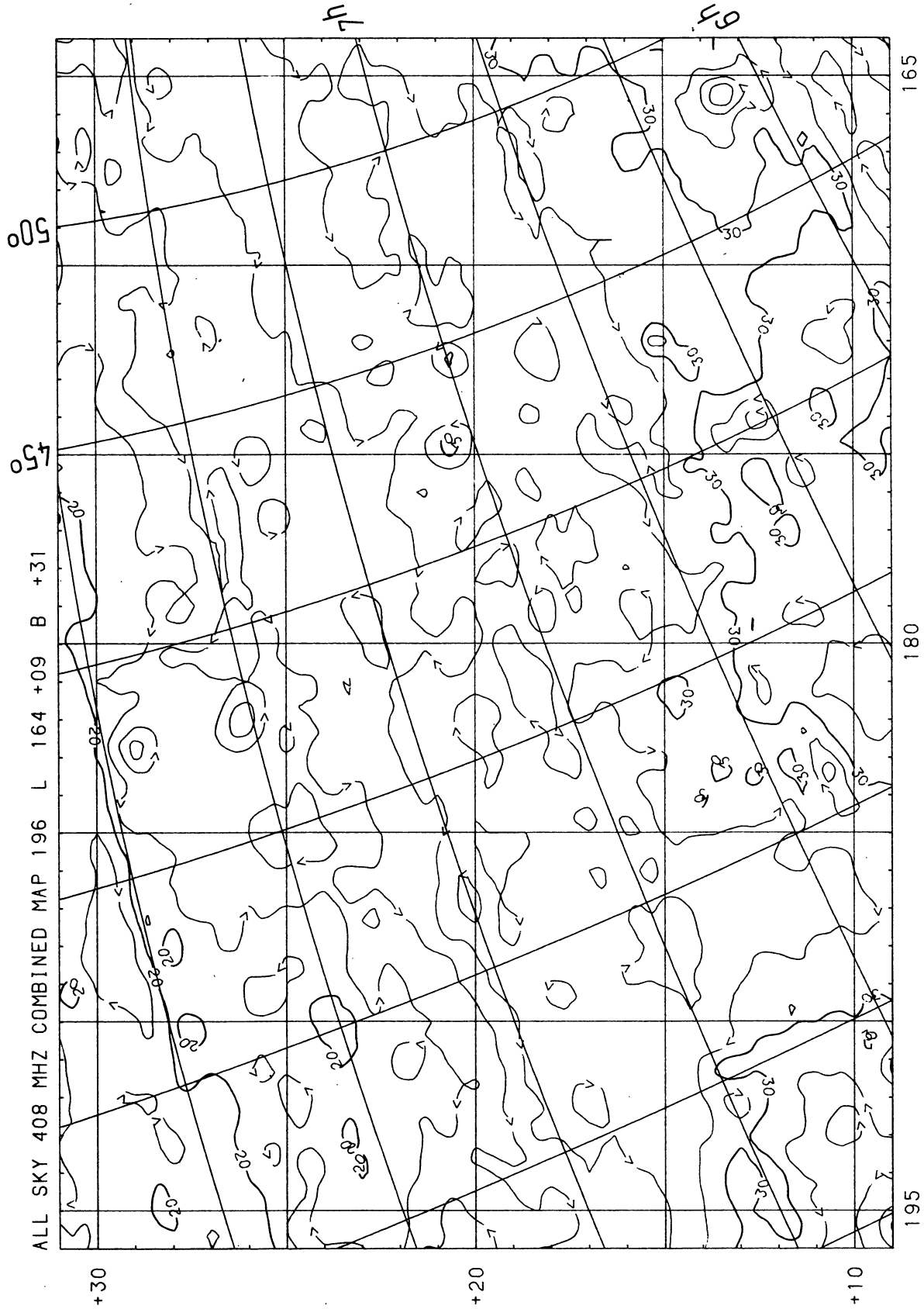

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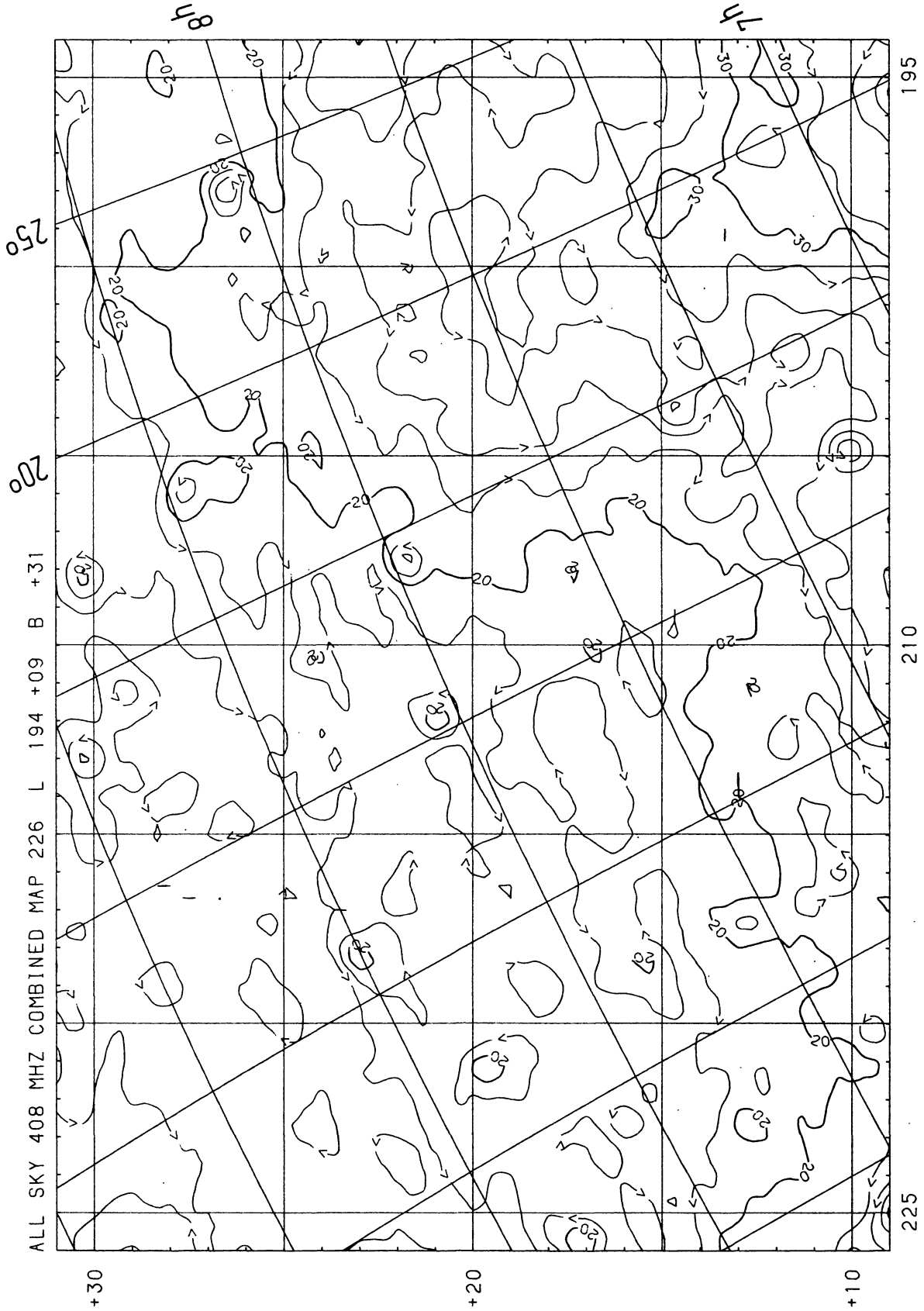

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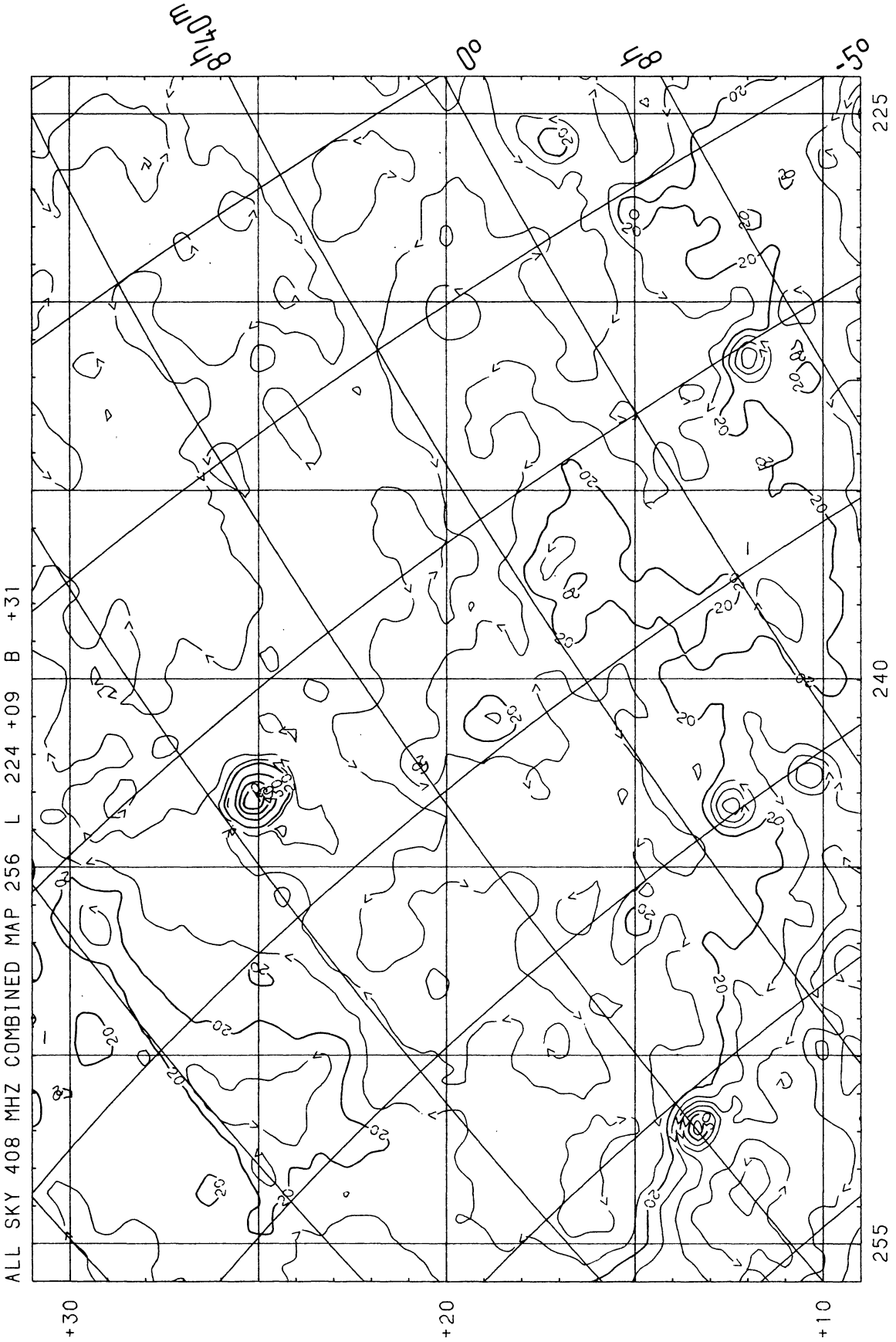

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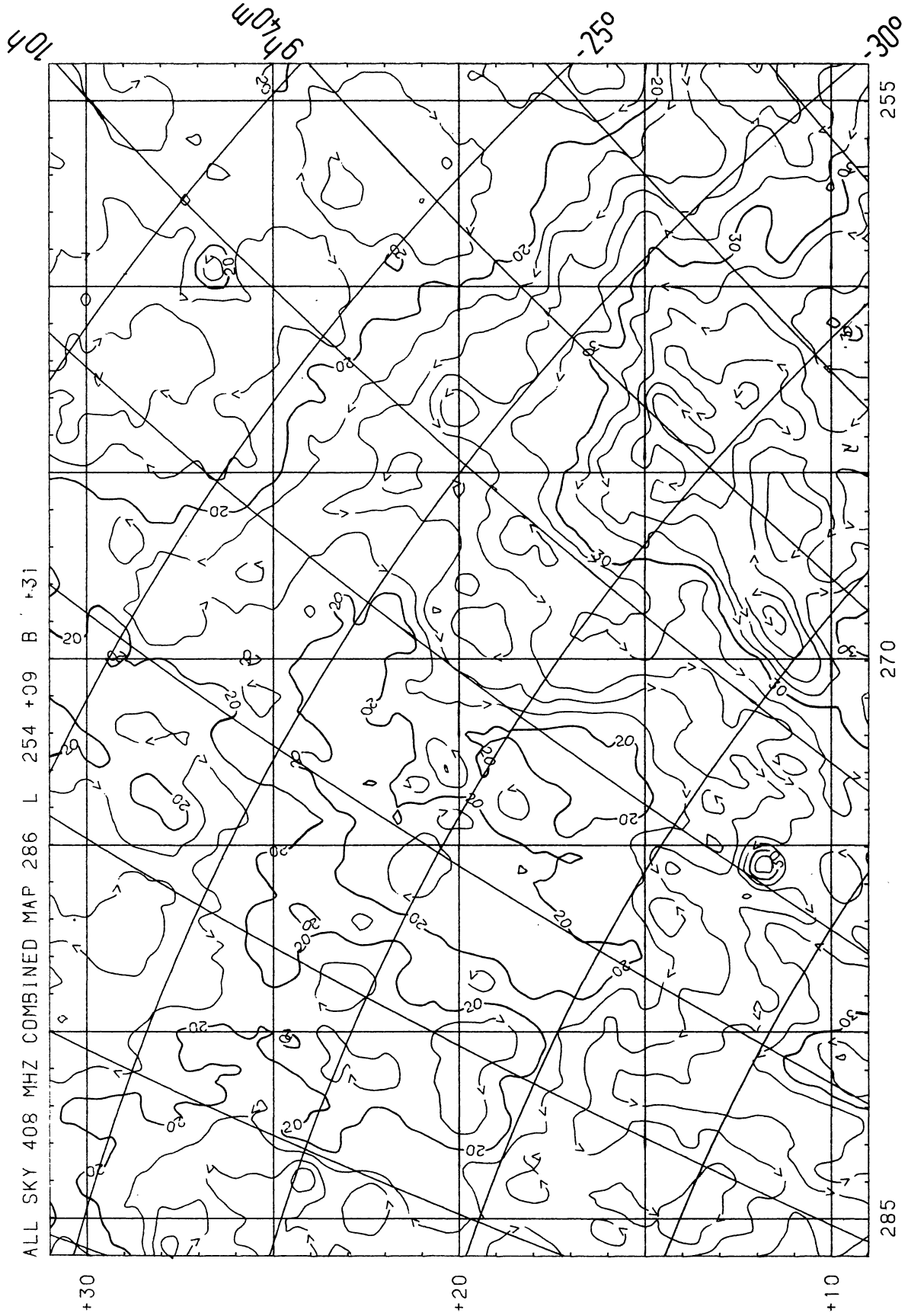

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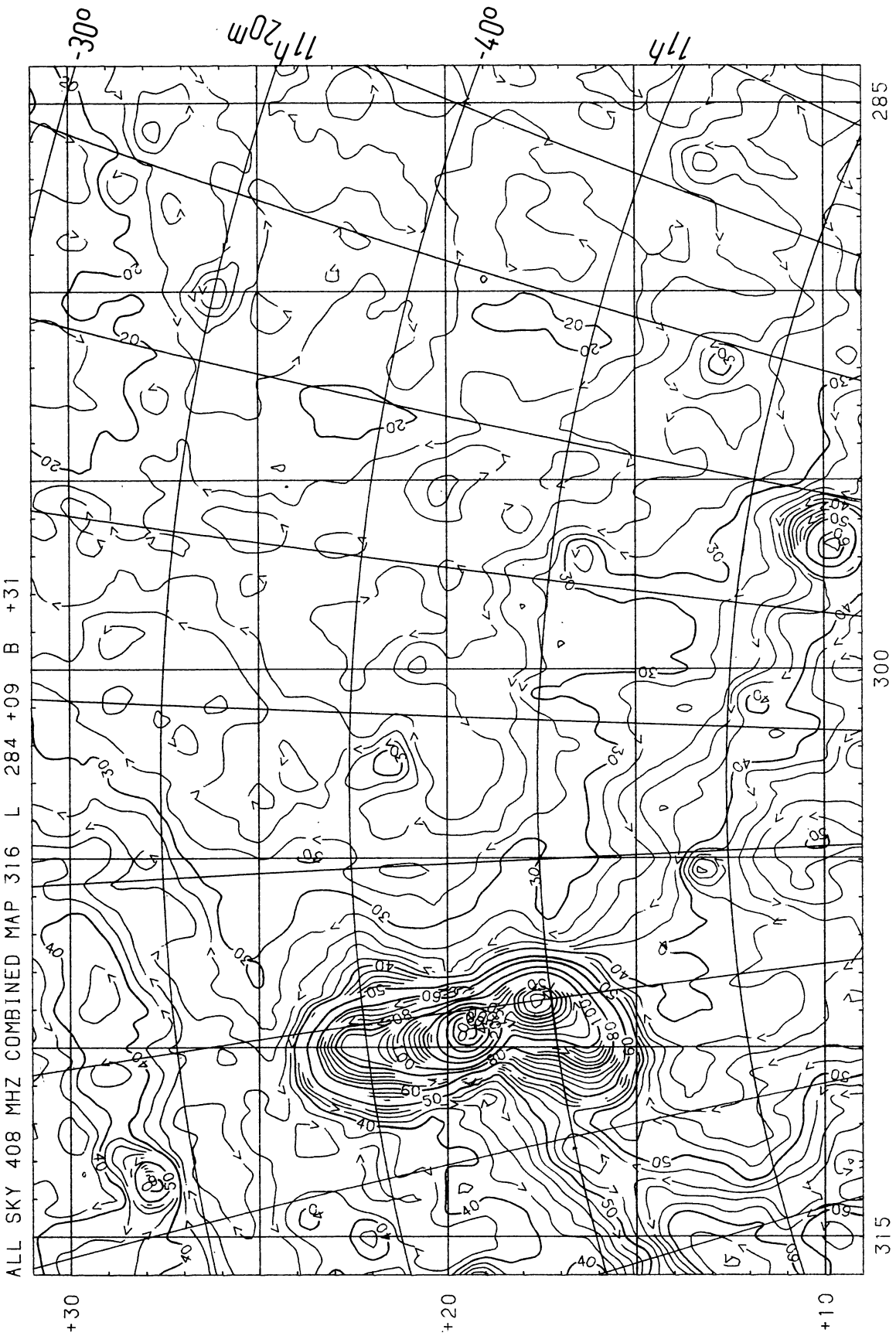

