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An Earth Radiation Budget Climate Model

Final Report

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ABSTRACT

A 2-D Earth Radiation Budget Climate Model has been constructed from an OLWR model and an earth albedo model. Each of these models use the same cloud cover climatology modified by a factor GLCLC which adjusts the global annual average cloud cover. The two models are linked by a set of equations which relate the cloud albedos to the cloud top temperatures of the OLWR model. These equations are derived from simultaneous narrow band satellite measurements of cloud top temperature and albedo.

Initial results include global annual average values of albedo and latitude longitude radiation for 45% and 57% global annual average cloud cover and two different forms of the cloud albedo - cloud top temperature equations.

An Earth Radiation Budget Climate Model

1. Introduction

A parameterized 2-D Earth Radiation Budget Climate Model has been constructed by combining the Earth Outgoing Longwave Radiation Climate Model of Yang, et al. (1984, 1987) with a modified version of the Time Variable Model of Earth's Albedo of Bartman (1980, 1981).

These two models, separately, describe the average earth's outgoing longwave radiation and the average earth's albedo with good accuracy. Combining them should yield model estimates of earth radiation balance (net radiation). Also, since each of the models uses the cloud climatology of Sherr et al. (1968), combining them could conceivably give useful results regarding the effects of clouds on the earth radiation Budget (cloud forcing functions).

2. Description of the Earth Radiation Budget Climate Model

2.1 Outgoing Longwave Radiation (OLWR) Model

The characteristics of the OLWR model of Yang are indicated schematically in Fig. 1. The model calculates OLWR using Warren and Thompson's parameterization (1982) of the radiative transfer model of Wiscomb (1976), using monthly average fields of surface temperature (T_s), fractional cloud cover (A_c), cloud top temperature (T_c), and moisture on a 10^o x 10^o (Lat., Lon.) grid over the globe. Climatological temperatures and dew point data are obtained from Crutcher and Meserve(1970) and Taljaard et al. (1971). Cloud cover data are from Sherr et al. (1968), modified by a constant factor obtained from the albedo

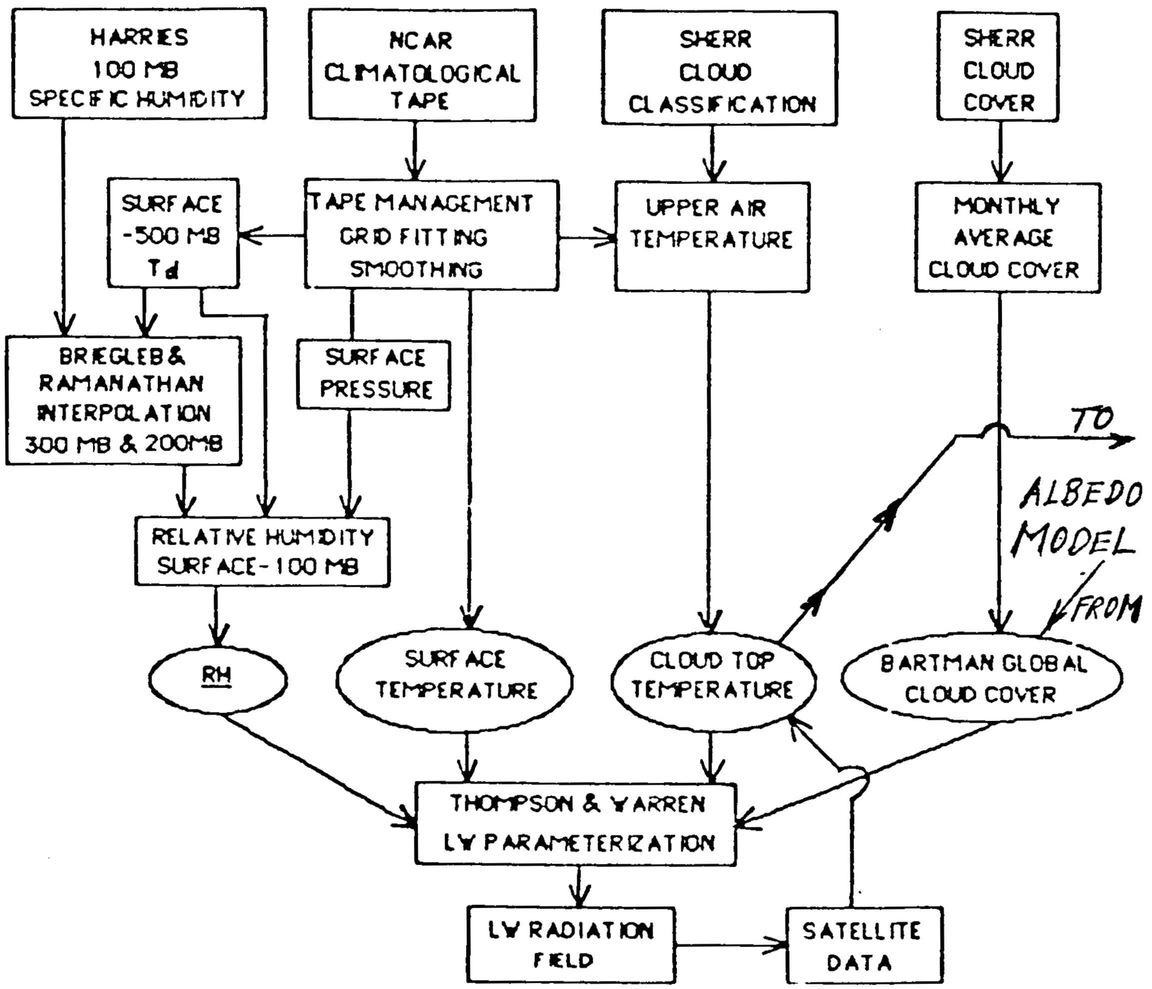

FIGURE 1. METHODOLOGY OF YANGS EARTH OUTGOING LONGWAVE (OLWR) CLIMATE MODEL.

model. This factor adjusts the value of global annual average cloud cover (GLCLC).

The parameterized equations for clear and cloudy sky OLWR (C_1 and C_2) are summarized in tables 1 and 2 which are taken from Yang (1984). The quantity $\underline{RH}$ is a vertical average of relative humidity. Since the climatological dew point data are limited to pressure altitudes less than 500 mb, values of $\underline{RH}$ above 500 mb were obtained (at 300, 200, and 100 mb) by an interpolation method (Briegleb and Ramanathan (1982)) using the formula of Harries (1976) for 100 mb specific humidities. Cloud top temperatures, T_c, were obtained by assigning cloud top heights to specific pressure levels; near surface, 850, 700, 500, 300 and 200 mb, so that the cloudy sky values of OLWR match climatological OLWR data compiled from NOAA scanning radiometer measurements (Abel and Gruber, 1979). Cloud top temperatures are then used in the modified earth albedo model.

2.2 Earth Albedo Model

A schematic diagram which describes the characteristics of the original time variable earth albedo model is shown in Fig. 2. The earth's albedo is calculated for 24 different Greenwich mean times, as the earth turns underneath the sun. This is repeated for an average day of each month of the year as the solar declination changes. Hence the phase "time variable earth's albedo," emphasizing that the earth's albedo and absorbed solar radiation is varying continuously.

Surface albedo data used in the model were derived from the seasonal values of Hummel and Reck (1979), monthly average zonal

Table 1. Parameterization for clear-sky outgoing IR irradiance at the top of the atmosphere (z = 50 km) (after Warren and Thompson

c_1 = outgoing clear sky IR (W m $^{-2}$).

T_s = surface air temperature (°C) (-118°C $<T_s<$ 57°C).

$\underline{RH}$ = height-mean relative humidity from 0 to 12 km (Eq. 2.4) (0.2 $<\underline{RH}<$ 1.0).

PARAMETERIZATION:

$$c_1 = a_0 + a_1 T_s + a_2 T_s^2 + a_3 T_s^3,\ \text{where}$$

$$a_n = b_{0n} + b_{1n}\underline{RH} + b_{2n}\underline{RH}^2,\ n = 0, 1, 2, 3.$$

$\underline{n = 0}$

$b_{00} = 2.43414 \times 10^{2}$
$b_{10} = -3.47968 \times 10^{1}$
$b_{20} = 1.02790 \times 10^{1}$

$\underline{n = 1}$

$b_{01} = 2.60065 \times 10^{0}$
$b_{11} = -1.62064 \times 10^{0}$
$b_{21} = 6.34856 \times 10^{-1}$

$\underline{n = 2}$

$b_{02} = 4.40272 \times 10^{-3}$
$b_{12} = -2.26092 \times 10^{-2}$
$b_{22} = 1.12265 \times 10^{-2}$

$\underline{n = 3}$

$b_{03} = -2.05237 \times 10^{-5}$
$b_{13} = -9.67000 \times 10^{-5}$
$b_{23} = 5.62925 \times 10^{-5}$

Table 2. Parameterization of cloud modification term for outgoing IR irradiance at the top of the atmosphere ($Z = 50$ km) (after Warren and Thompson)

c_2A_c = cloud modification term (W m^{-2}) [see Eq. (2.2)].

A_c = fractional total cloud amount.

$T_{sc} = T_s - T_c$ ($0 < T_{sc}$, 60K).

T_s = surface air temperature ($-118°C < T_c < 57°C$).

T_c = cloud top temperature ($-118°C < T_c < 57°C$).

$\underline{RH}$ = height-mean relative humidity [Eq. (2.4)] ($0.2 < \underline{RH} < 1.0$).

PARAMETERIZATION:

$$c_2 = c_1 (T_s, \underline{RH}) - c_1(T_c, \underline{RH}) + f(T_{sc}, \underline{RH})$$
(for c_1 see Table 2.1)

$$f(T_{sc}, \underline{RH}) = f_1(T_{sc}) + f_2(T_{sc}, \underline{RH})$$

$$f_1 = d_0 + d_1T_{sc} + d_2T^2_{sc}$$

$$f_2 = d_3T_{sc}(T_{sc} + d_4) (\underline{RH} + d_5)$$

$d_0 = -3.1$

$d_1 = -0.4146$

$d_2 = 4.084 \times 10^{-3}$

$d_3 = -4.44 \times 10^{-3}$

$d_4 = 80.0$

$d_5 = -0.40$

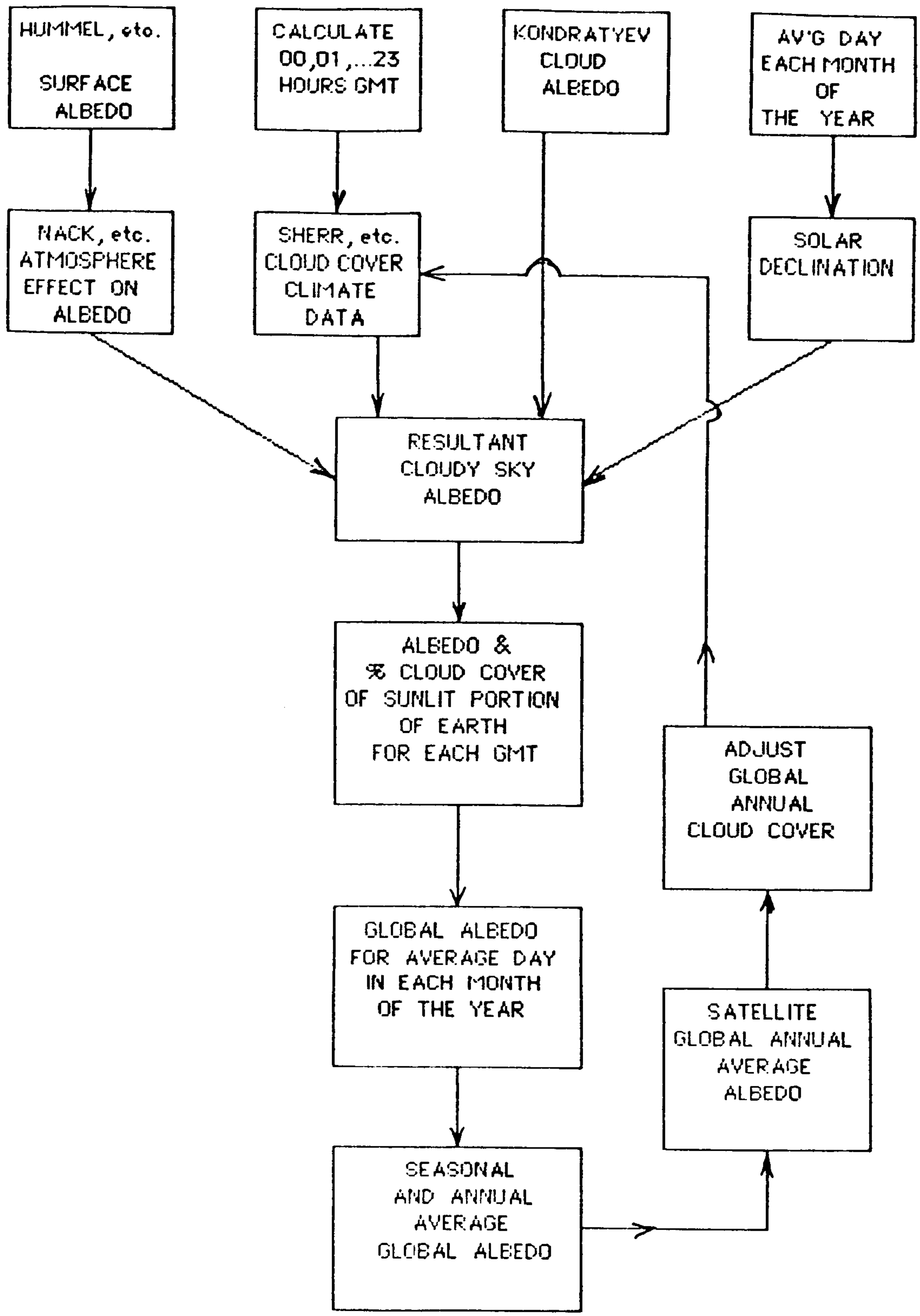

FIGURE 2. METHODOLOGY OF ORIGINAL ALBEDO MODEL

values of Robock (1980) and directional albedo functions for land, ocean and snow/ice regions of Larson and Barkstrom (1977).

In the initial (1980) version of this albedo model, cloud albedos were derived from the directional reflection function of Larson and Barkstrom (1977) with multiplying factors which attempted to adjust the Larson and Barkstrom functions to apply to each specific cloud climate region of Sherr et al. (1968). These multiplying factors were selected using cloud albedo data of Kondratyev (1973). In this initial version of the model, the global annual albedo of the earth was adjusted to satellite measured values of 30% by adjusting the global annual average percent cloud cover to 45%. This was done with a cosntant multiplying factor for all of the Sherr et al. (1968) cloud cover data, which before modification had a global annual average of 60%.

This formulation of cloud albedo was modified for the Earth Radiation Budget Climate Model in order to relate cloud top temperatures of the OLWR model to the cloud albedos of the albedo model. A schematic diagram of the modified earth albedo model is shown in Fig. 3.

3. Cloud Albedo as a Function of Cloud Top Temperature

The data used in establishing the cloud top temperature - cloud albedo relationships are shown in Fig. 4 from Henderson-Sellers (1984) which was derived from data in Bunting and d'Entremont (1982). The 29 cloud climatological types were classified by Sherr et al. (1968) as follows (see table 3):

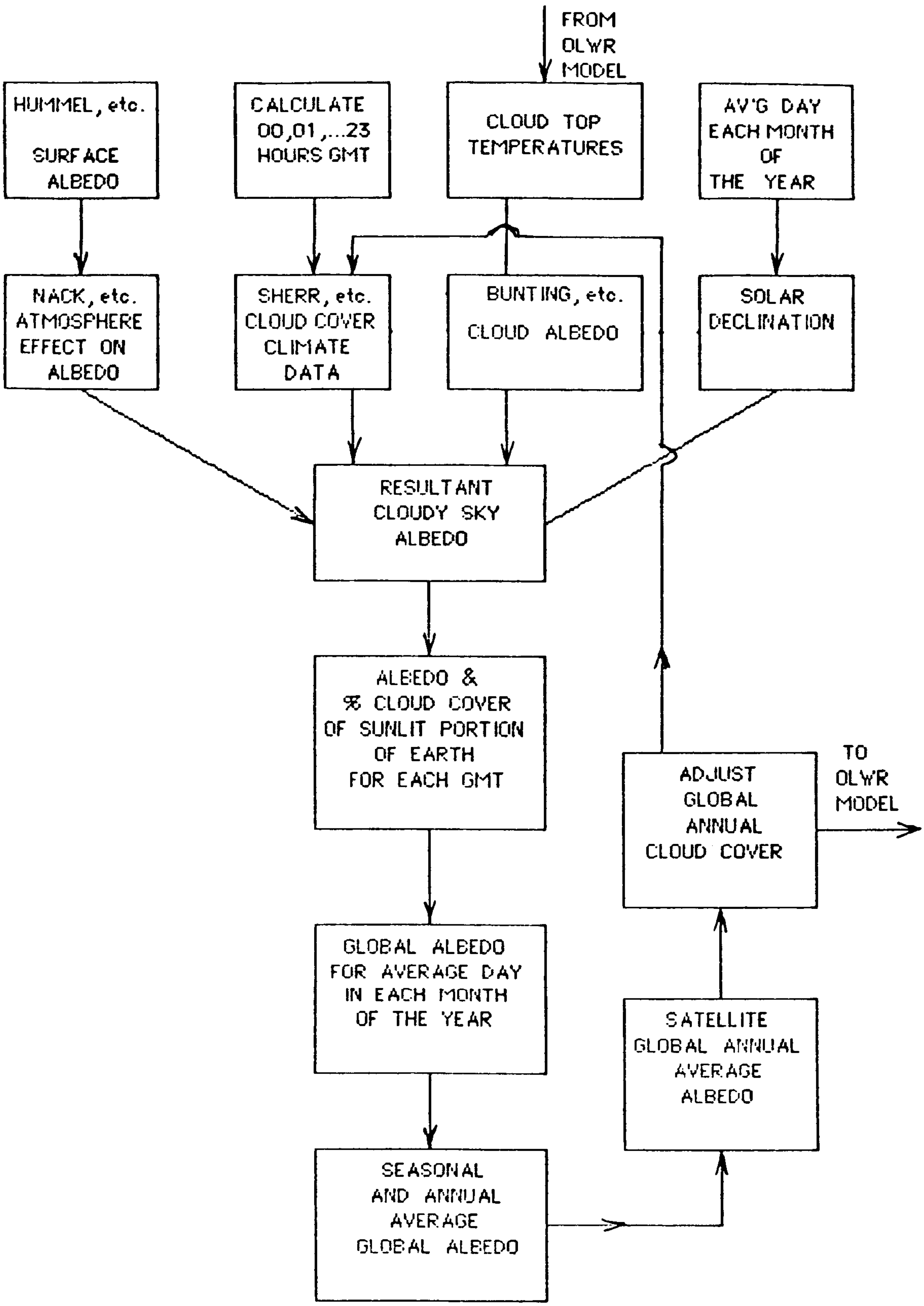

FIGURE 3. METHODOLOGY OF MODIFIED ALBEDO MODEL

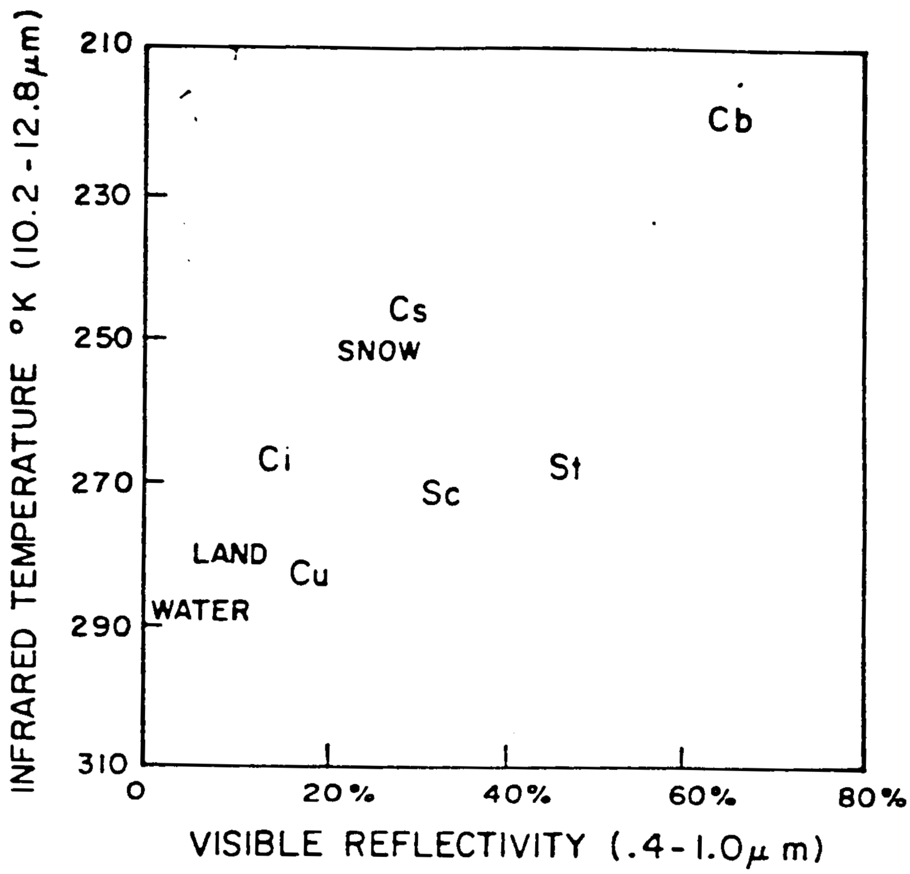

FIGURE 4. Mean temperatures and reflectivities for various clear areas and cloud types sensed by a DMSP satellite during December 1979 on passes over North and South America (after Air Force Geophysics Laboratory Technical Report, No. 82-0027, Bunting and d'Entremont, 1982, Hanscom, Mass. 01731, USA). (Figure from Henderson-Sellars, page 212)

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TABLE 3. General description of cloud climatological regions after Sherr et al. (1968).

1	2	3	4	5	6	7	8	9
Region Number	General Description	Location	Seasonal Change in Cloud Amount	Mean Monthly Cloud Amount Jun-Aug (in Percent)	Mean Monthly Cloud Amount Dec-Mar (in Percent)	Predominant Cloud Type	Diurnal Variation in Cloud Amount	Hour of Maximum Cloud Amount (Local Time)
01	Essentially Clear	Major Desert Area	Small	• 20	• 20	--	Small	----
02	Little Cloudiness	Sub-Desert Areas	Small	• 40	• 40	--	Small	----
03	Tropical Cloudy	Near Equator	Small	> 60	> 60	Convective	Large	1600
04	Tropical Moderate Cloudiness	North or South of Region 03	Small	~ 50	~ 50	Convective	Large	1600
05	Desert Marine	Over Ocean - off West Coasts	Small	~ 50	~ 50	Stratiform	Large	0800
06	Desert Marine Cloudy Winter	Over Ocean - West of Peru	Extreme	> 70	< 30	Stratiform	Large	0800
07	Desert Marine Cloudy Summer	Over Ocean - West of Baja California	Extreme	> 70	• 30	Stratiform	Large	0800
08	Mid Latitude - Clear Summer	North America	Extreme	• 40	~ 70	Synoptic Scale	Small	----
09	High Latitude - Cloudy Summer	North America, Asia	Moderate	~ 70	~ 50	Synotpic Scale	Small	----
10	High Latitude - Clear Winter	Asia, North America	Extreme	~ 70	• 30	Synoptic Scale	Small	----
11	Mid Latitude - Land	Northern Hemisphere	Moderate	~ 50	~ 70	Synoptic Scale	Small	----
12	Tropical - Cloudy Summer	North of Region 03	Moderate	> 60	~ 50	Convective	Large	1600
13	Mid Latitude - Ocean	Northern Hemisphere	Moderate	~ 60	> 70	Synoptic Scale	Small	----

TABLE 3 continued.

1	2	3	4	5	6	7	8	9
14	High Latitude - Ocean	Northern Hemisphere	Moderate	$>$ 80	$\sim$ 70	Synoptic Scale	Small	----
15	Polar	Northern Hemisphere	Small	$\sim$ 60	$\sim$ 60	Synoptic Scale	Small	----
16	Tropical - Seasonal Change	North of Region 03	Extreme	$>$ 70	$<$ 40	Convective	Large	1600
17	Tropical - Clear Winter	Northern Hemisphere Near Region 16	Moderate	$\sim$ 50	$<$ 30	Convective	Large	1600
18	Mediter-ranean	Northern Hemisphere Europe, Western North America	Extreme	$\sim$ 30 --	-- $\sim$ 60	Convective Synoptic Scale	Small Small	---- ----
19	Sub Tropical	Northern Hemisphere $\sim$ 30N	Moderate	$\sim$ 50 --	-- $>$ 60	Convective Synoptic Scale	Large Small	1600 ----
20	Sub Tropical - Ocean	Northern Hemisphere $\sim$ 30N	Moderate	$\sim$ 50 --	-- $>$ 60	Convective Synoptic Scale	Small Small	---- ----
21	Tropical - Cloudy Summer	South of Region 03	Moderate	$\sim$ 50	$>$ 60	Convective	Large	1600
22	Mid Latitude Ocean	Southern Hemisphere	Moderate	$\sim$ 70	$\sim$ 60	Synoptic Scale	Small	----
23	High Latitude - Ocean	Southern Hemisphere	Moderate	$\sim$ 70	$>$ 80	Synoptic Scale	Small	----
24	Polar	Southern Hemisphere	Small	$\sim$ 60	$\sim$ 60	Synoptic Scale	Small	----
25	Tropical - Seasonal Change	South of Region 03	Extreme	$<$ 40	$>$ 70	Convective	Large	1600
26	Tropical - Clear Winter	South of Region 25: Africa, Australia	Moderate	$<$ 30	$\sim$ 50	Convective	Large	1600
27	Mediter-ranean	Southern Hemisphere Australia, Chile	Extreme	-- $\sim$ 60	$\sim$ 30 --	Convective Synoptic Scale	Small Small	---- ----
28	Sub Tropical Land	Southern Hemisphere $\sim$ 30S	Moderate	-- $\sim$ 60	$<$ 50 --	Convective Synoptic Scale	Large Small	1600 ----
29	Sub Tropical - Ocean	Southern Hemisphere $\sim$ 30S	Moderate	-- $>$ 60	$\sim$ 50 --	Convective Synoptic Scale	Small Small	---- ----

a. "Essentially clear" or "little cloudiness": cloud types 1 and 2 (assumed to be cumulus in this model).

b. "Stratiform; over the ocean off of the west coast of continents": cloud types 5, 6 and 7 (stratus or stratocumulus in this model).

c. "Convective; tropical": cloud types 3, 4, 12, 16, 17, 21, 25 and 26 (cumulus or cumulonimbus in this model).

d. "Synoptic scale": cloud types 8, 9, 10, 11, 13, 14, 15, 22, 23 and 24 (cumulus, stratocumulus or cumulonimbus in this model).

e. "Convective in June to August and synoptic scale in December to March": cloud types 18, 19 and 20.

f. "Convective in December to March and synoptic scale in June to August": cloud types 27, 28 and 29.

Since the time periods described in e. and f. above did not encompass the entire year, they were extended to be June to November and December to May for this model.

The equations relating cloud albedo (RCT) to cloud top temperature (CTT) derived by regression from the data of Fig. 4 for the cloud type classifications listed above are:

(a) Cumulus: $RCT = .185$ (1)

(b) Stratiform:

$$RCT = .329 \quad \text{for } CTT > -2.65^{\circ}T \tag{2}$$

$$RCT = .2455 - .0315\ CTT \quad \text{for } CTT \leq -2.65^{\circ}C \tag{3}$$

(c) Convective:

$$RCT = .185 \quad \text{for } CTT > 9.35^{\circ}C \tag{4}$$

$$RCT = .2492 - .006867\ CTT \quad \text{for } CTT \leq 9.35^{\circ}C \tag{5}$$

(d) Synoptic Scale:

$$RCT = .185 \quad \text{for } CTT > 9.35^{\circ}C \tag{6}$$

$$RCT = .33561\ CTT - .00017618\ CTT^2 \quad \text{for } CTT \leq 9.35^{\circ}C \tag{7}$$

The parameterized equations for the albedo of a $10^{\circ} \times 10^{\circ}$ (Lat., Lon.) region of the earth for a solar zenith angle θ are summarized in table 4, where:

TABLE 4. PARAMETERIZED EQUATIONS FOR THE ALBEDO OF A 10°x10°(LAT.,LON.) REGION OF THE EARTH.

FORMAT:

CLEAR SKY ALBEDO

+CLOUDY SKY ALBEDO

FOR OCEAN AREAS:

$$\left(A(I,J,K).FO(\theta).0.01M_g+A_g\right).100\left(1-PC(LT,NT,N).\frac{GLCLC}{60}\right)$$

$$+RCT(I,J,K).FC(\theta).100.PC(LT,NT,N)\frac{GLCLC}{60}$$

FOR LAND AREAS:

$$\left(A(I,J,K).FL(\theta).0.01M_g+A_g\right).100\left(1-PC(LT,NT,N).\frac{GLCLC}{60}\right)$$

$$+RCT(I,J,K).FC(\theta).100.PC(LT,NT,N)\frac{GLCLC}{60}$$

FOR SNOW-ICE AREA:

$$\left(A(I,J,K).FS(\theta).0.01M_g+A_g\right).100\left(1-PC(LT,NT,N).\frac{GLCLC}{60}\right)$$

$$+RCT(I,J,K).FC(\theta).100PC(LT,NT,N)\frac{GLCLC}{60}$$

WHERE:

$$FO(\theta)=\left(.03+.630\left(1+\left(\frac{1.47-\theta}{.15}\right)^2\right)^{-1}\right)(FW(K,N))^{-1}$$

$$FL(\theta)=.458(1-COS(\theta).LN(1+(COS(\theta))^{-1})).(FL(K,N))^{-1}$$

$$FS(\theta)=FC(\theta)=.797(1-.176COS(\theta))(FS(K,N))^{-1}$$

I = N = index for month of the year
J = longitude index
K = latitude index
LT = local time index
NT = cloud climatological type index
θ = solar zenith angle
GLCLC = global annual average cloud cover
A (I,J,K) = surface albedo for month I, longitude region J, and latitude region K (Bartman, 1980)
FO(θ) = Directional reflectance function for ocean areas
FL(θ) = Directional reflectance function for land areas
FS(θ) = Directional reflectance function for snow/ice areas
FC(θ) = Directional reflectance function for clouds
M_s = the slope function of Nack and Curran (relating surface albedo to albedo of the top of the atmosphere
A_s = the intercept constant of Nack and Curran
PC(LT,NT,N) = percent cloud cover
GLCLC = global annual average percent cloud cover
RCT(I,J,K) = cloud albedo
FW(K,N) = a constant determined by the range of sun angles for latitude index K and month N, for ocean albedos
FL(K,N) = as above, for land albedos
Fs(K,N) = as above, for snow/ice and cloud albedos.

