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# The Thermal Influence of Continents on a Model-Generated January Climate[1]

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N 1

## Introduction

The thermal influence of the continents on the January climate generated with the GISS coarse-mesh model (Hansen et al., 1980) has been studied by comparing two climate simulations, as described in a preliminary report by Spar (1981). Both climate computations are initialized with the same horizontally uniform state of rest. However, one (run 000) is carried out on a "water planet" (without continents), while the second (002) is repeated on a planet with geographically realistic but flat (sea level) continents. The continents in this experiment have a uniform albedo of 0.14, except where snow accumulates, a uniform roughness height of 0.3 m, and zero water storage capacity. Both runs are carried out for a "perpetual January" (solar declination fixed at January 15) consisting of 15 simulated Januaries for run 000 and 25 Januaries for run 002. For the computation of each model January climatology, the first 2 months of run 000 and the first 5 months of run 002 are discarded as transients before averaging.

As noted by Spar (1981), the model in the perpetual January mode produces excessive snow accumulation over the continents of the Northern Hemisphere, as well as a somewhat unrealistic continental snow line. However, the latter does stabilize between about 30° N and 45° N, and the model does not produce catastrophic glaciation of the Northern Hemisphere. It was, therefore, deemed feasible to estimate the thermal influence of the continents on the January climate by comparing the 13-month mean "water planet" climate with the 20-month mean "flat continents" climate.

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## Statistical tests

The continental influence is evaluated by computing the differences between the two model mean climates. However, caution must be exercised in interpreting the differences between two sample means, as Chervin and Schneider (1976), for example, have noted in the context of other general circulation model experiments. In the present experiment, the statistical significance levels of the differences between the model means are estimated from the variances of the individual monthly means through use of the "student's t-test", in a manner similar to that of Chervin and Schneider (1976).

Maps of the significance levels are plotted, with isopleths of significance level drawn for values of 0.01 (99% confidence level), 0.10, 0.20, 0.30, etc. The regions of the significance level maps darkened by isopleths may be interpreted as areas where the differences between the two model climatologies are not statistically significant (either because the differences are too small or the sample variances are too large), while the blank areas are those where the differences are statistically significant at more than the 1% level. The mean difference maps should be evaluated with the aid of the significance level maps.

Meridional cross-sections of mean differences between the two model climatologies are also employed in this study, and, to accompany these, corresponding cross-sections of significance levels are provided, with isopleths drawn for the same values as on the maps.