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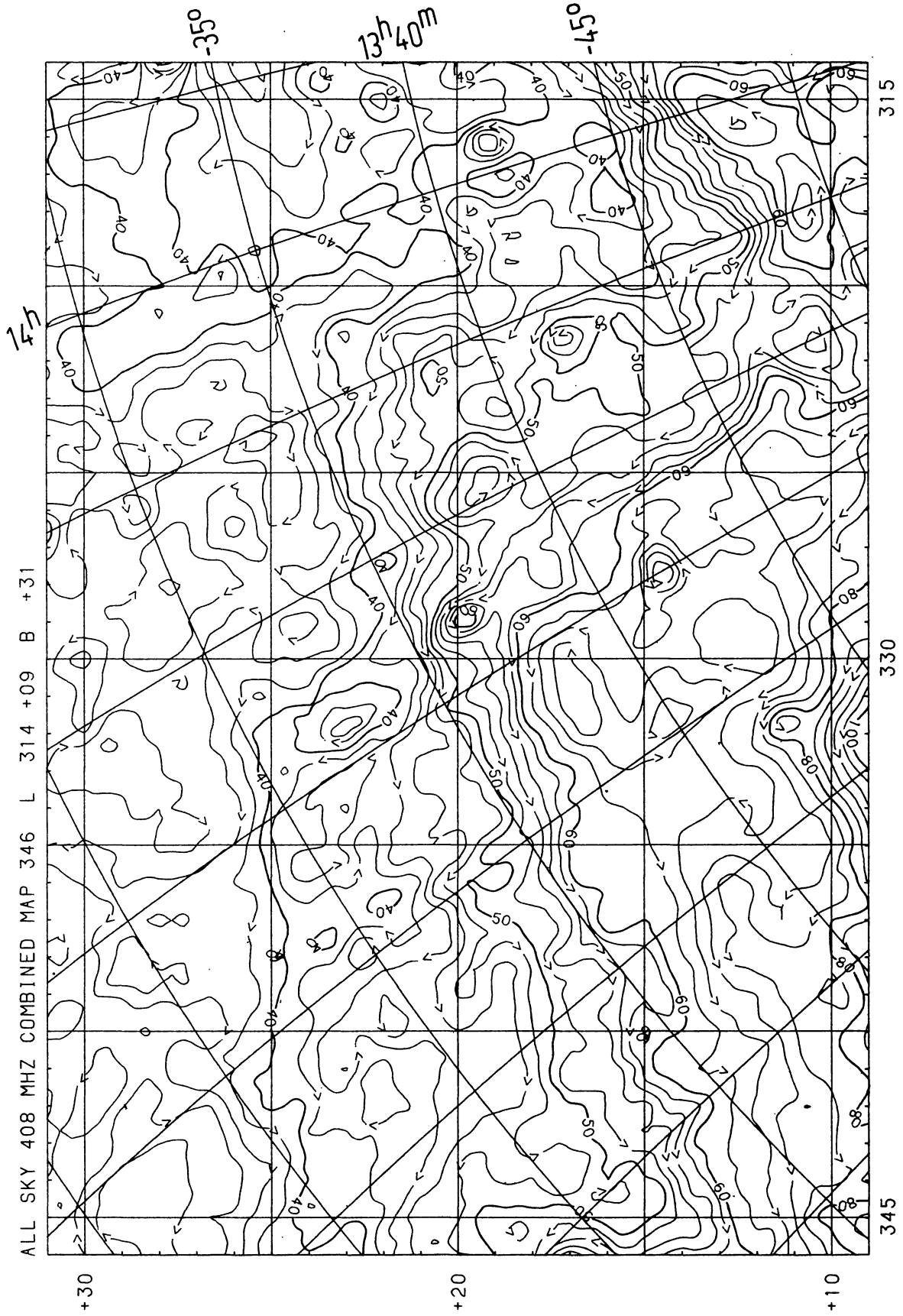

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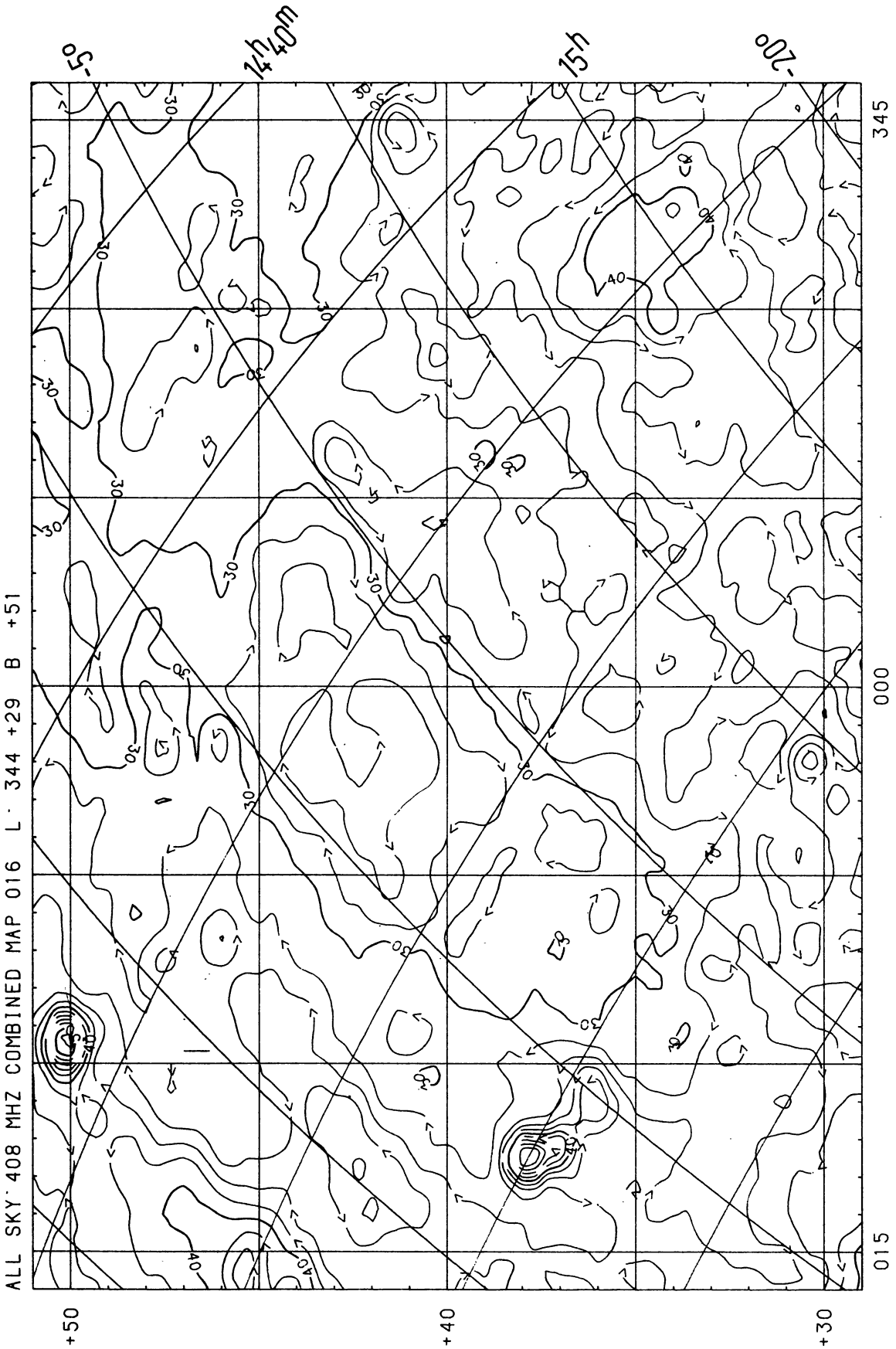

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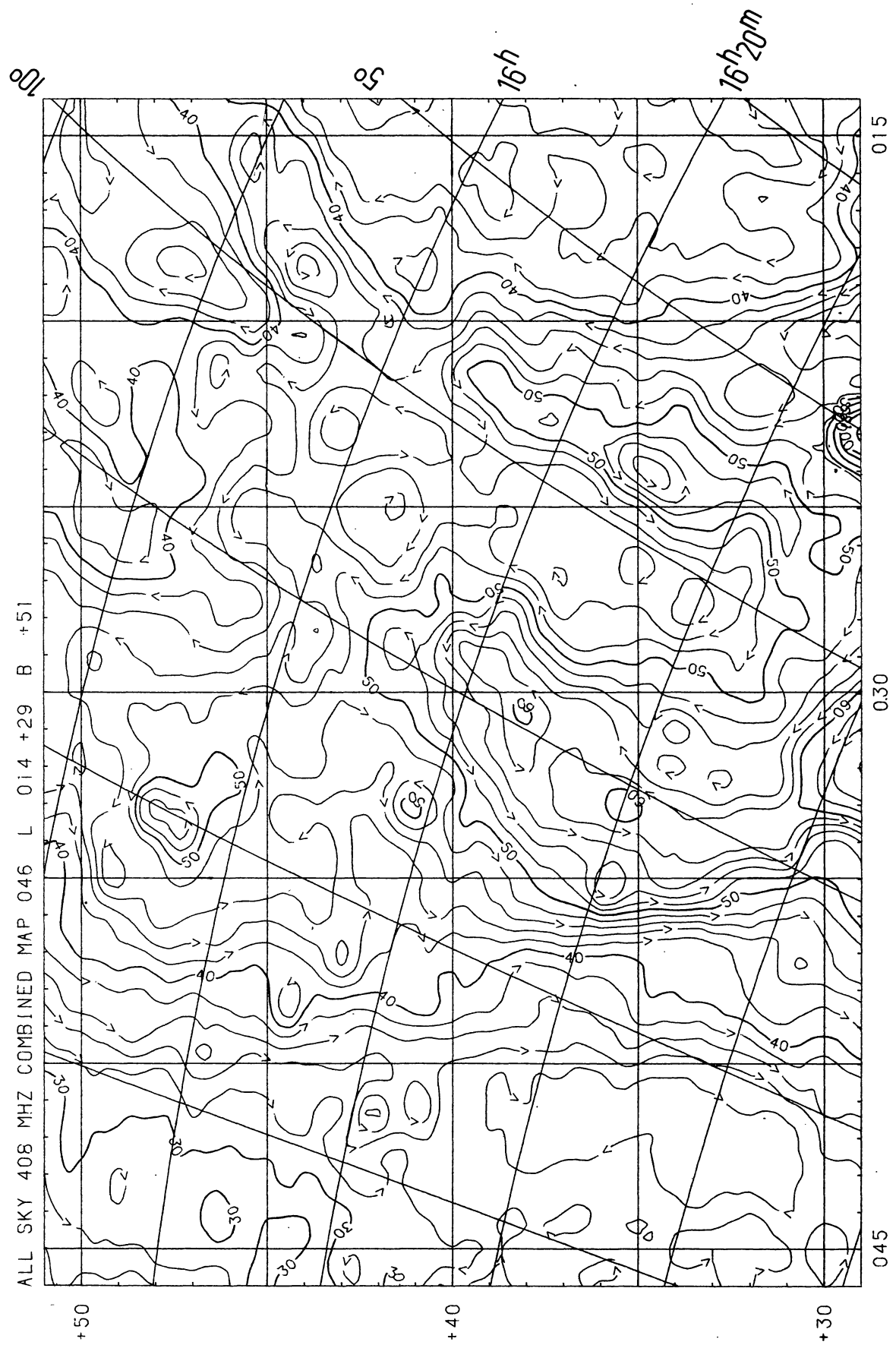

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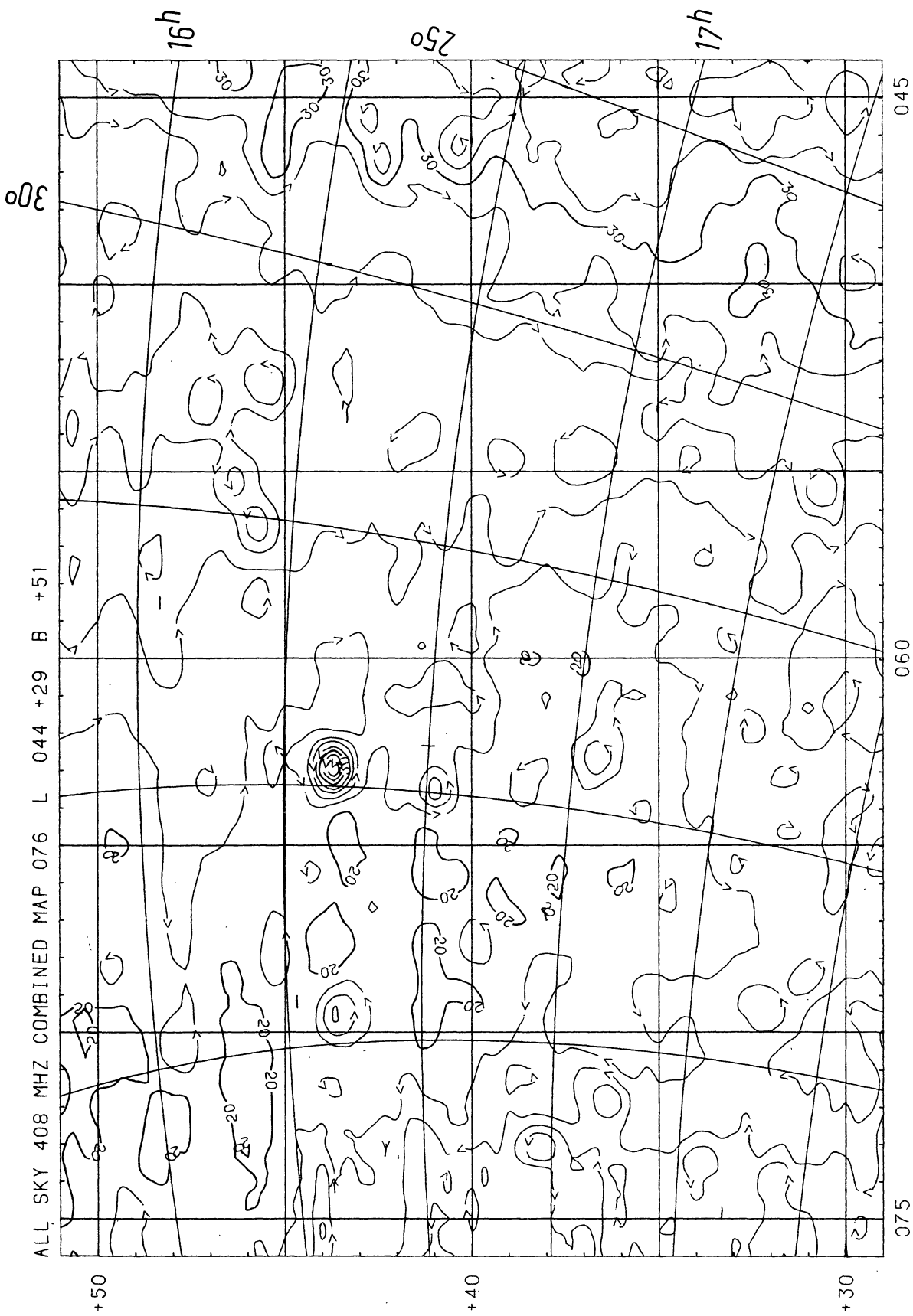

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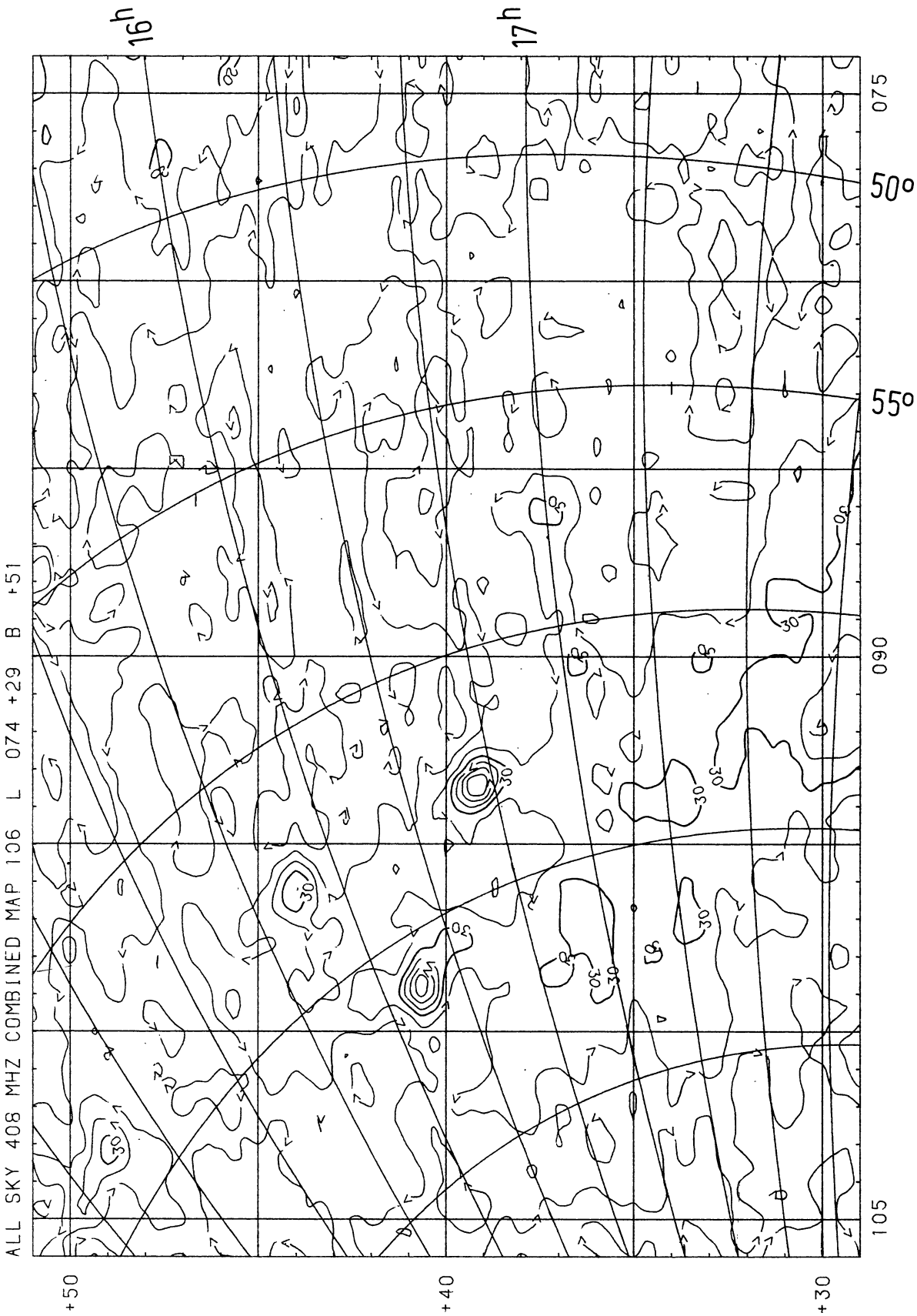