4. Results

The procedure used for calculations with this model are as follows:

a. Select a value of global annual cloud cover (GLCLC) to be used as a constant multiplying factor for the Sherr et al. cloud cover data. In the 1980 version of the albedo model, this was determined to be 45%.

b. With this value of GLCLC, for each month determine cloud top pressure altitudes (and therefore cloud top temperature) for each cloud type region of Sherr, so that the calculated values of OLWR closely approximate the measured values of NOAA (Abel and Gruber, 1979).

c. Use the same value of GLCLC and the cloud top temperatures determined in b. above in the albedo model to determine the latitude-longitude distribution of albedo for each month and zonal and global average values of albedo for each month and for the year. The global annual average value of a albedo should be close to 30%, as determined from satellite measurements.

4.1 Results obtained with GLCLC equal to 45%

The OLWR results obtained with GLCLC equal to 45% are those obtained by Yang (1984). Cloud top pressure levels are shown in table 5a.

Zonal and global annual averages of albedo obtained with GLCLC = 45%, shown in column 1 of table 6, do not agree well with satellite measured values. In particular, a global annual average value of albedo of 27.35% was obtained.

A modification of the cloud top temperature - cloud albedo equations was found by "cut and try" techniques which would produce a global annual average albedo of 30.55% which is in better agreement with satellite measured values.

The modified equations for cloud albedo as a function of cloud top temperature are:

a. Cumulus: RCT = .185 (8)

b. Stratiform:

RCT = .329 for $CTT > 5.35$ (9)

RCT = .2455-.0315 (CTT-8) for $CTT \leq 5.35$ (10)

c. Convective

RCT = .185 for $CTT > 21.35$ (11)

RCT = .2492-.006867(CTT-12) for $CTT \leq 21.35$ (12)

d. Synoptic scale

RCT = .185 for $CTT > 21.35$ (13)

$$RCT = .33561-.015624(CTT-Delta) -.00017618\ (CTT-Delta)^2$$

for $(CTT \leq 21.35)$ (14)

where Delta = 8 for $K < 10$ and $(4 < N < 9)$ and Delta = 0 otherwise.

CLOUD TYPE

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
J	3	3	5	3	3	4	3	5	1	1	3	3	3	3	1	3	1	3	4	3	4	3	3	3	6	4	3	3	3
F	3	3	5	3	3	4	2	4	2	1	3	3	4	3	1	3	1	3	3	3	4	3	3	2	6	4	3	3	3
M	2	3	5	3	3	4	3	4	2	1	3	3	3	3	1	3	1	2	3	3	4	3	3	2	5	4	3	3	3
A	2	3	5	3	2	3	3	3	2	3	3	3	3	3	1	4	1	2	4	3	3	3	3	3	4	3	3	3	3
M	1	2	4	3	2	3	3	3	2	3	2	3	4	3	1	4	3	2	4	3	3	3	3	3	4	1	3	3	3
J	1	2	4	3	2	3	1	3	3	3	3	3	4	3	2	4	4	1	5	3	1	3	3	3	3	1	2	3	3
J	1	3	4	3	3	3	2	2	3	4	3	3	3	3	3	4	4	1	6	3	1	3	3	3	2	1	2	3	3
A	1	3	4	3	3	3	1	3	3	3	3	3	3	3	3	5	3	1	6	3	2	3	3	3	3	1	2	3	3
S	1	3	4	3	3	4	2	1	3	3	3	4	4	3	3	4	4	1	4	3	3	3	3	3	4	2	3	3	3
O	1	2	4	3	3	3	1	3	3	3	3	4	4	4	3	4	3	2	4	3	3	3	3	3	5	3	3	3	3
N	1	1	4	3	3	3	1	4	3	2	3	3	4	3	3	3	3	2	3	3	3	3	3	2	5	3	3	3	3
D	3	3	4	3	3	4	2	4	3	1	3	3	3	3	2	3	1	3	3	3	4	3	3	3	6	4	2	2	3

TABLE 5a. CLOUD TOP LEVEL INDEX. 1, NEAR SURFACE; 2, 850MB; 3, 700MB; 4, 500MB; 5, 300MB; AND 6, 200MB. (GLCLC=45%), AFTER YANG(1984)

CLOUD TYPE

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
F	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
M	3	2	4	-	2	3	-	-	-	-	2	-	4	2	-	-	-	1	4	2	3	4	4	3	4	3	2	2	4
A	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
M	-	3	3	-	3	2	2	4	3	2	3	-	3	2	-	3	2	1	5	2	2	-	2	2	3	-	2	4	4
J	-	3	3	2	3	2	-	2	2	4	2	2	3	2	-	-	3	-	4	-	2	2	2	2	-	-	-	-	2
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	2	-	-	-	-	-
A	-	2	3	-	2	4	-	2	2	4	2	4	4	4	2	4	4	-	5	2	-	-	2	-	-	-	-	-	-
S	-	2	3	-	2	3	-	-	2	-	-	3	3	4	2	3	3	-	5	-	2	-	-	4	3	-	2	2	4
O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-

TABLE 5b NEW VALUES OF CLOUD TOP LEVEL INDEX OBTAINED WITH GLCLC=57%.

TABLE 6. MONTHLY AVERAAGE ALBEDO

% CLOUD COVER	45	45	57	57
CLOUD TOP TEMP.	CT1	CT1	CT1	CT2
EQUATIONS USED	(1)-(7)	(8)-(14)	(1)-(7)	(1)-(7)
JAN	28.92	31.64	32.37	31.66
FEB	28.07	30.73	31.28	29.05
MAR	27.71	30.22	30.72	30.11
APR	27.60	30.10	30.32	27.90
MAY	26.84	30.79	29.21	27.75
JUN	26.50	30.86	29.03	25.37
JUL	25.41	29.83	27.94	27.91
AUG	25.08	29.20	27.73	26.97
SEP	26.80	29.61	29.81	28.22
OCT	27.77	30.57	30.83	30.26
NOV	28.20	31.02	31.34	30.82
DEC	28.88	31.83	32.24	31.55
ANNUAL AVERAGE	27.35	30.55	30.27	29.02

4.2 Results obtained with GLCLC equal to 57%

A higher albedo would also be obtained with the original equations (equations 1 to 7) for cloud albedo if a larger value of global annual average cloud cover (CLCLC) were used. For a value of GLCLC of 57%, a global annual albedo of 30.27 is obtained, as shown in column 3 of table 6. However, this value of 57% must also be used in the OLWR model. When that is done, some cloud top levels are changed (see table 5b.) and some cloud top temperatures are increased. The net effect is an increase in albedo (column 4 in table 6). A further increase of GLCLC above 57% is indicated.

Although the calculations have not been made, a rough extrapolation of this process (increasing global annual average cloud cover, increasing cloud top temperatures) indicates that a value of 60-65% global annual average cloud cover would yield values of OLWR in agreement with the NOAA data and global annual average albedo of about 30%.

4.3 Contour Maps of OLWR and Albedo

Contour maps of OLWR and albedo, for each month of the year, are shown in the appendices to this report for model versions as indicated in table 7 below. These results are not discussed since they are preliminary and may be changed significantly by further work.

Table 7. Contour Maps in Appendices for Model Versions Indicated

	OLWR	Albedo	GLCLC	Cloud Albedo Equations
Appendix 7.1	x	x	45%	1 - 7
Appendix 7.2		x	45%	8 - 14
Appendix 7.3	x	x	57%	1 - 7

5. Conclusions and Recommendations for Further Work

A 2-D Earth Radiation Budget Climate Model has been constructed from an OLWR model (Yang, 1984) and an earth albedo model (Bartman, 1980, 1981). Each of these models use the cloud cover climatology of Sherr et al. (1968) modified by a factor GLCLC which adjusts the global annual average cloud cover. The two models are linked by a set of equations which relate the cloud albedos to the cloud top temperatures of the OLWR model. These equations are derived from simultaneous narrow band measurements of cloud top temperature and albedo (Bunting and d'Entremont, 1982).

Initial results obtained, so far, indicate that:

a. With a global annual average cloud cover of 45% and a modified set of the cloud albedo equations, the model will produce values of OLWR and of global annual average albedo in reasonable agreement with satellite measurements.

b. With an unmodified set of cloud albedo equations, a global annual average cloud cover greater than 57% would be required to produce model results in reasonable agreement with satellite earth radiation budget measurements.

The work on the model is incomplete. Additional work which needs to be done includes:

a. A study of the cloud albedo equations, with consideration of the difference between wide band cloud albedos and the measured narrow band cloud albedos. This study should yield an improved set of cloud albedo equations.

b. Use of the improved cloud albedo equations in the model to find the value of global annual average cloud cover which yields OLWR and albedos in best agreement with satellite measured values considering global, zonal and latitude-longitude distributions of OLWR, albedo and net radiation.

c. Calculation of net radiation and cloud forcing functions for the improved earth radiation budget climate model.

6. References

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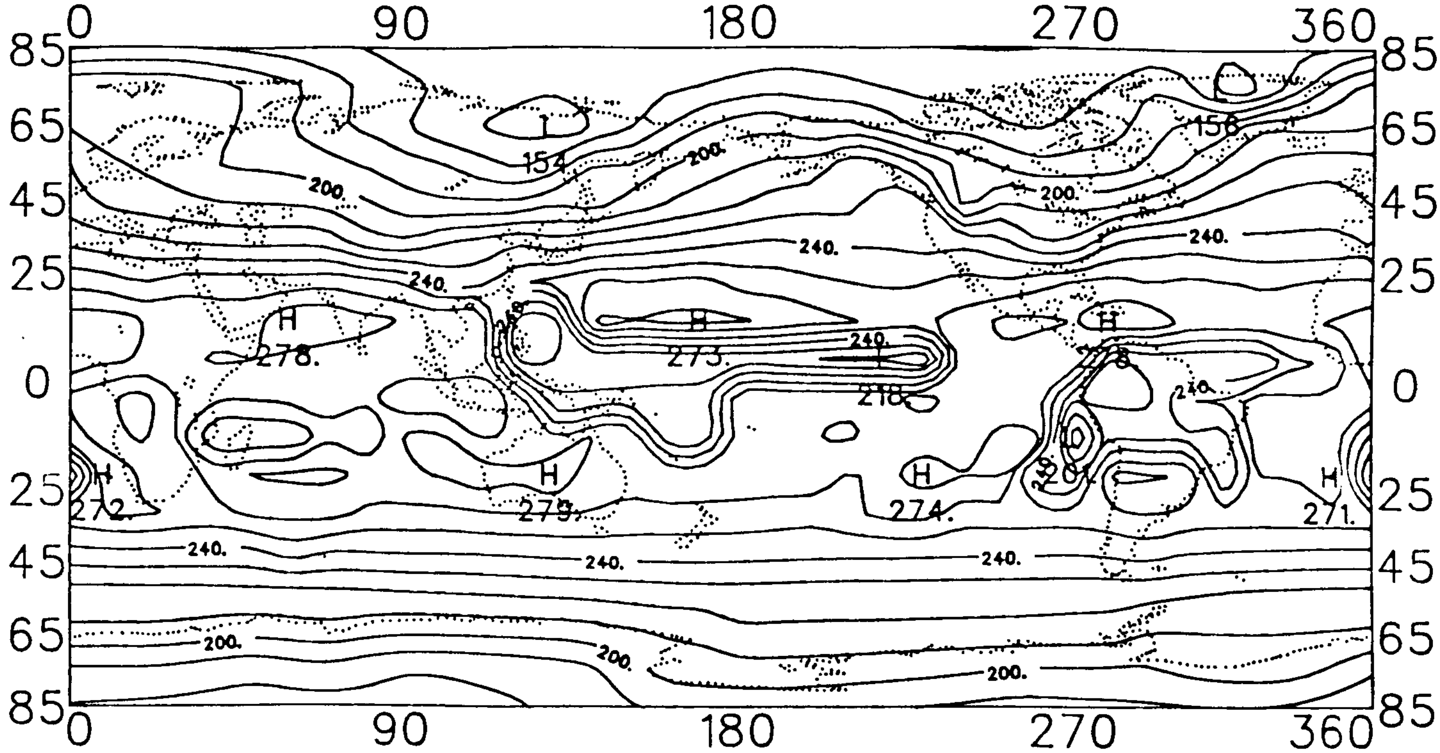
Appendix 7.1

Contour Maps of OLWR and Albedo for GLCLC equal to 45% using equations 1-7.



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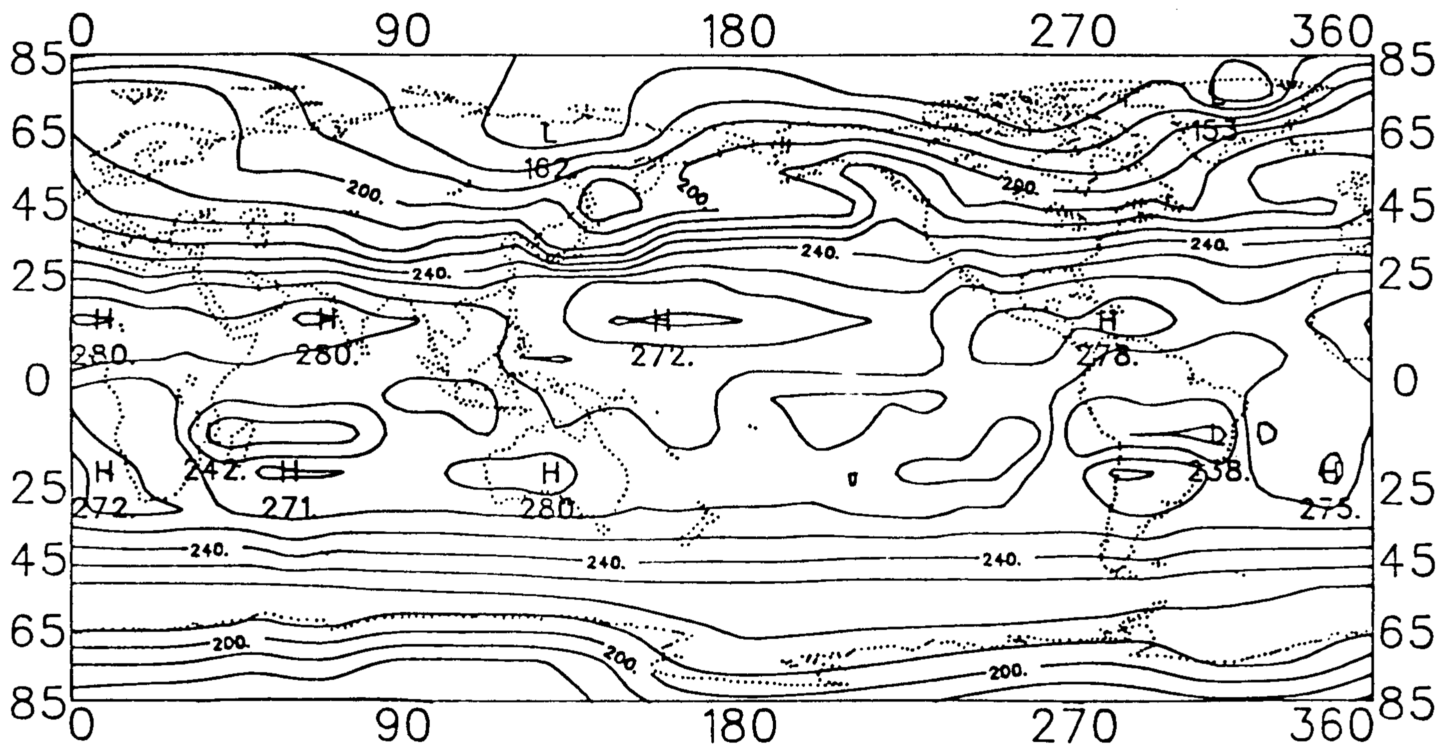

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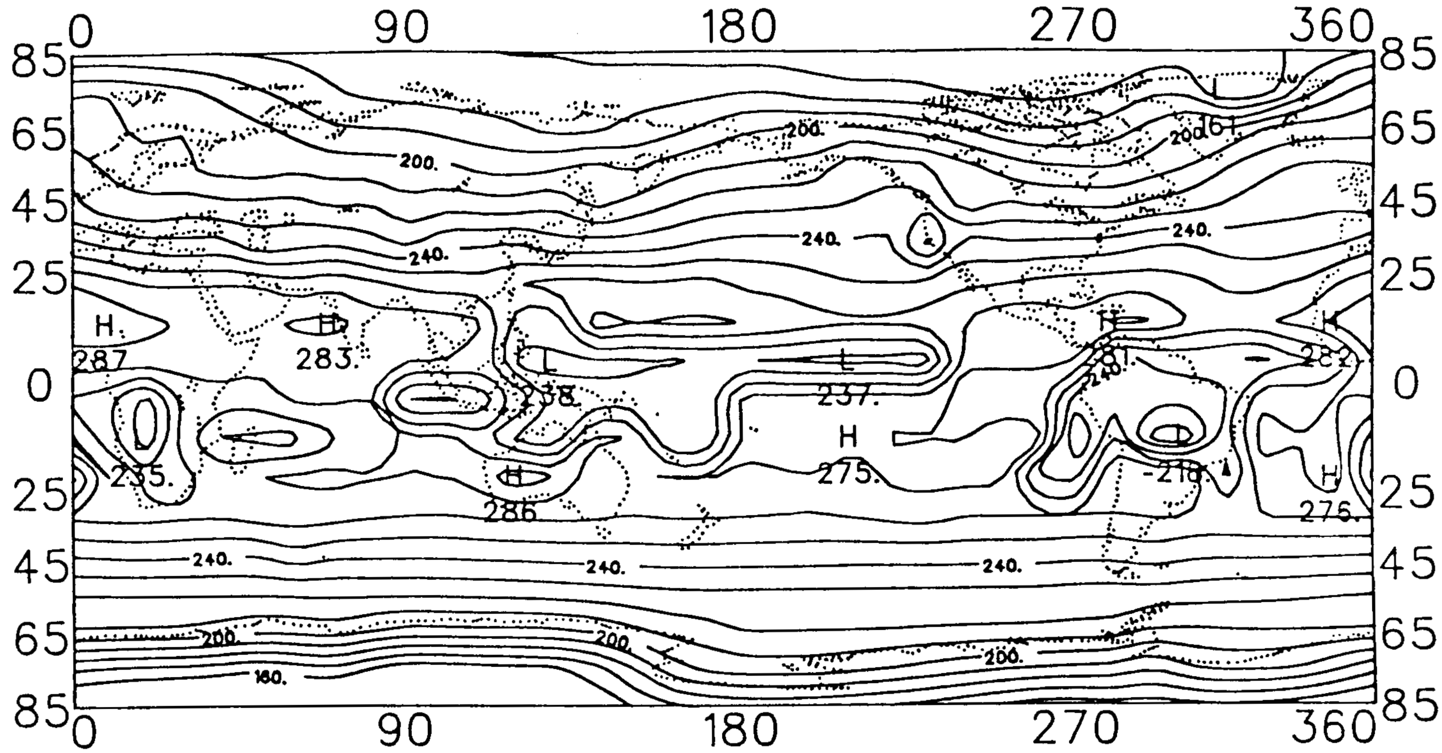

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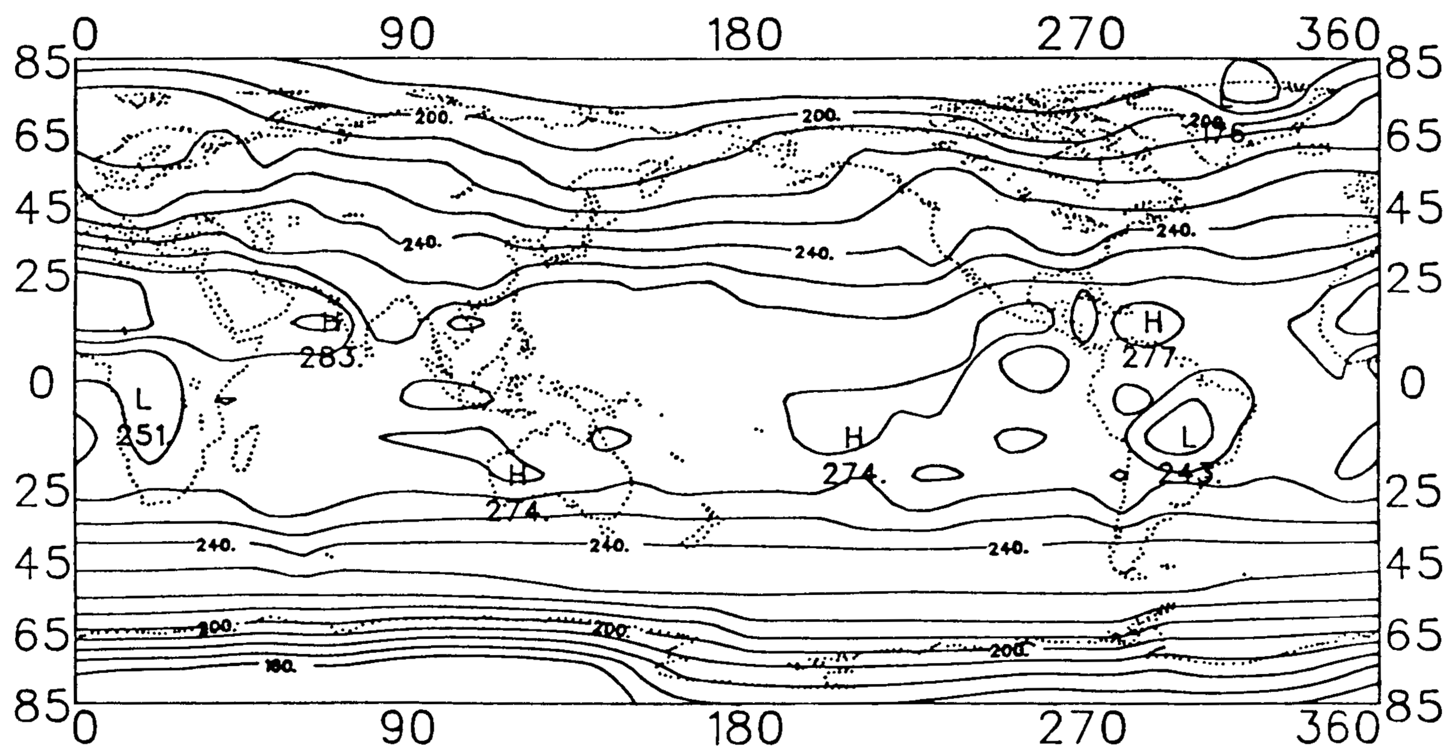

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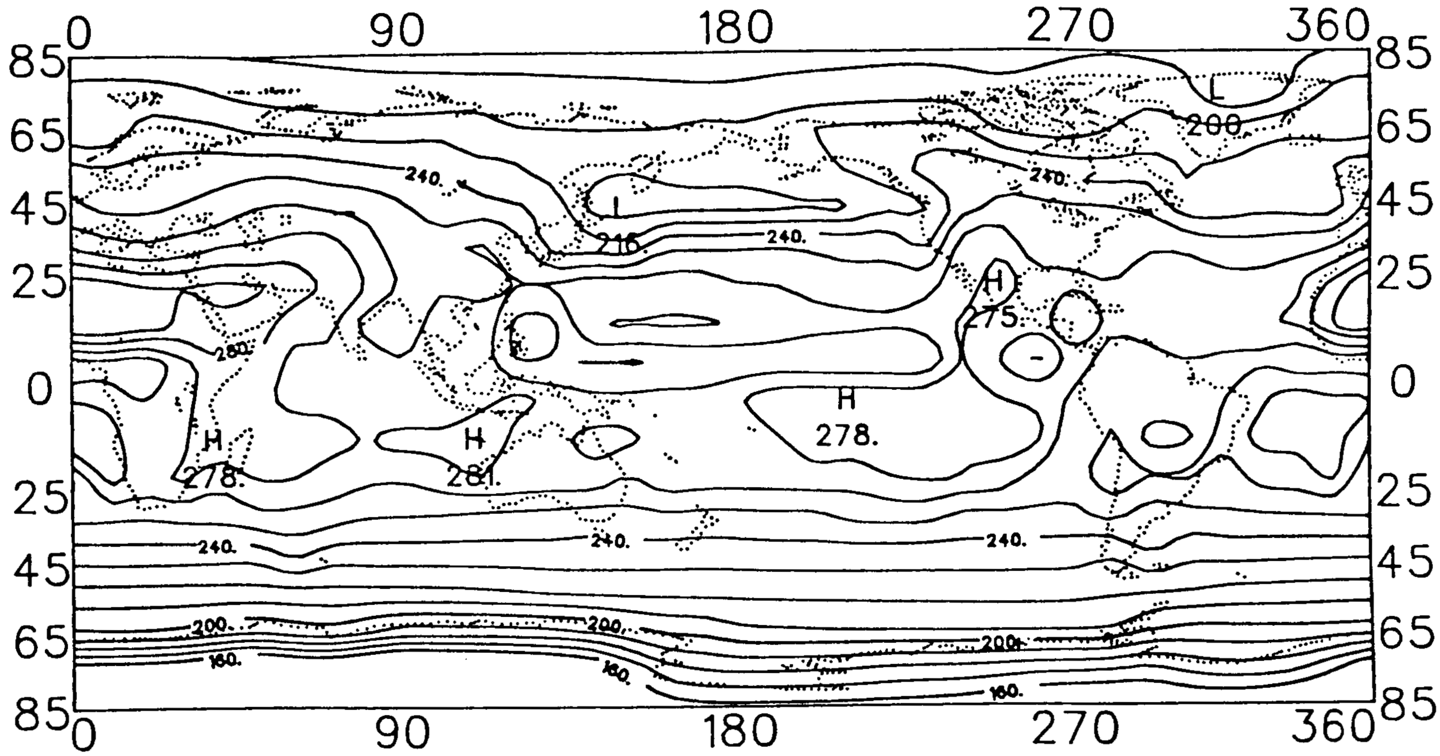

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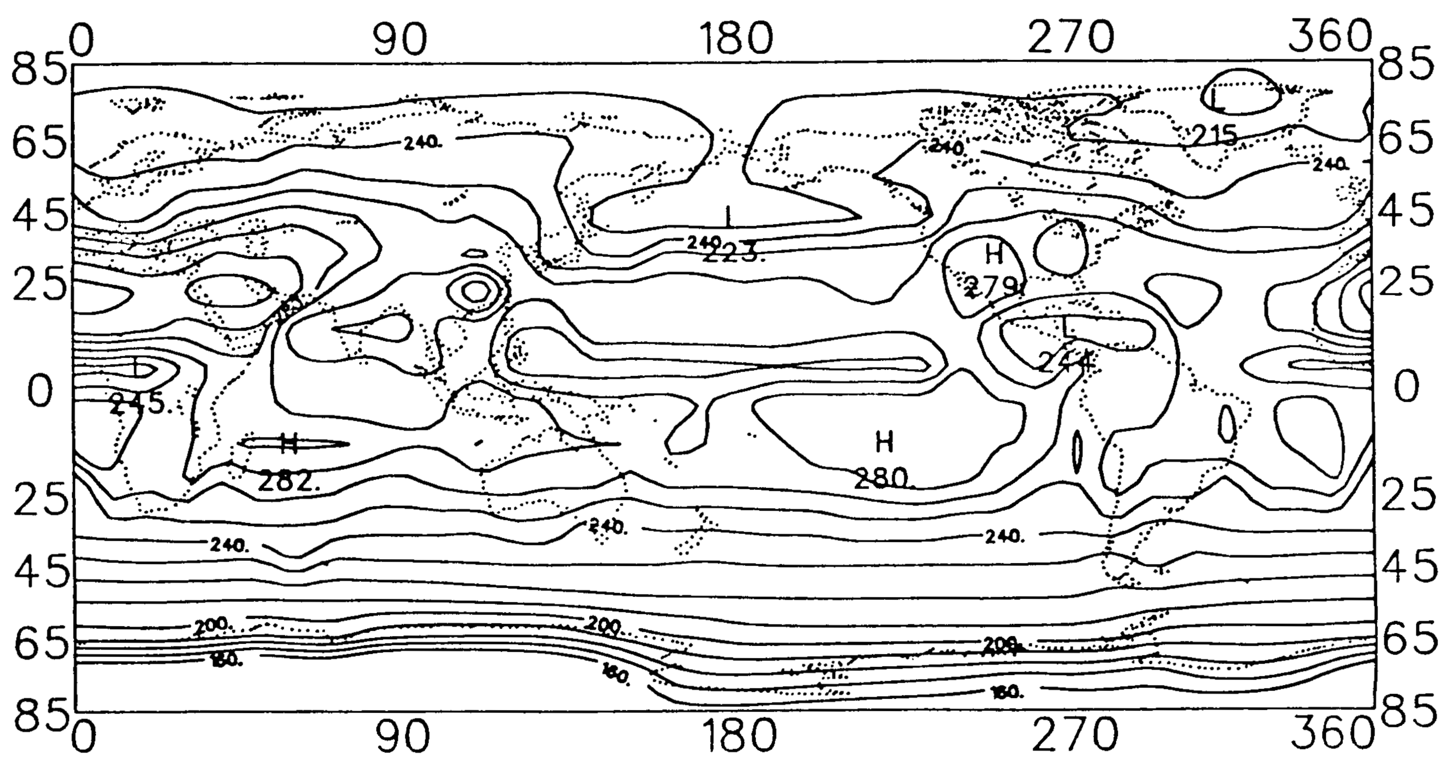

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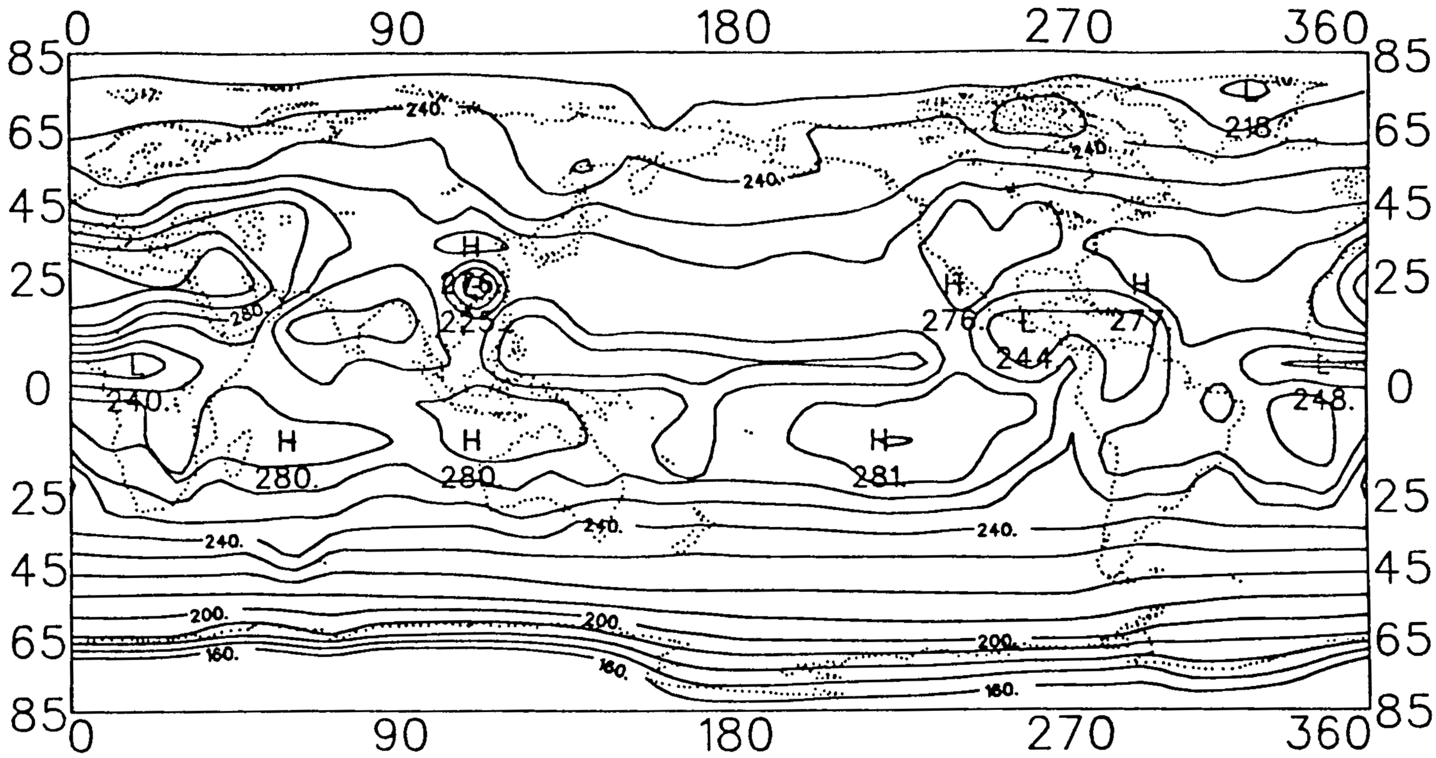

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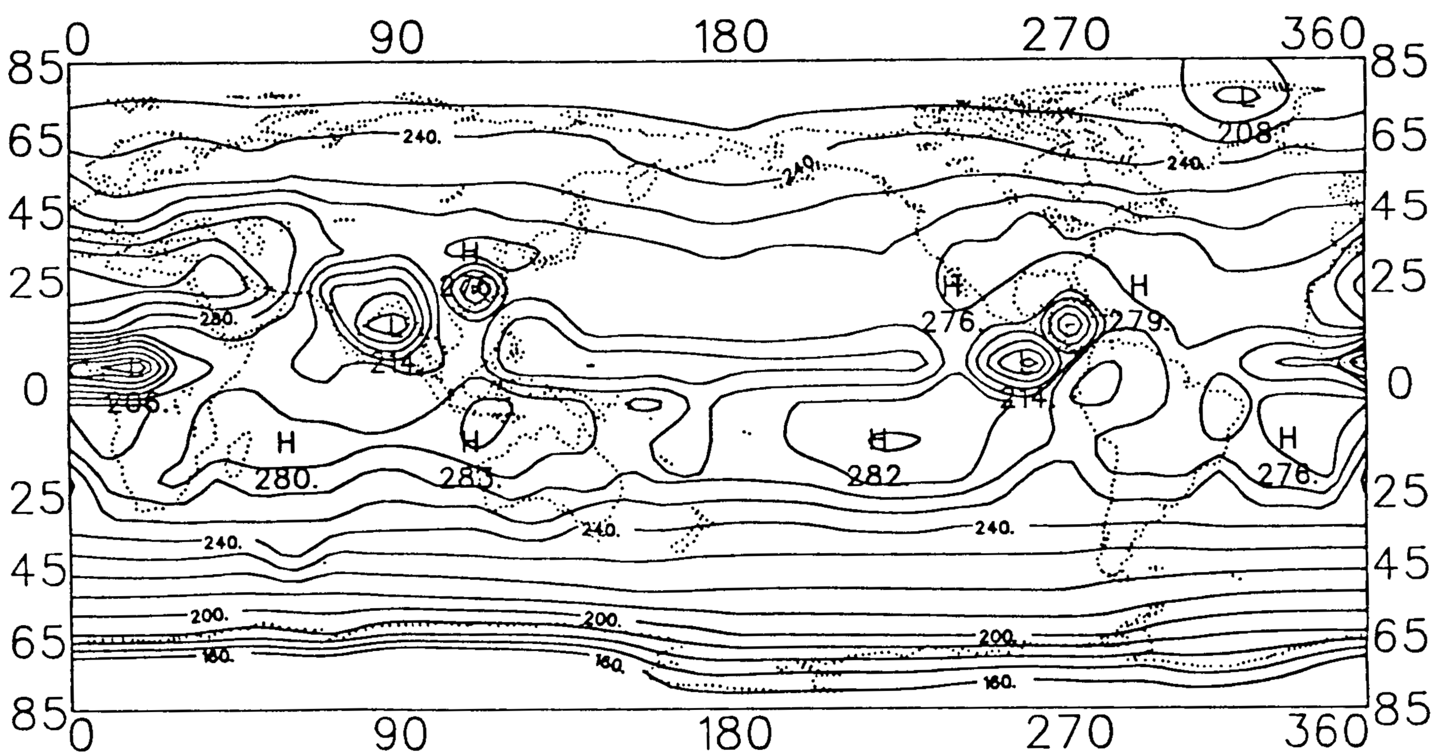

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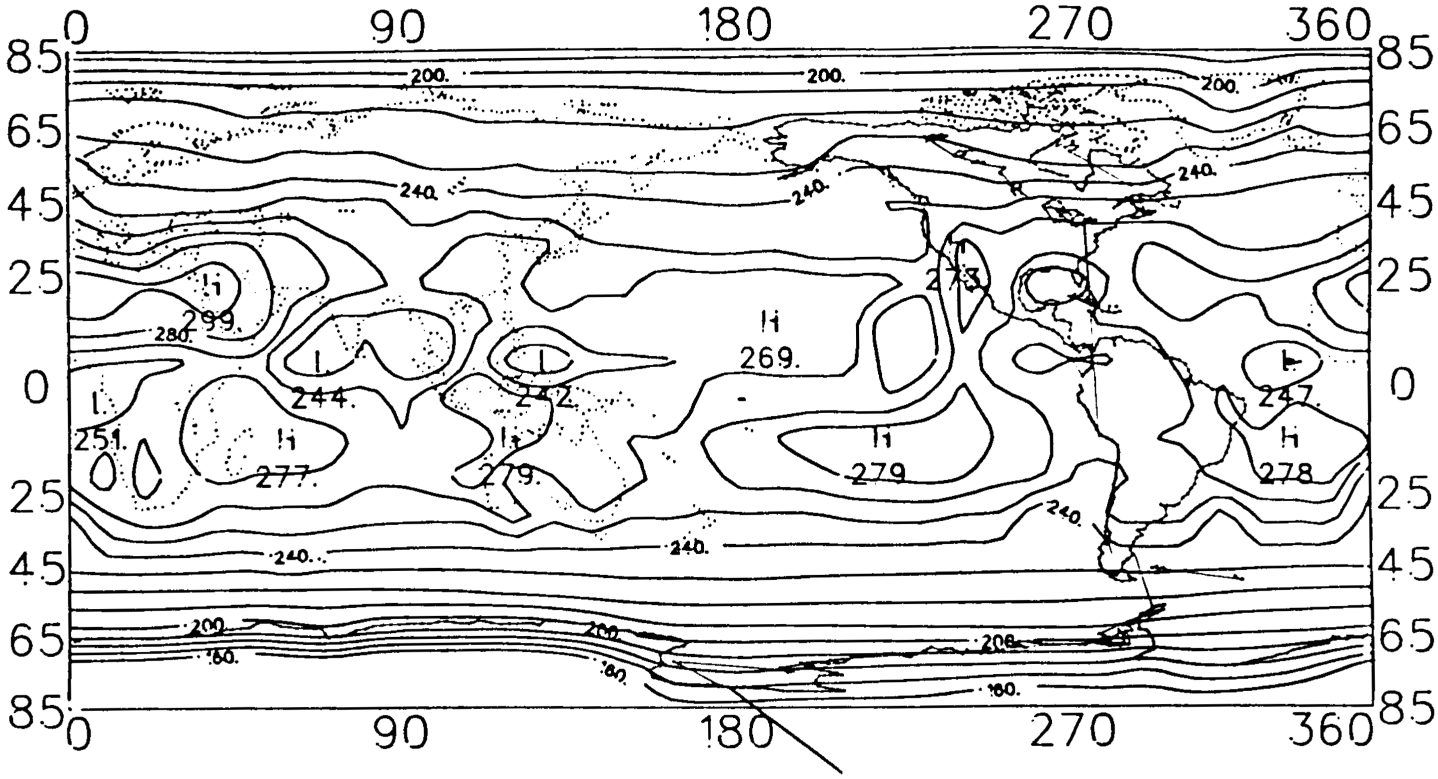

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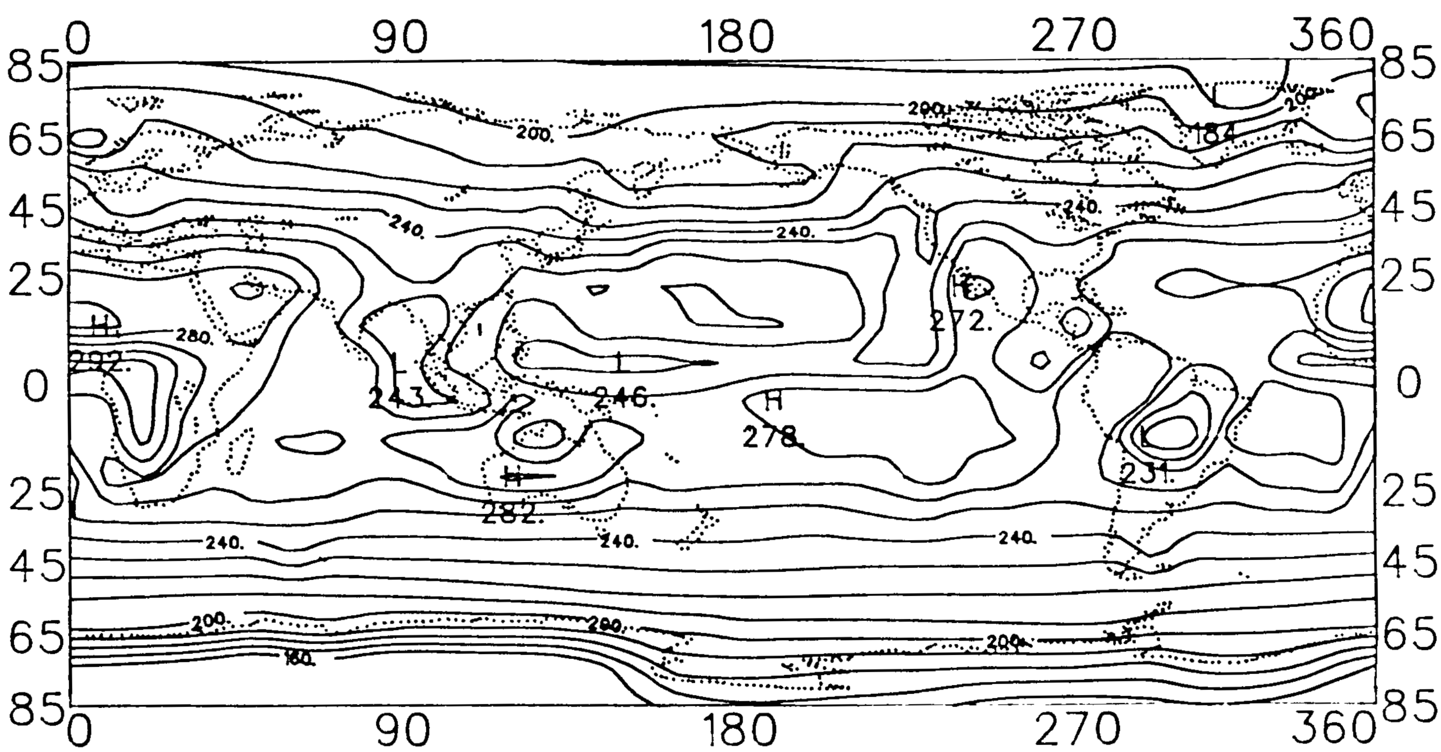

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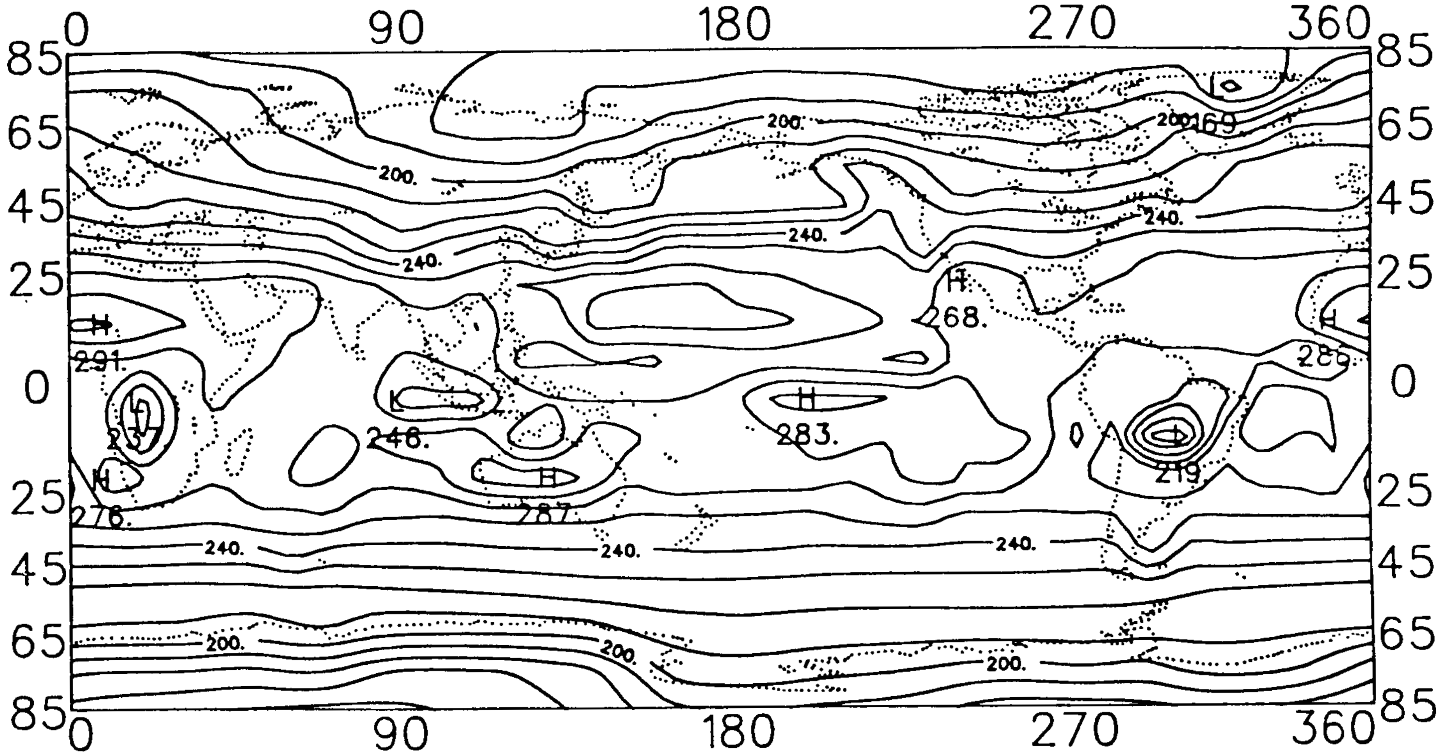

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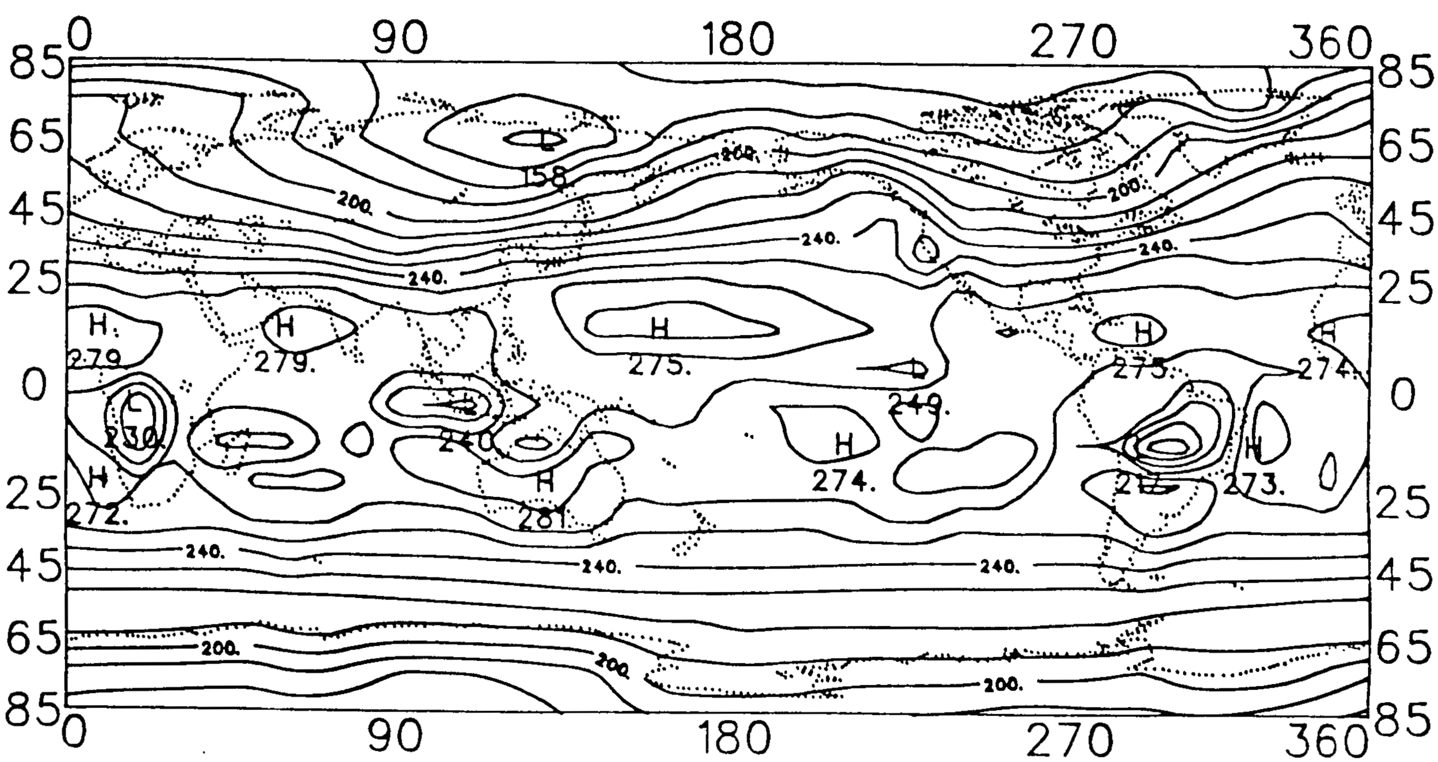

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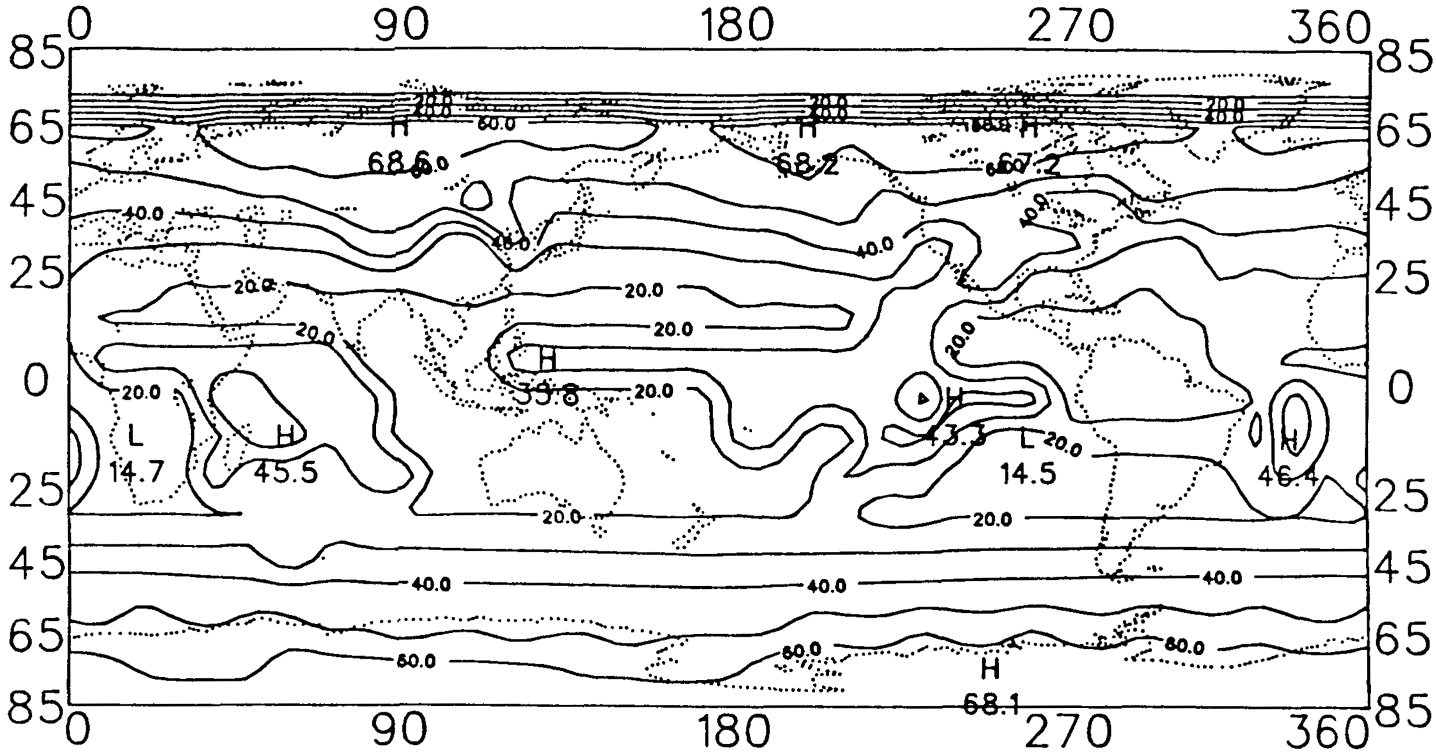

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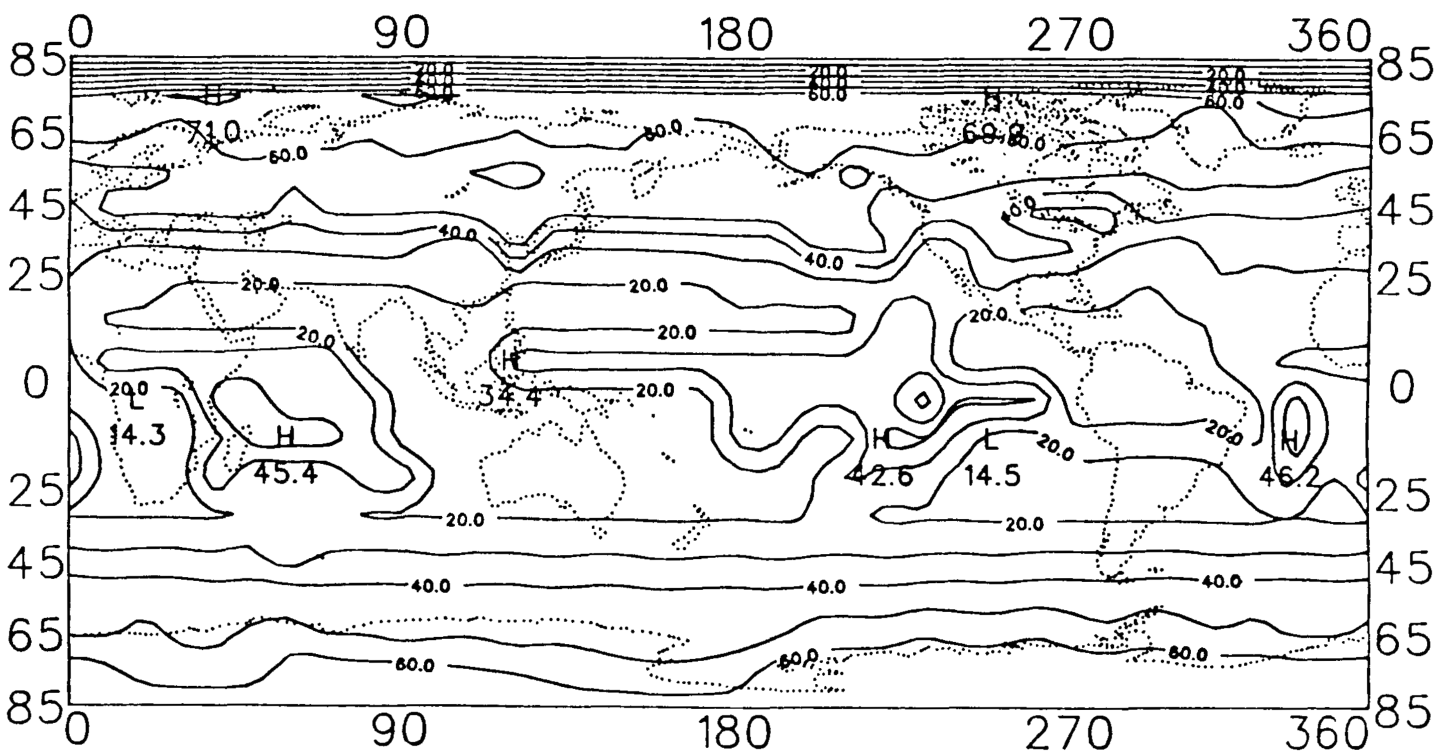

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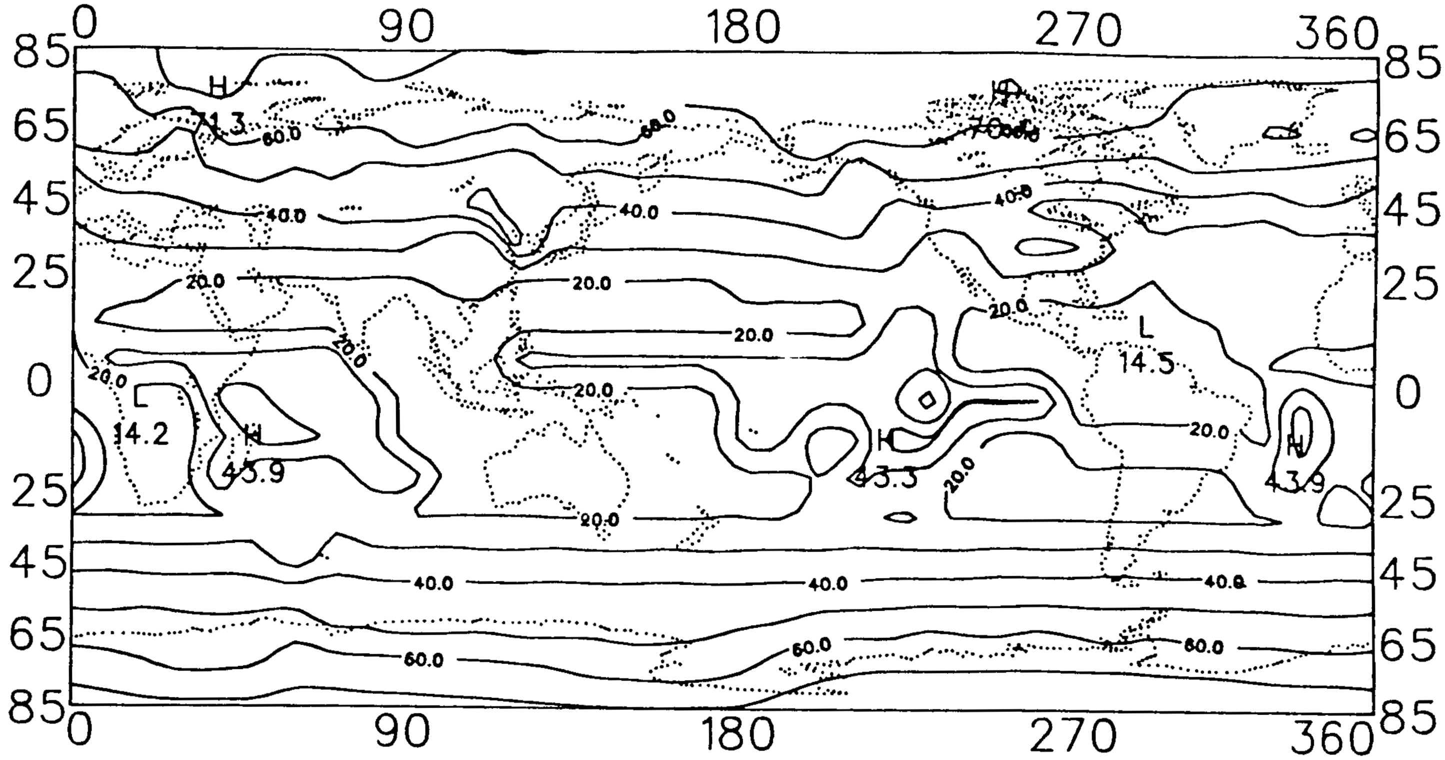