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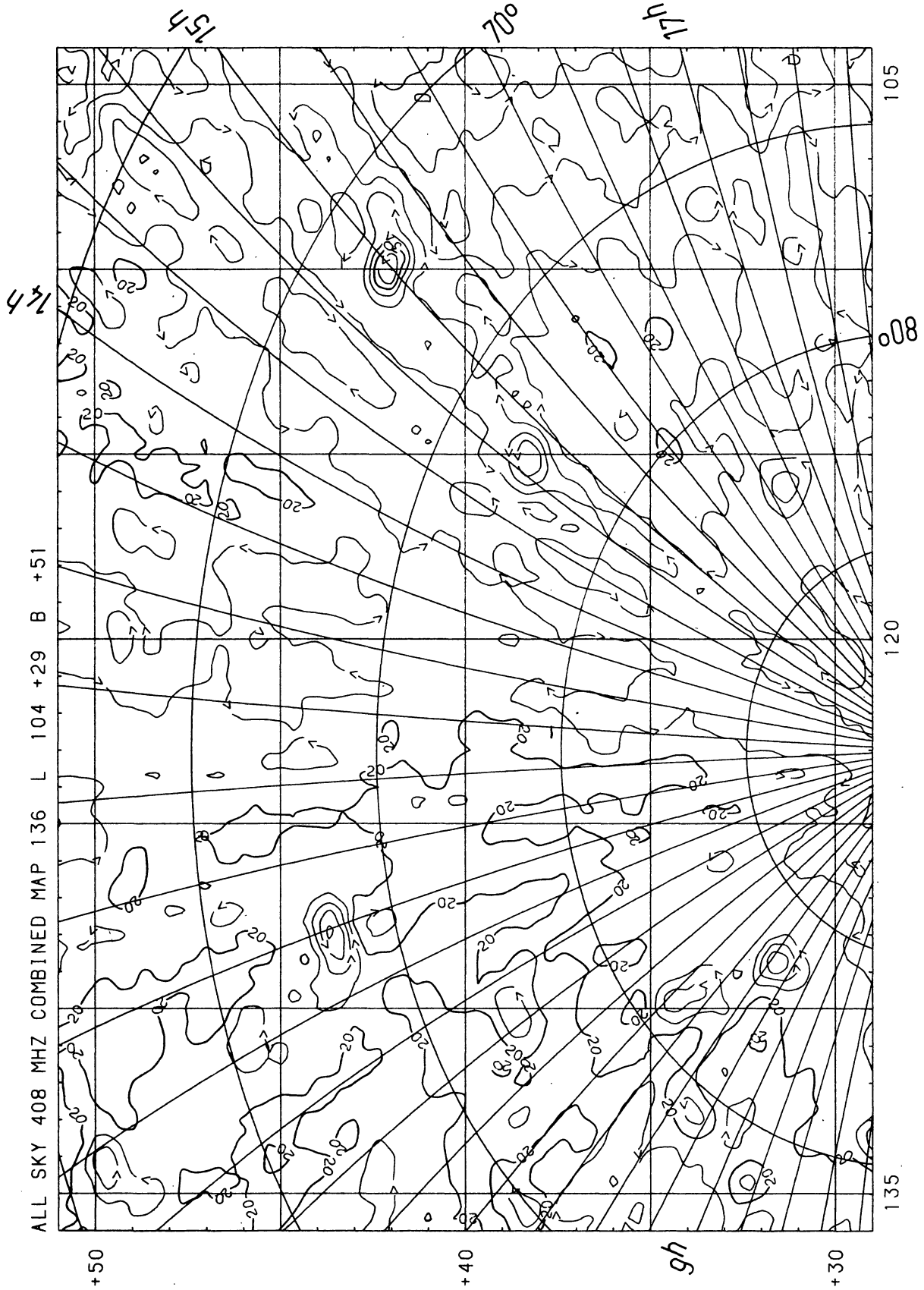

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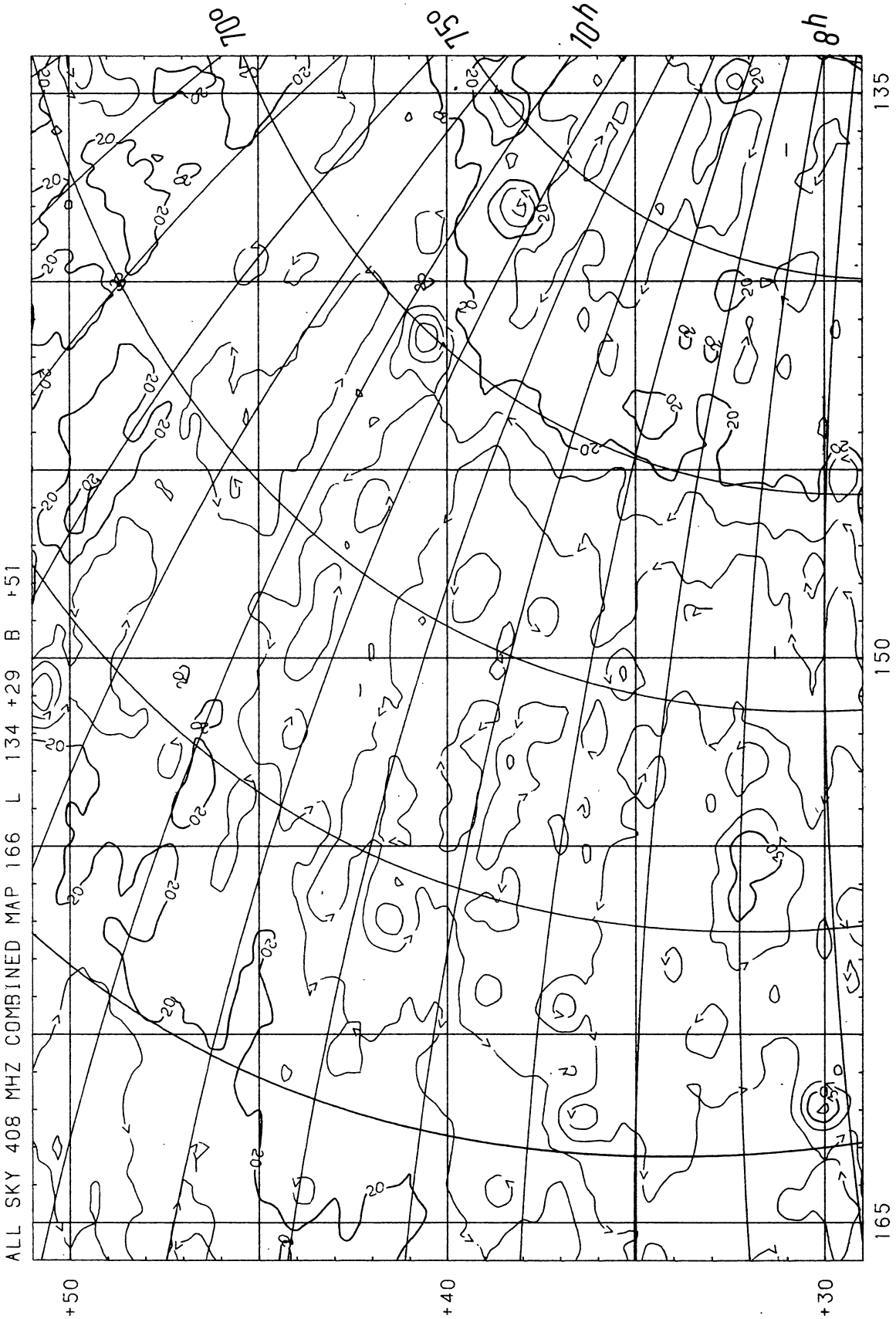

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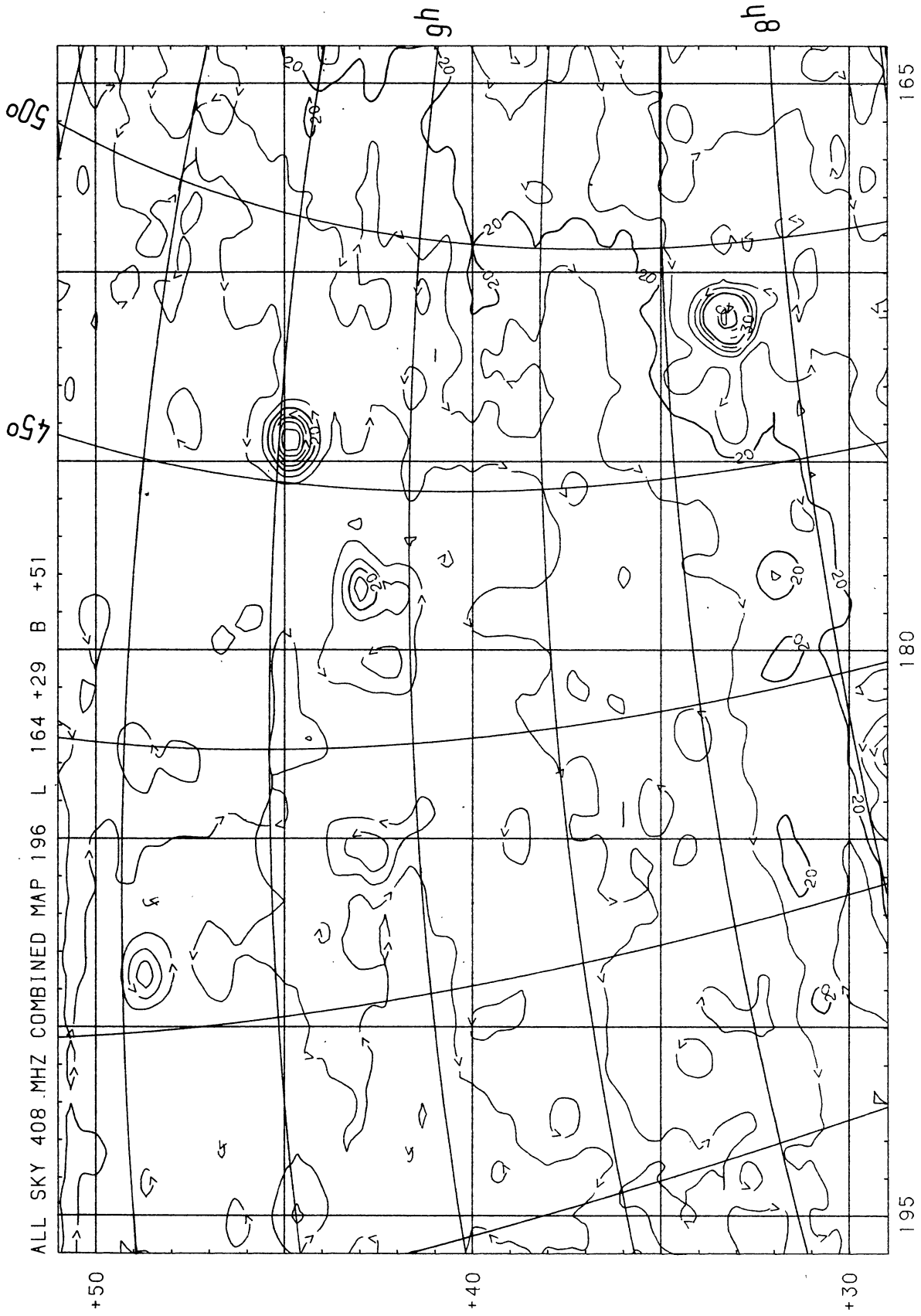

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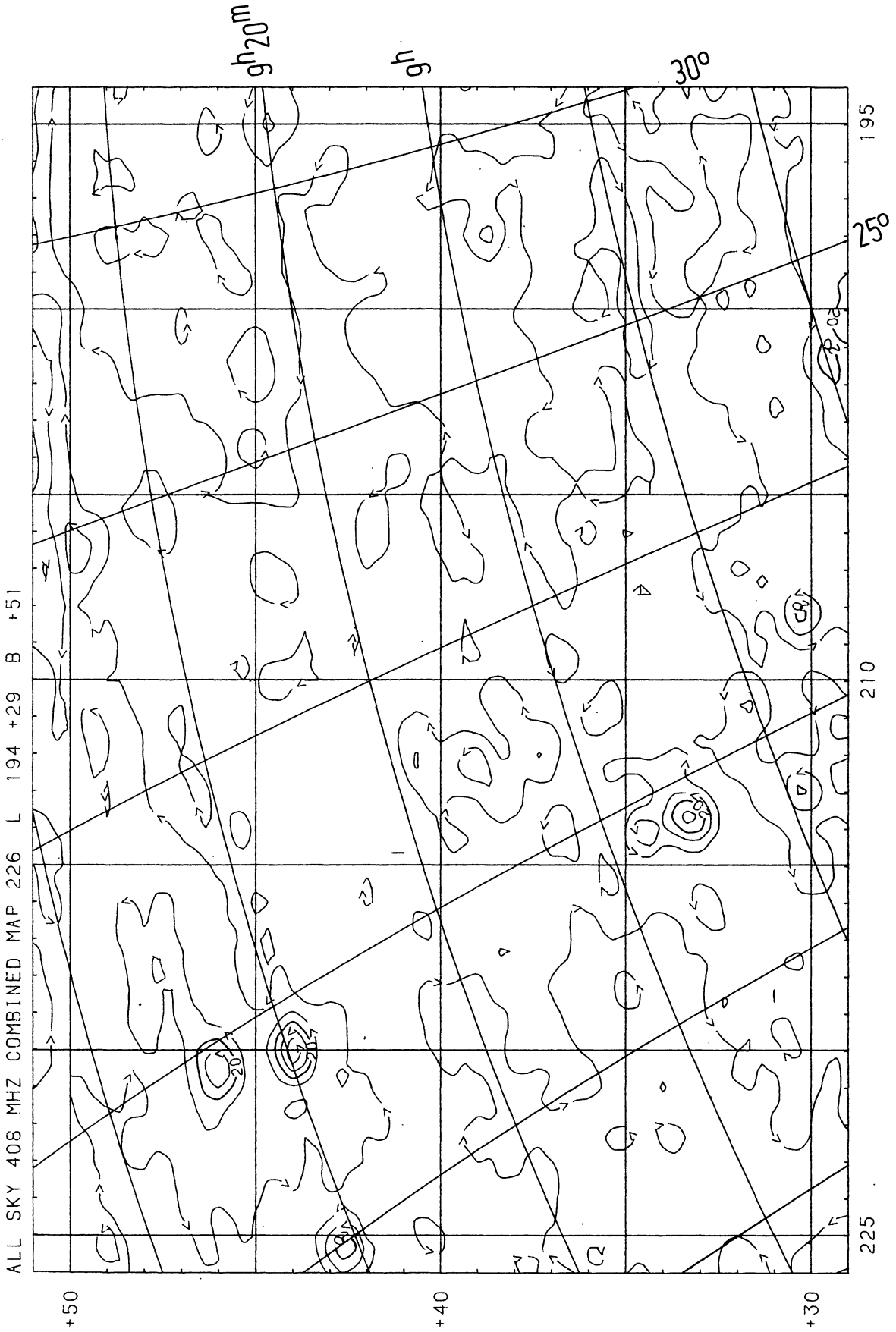

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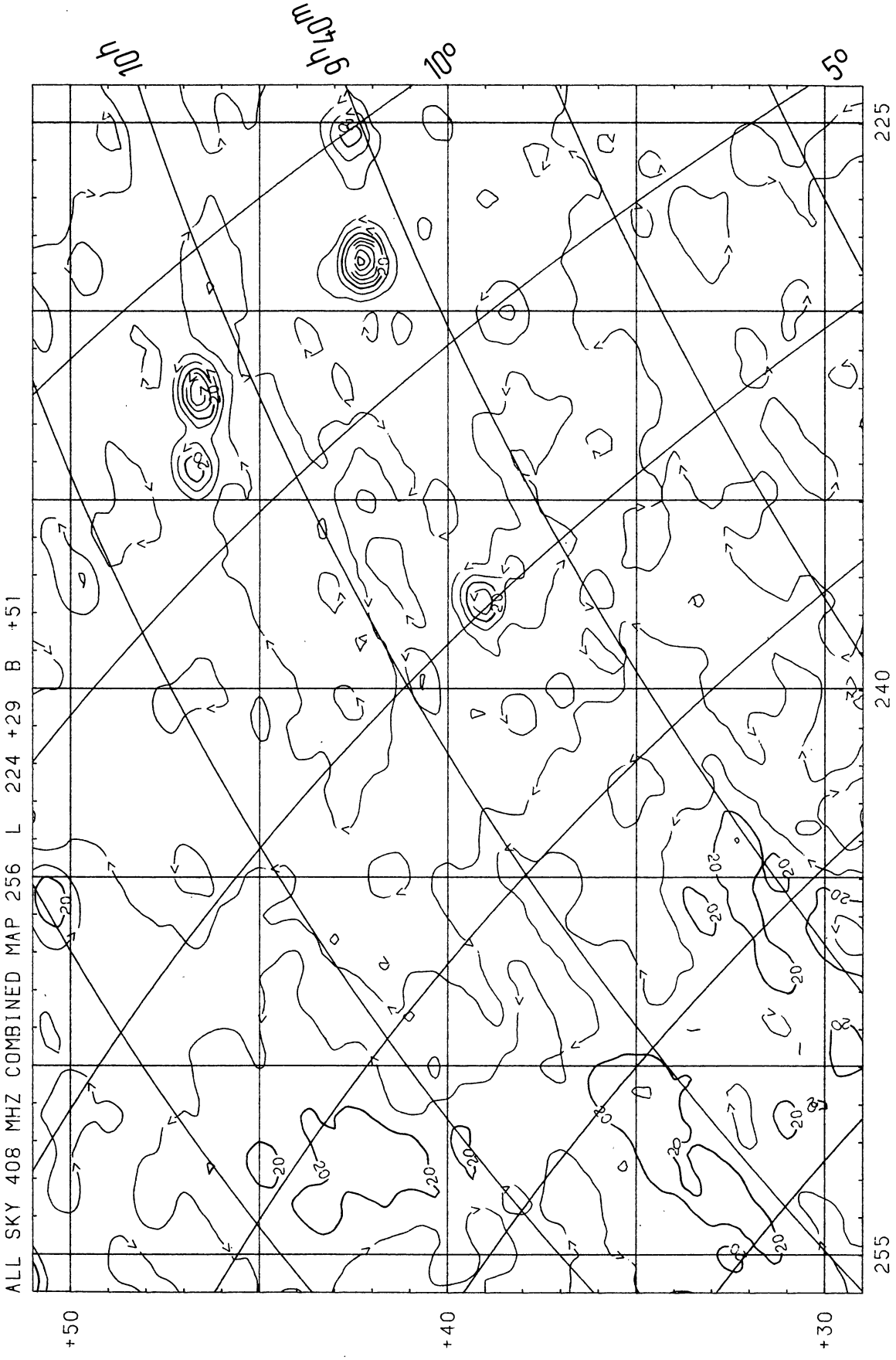