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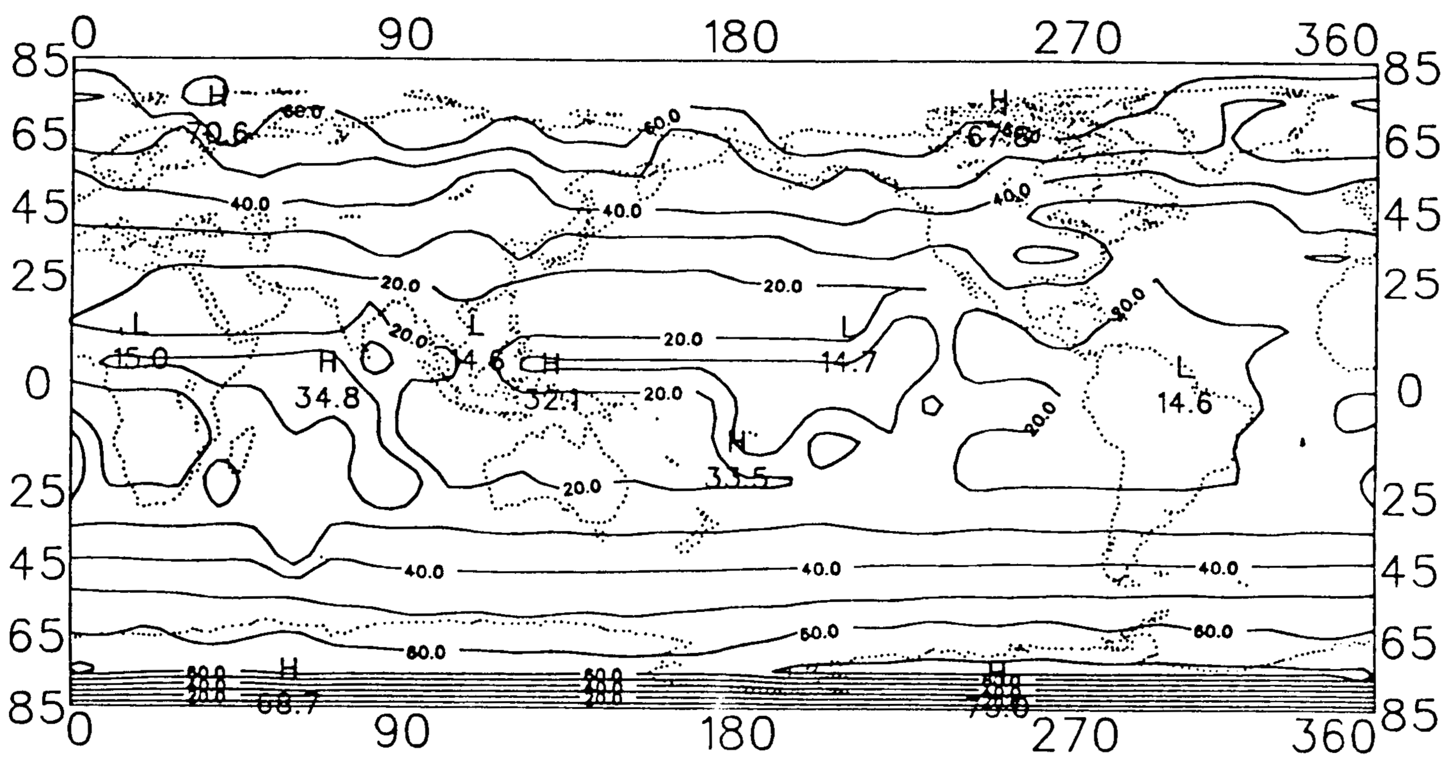

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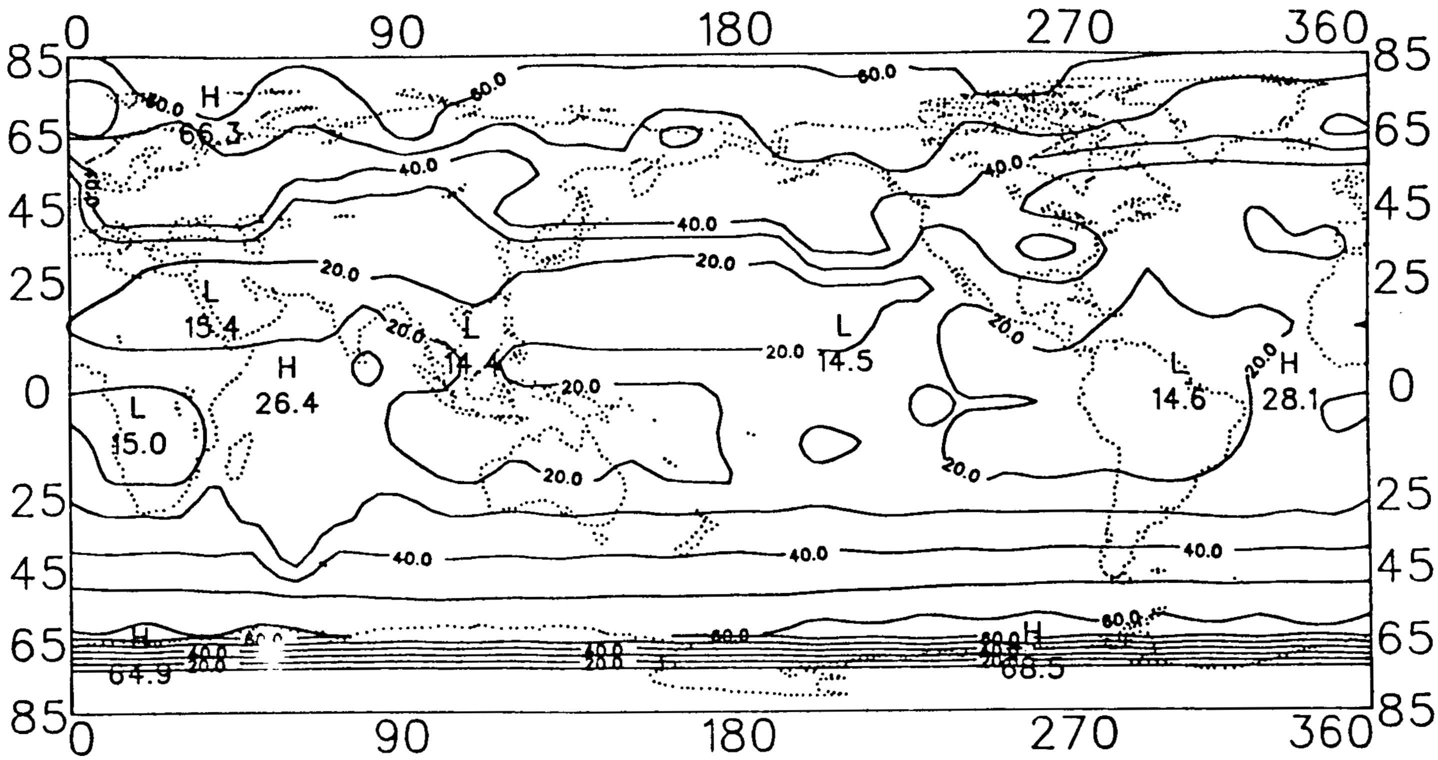

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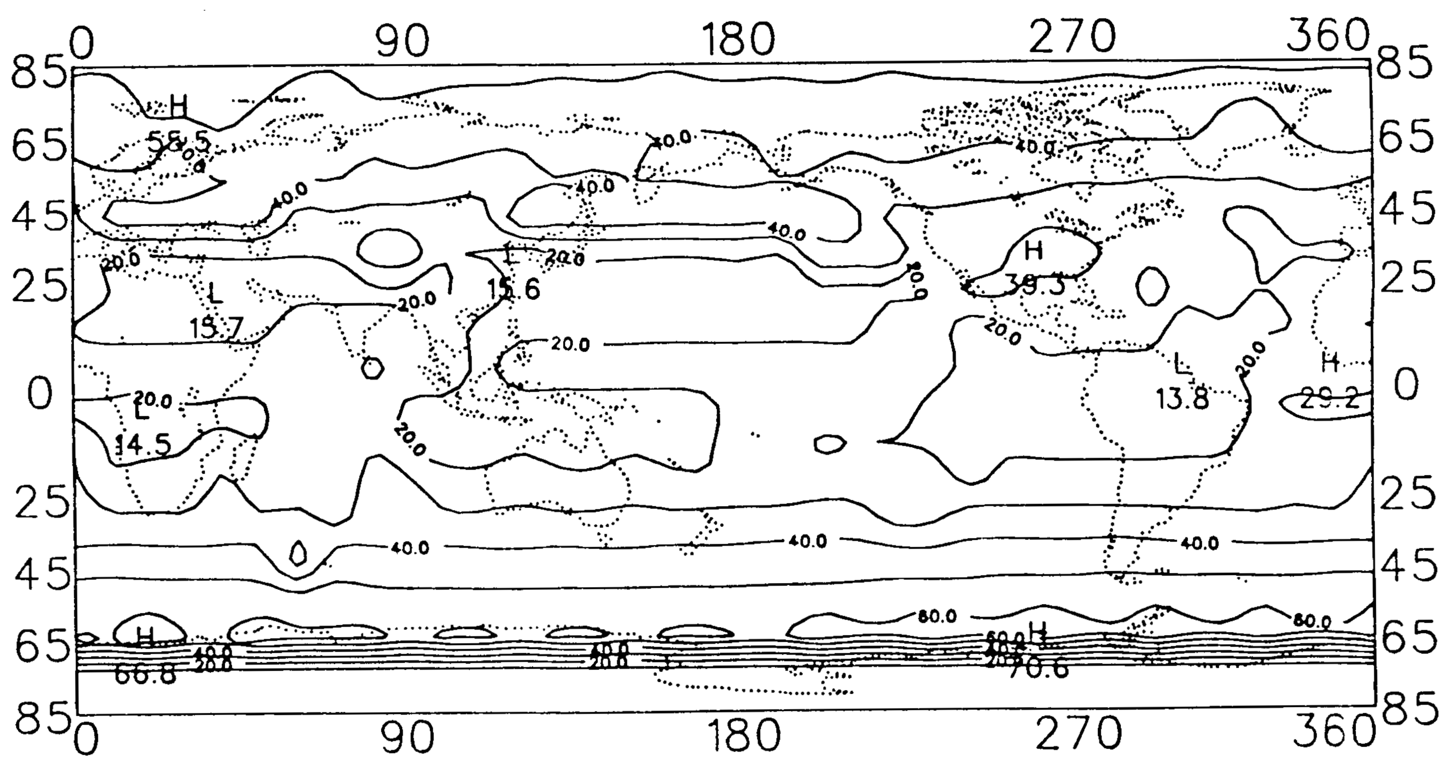

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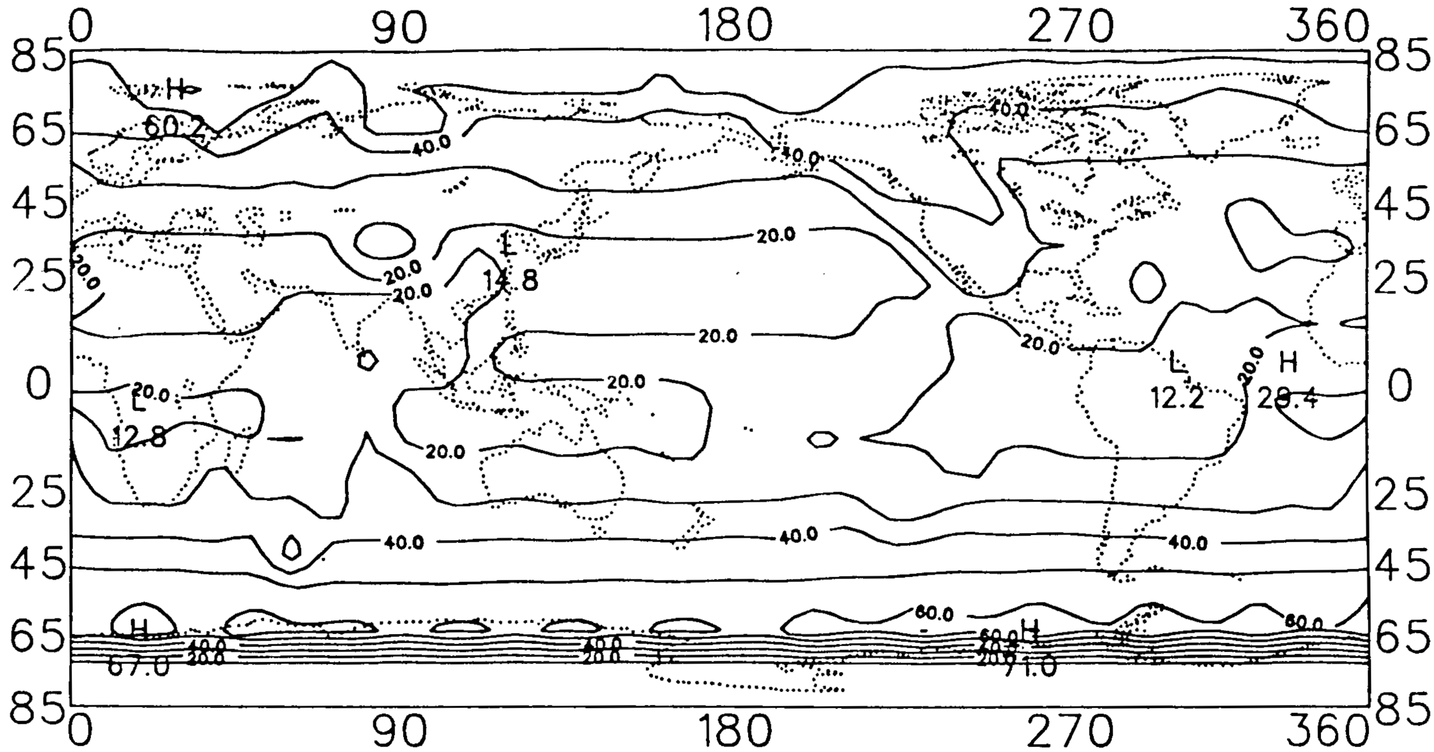

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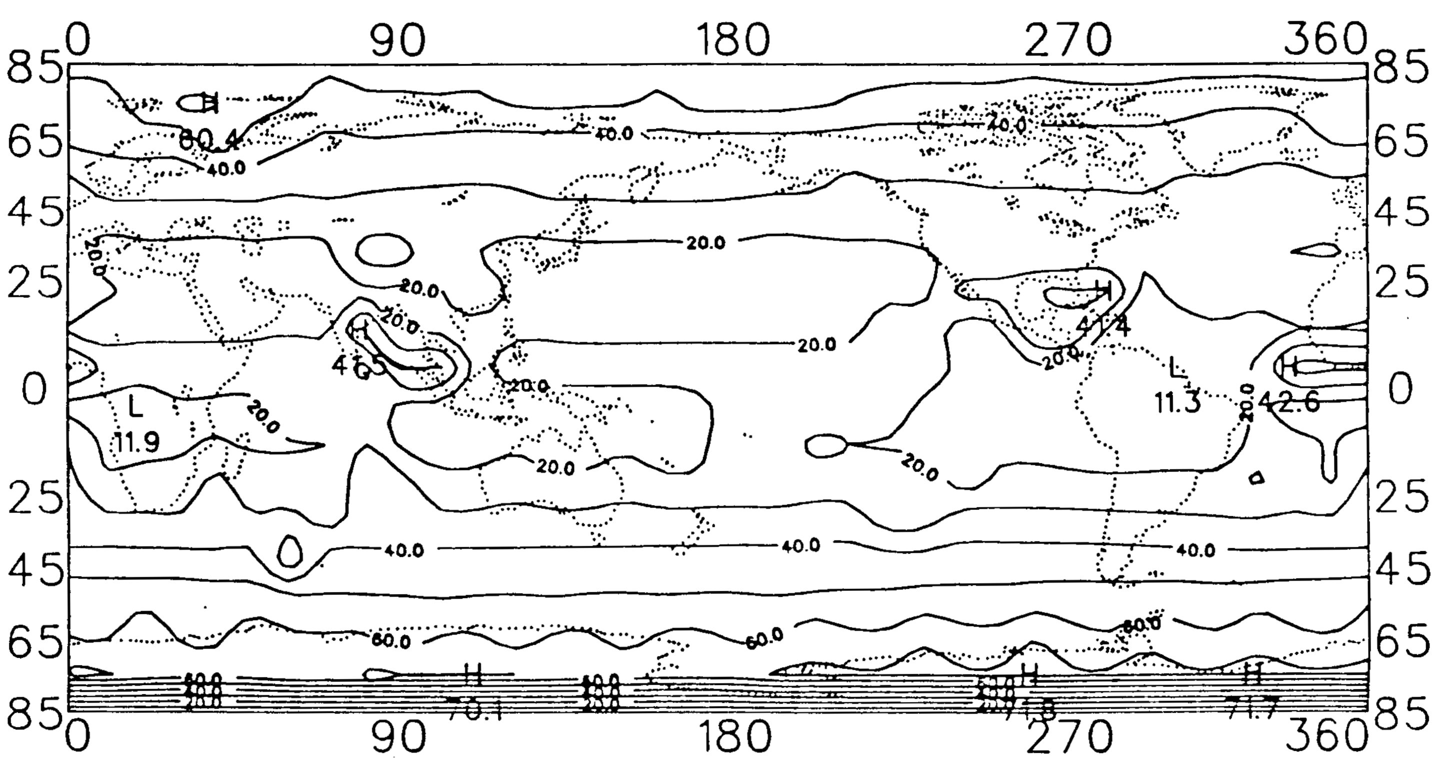

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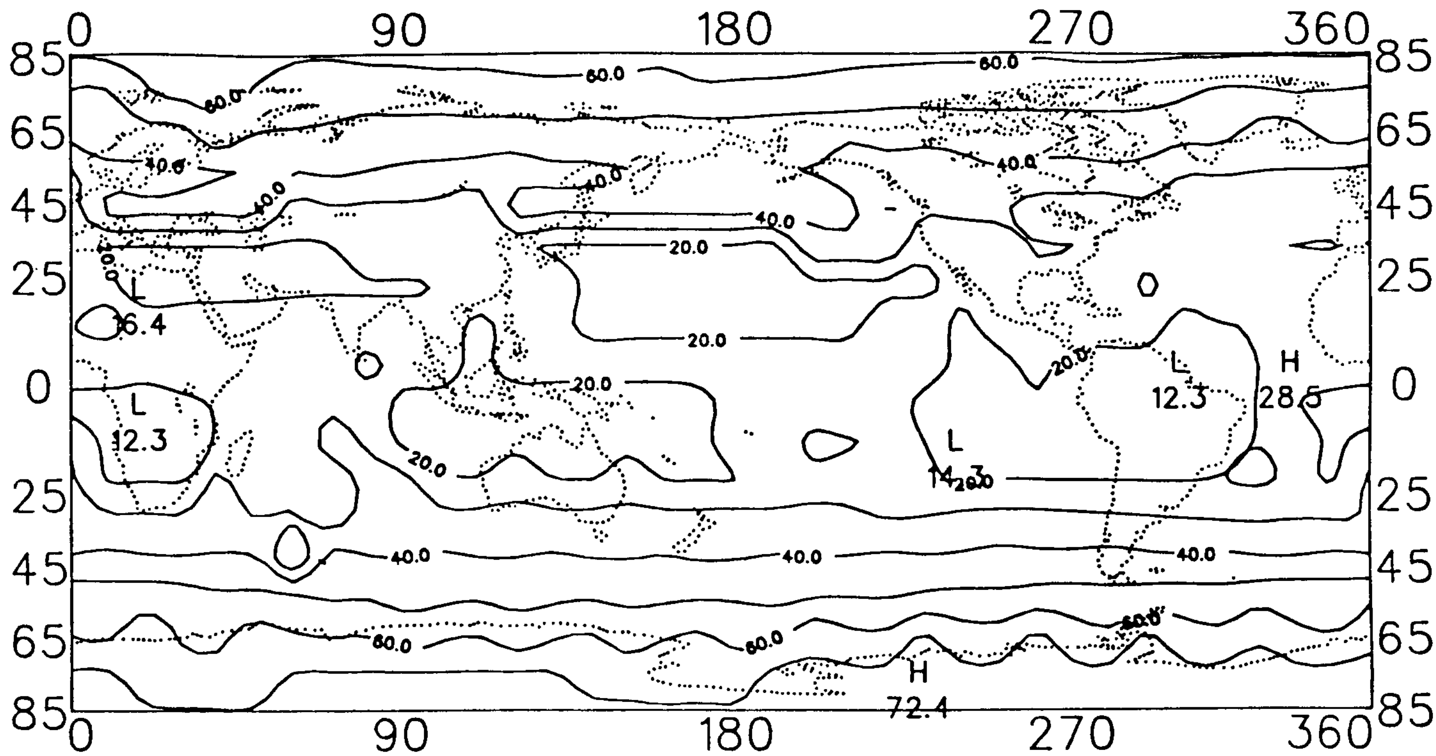

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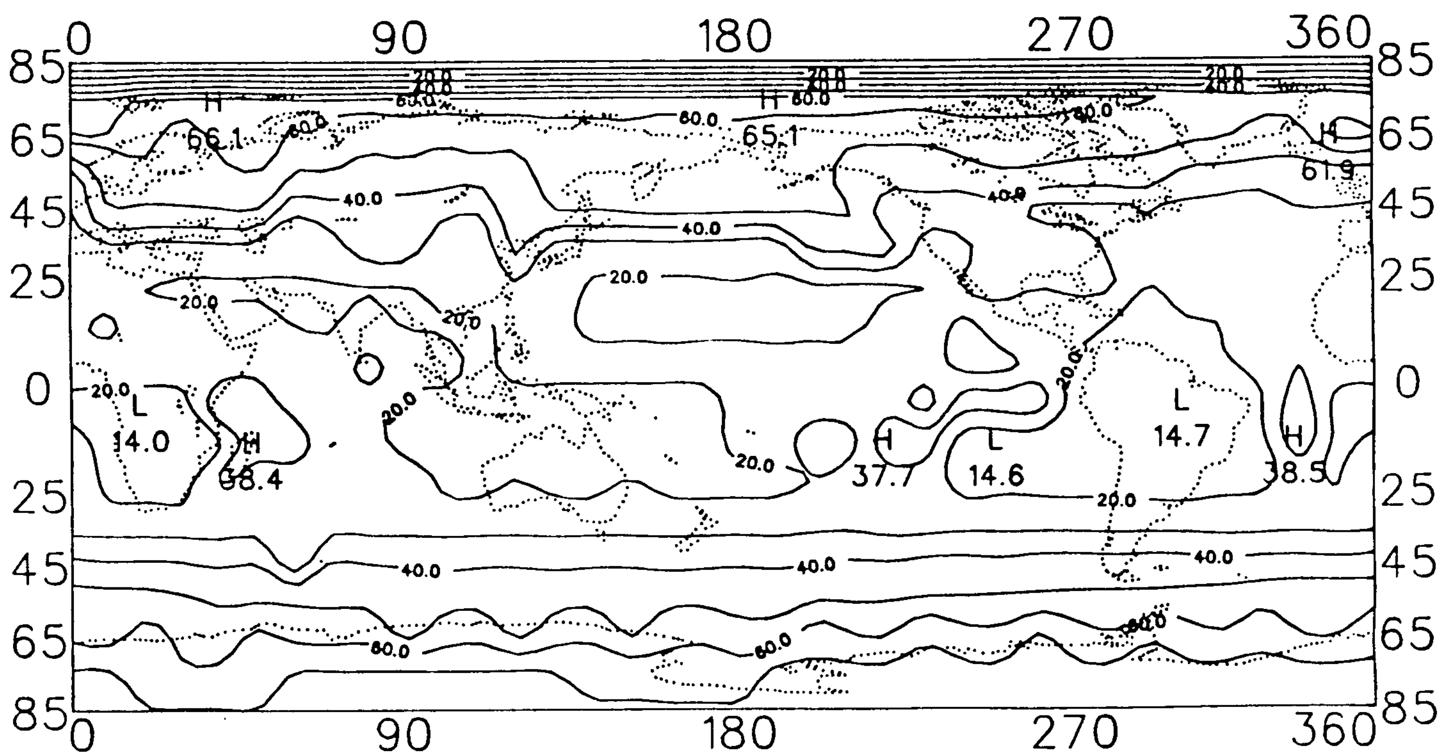

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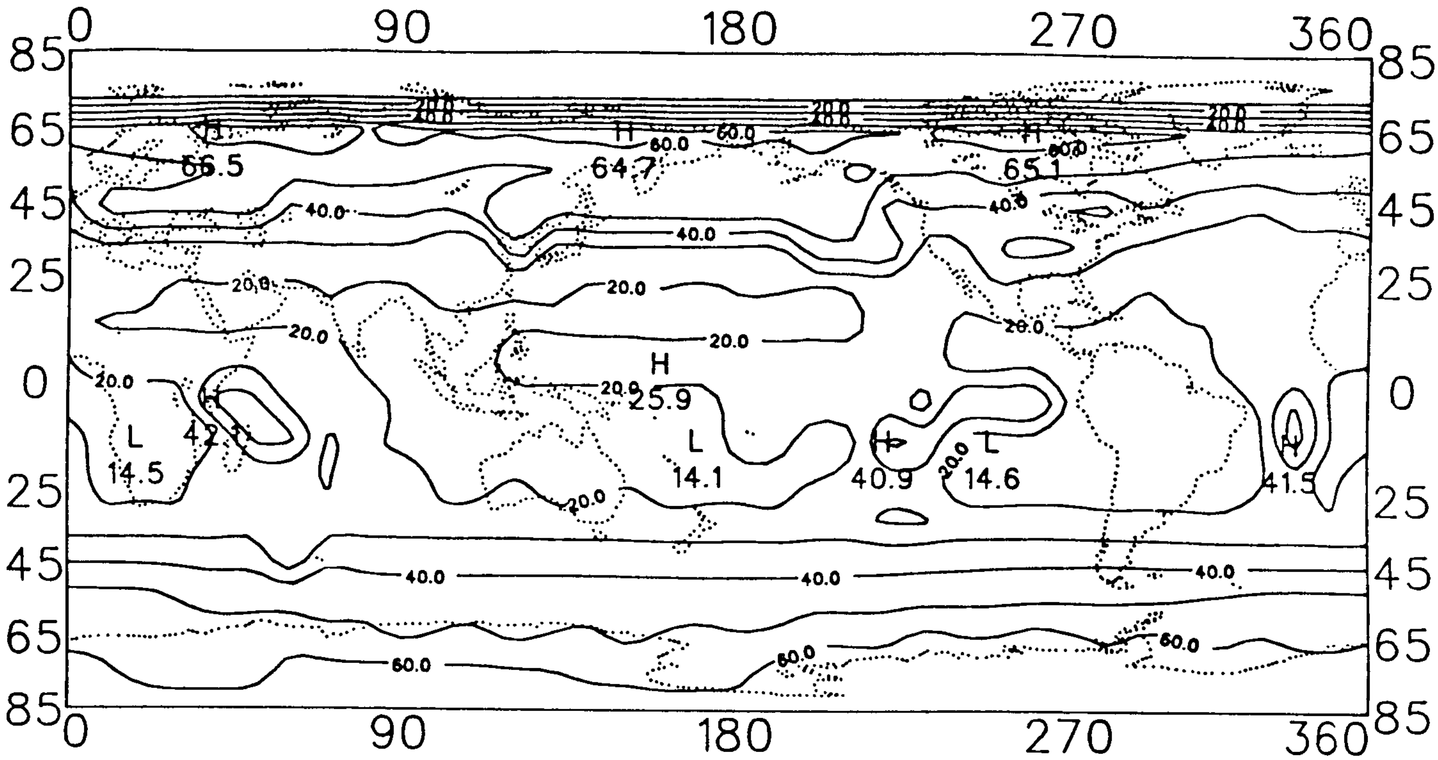

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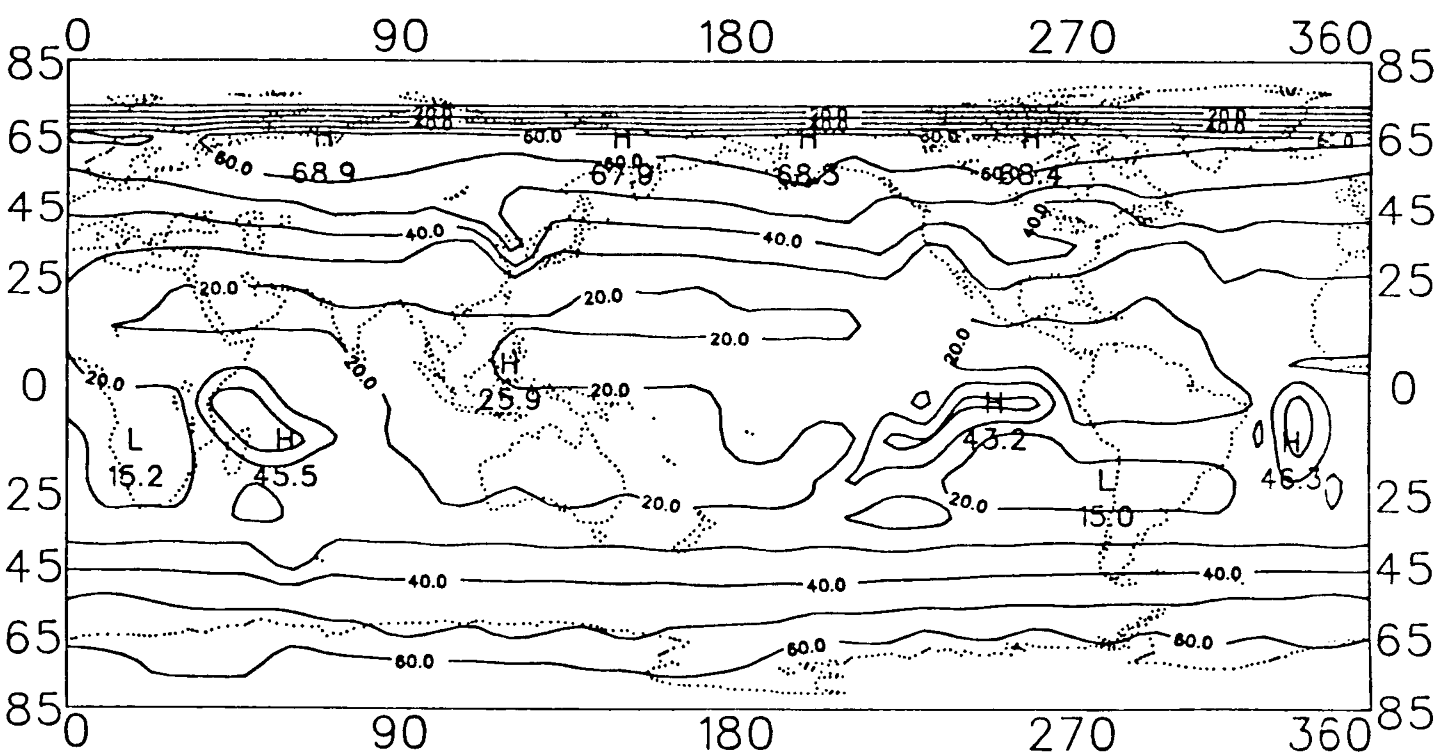

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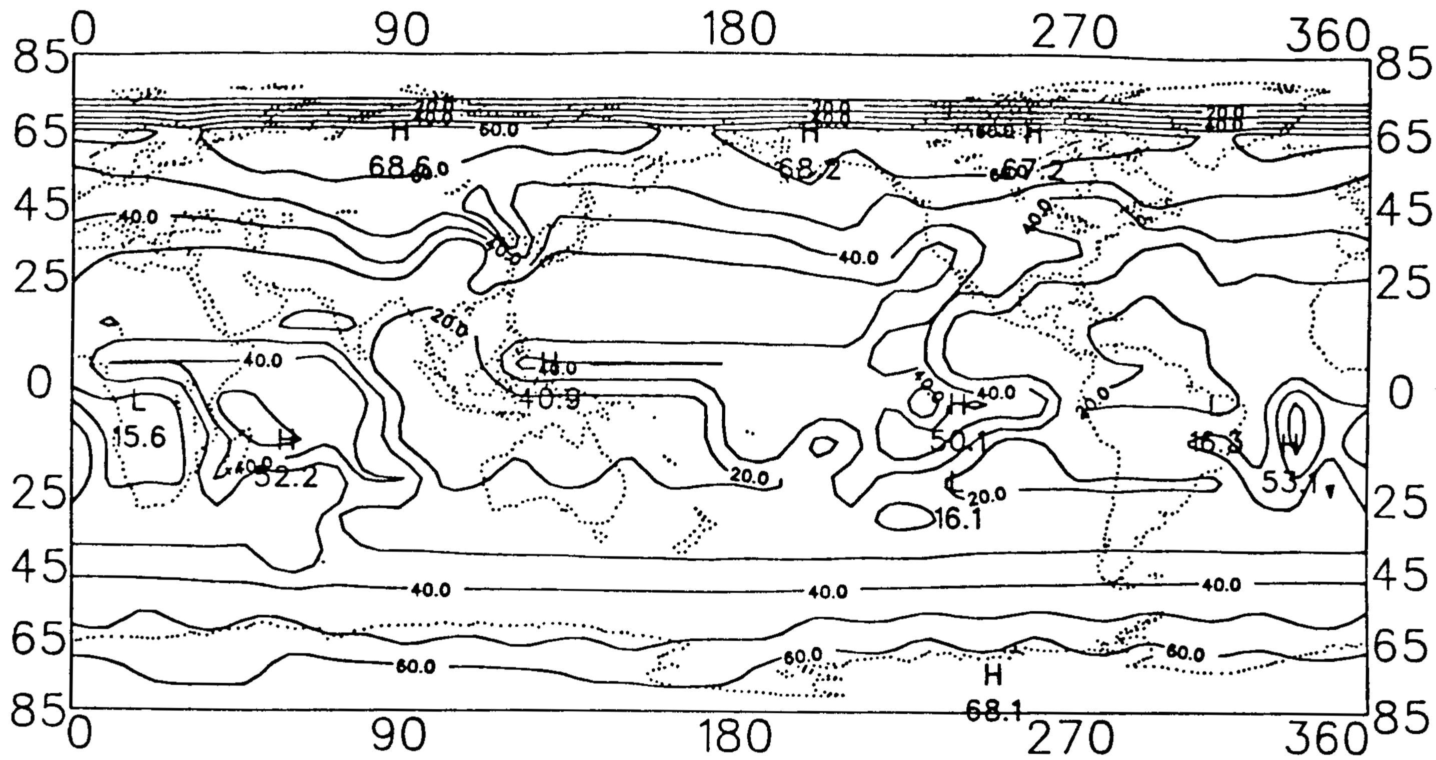
Appendix 7.2

Contour Maps of Albedo for GLCLC equals to 45%, using equations 8-14.