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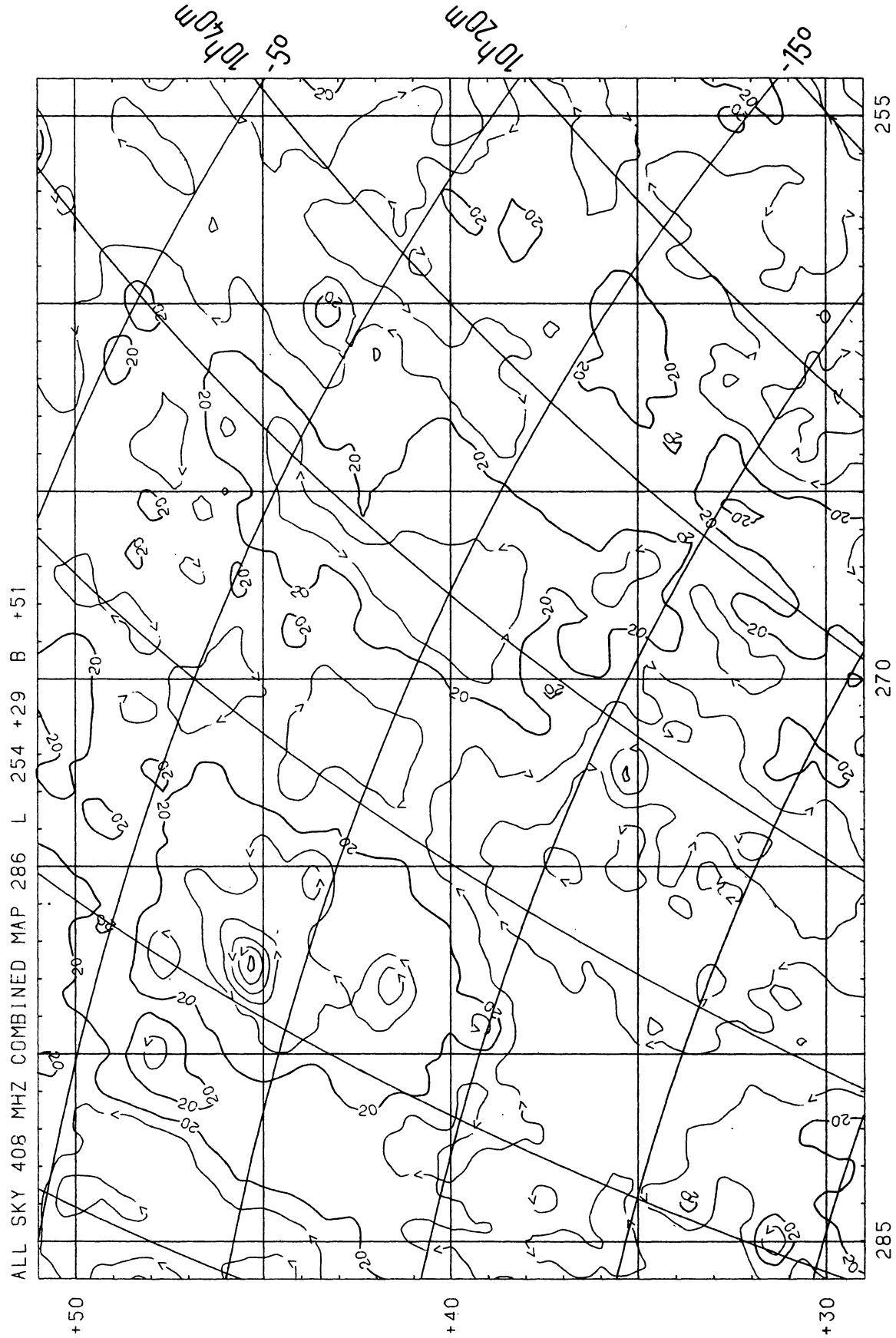

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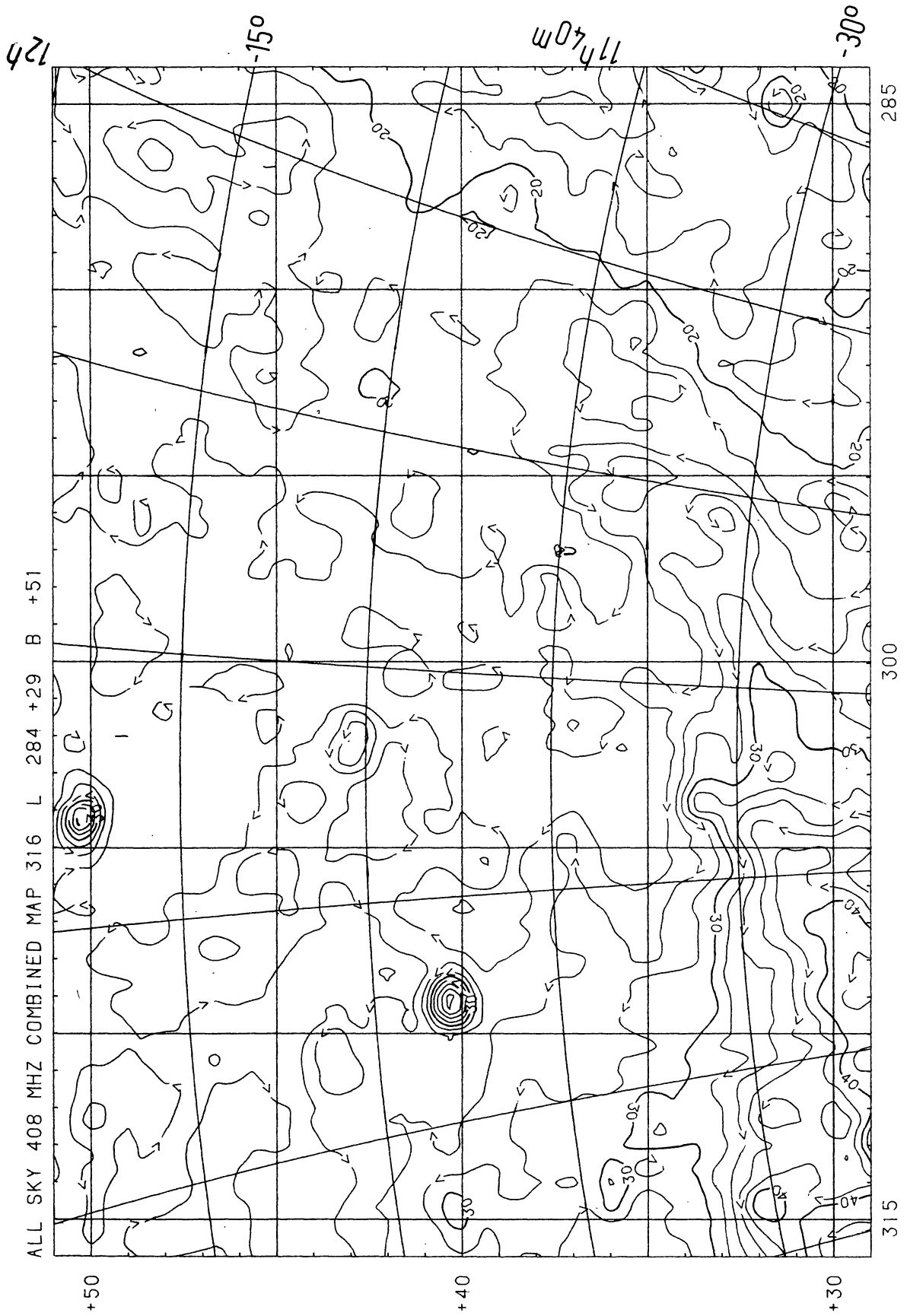

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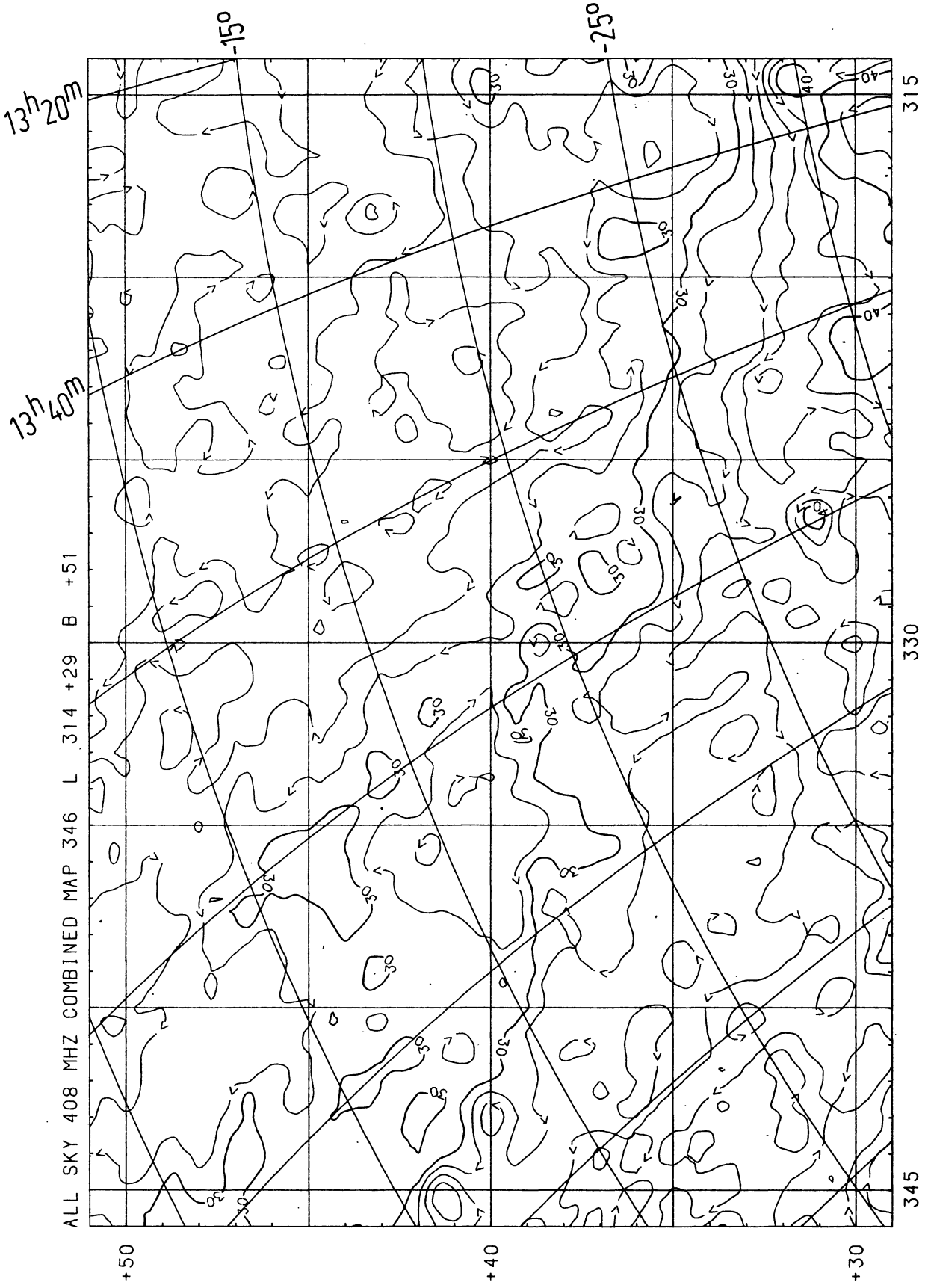

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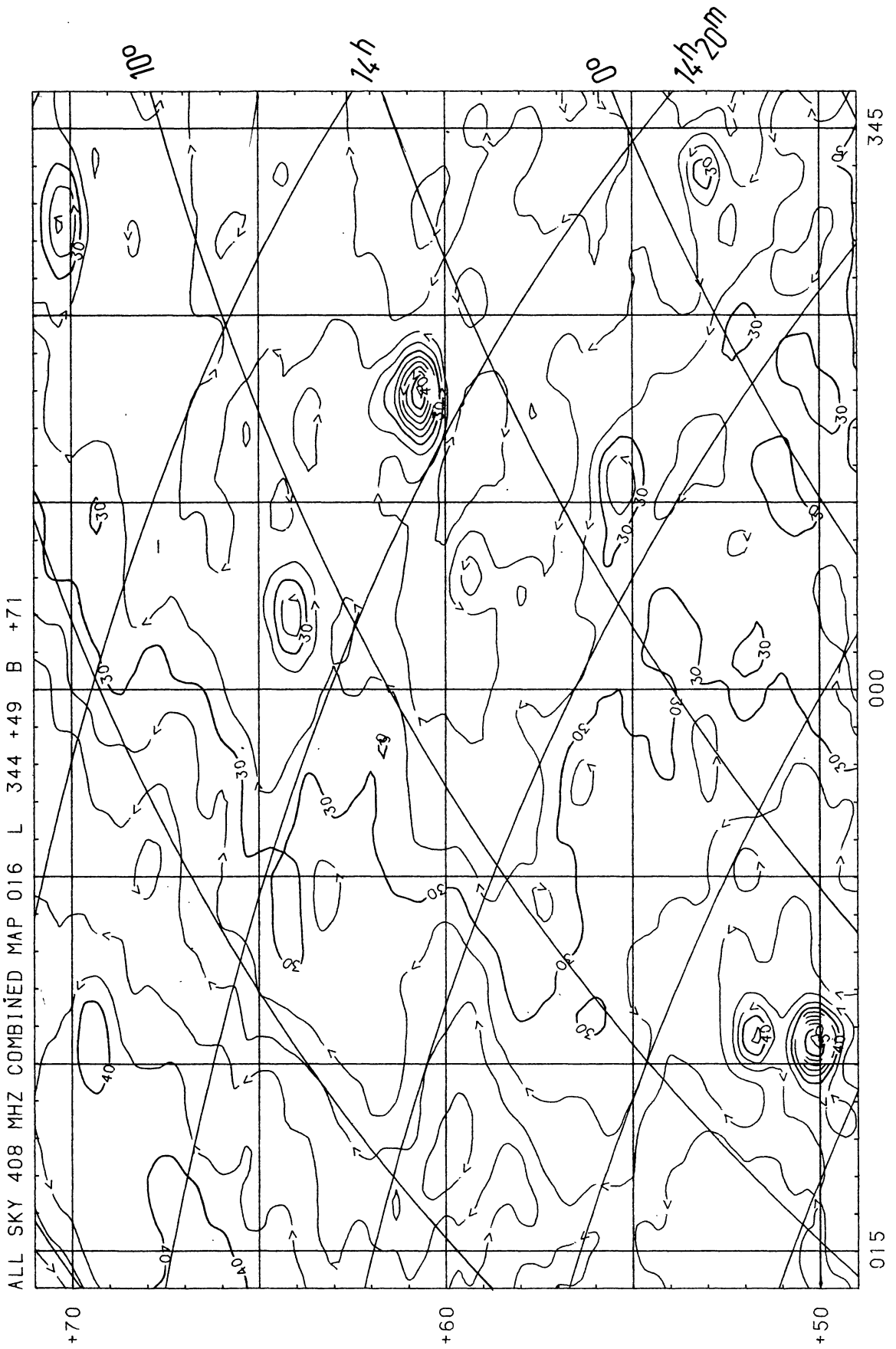

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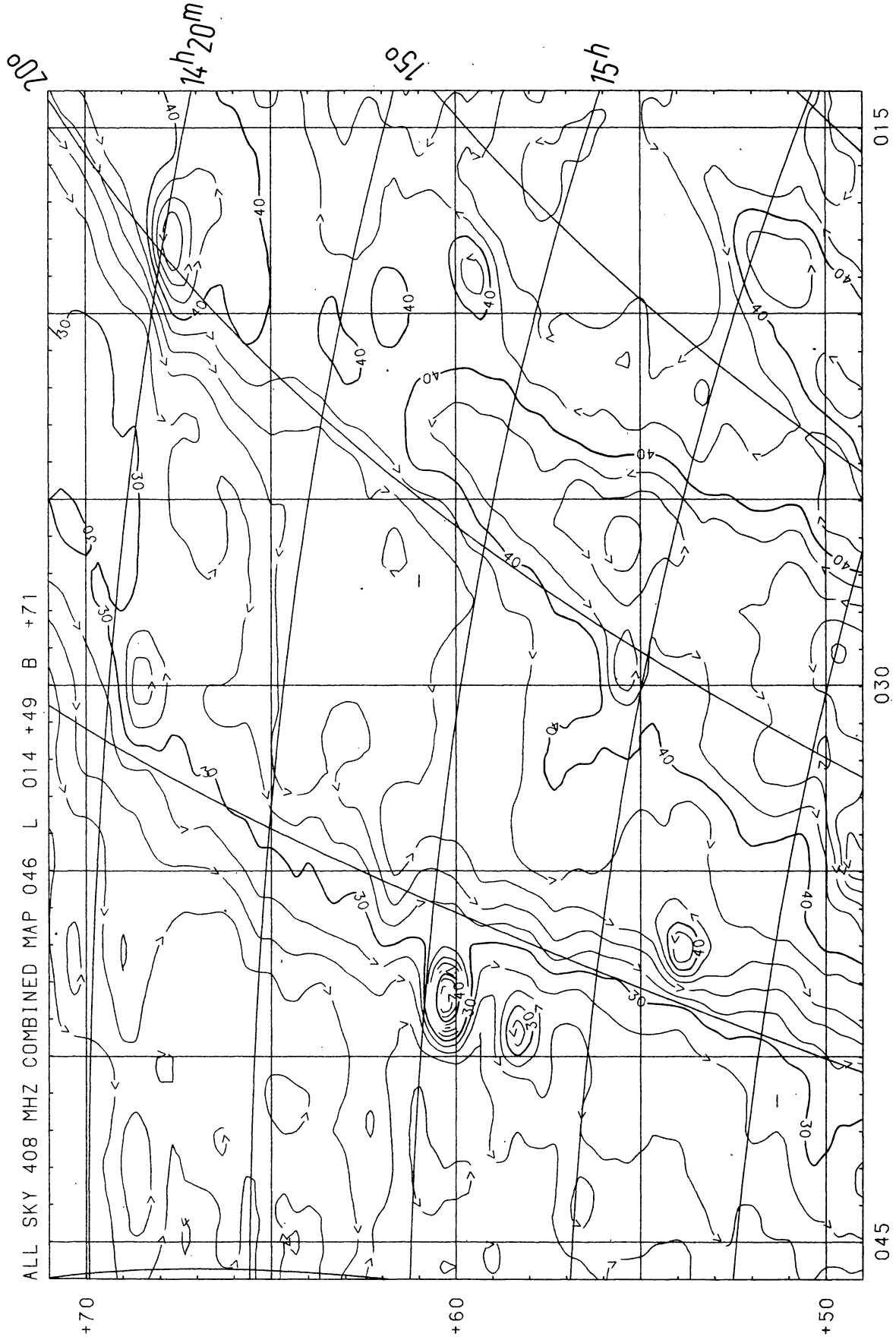