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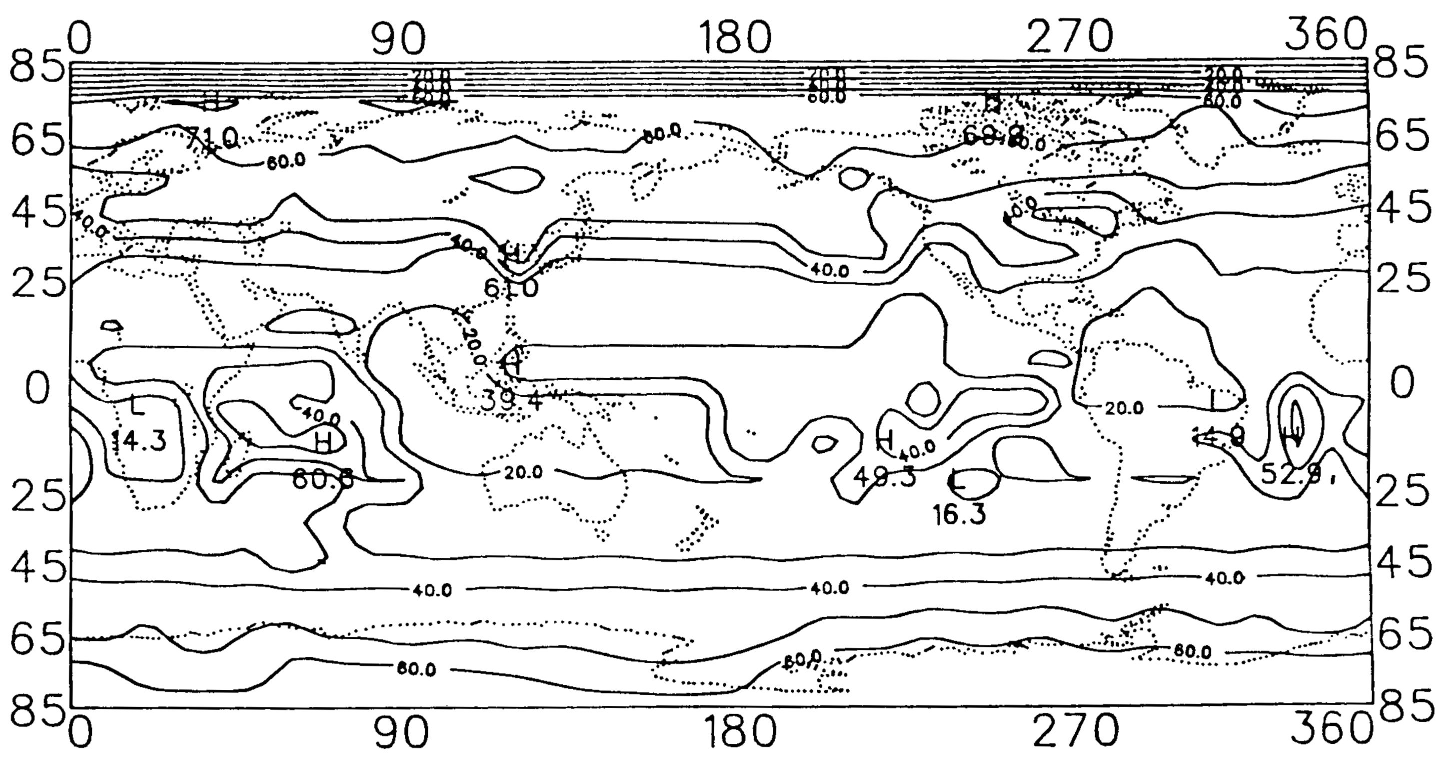

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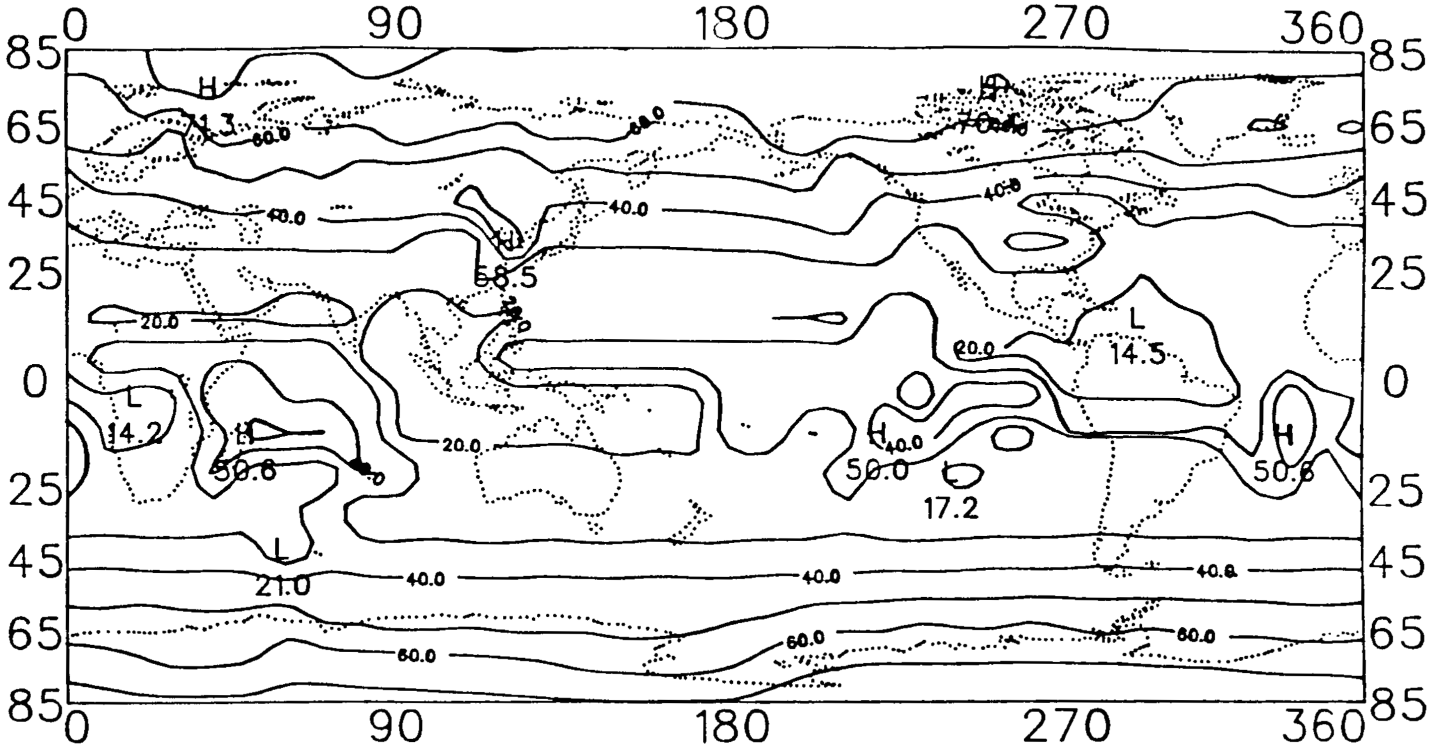

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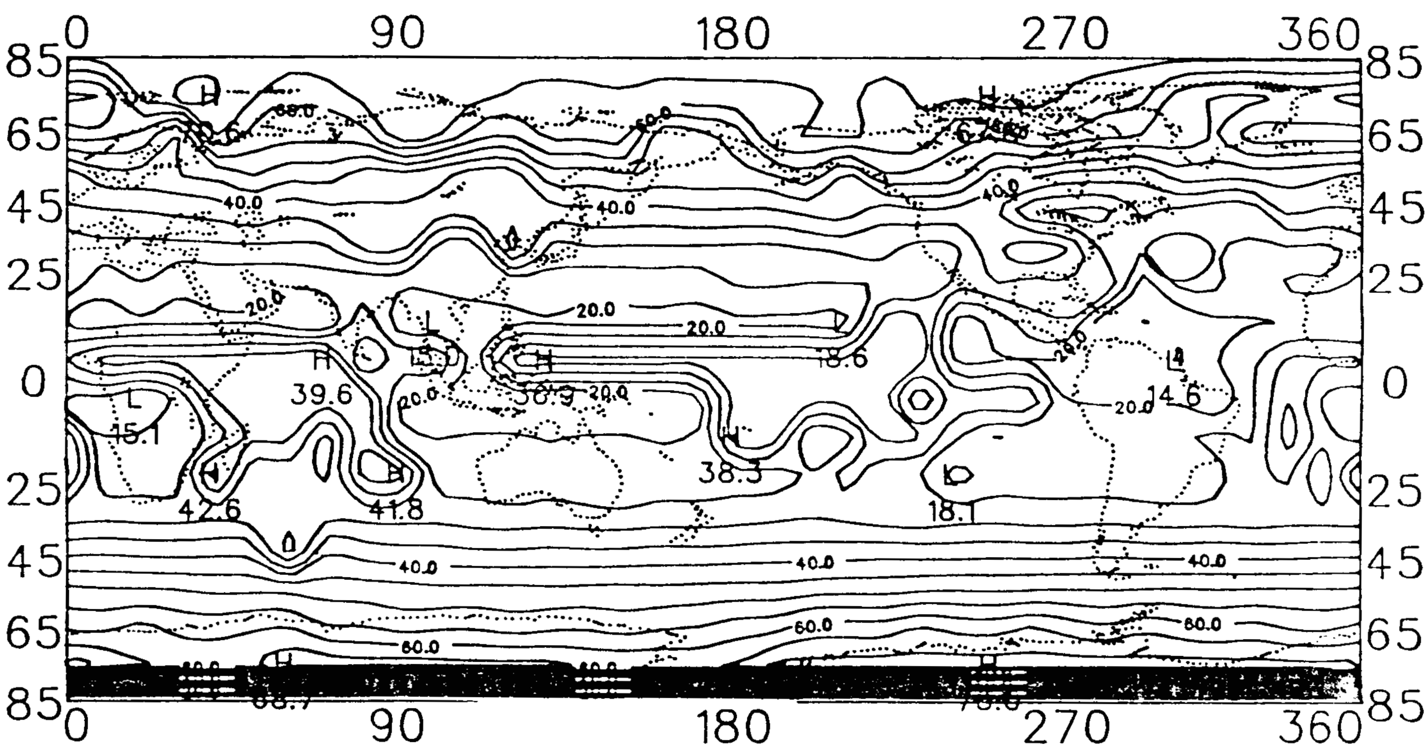

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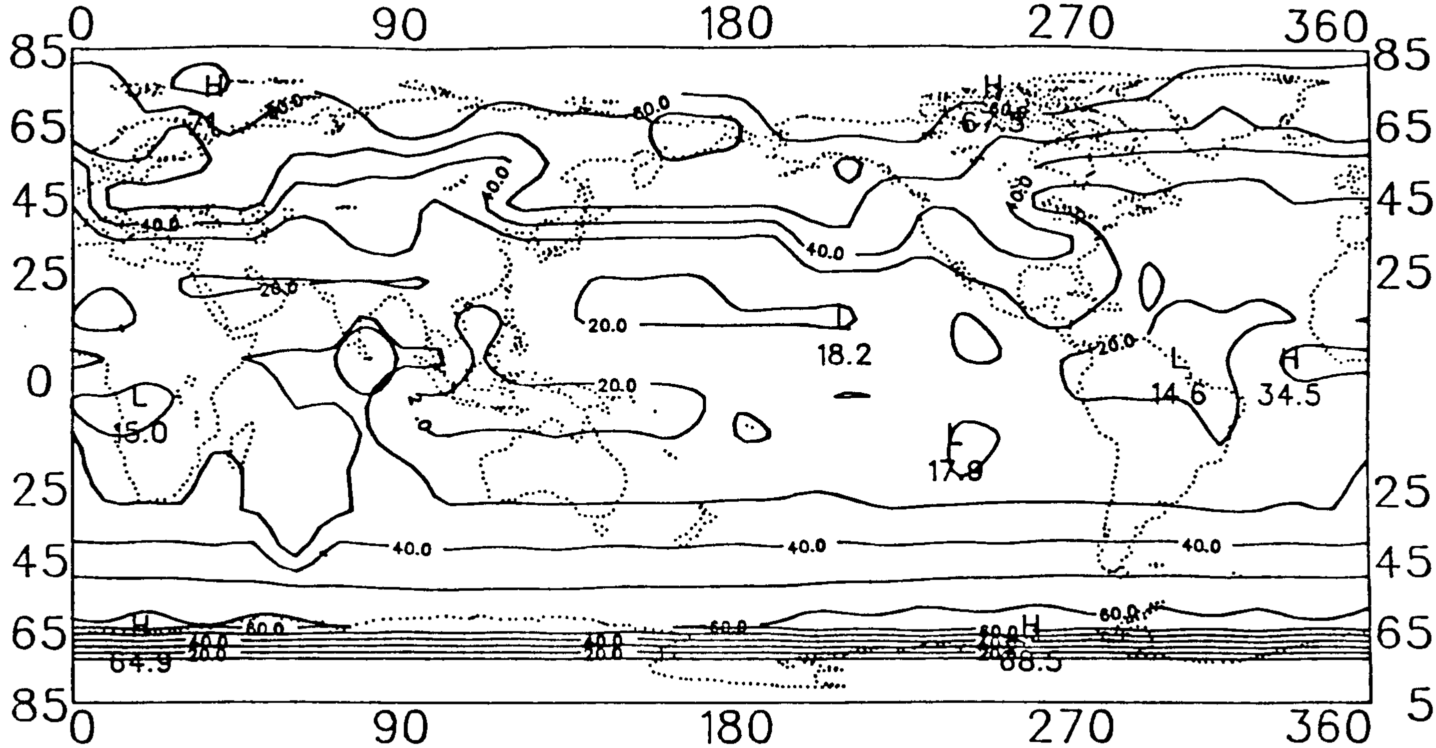

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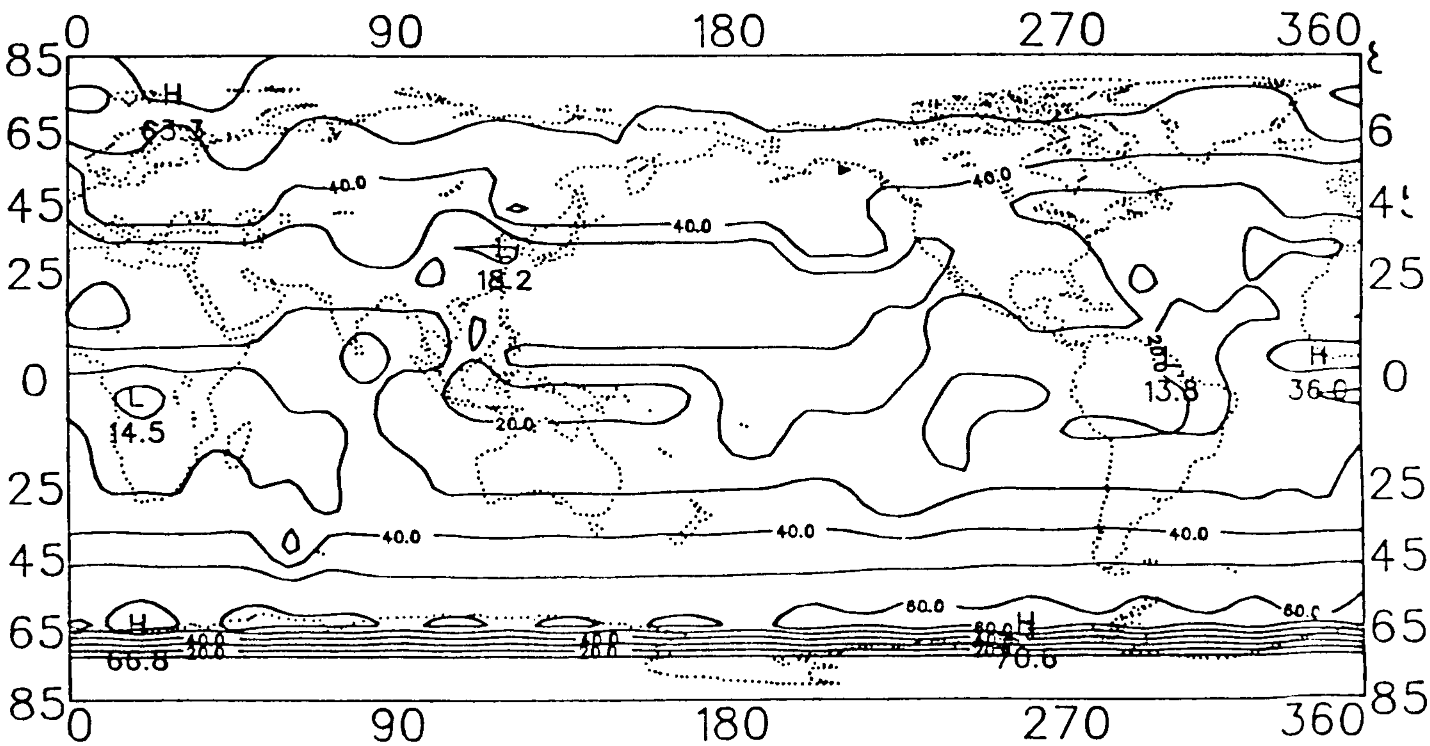

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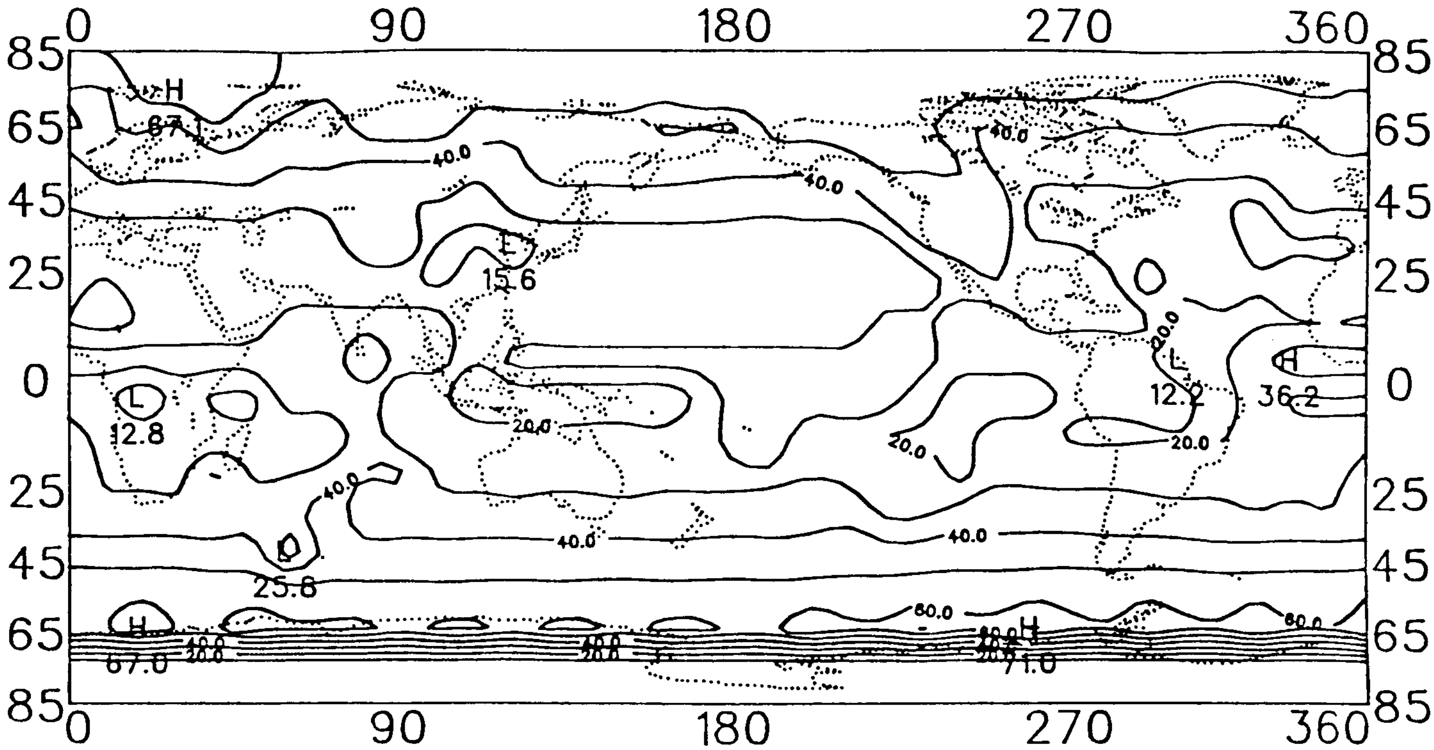

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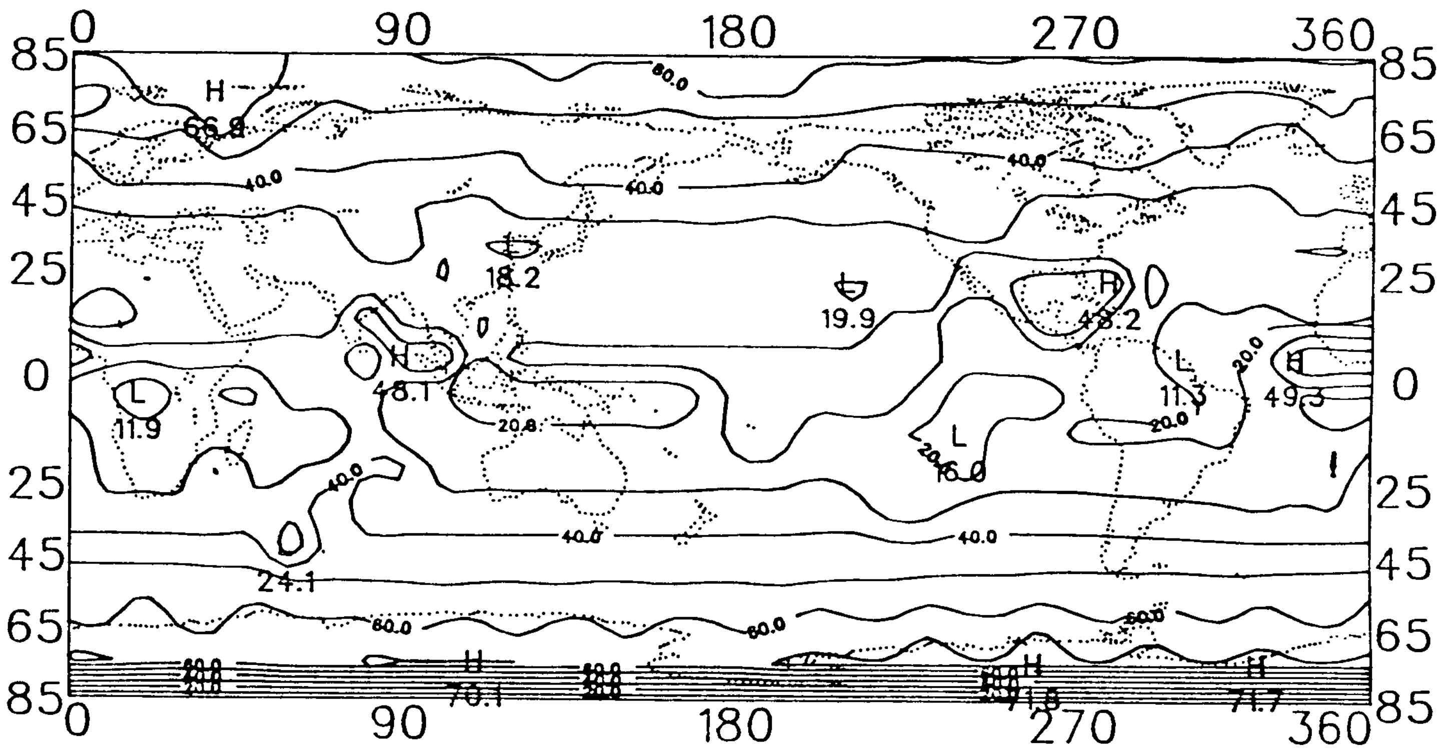

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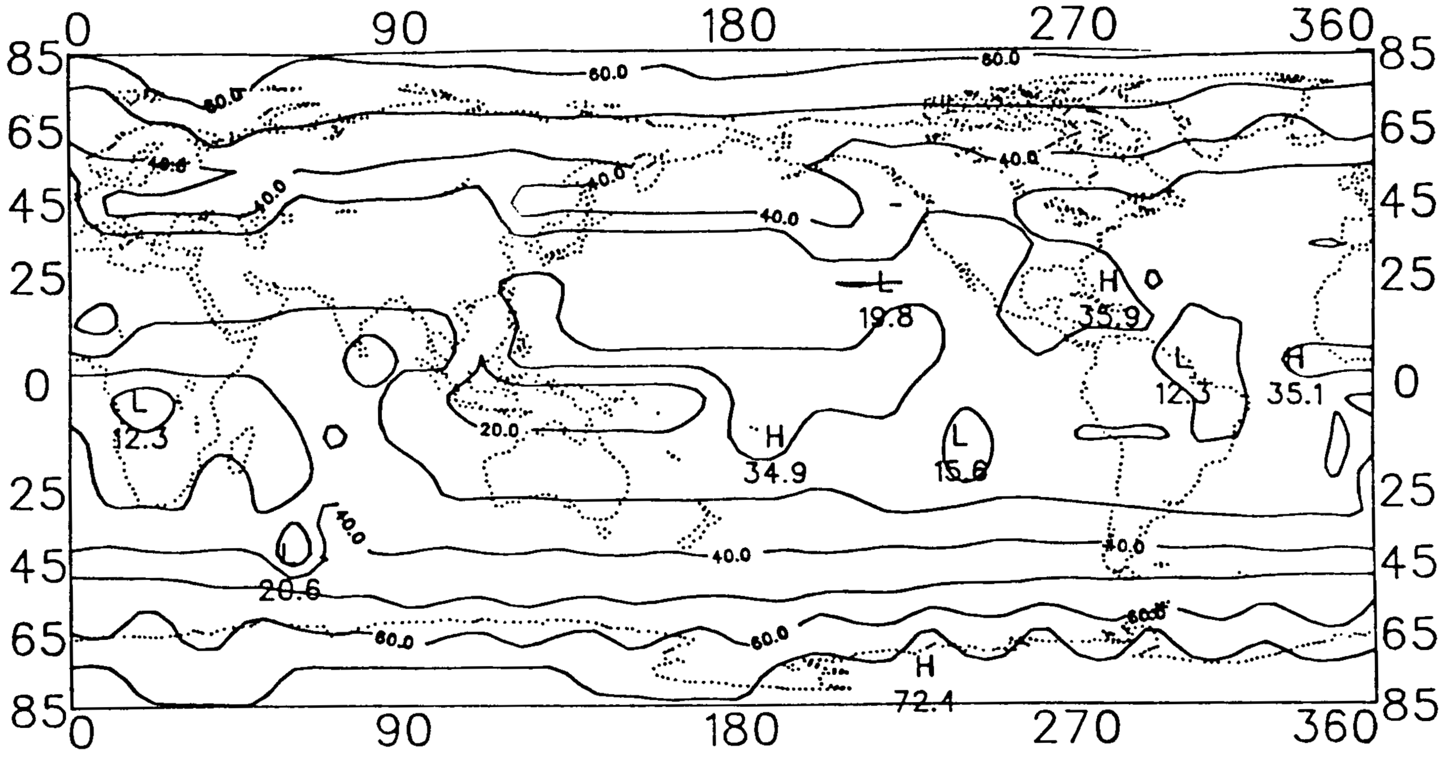