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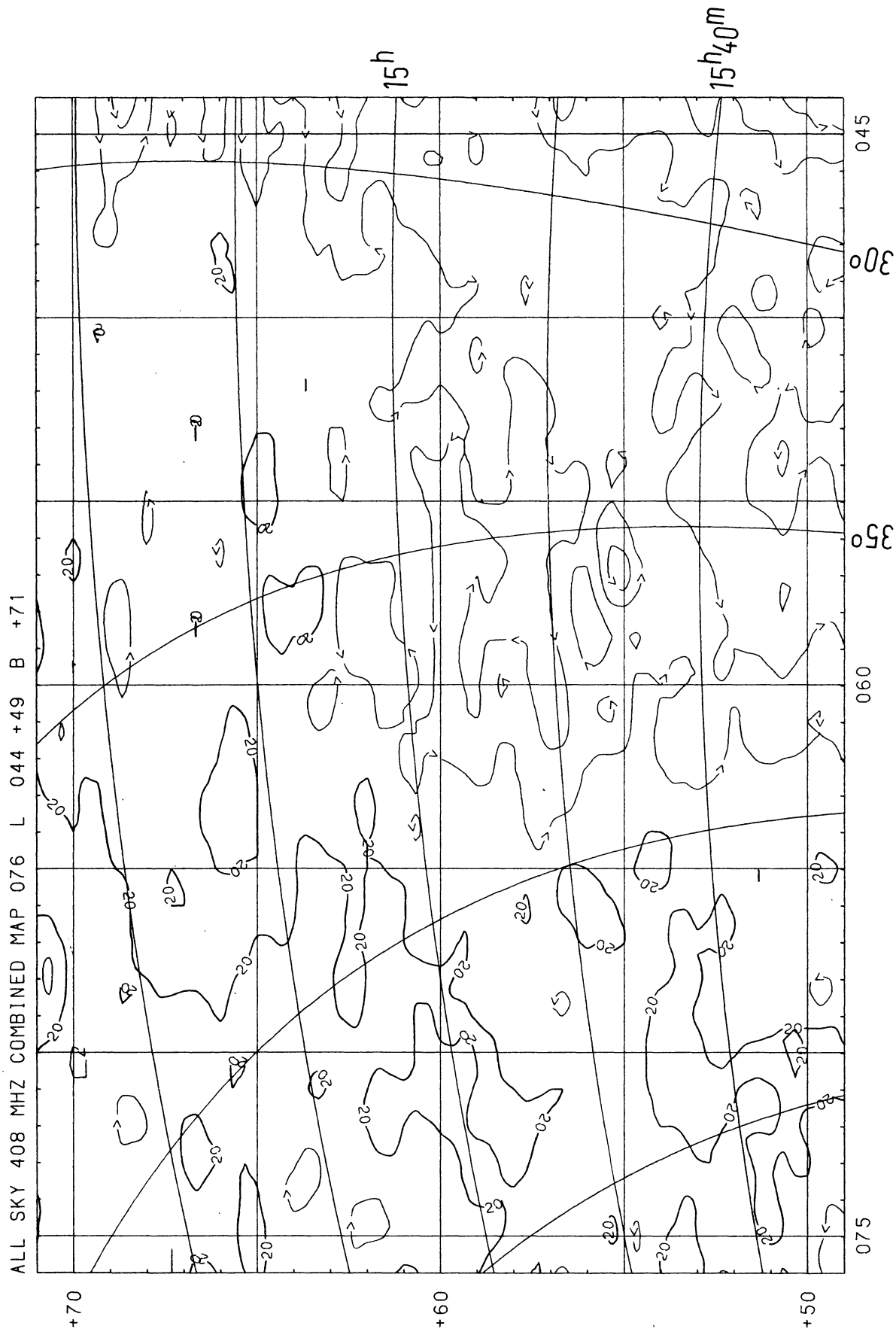

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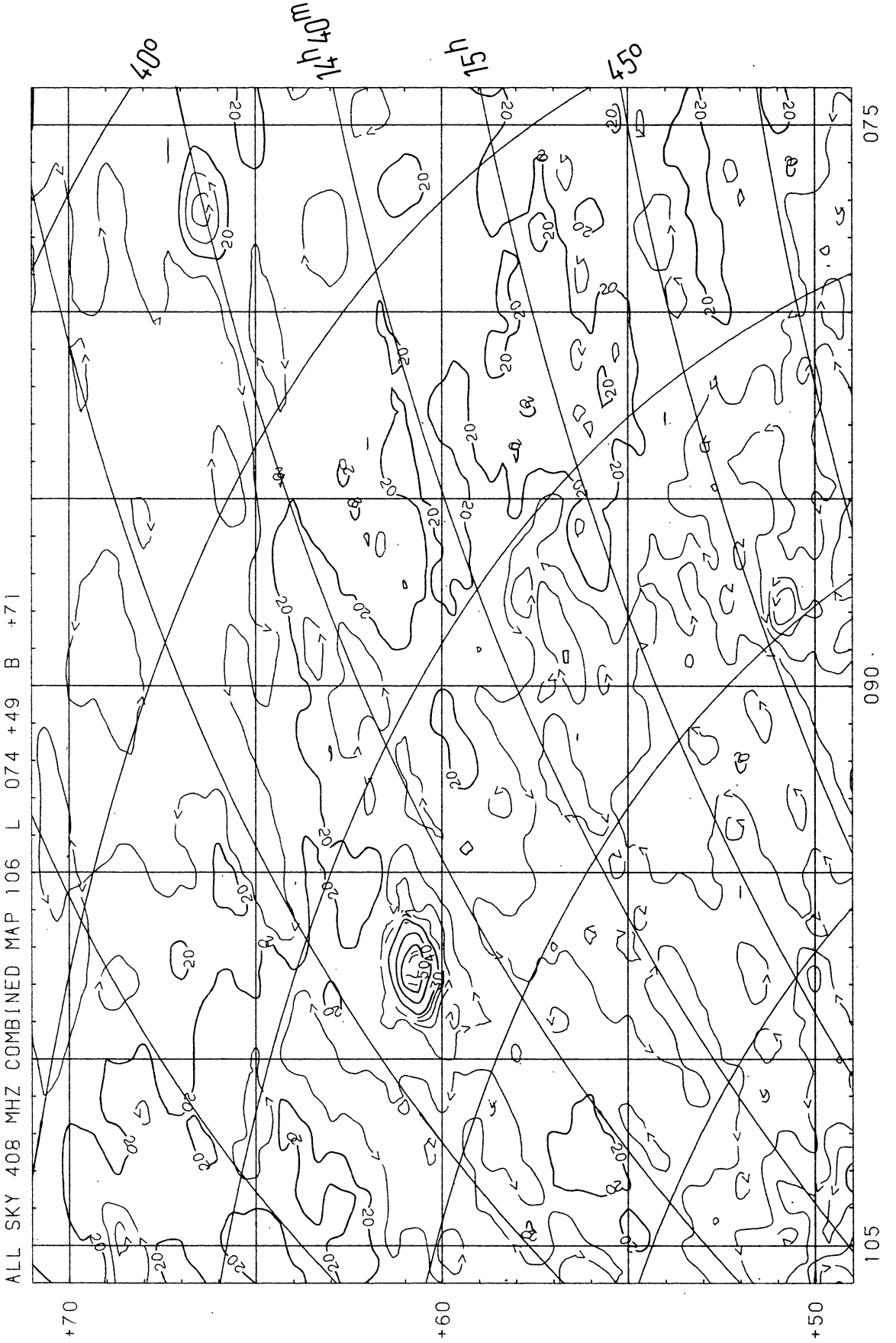

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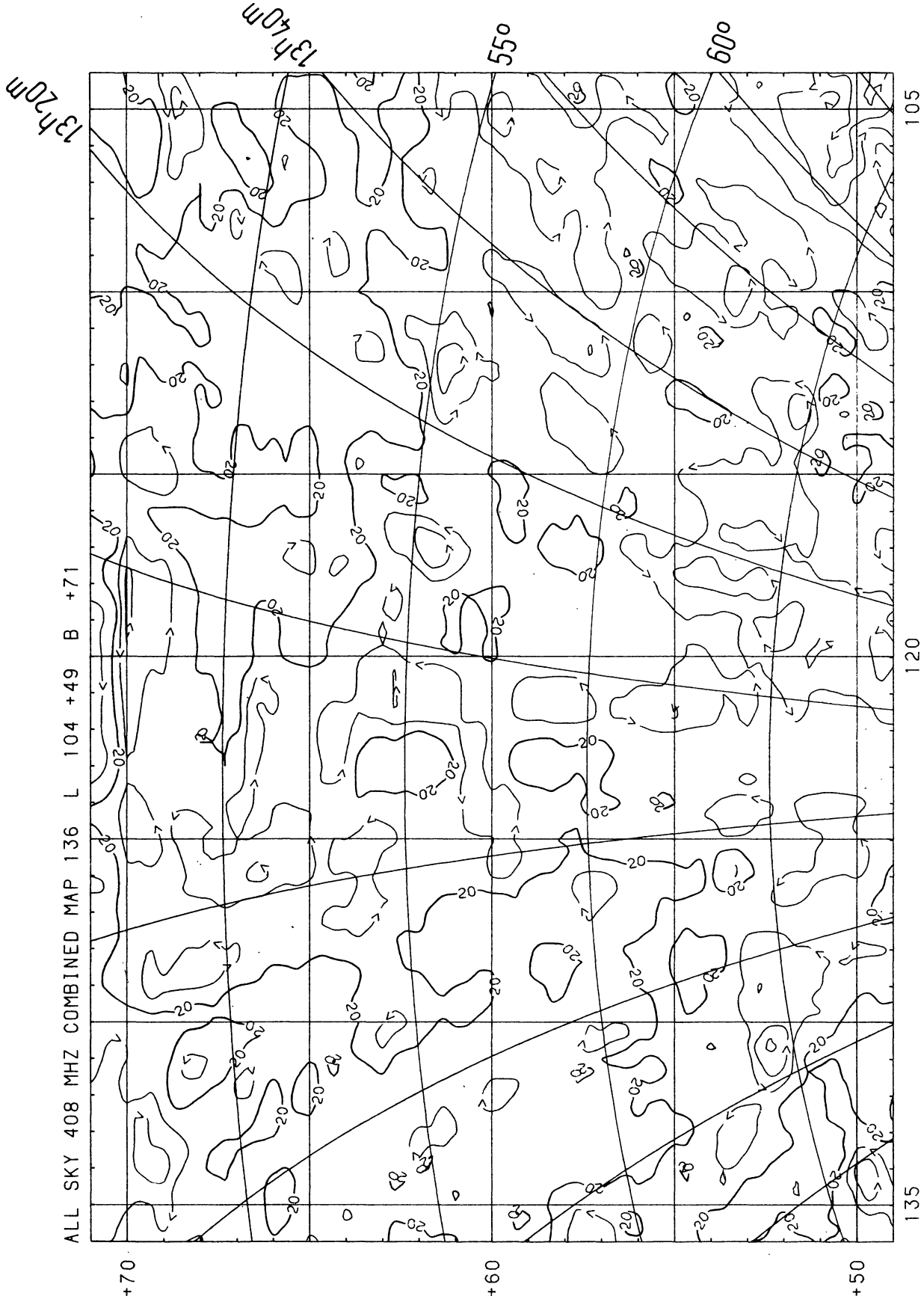

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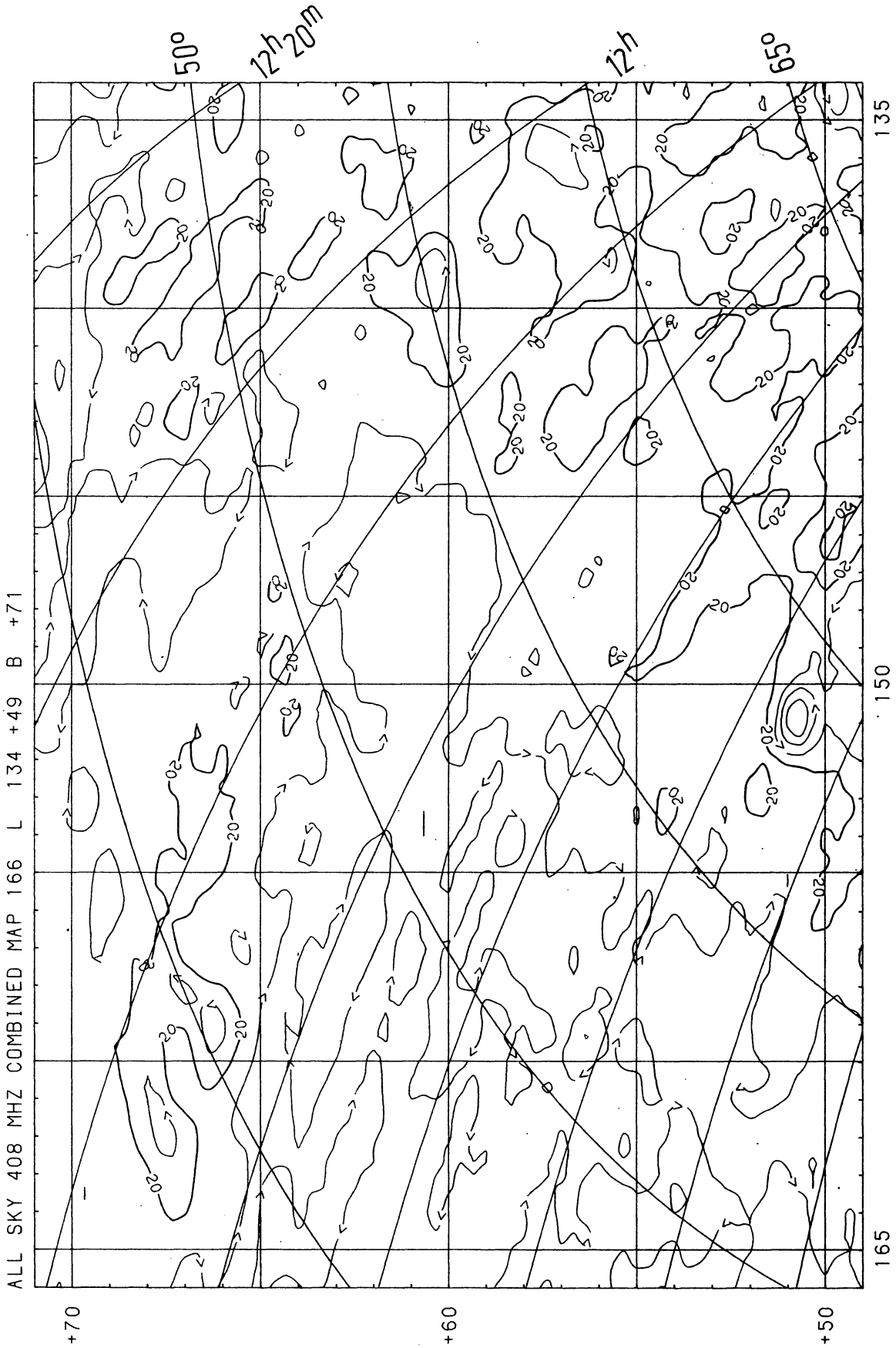

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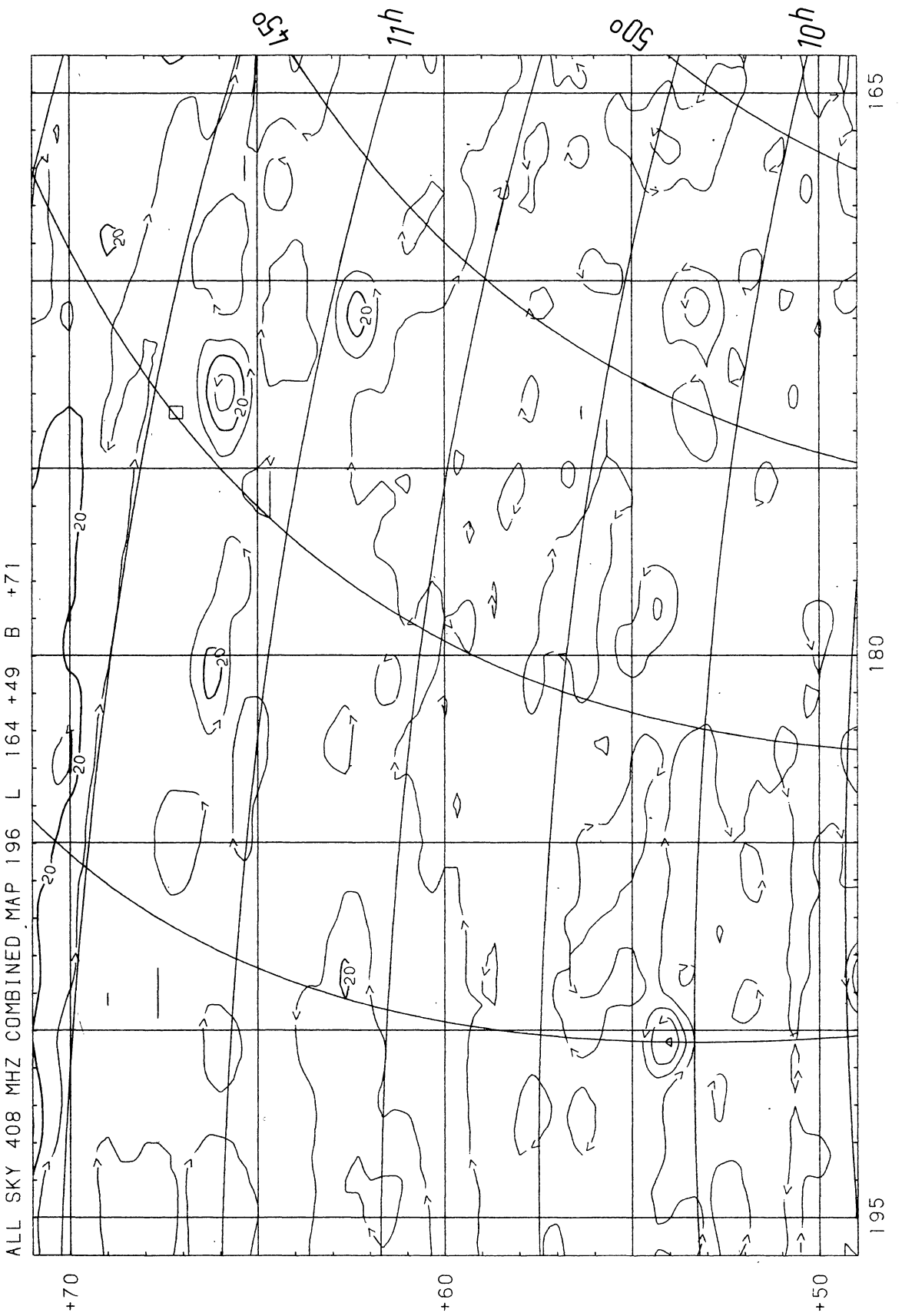