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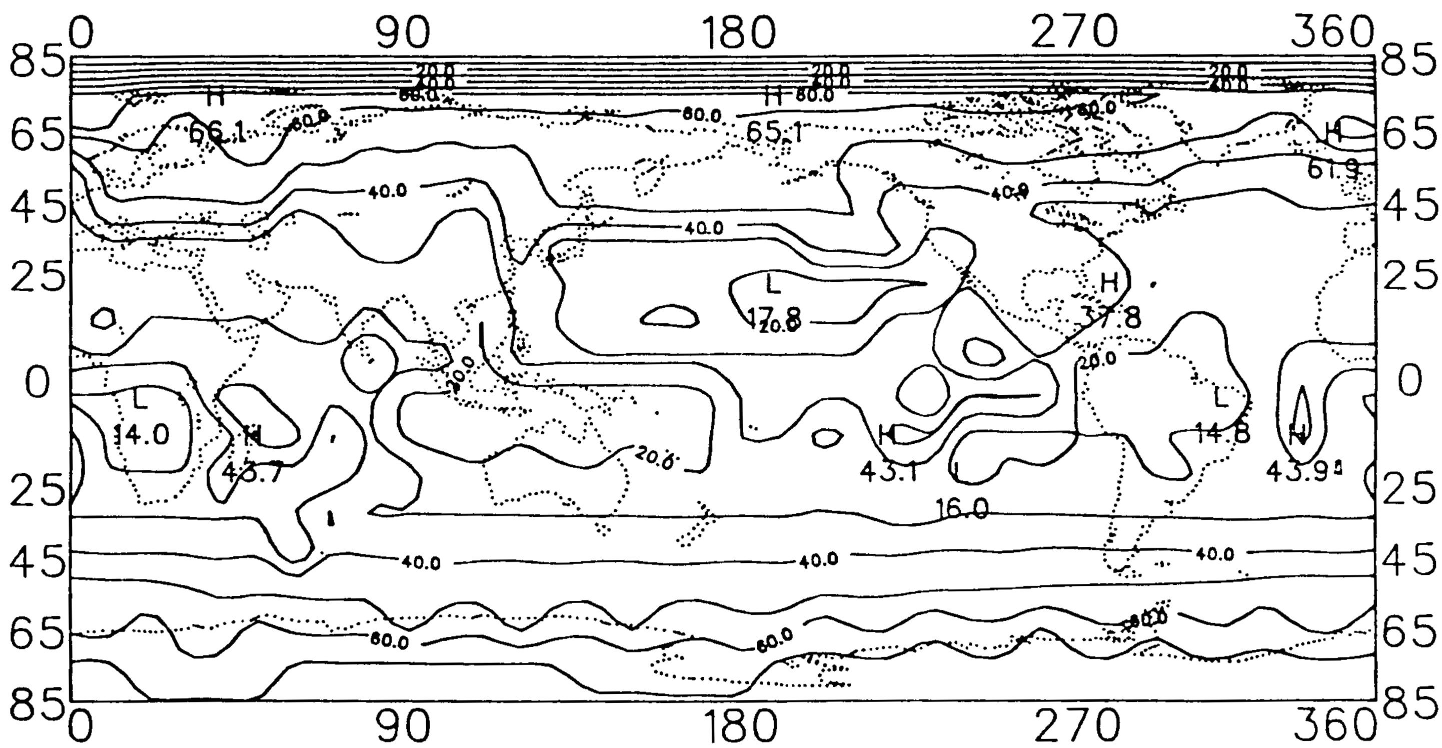

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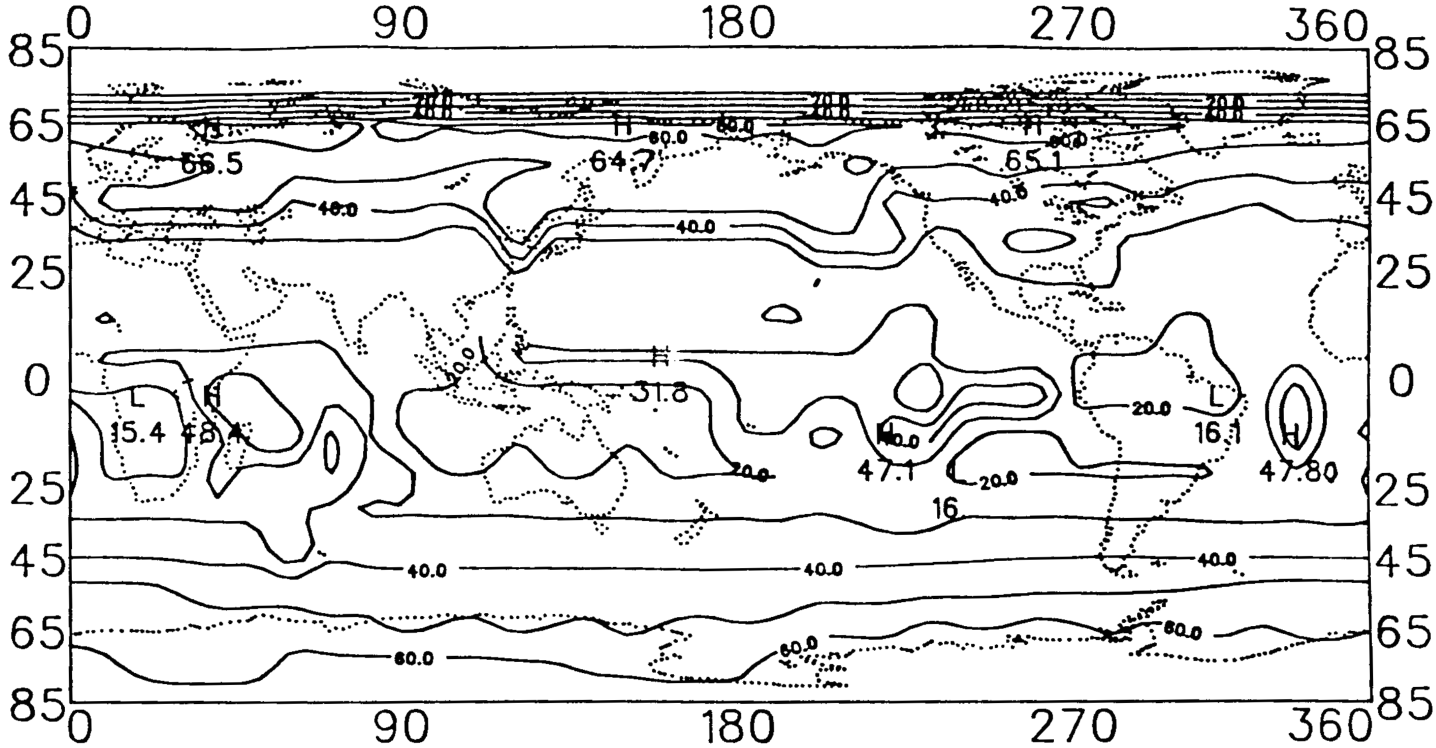

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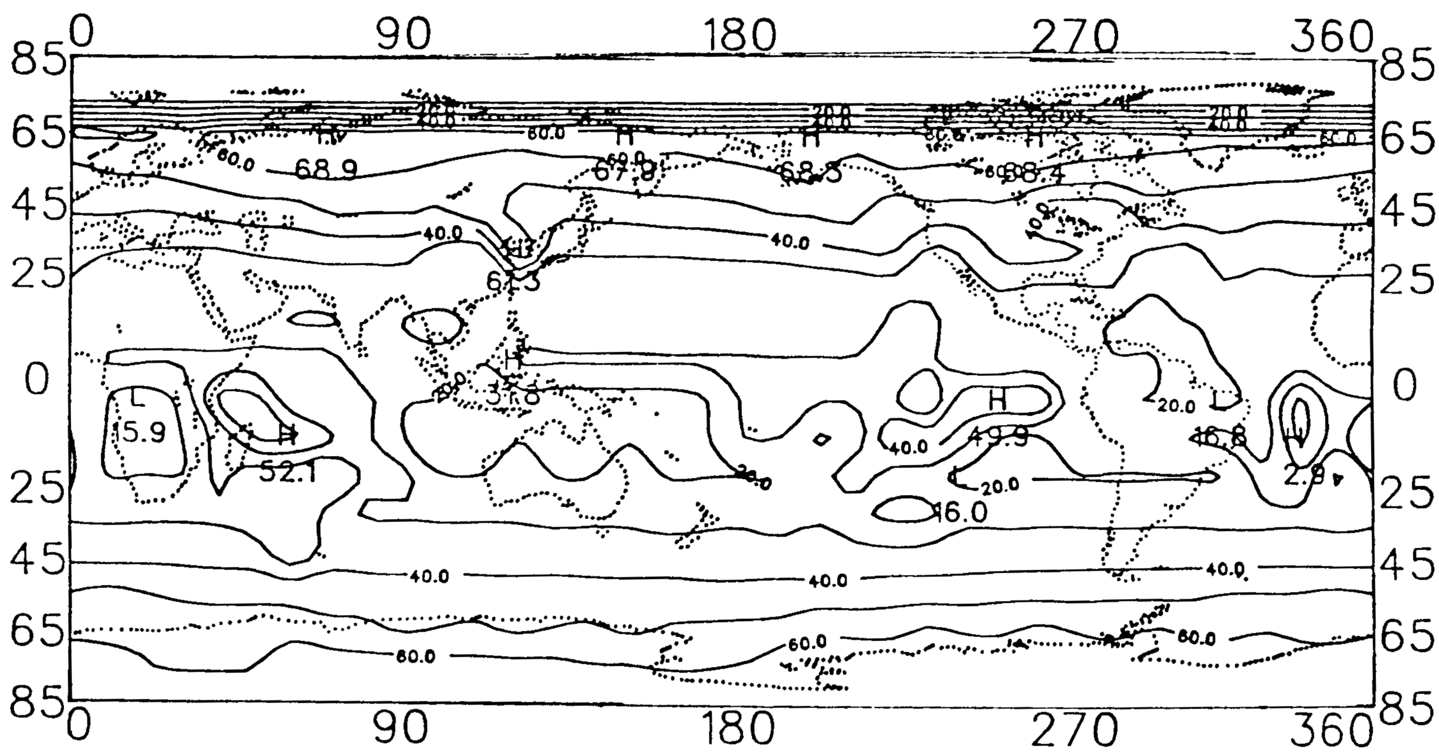
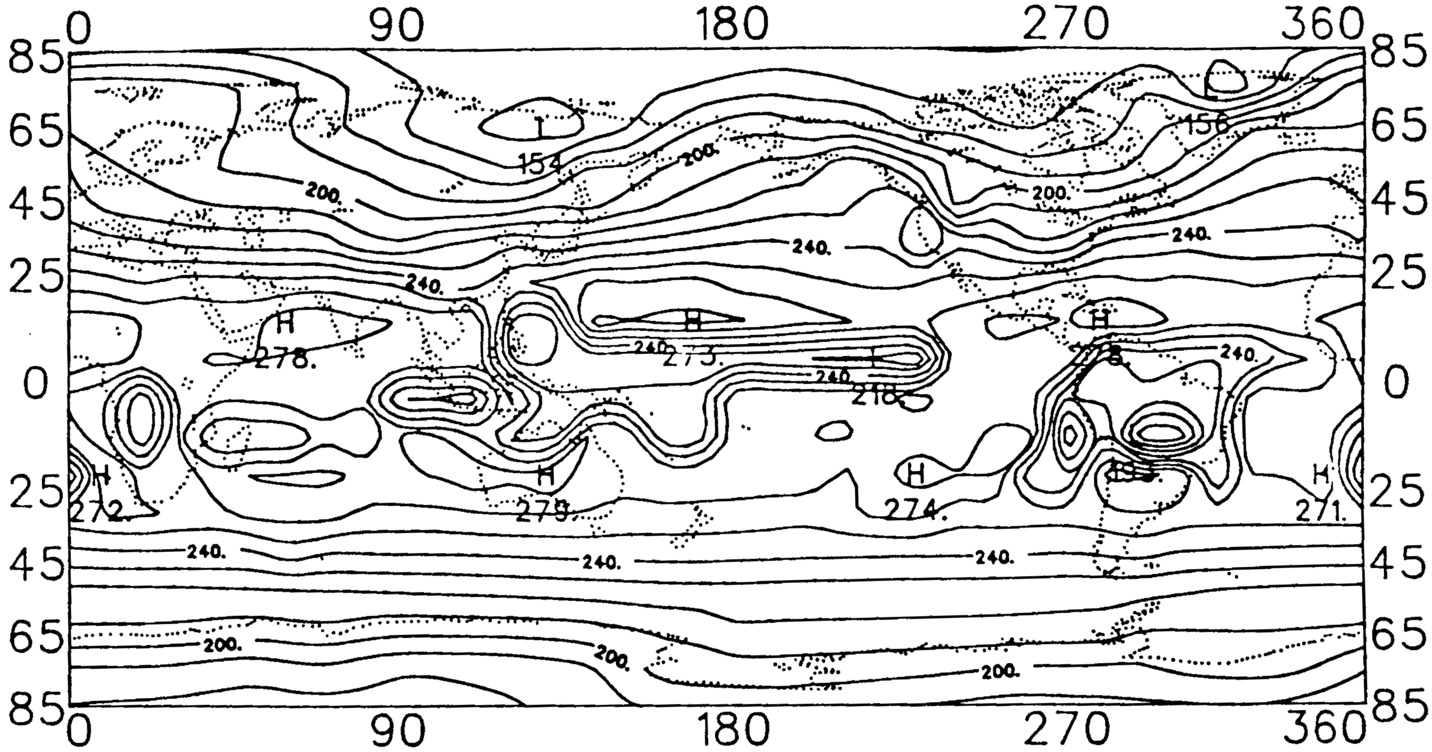


CLOUDY SKY ALBEDO DECEMBER (45M),%

Appendix 7.3

Contour Maps of OLWR and Albedo for GLCLC

equal to 57%, using equations 8-14.



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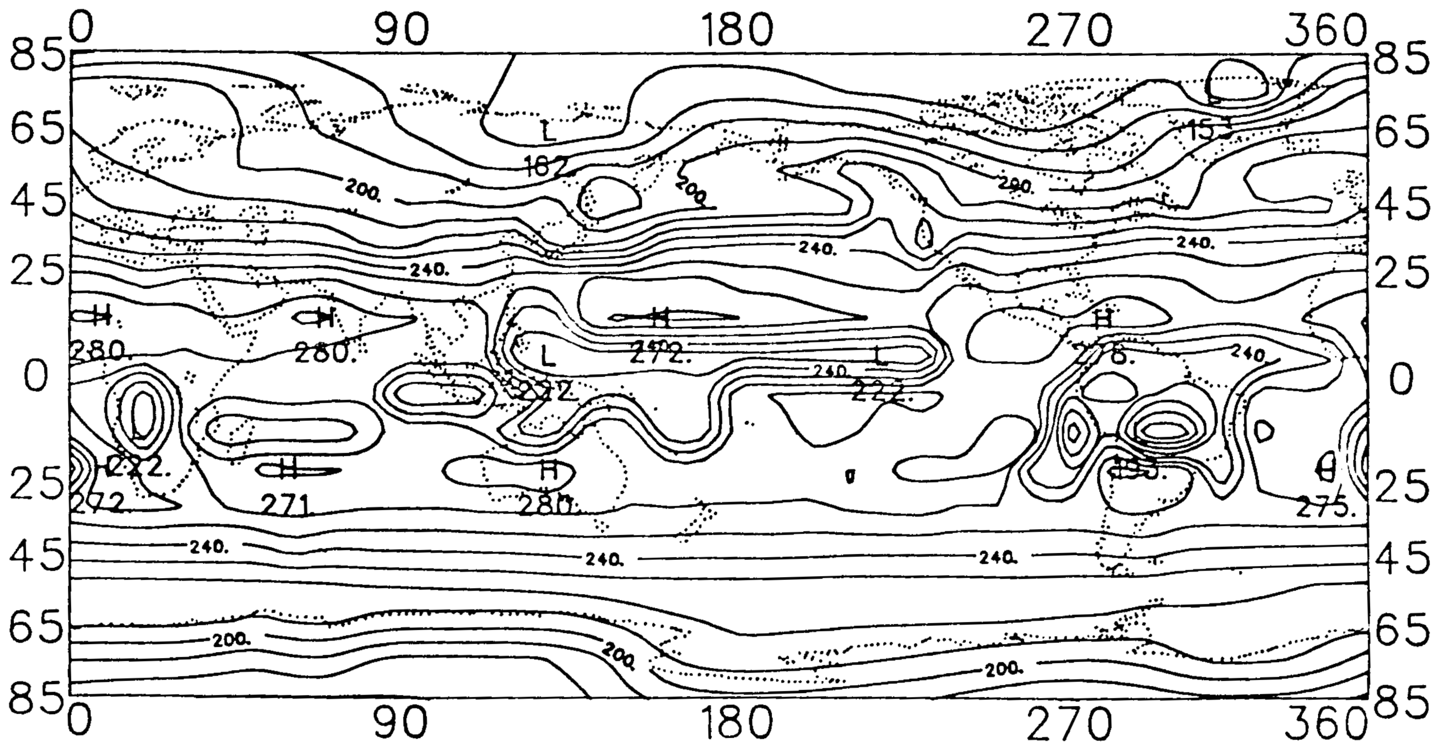

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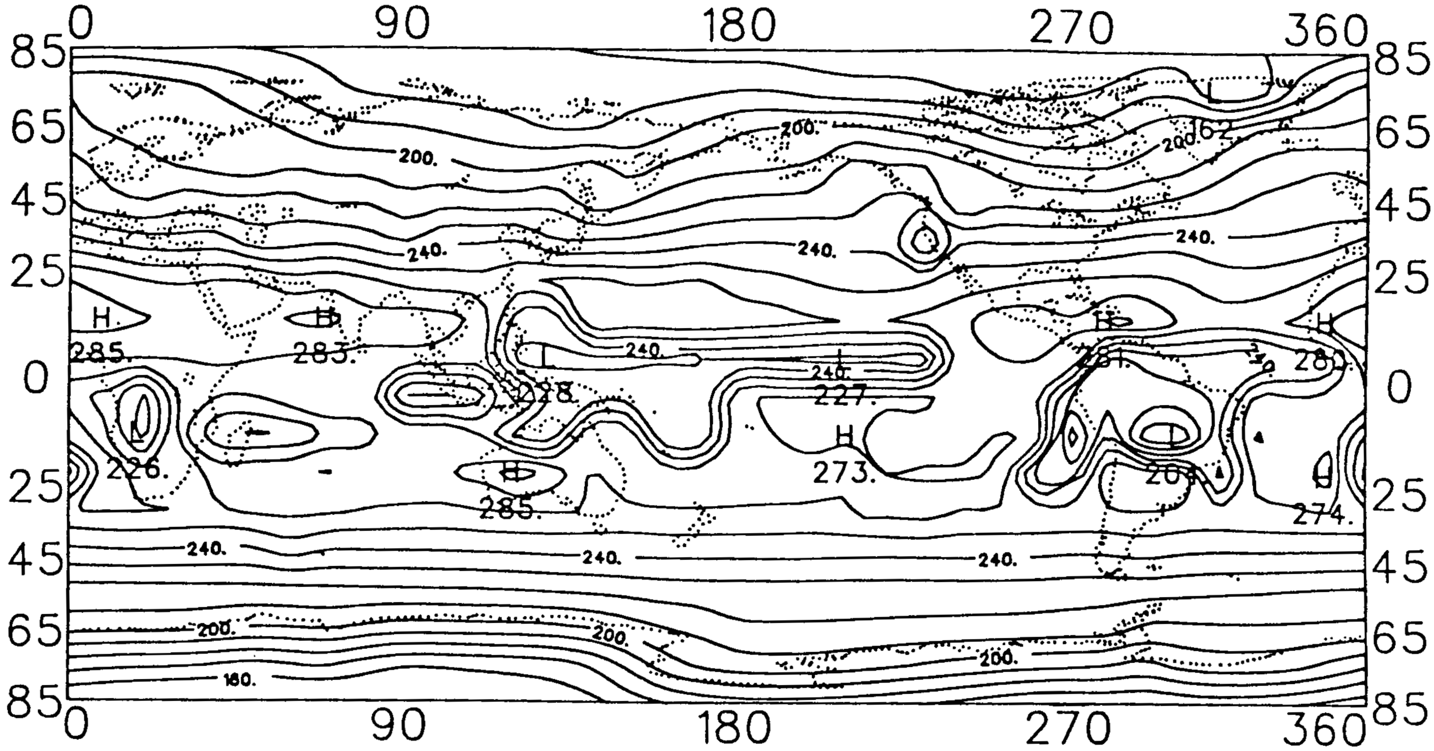

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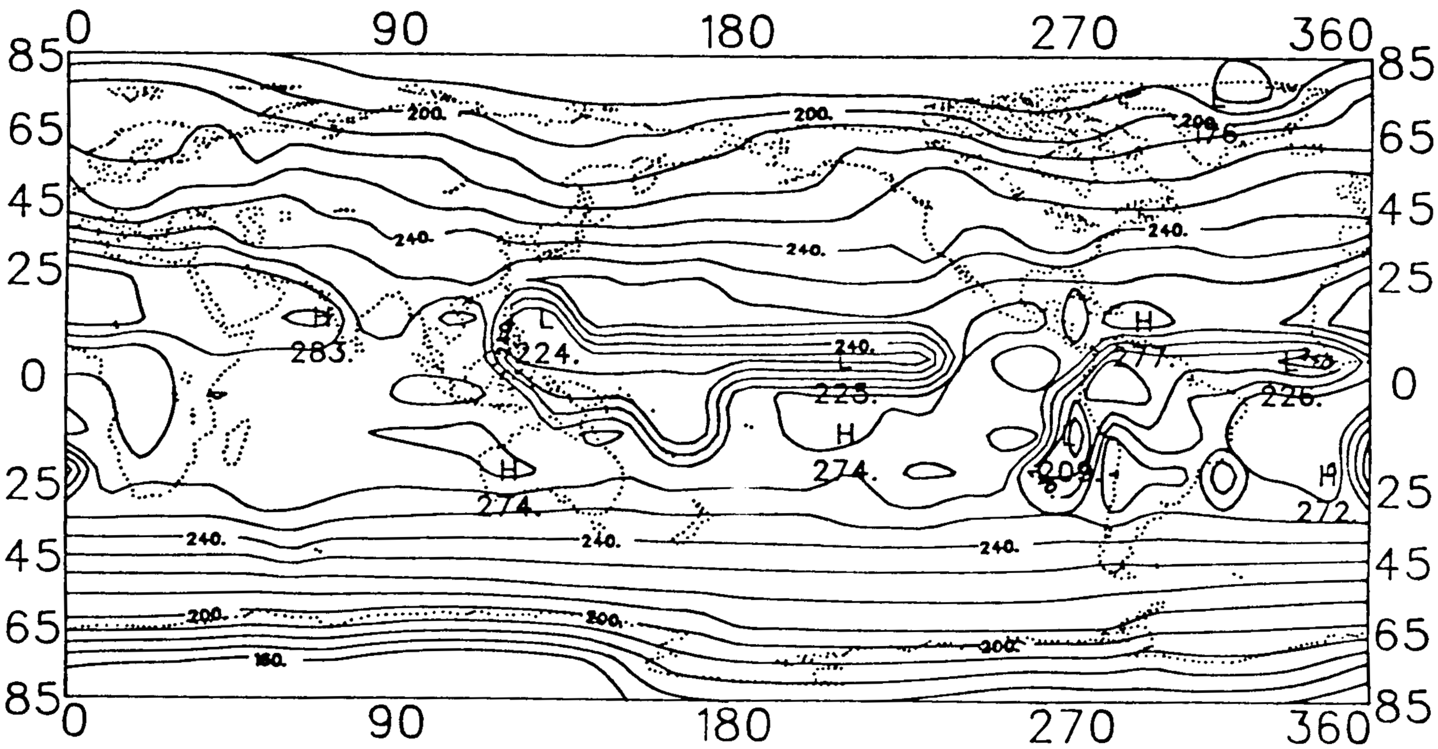

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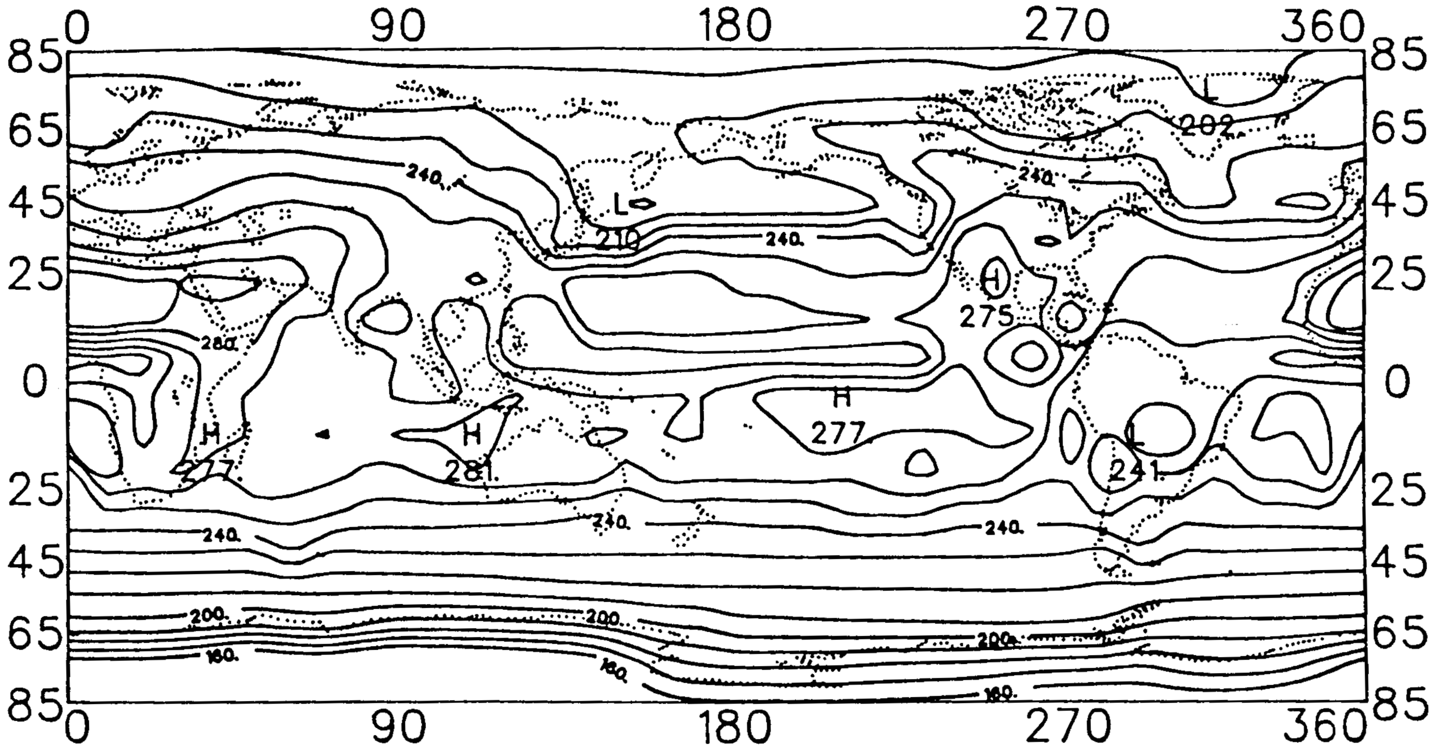

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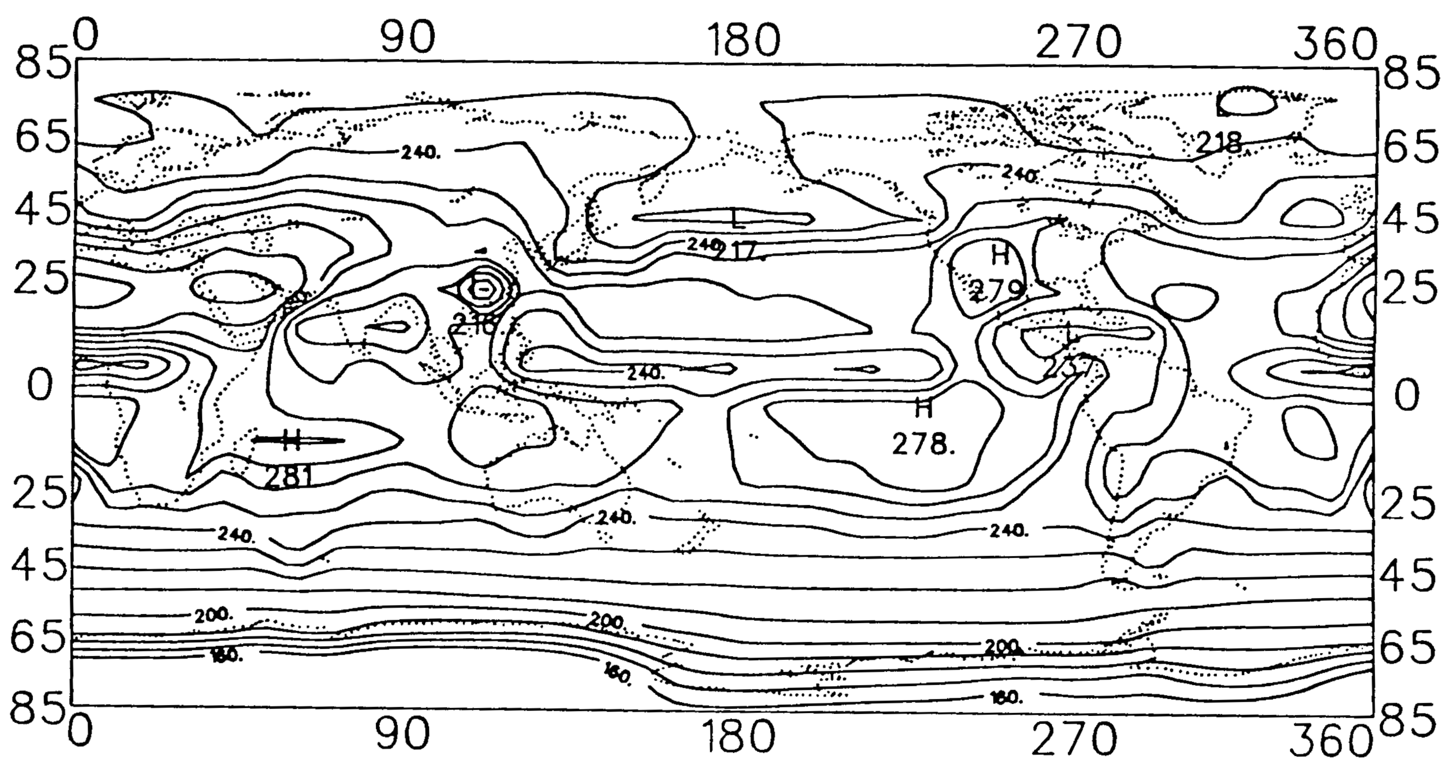

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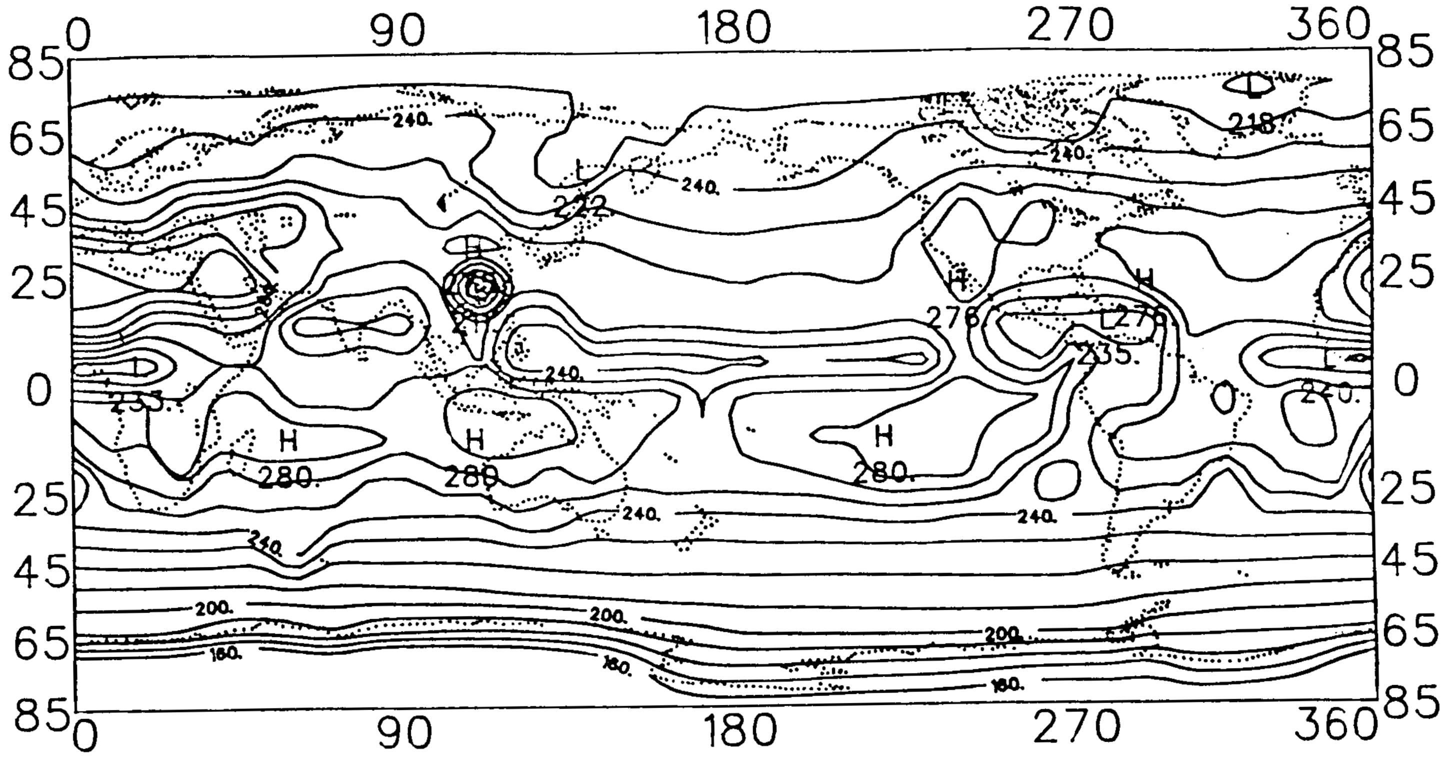

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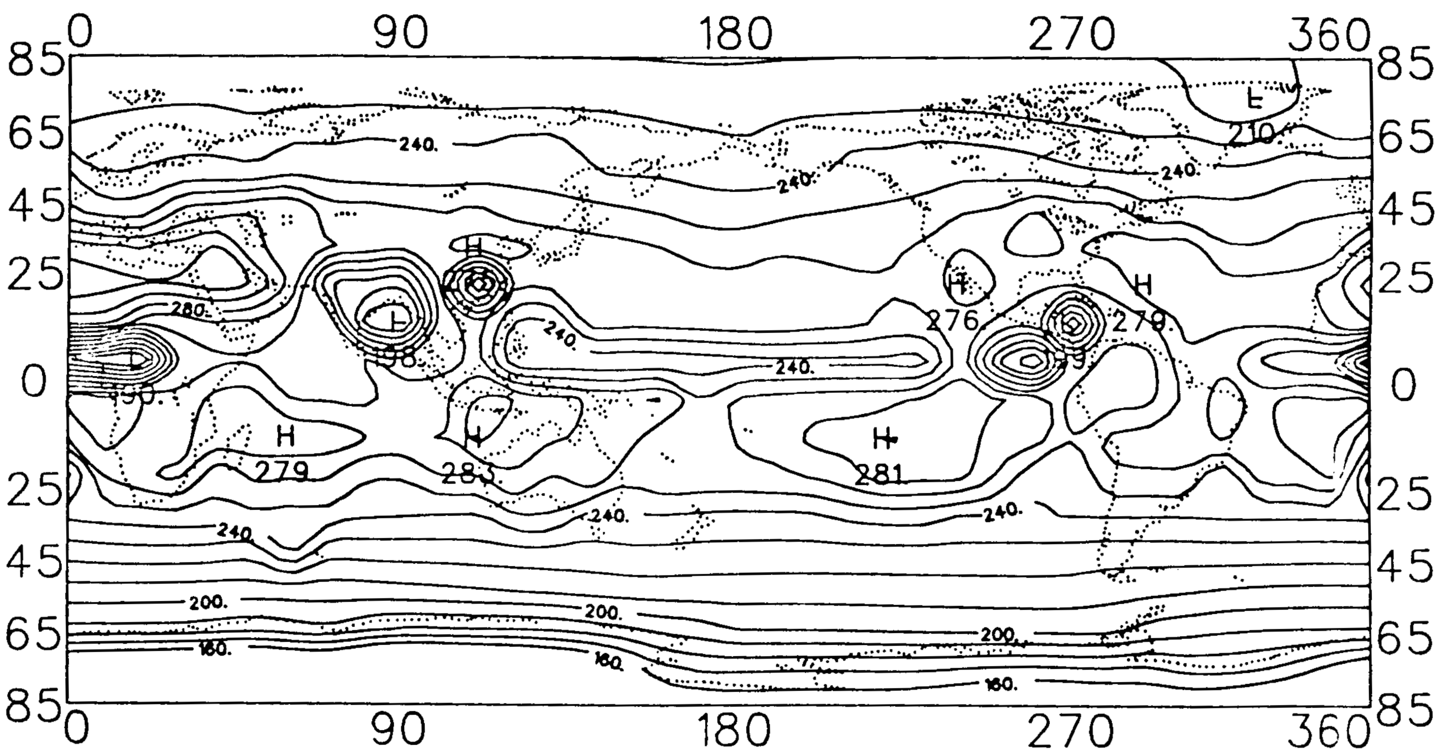

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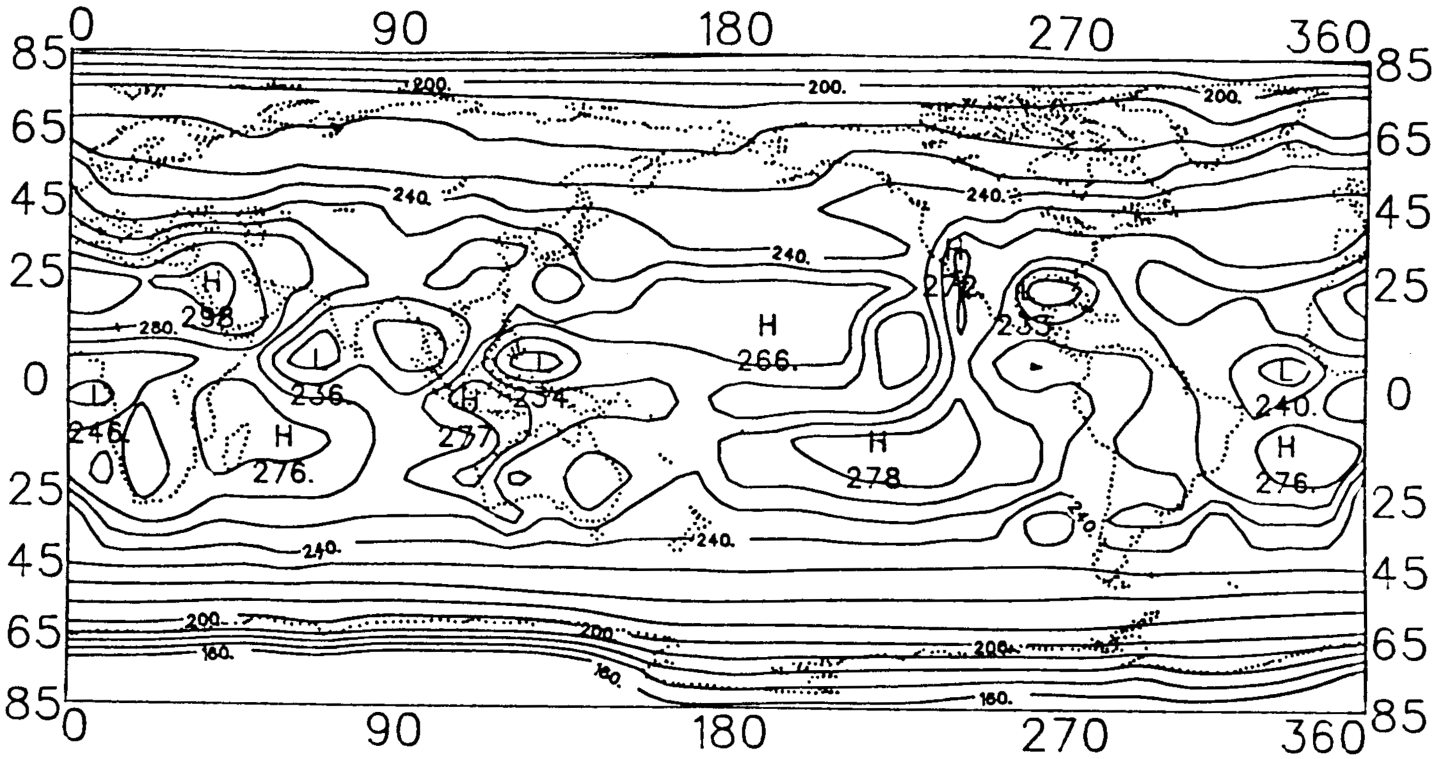

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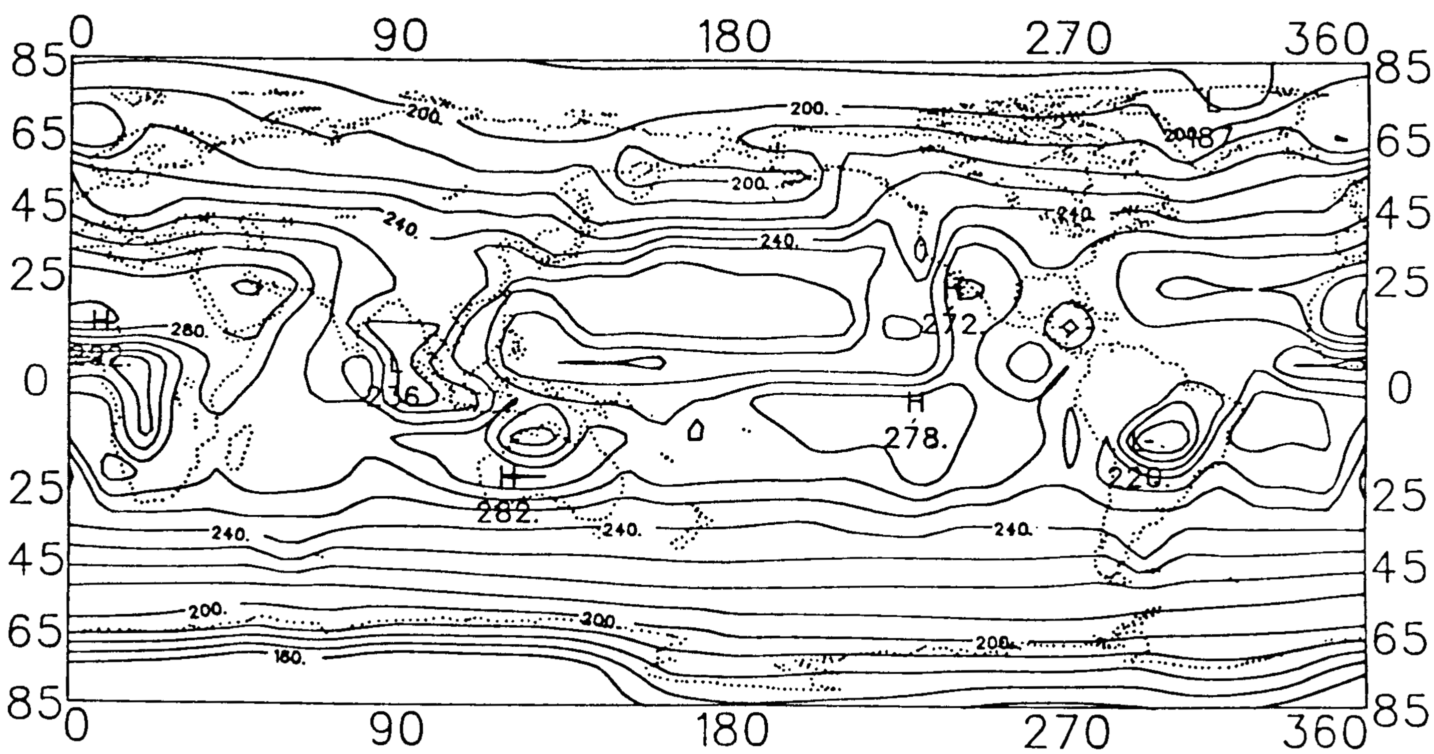

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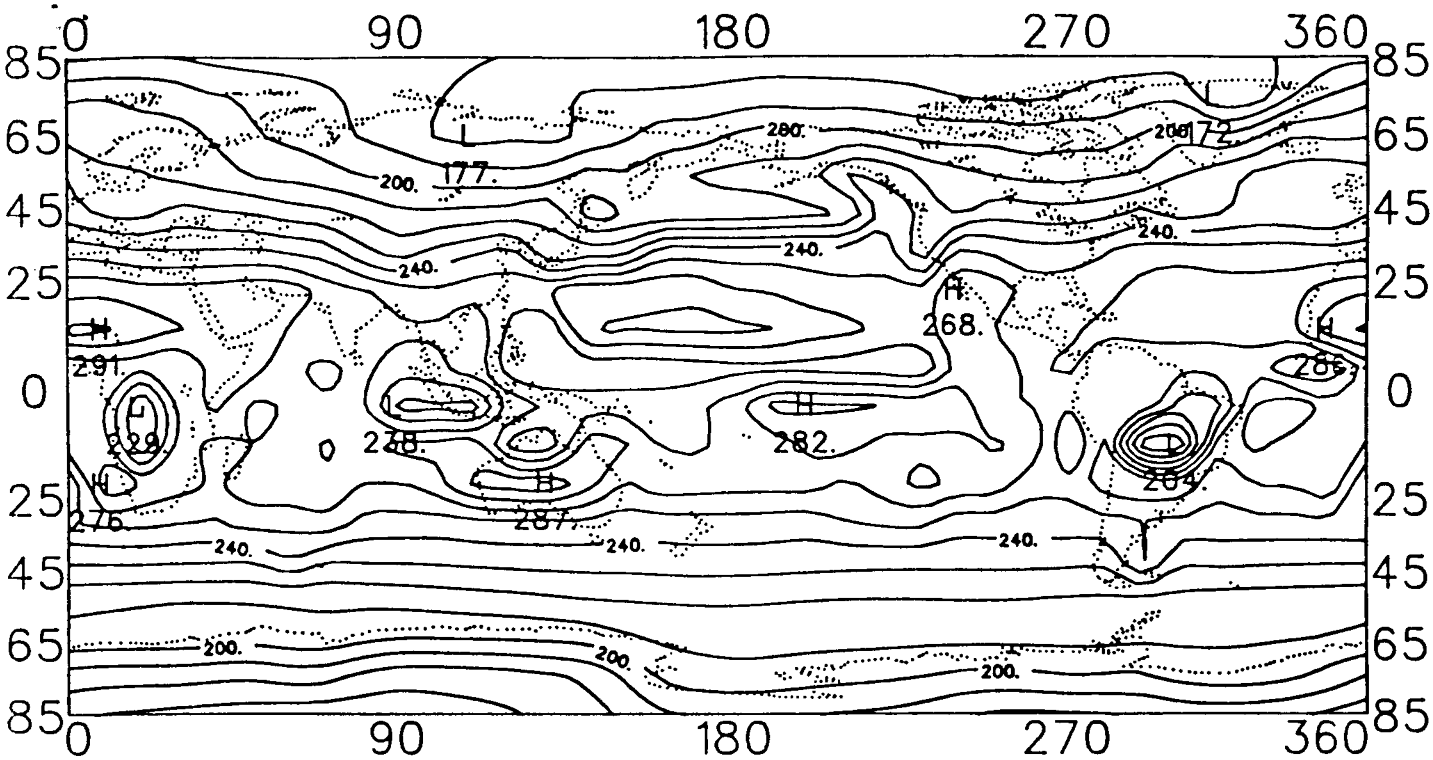

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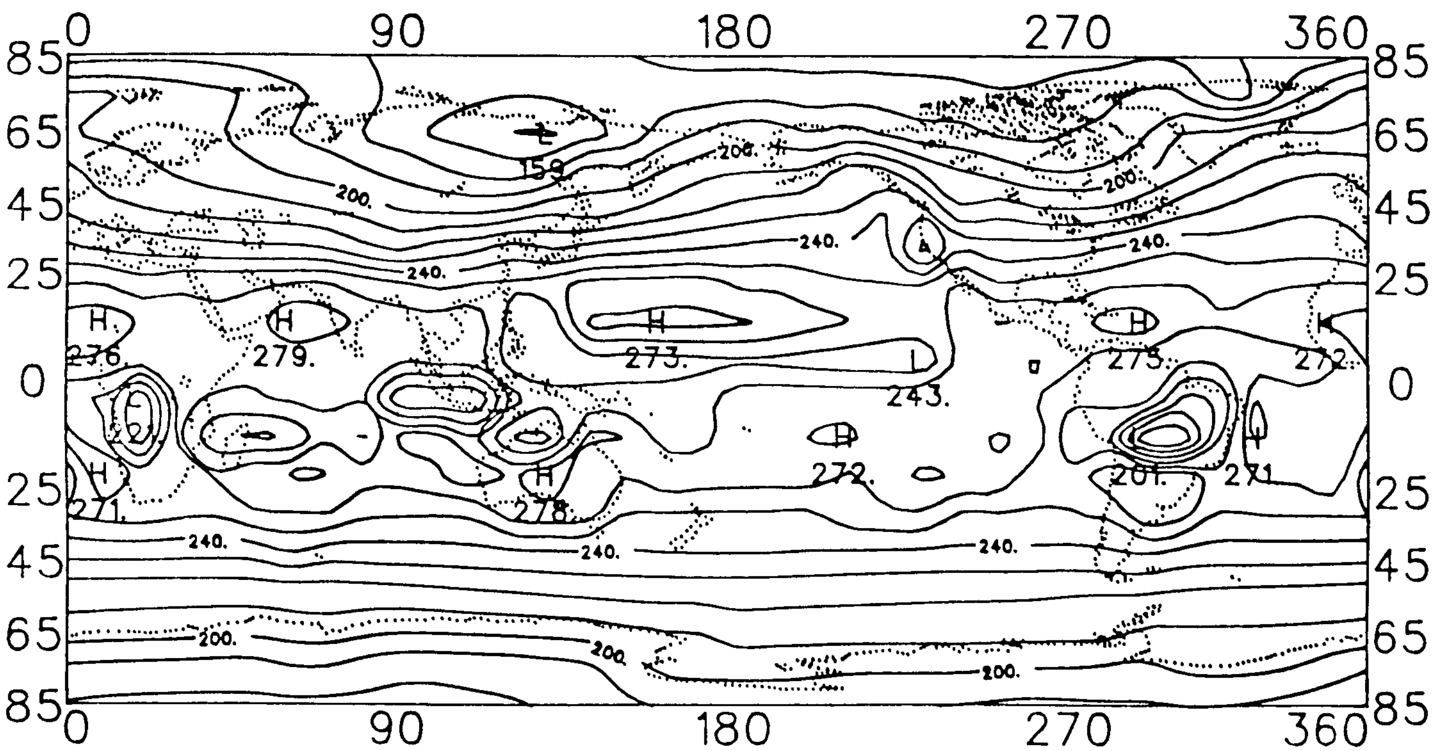

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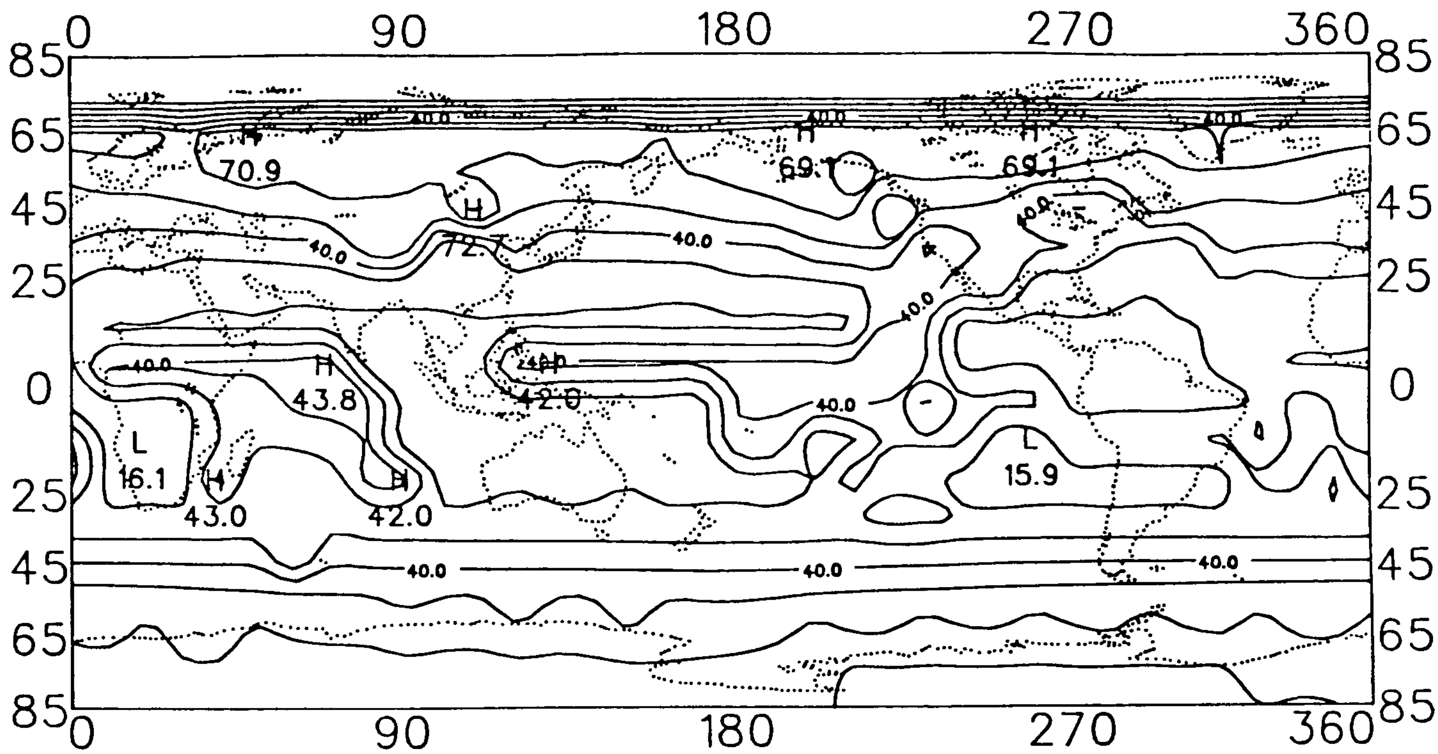

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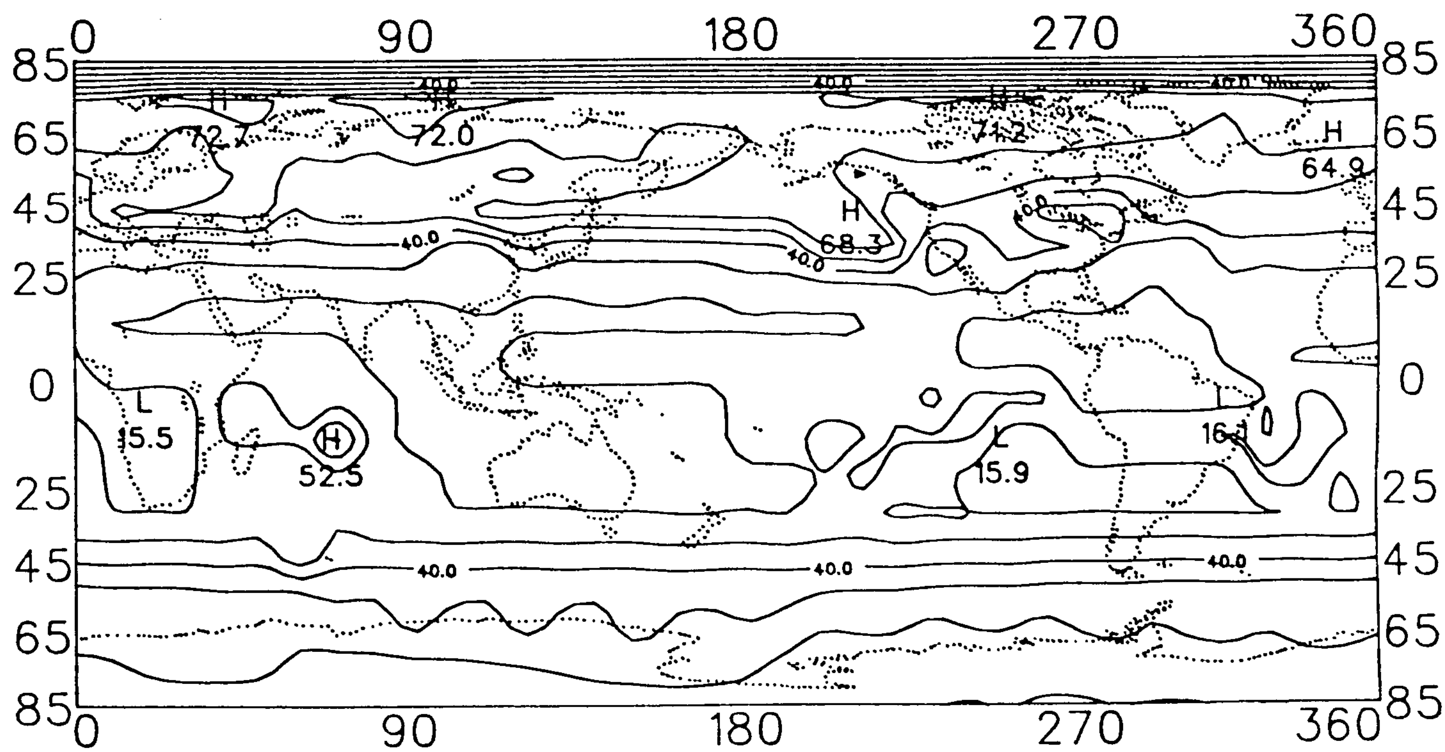

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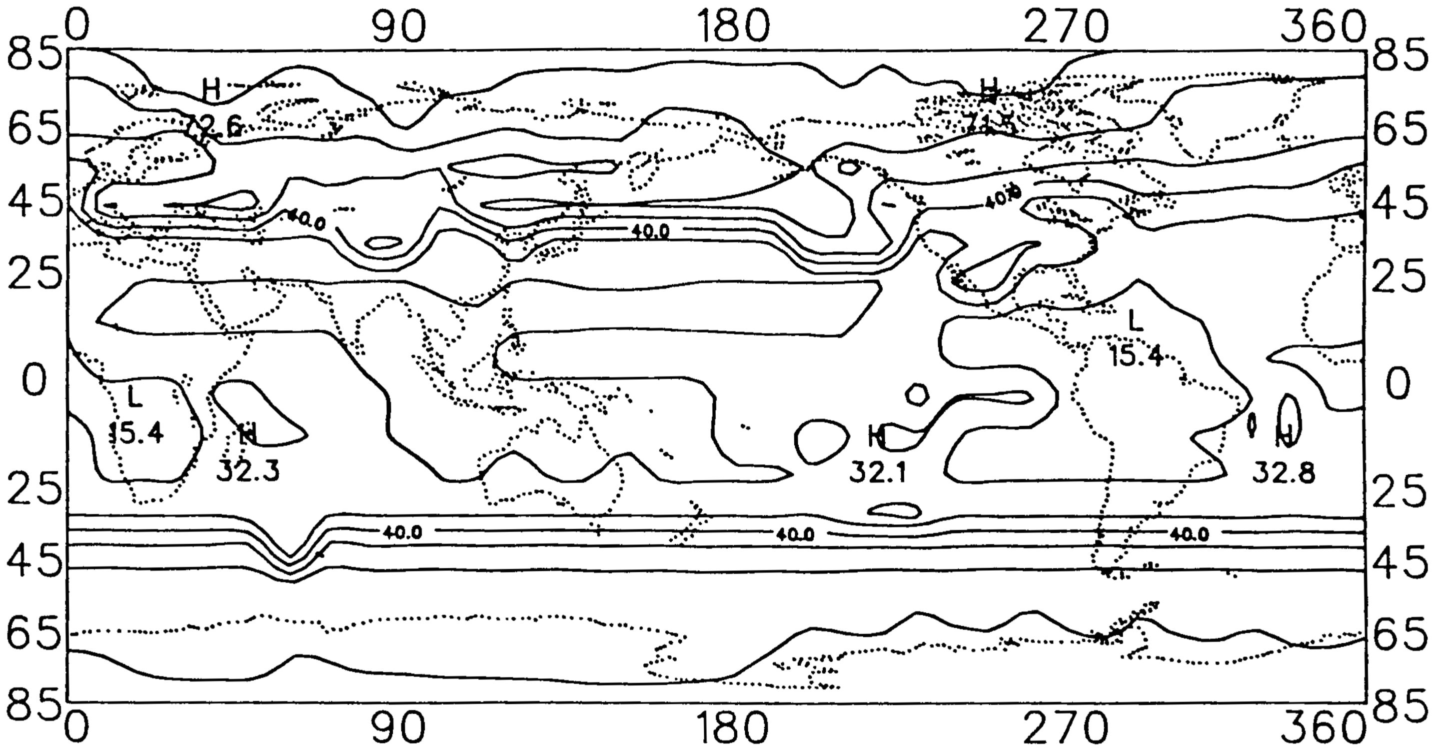