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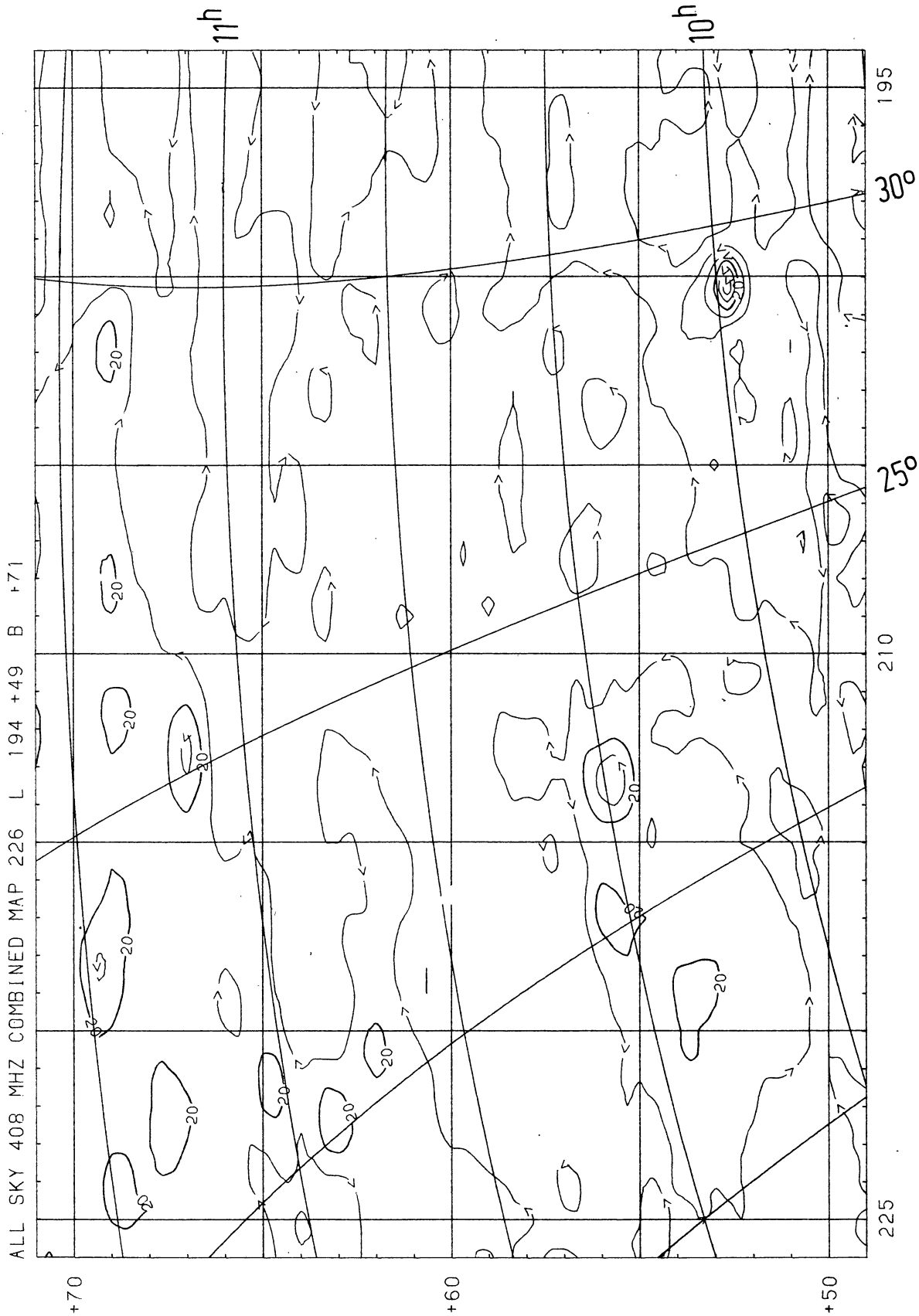

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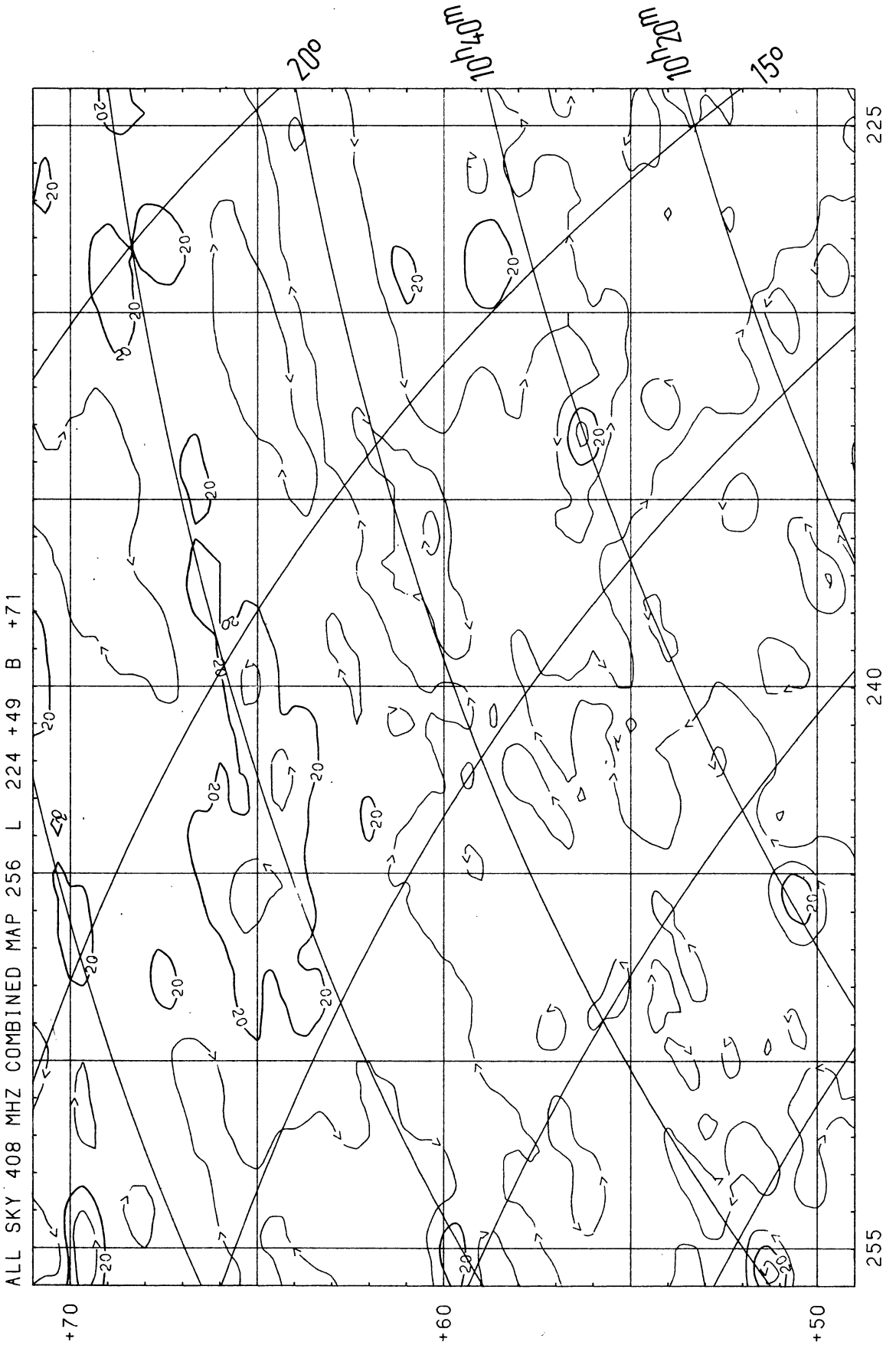

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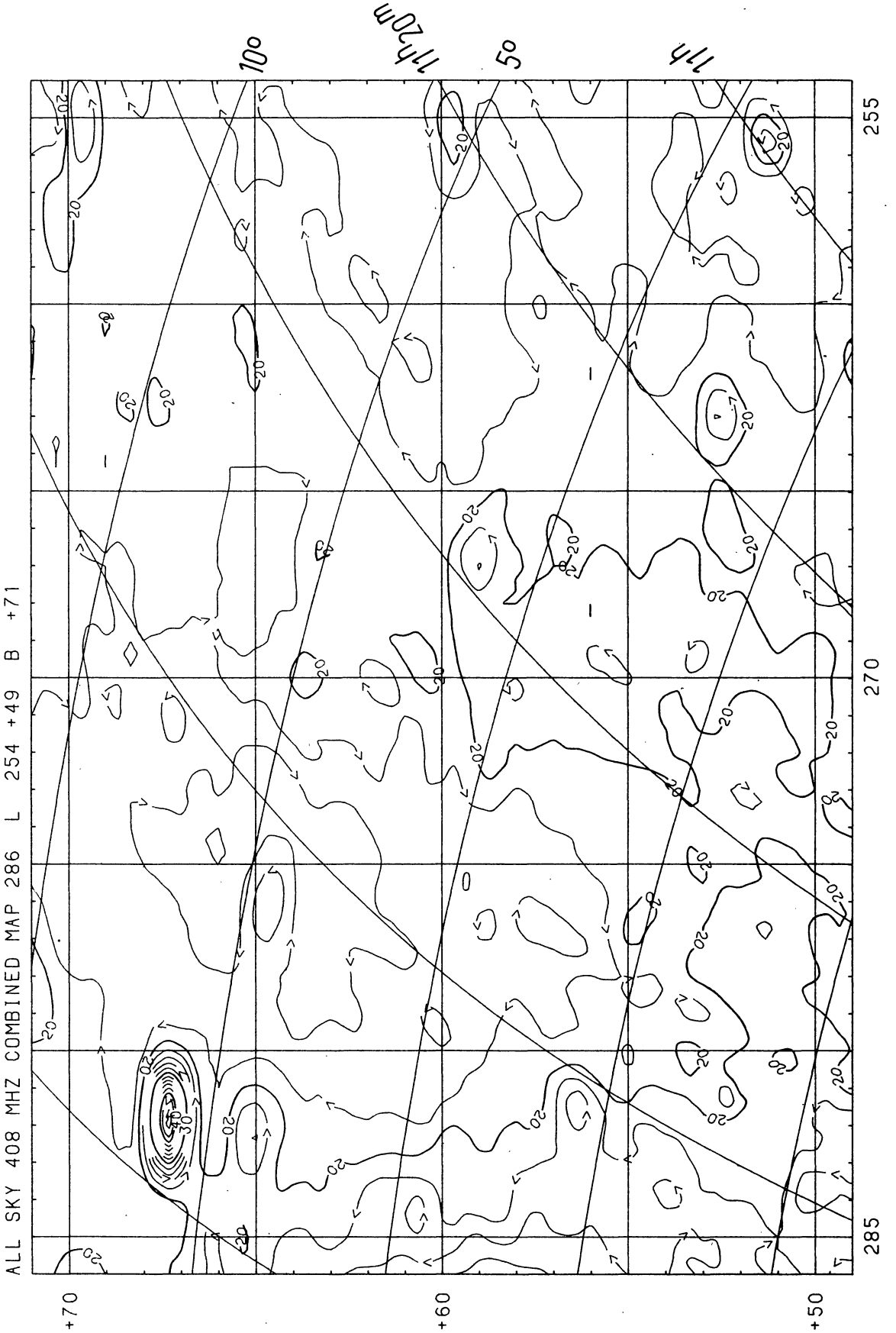

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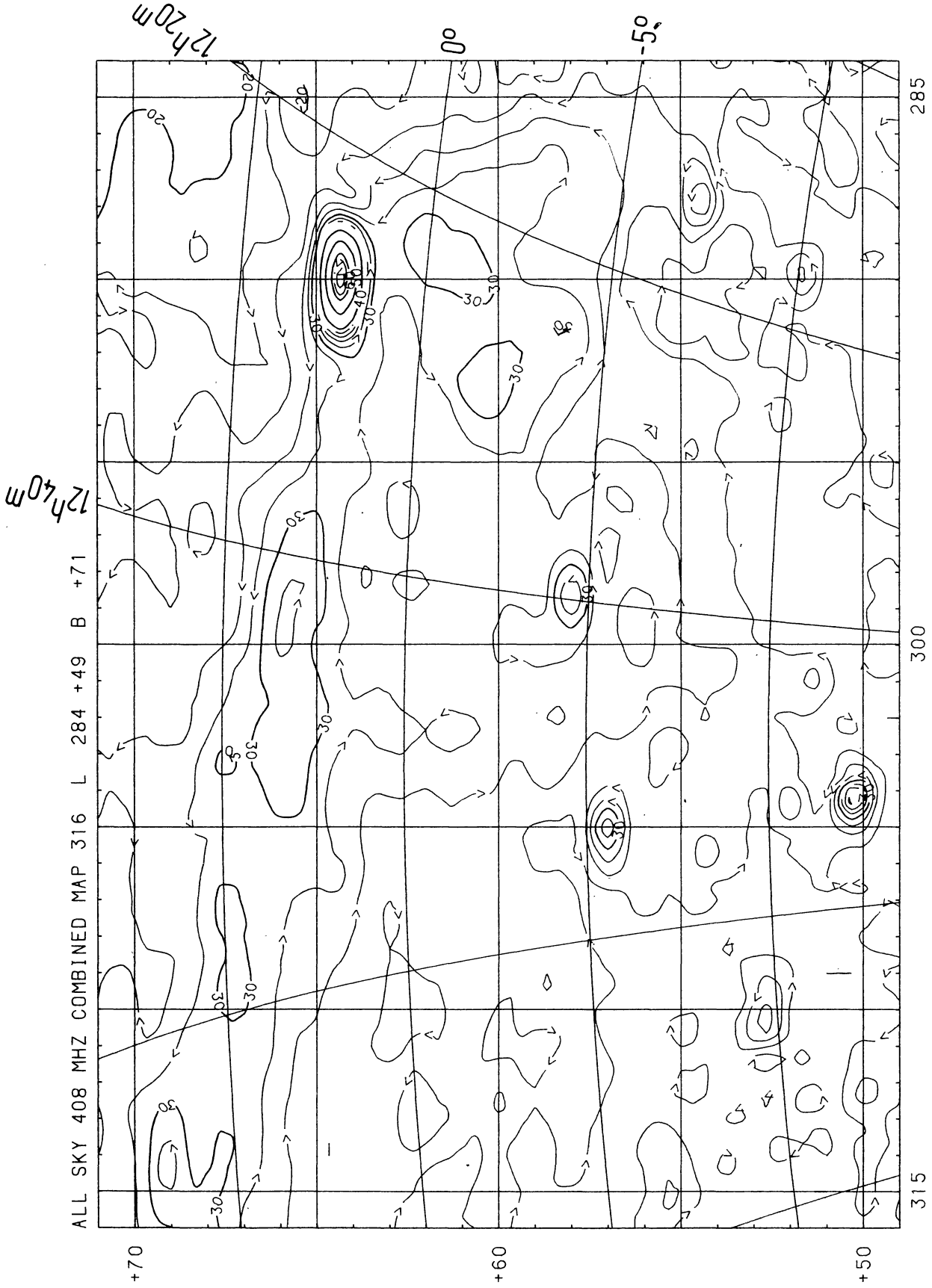

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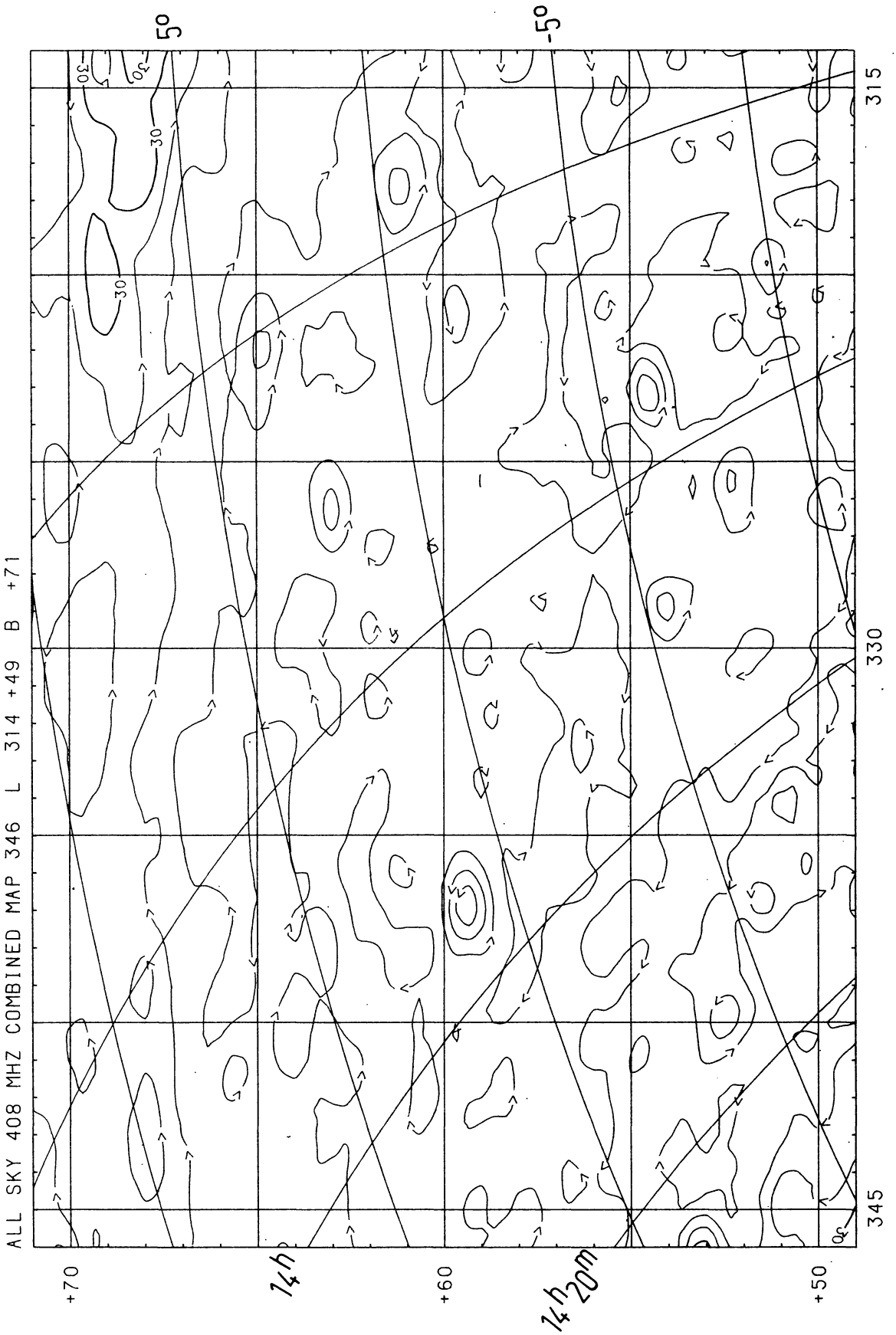

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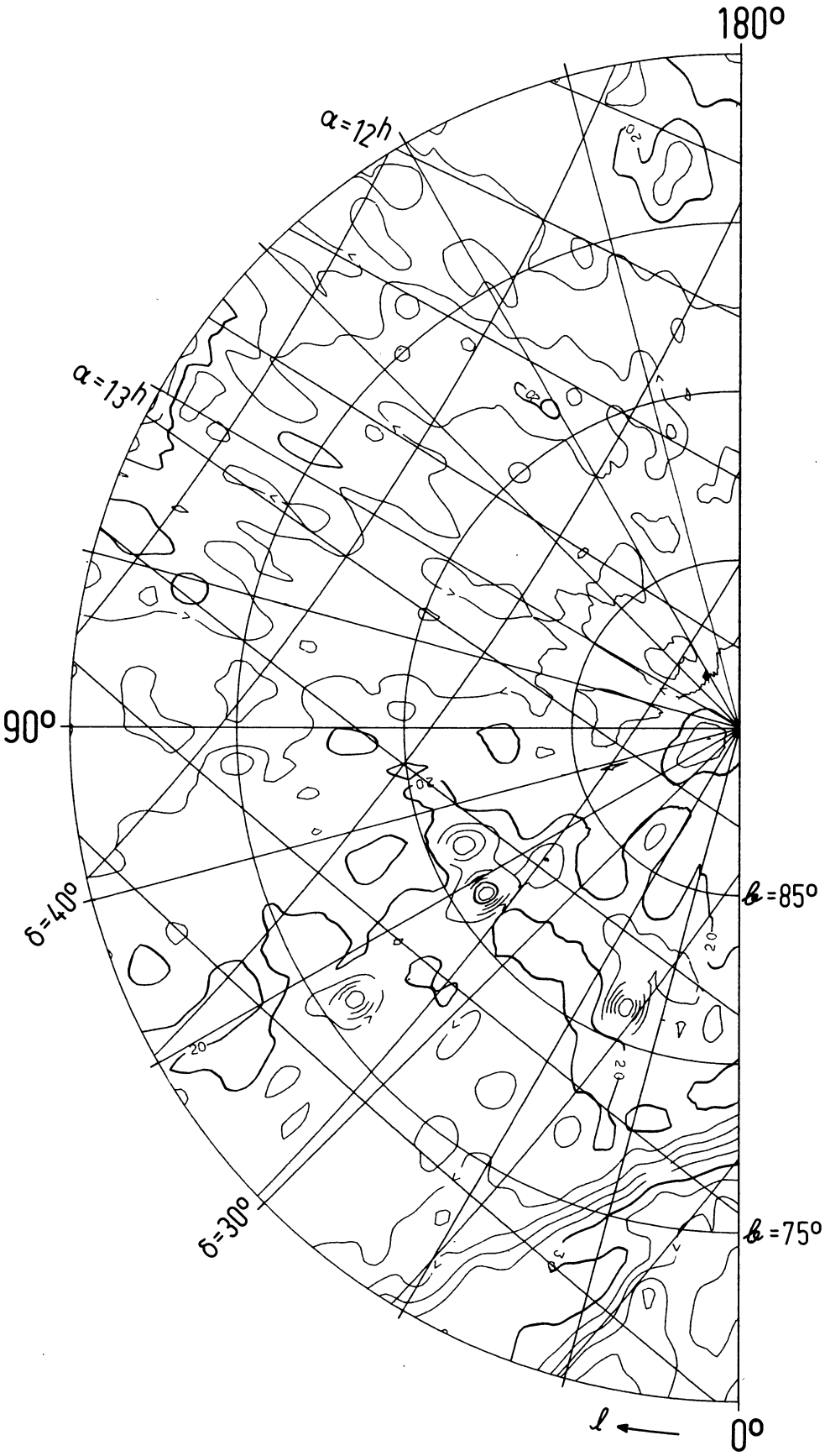
North galactic Pole.