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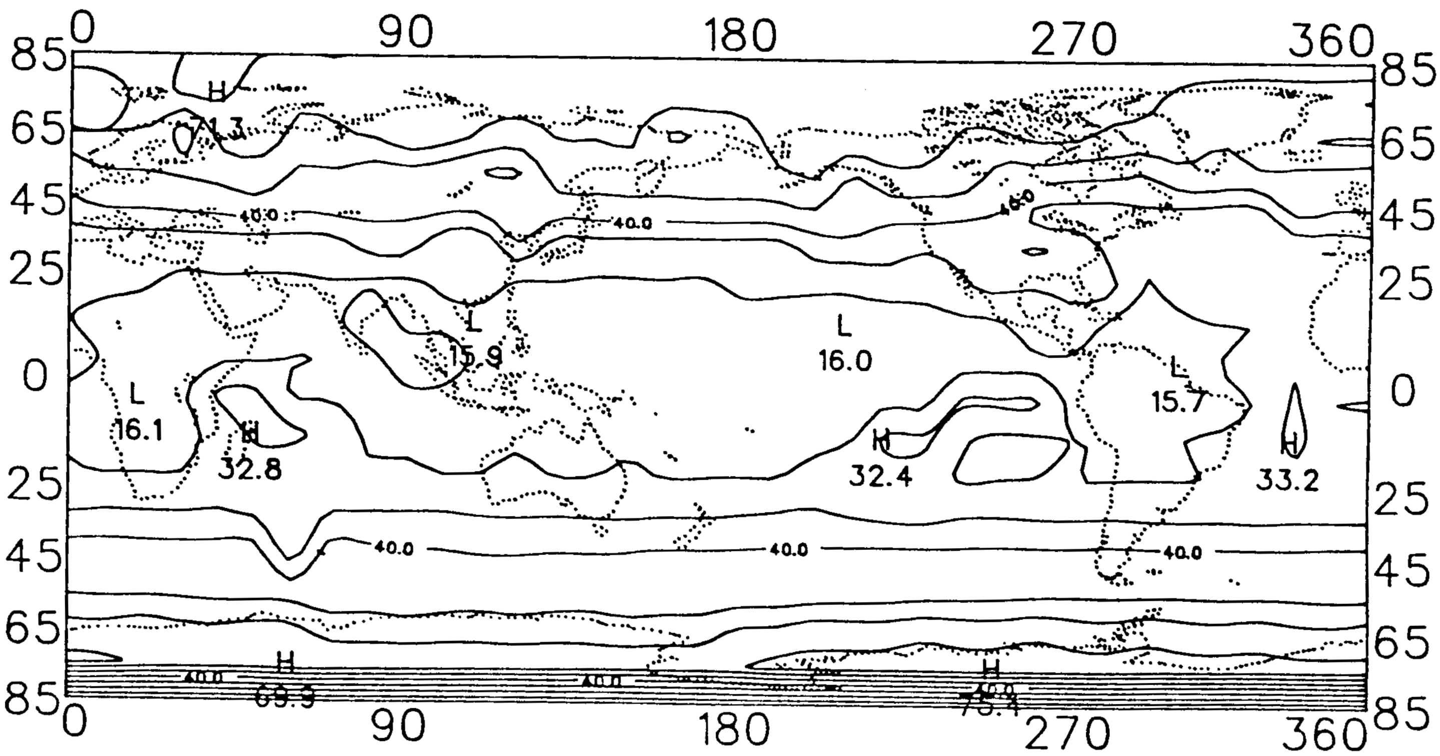

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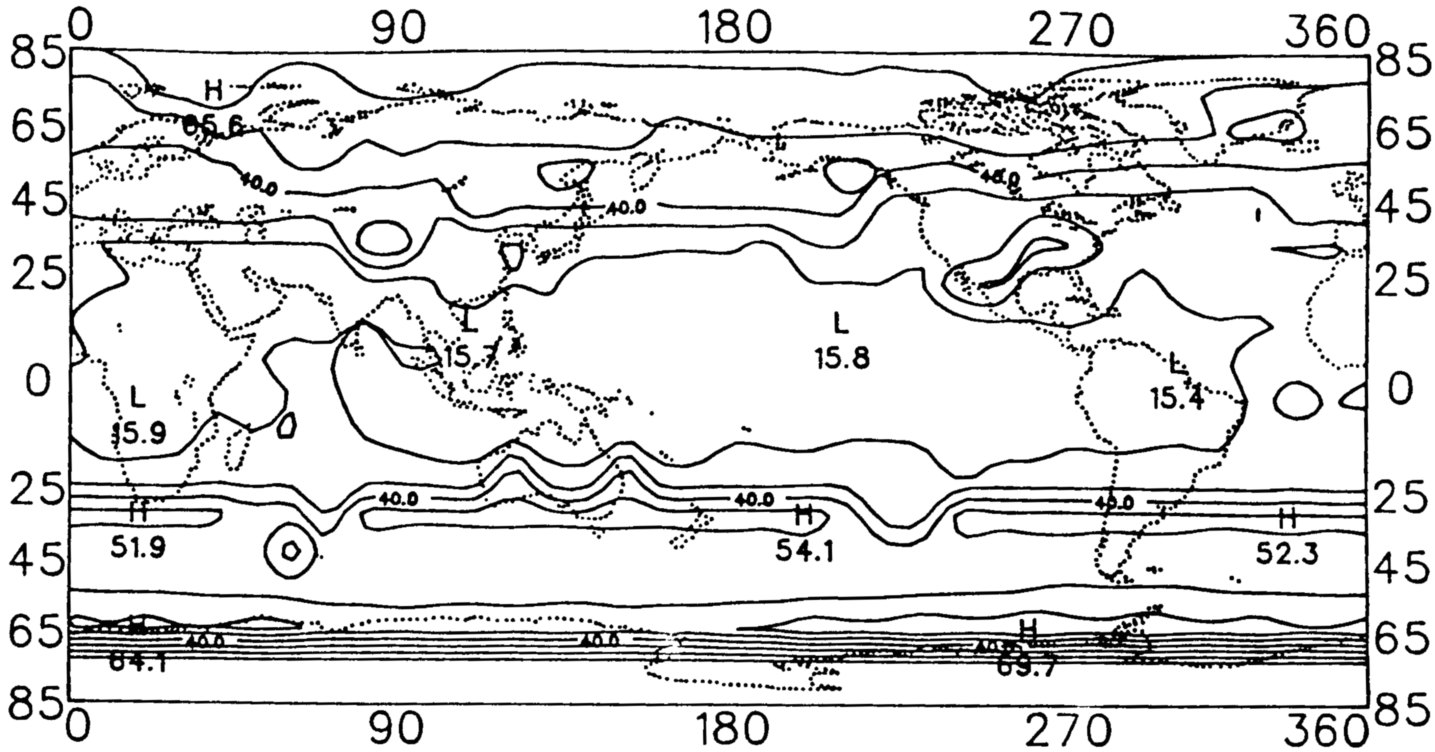

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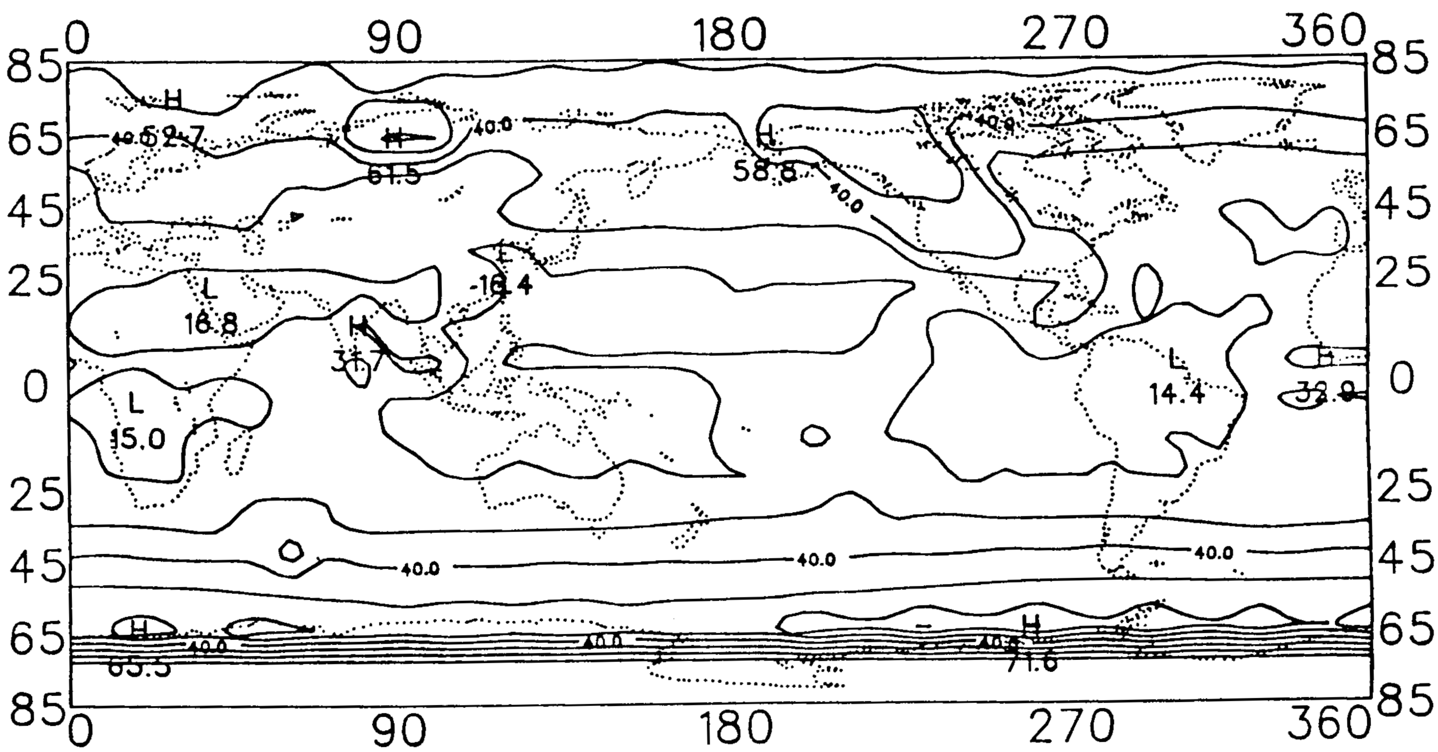

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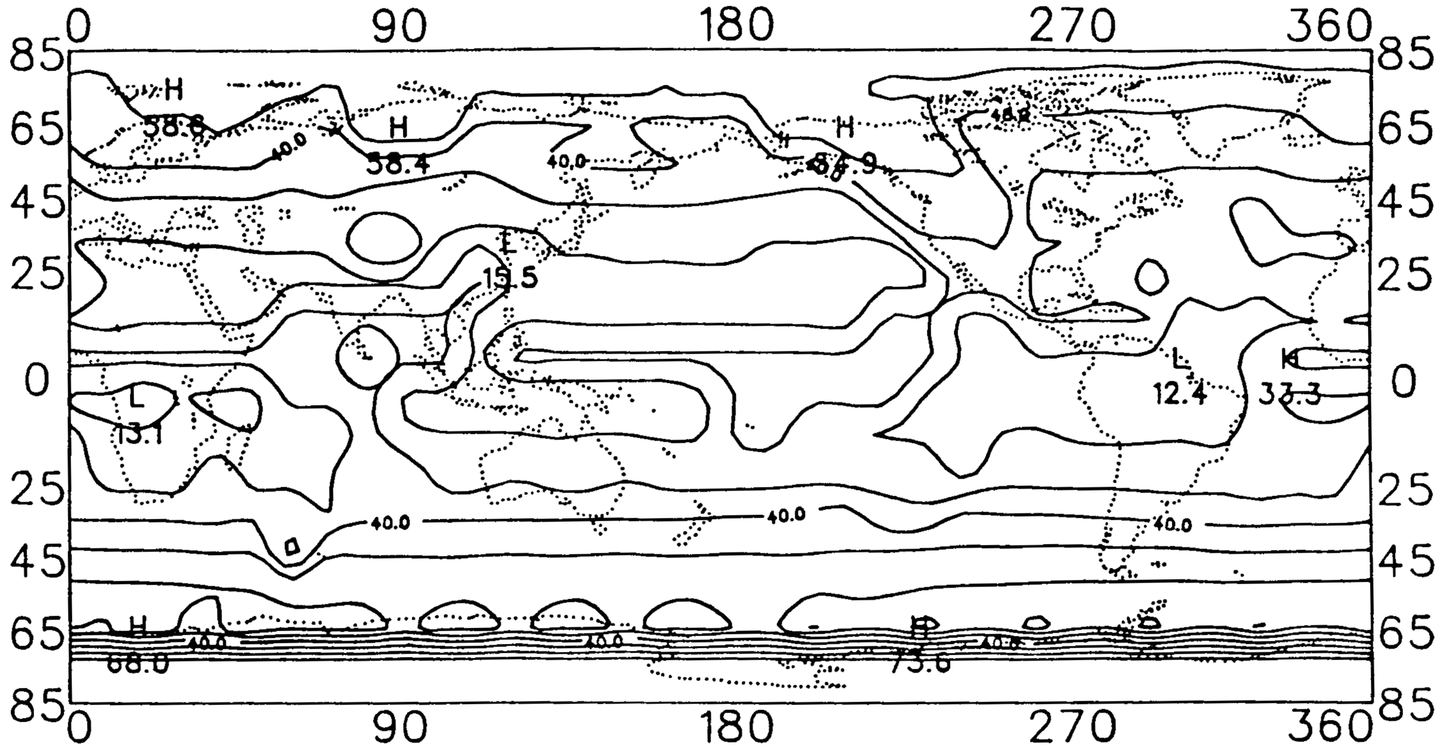

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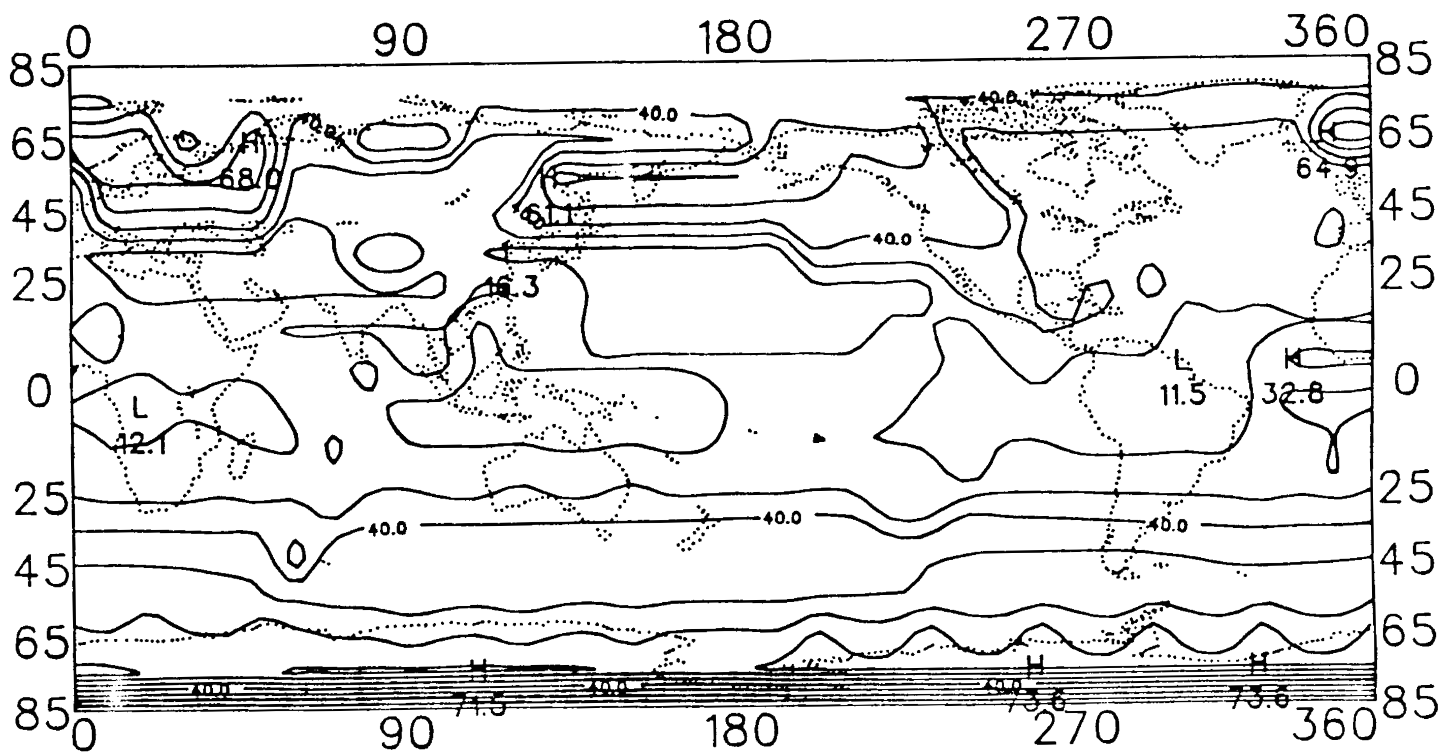

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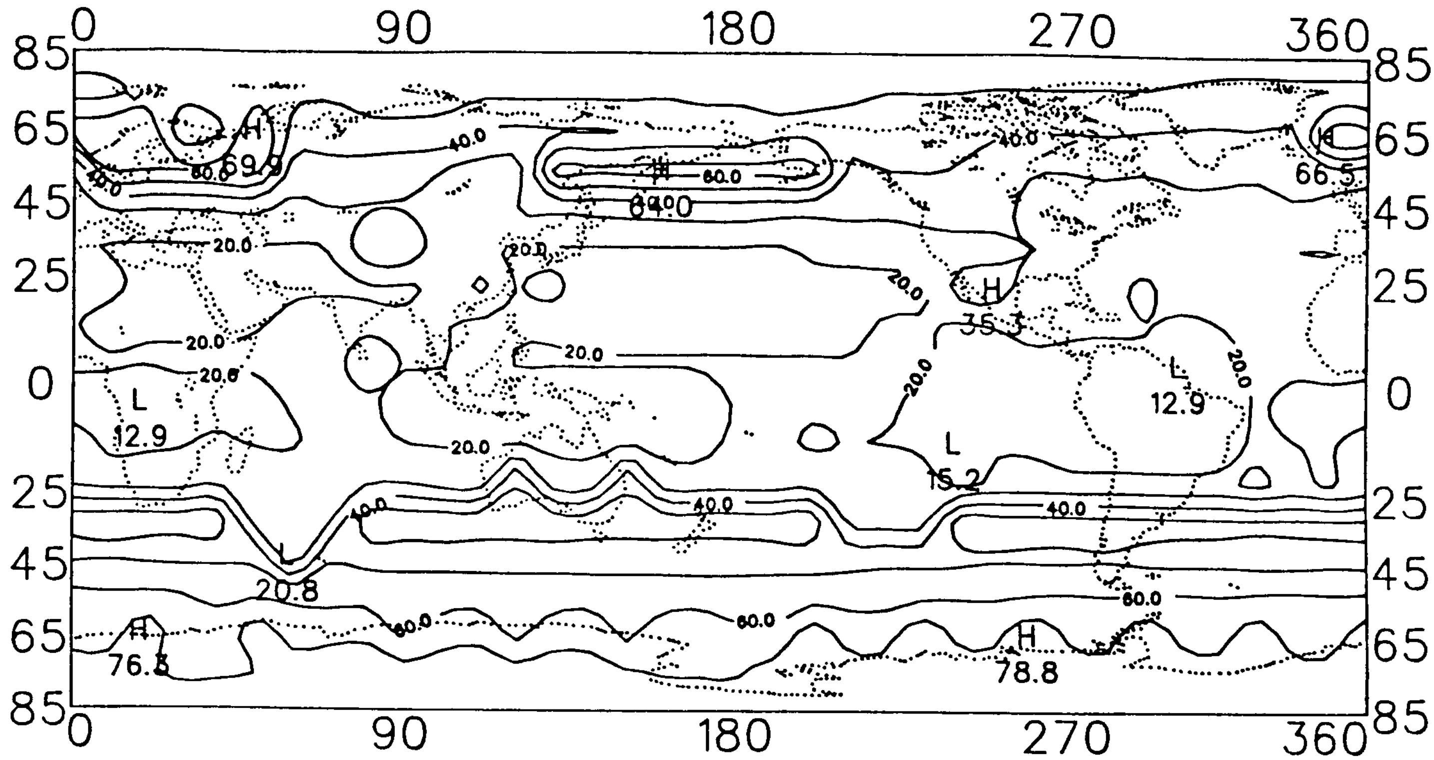
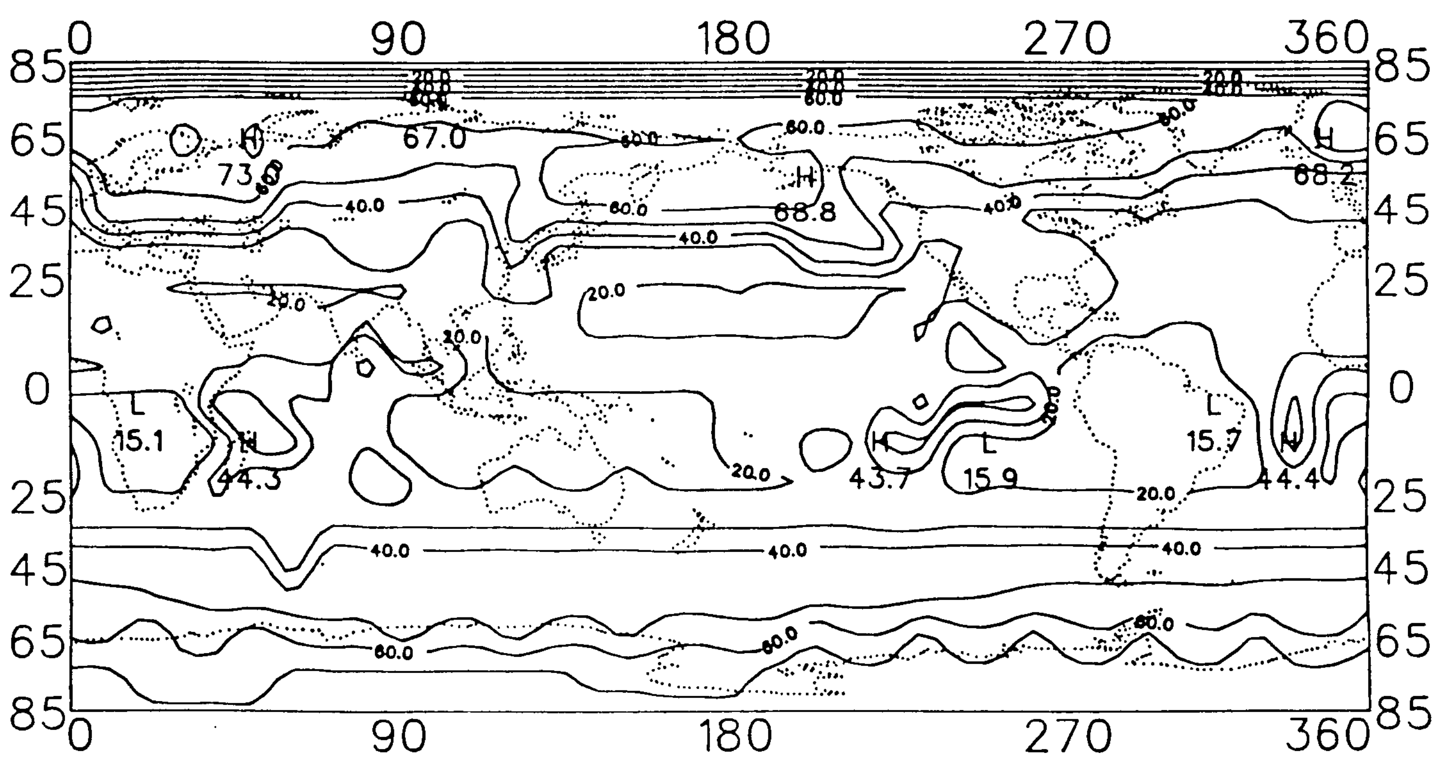


CLOUDY SKY ALBEDO SEPTEMBER (57),%



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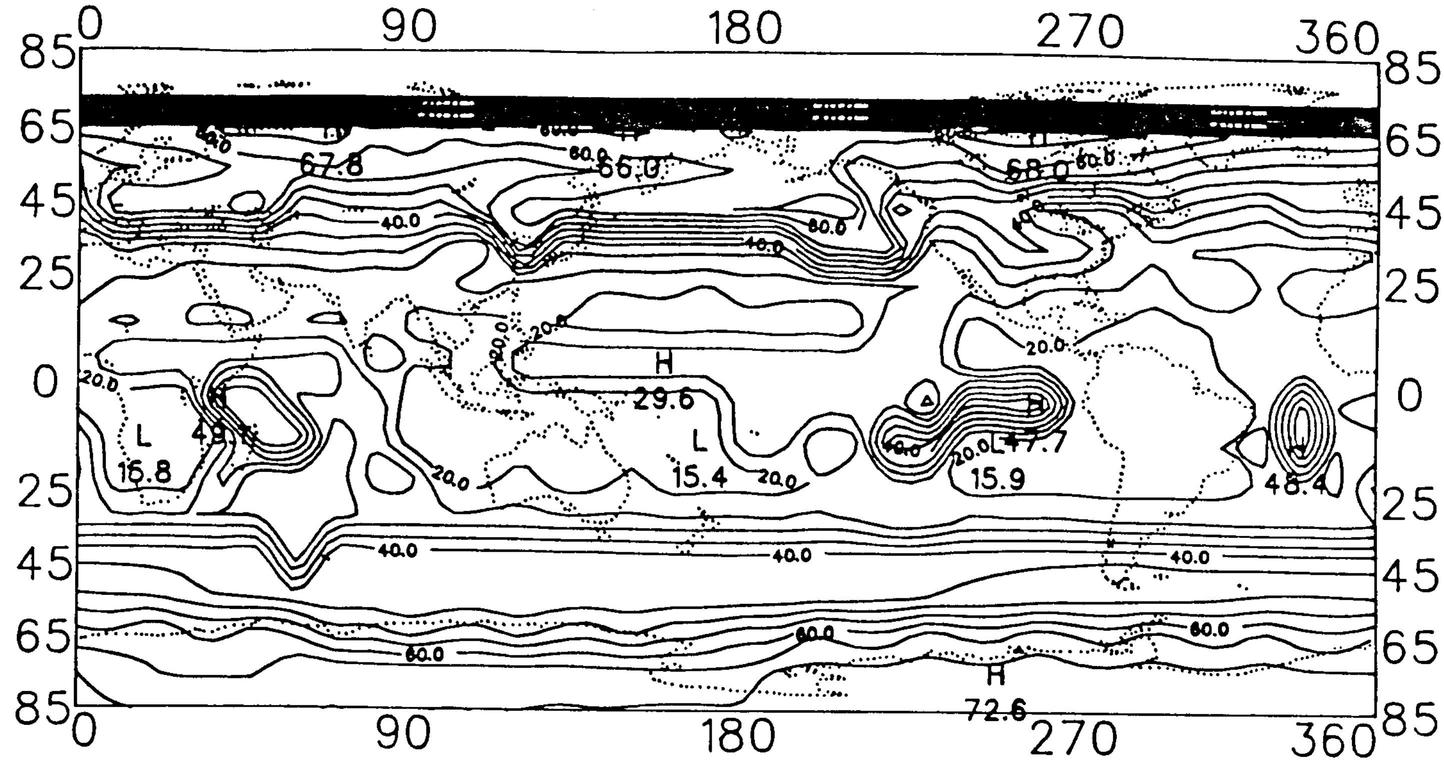

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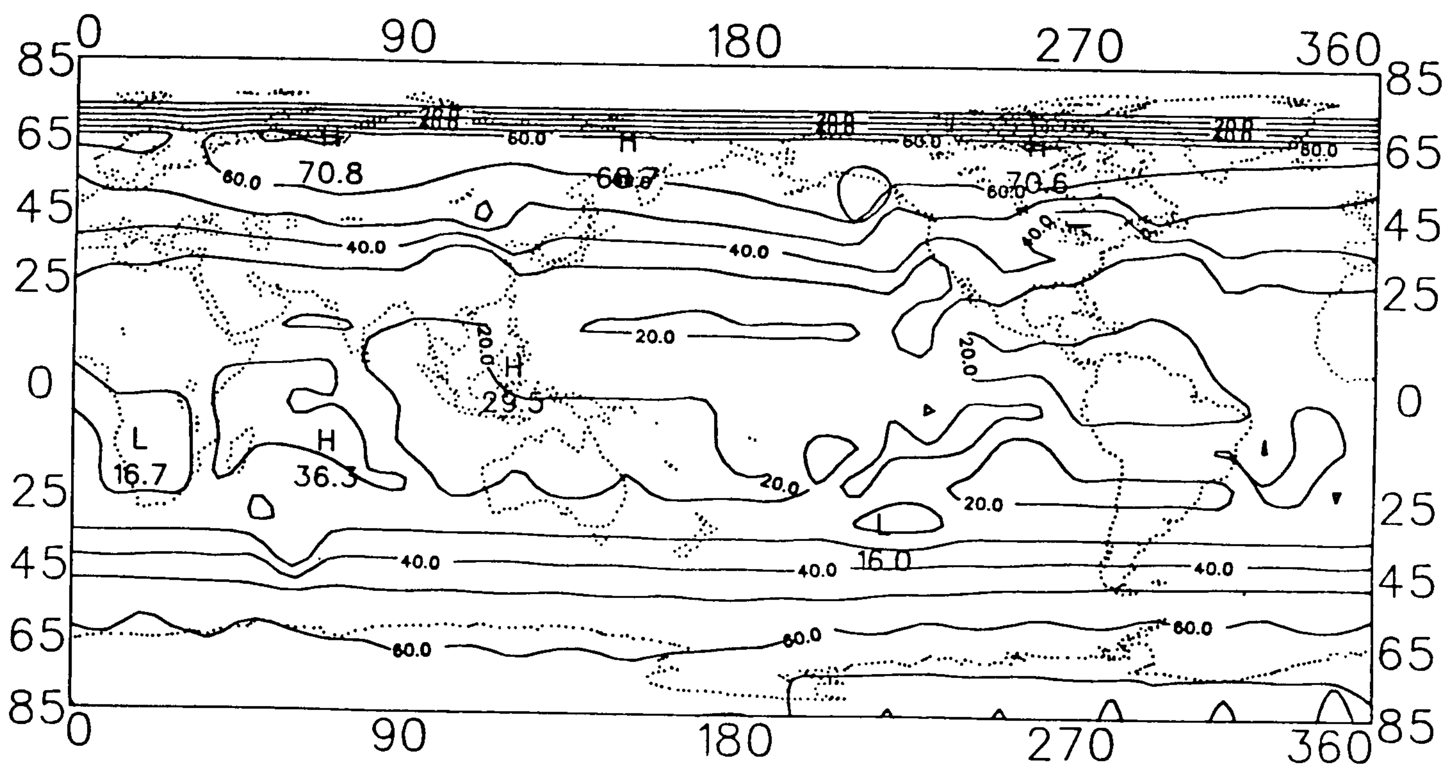

CLOUDY SKY ALBEDO DECEMBER (57),%

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