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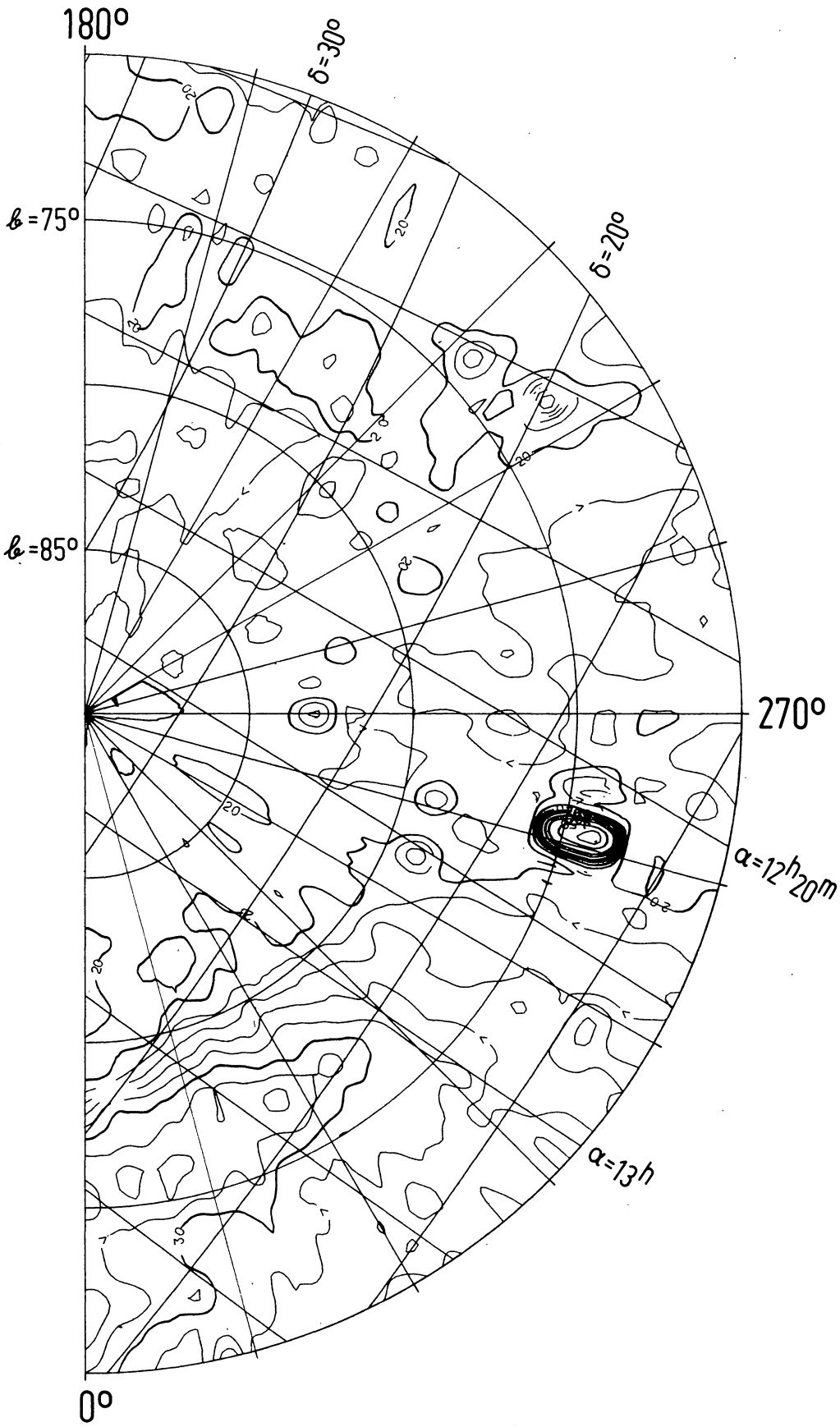

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FIGURE 4. — The atlas presented in equal-area Galactic coordinates as a colour photograph. The limited horizontal resolution of 512 pixels means that the data base is undersampled with only 1.21 pixels per half power beamwidth, thus giving a slightly smoothed image. However several interesting aspects of the large scale Galactic emission at 408 MHz can be clearly identified including the relationships of the extended low surface brightness features such as the Galactic Loops and the North Polar Spur. Centaurus A at $l = 310°, b = +20°$ and the Large Magellanic Cloud at $l = 280°, b = -31°$ are also visible.

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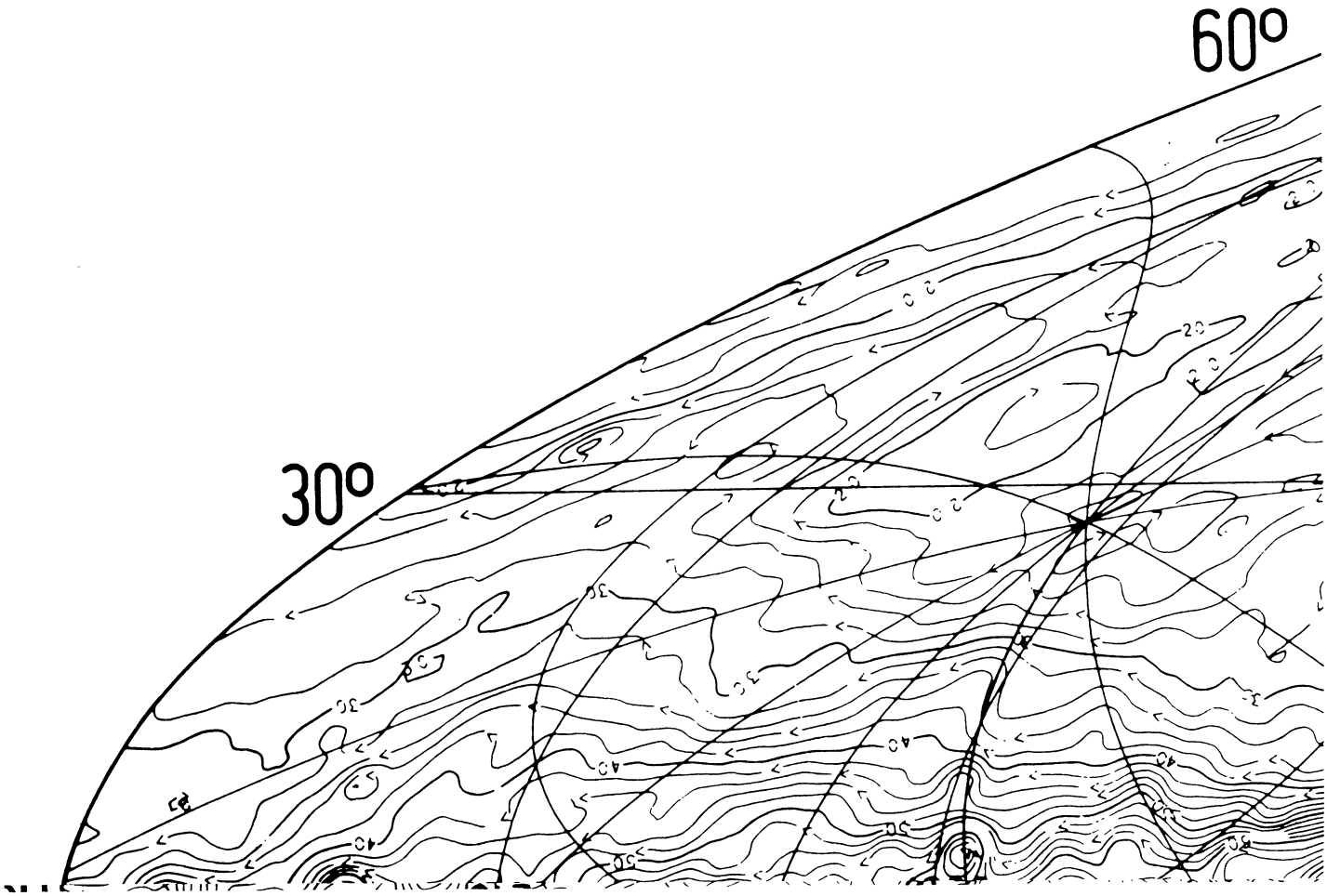

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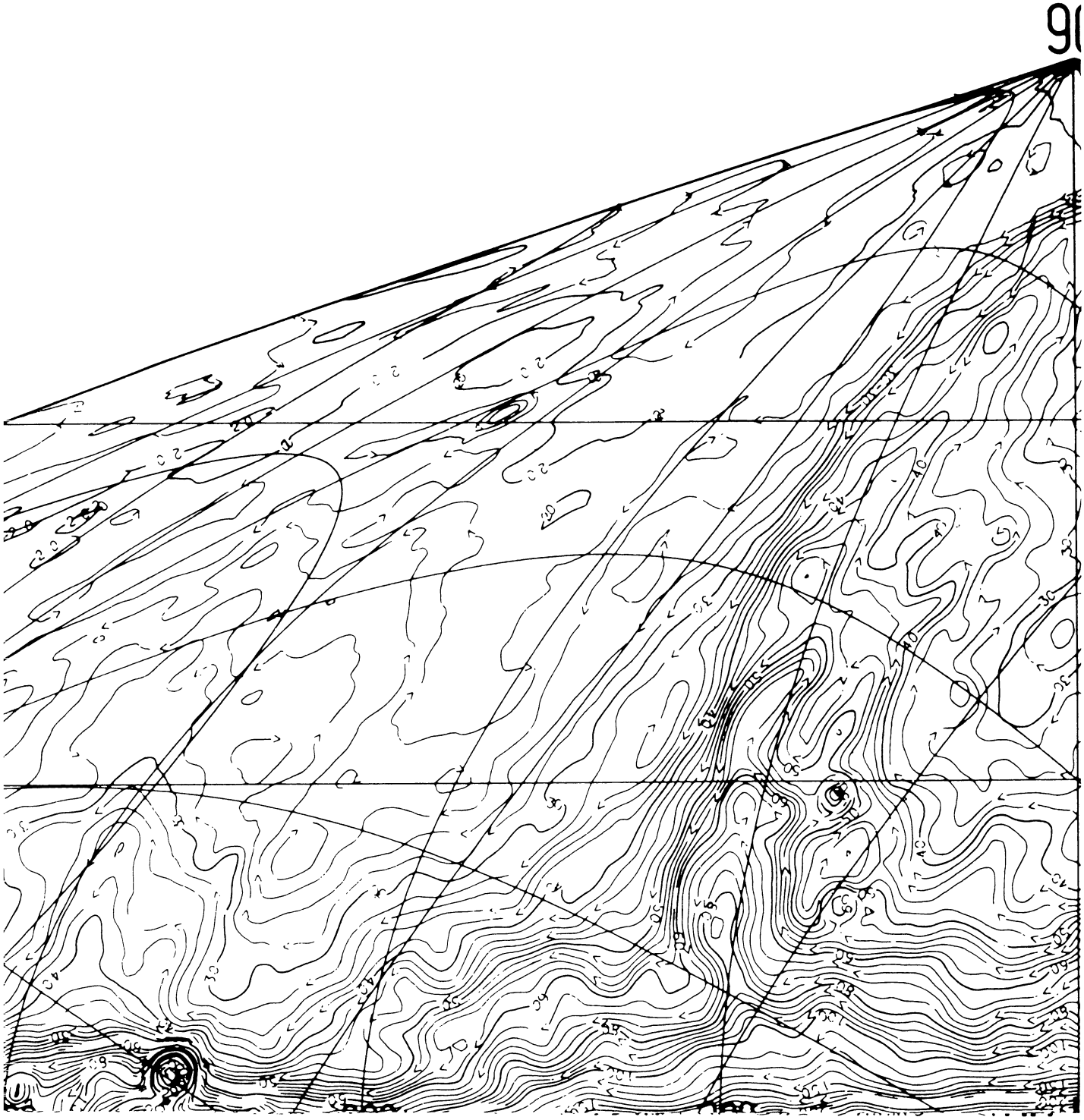
ALL-SKY 408 MHz RAI



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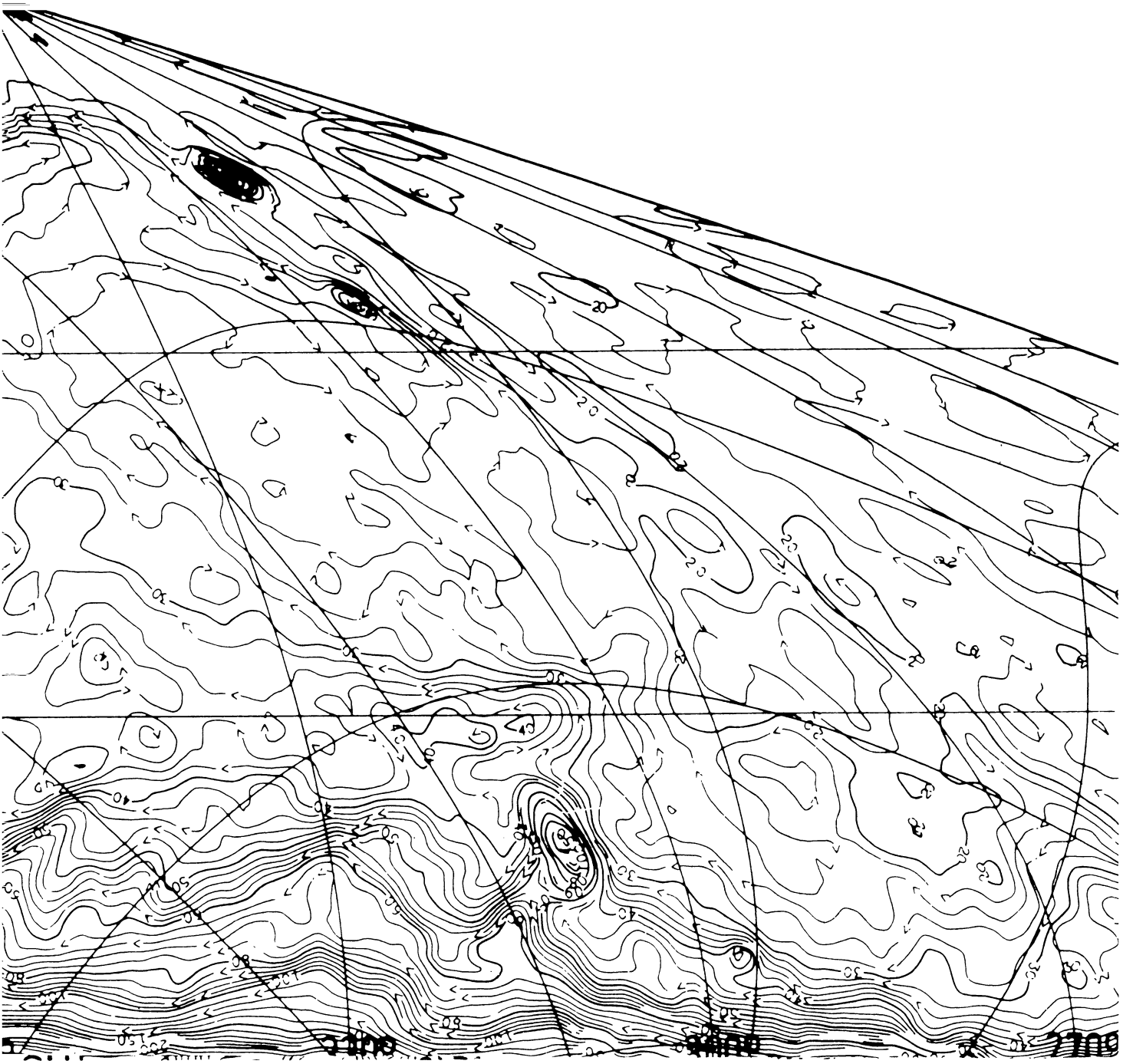
)IO CONTINUUM SURVEY



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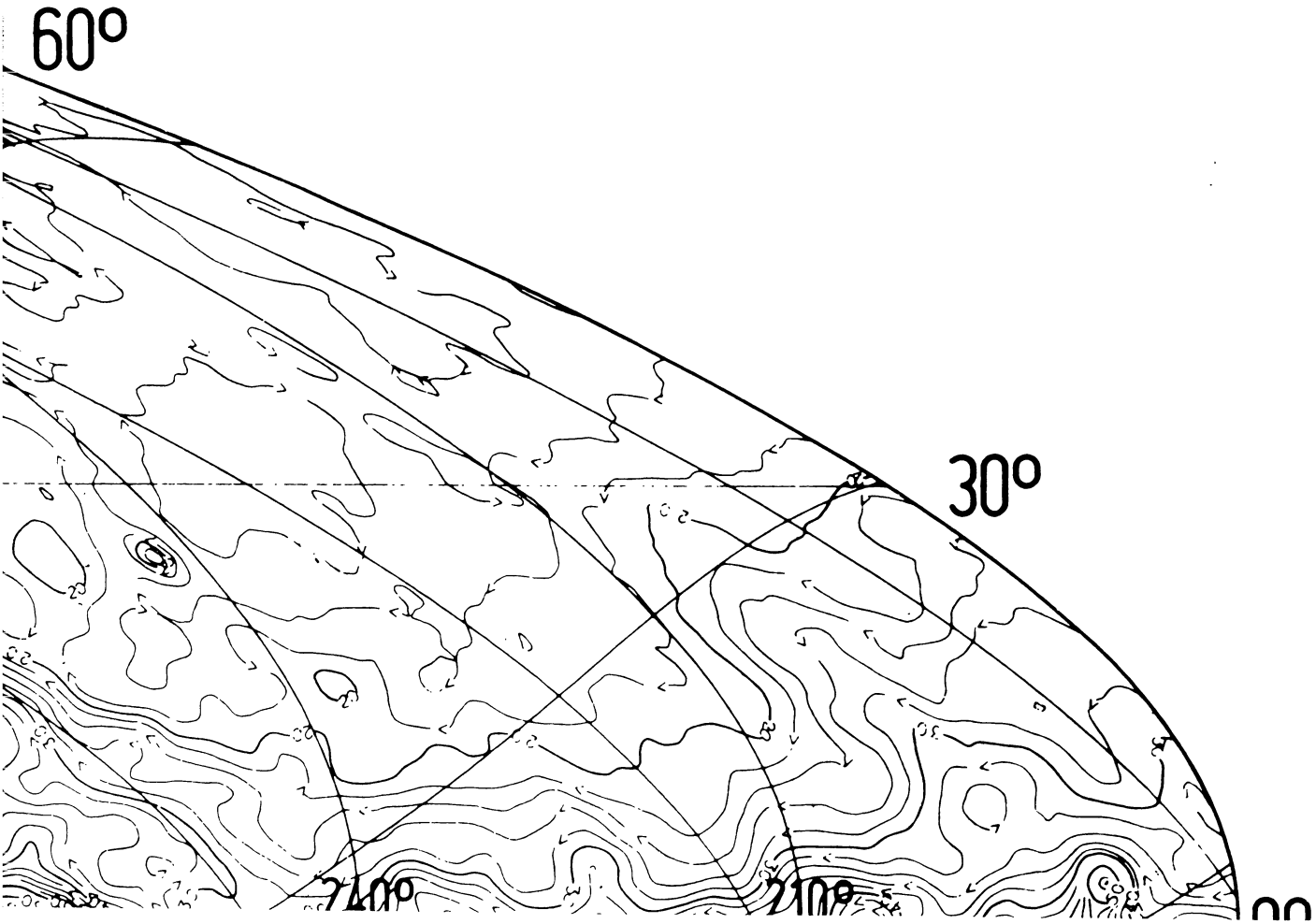

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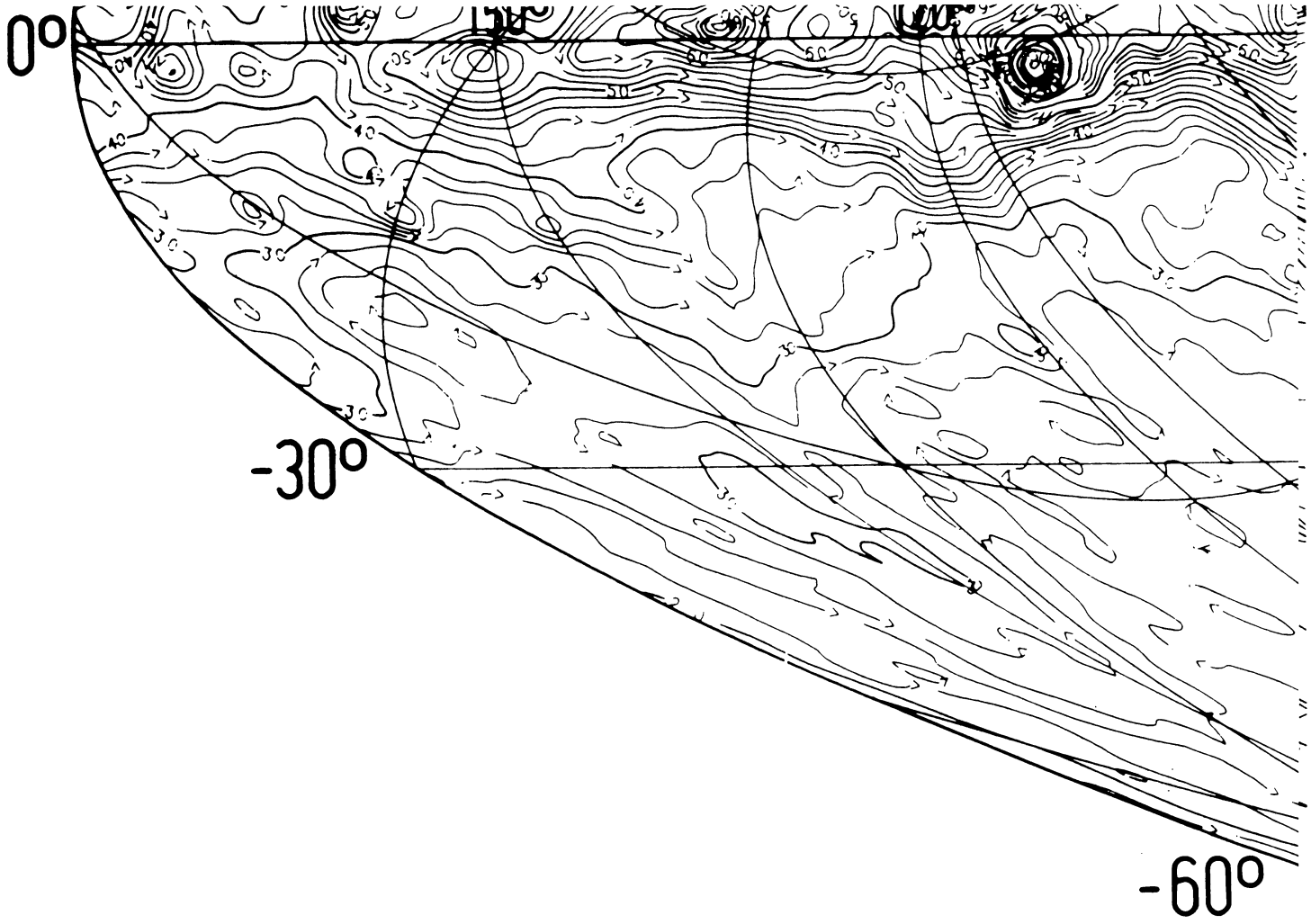

C.G.T. HASLAM
C.J. SALTER
H. STOFFEL
W.E. WILSON

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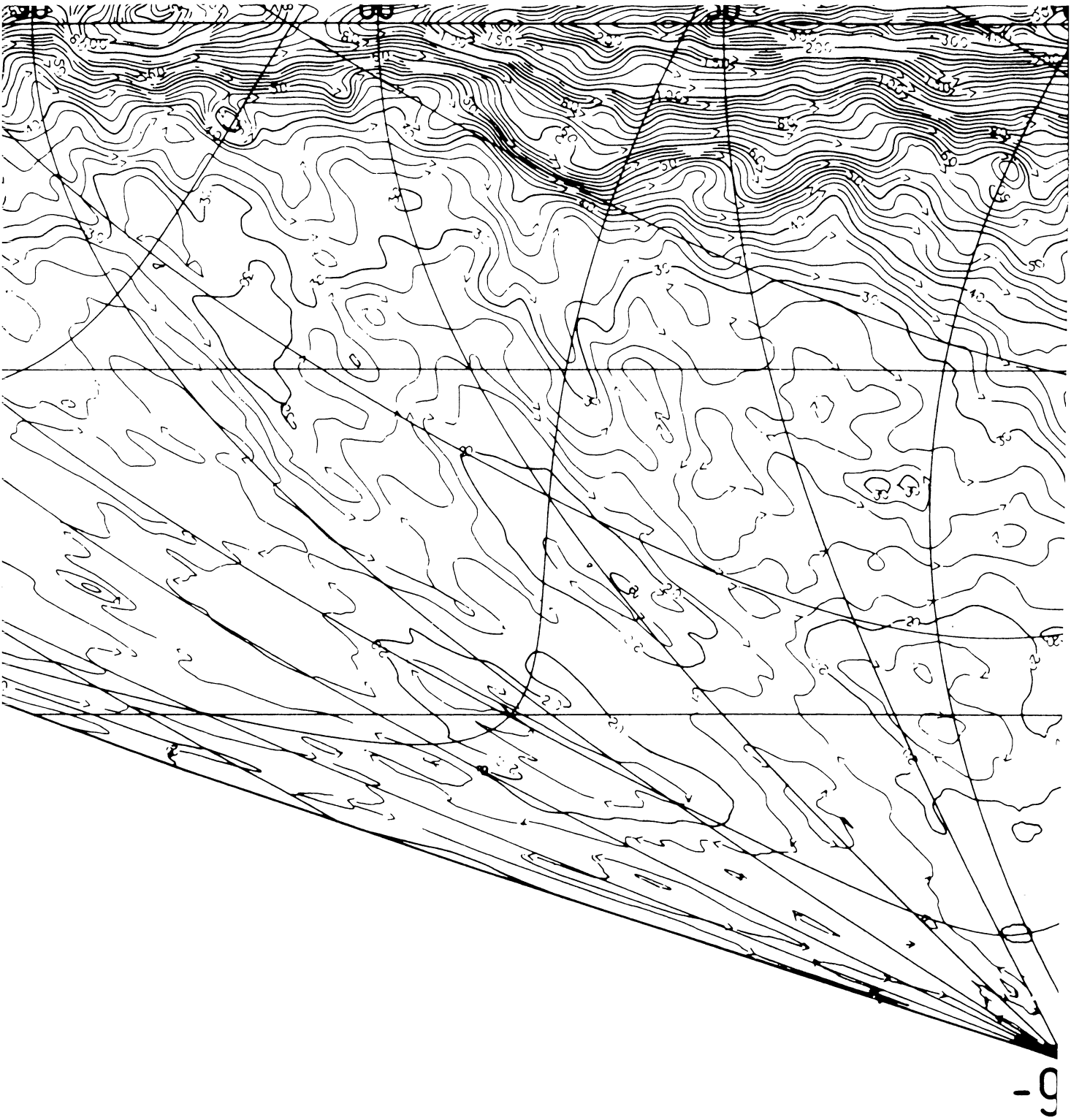

FIGURE 5. — The 408 MHz all-sky survey smoothed to a resolution (

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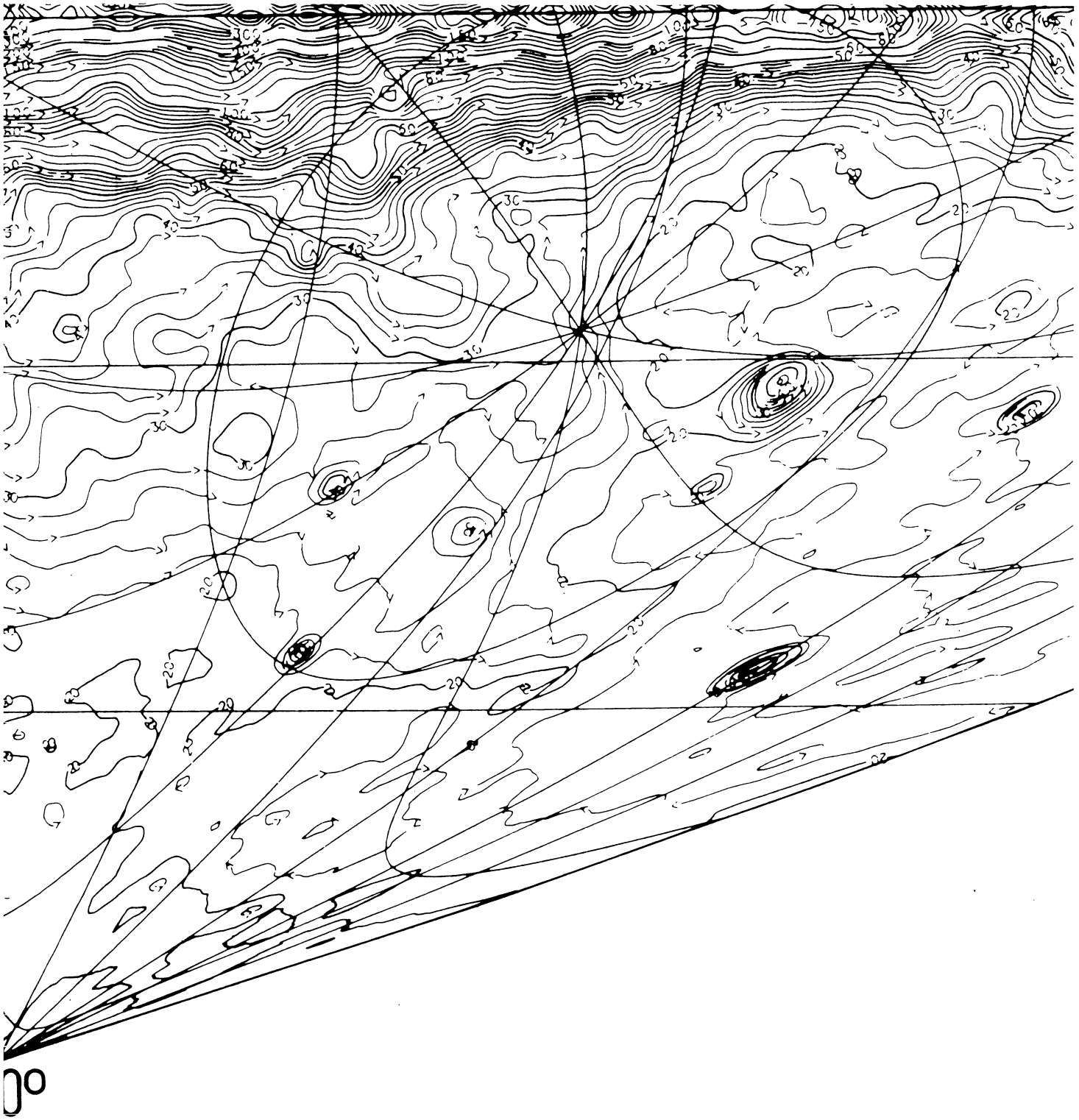

f 2°.0 × 2°.0. The contours are in K of beam brightness temperature.

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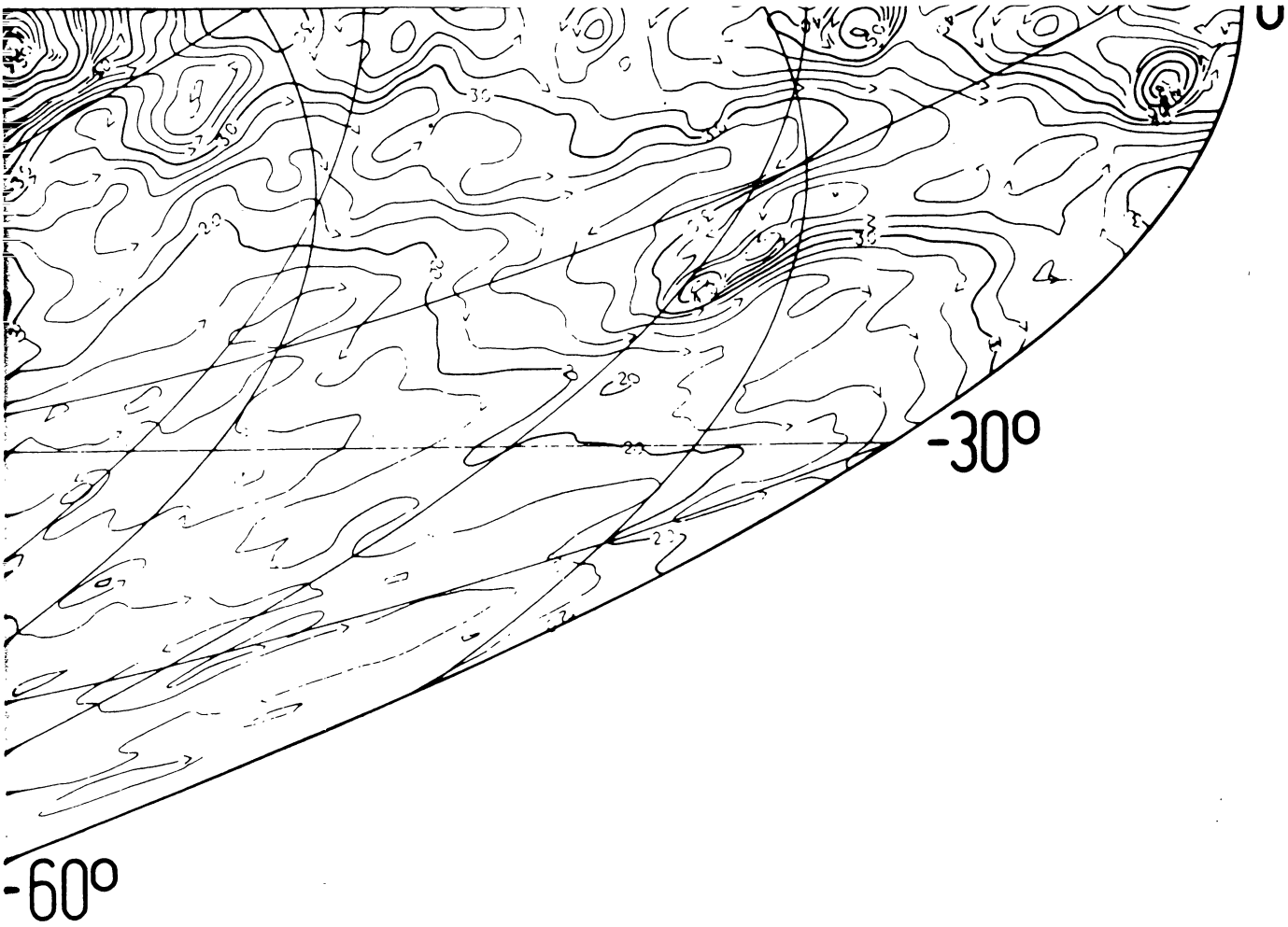

ANGULAR RESOLUTION OF MAP SHOWN HERE: 2.° 0

ORIGINAL DATA BASE:

ANGULAR RESOLUTION: 0.° 85

T_B RESOLUTION : 2°K (CONFUSION LIMITED)

T_B SCALE : BETTER THAN 10%

T_B ZERO ERROR: <4°K ABSOLUTE

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