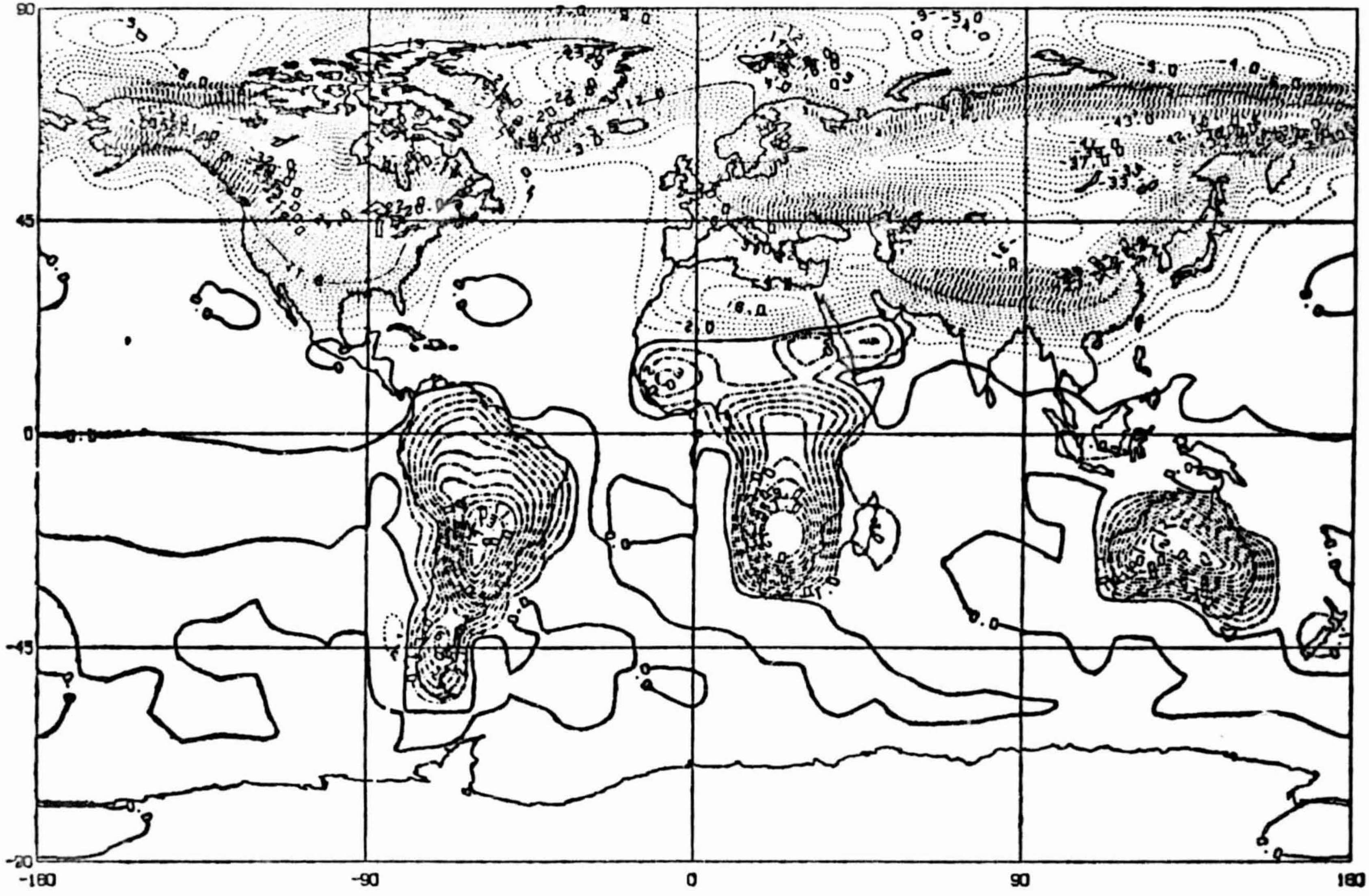
## Mean difference maps

Figures 1, 2, and 3 illustrate the direct thermal influence of the continents on (1) the surface air temperature, (2) the mean temperature of the layer 1000-850 mb, and (3) the mean temperature of the layer 850-700 mb. In each case, Figure (a) shows the mean difference, in °C, between the two mean January temperatures, while Figure (b) displays the significance levels of the differences between the means. Dashed lines indicate positive differences (warm continents) while dotted lines indicate negative differences (cold continents).

At all three levels, the temperatures over the continents are seen to be significantly higher in the tropics and in the Southern (summer) Hemisphere and lower in extratropical latitudes of the Northern (winter) Hemisphere than on the water planet, while over the oceans the temperature differences are generally small and not statistically significant. The magnitude of the continental thermal influence decreases with increasing height, more markedly over the cold continents than over the warm continents. The magnitude of the temperature effect is about the same over all three warm land masses in the Southern Hemisphere. However, in the Northern Hemisphere, the great Eurasian land mass is much colder than North America, and its effect extends higher into the atmosphere.

The influence of the continents on the mean January mass distribution is illustrated in Figures 4, 5, and 6, showing (a) the differences between the two mean sea-level pressure, 700 mb height, and 500 mb height fields, respectively, and (b) the significance levels of the mean differences, for the flat continents and water planet runs. Again dashed lines are used for positive differences (run 002 greater than run 000) and dotted lines for negative differences.

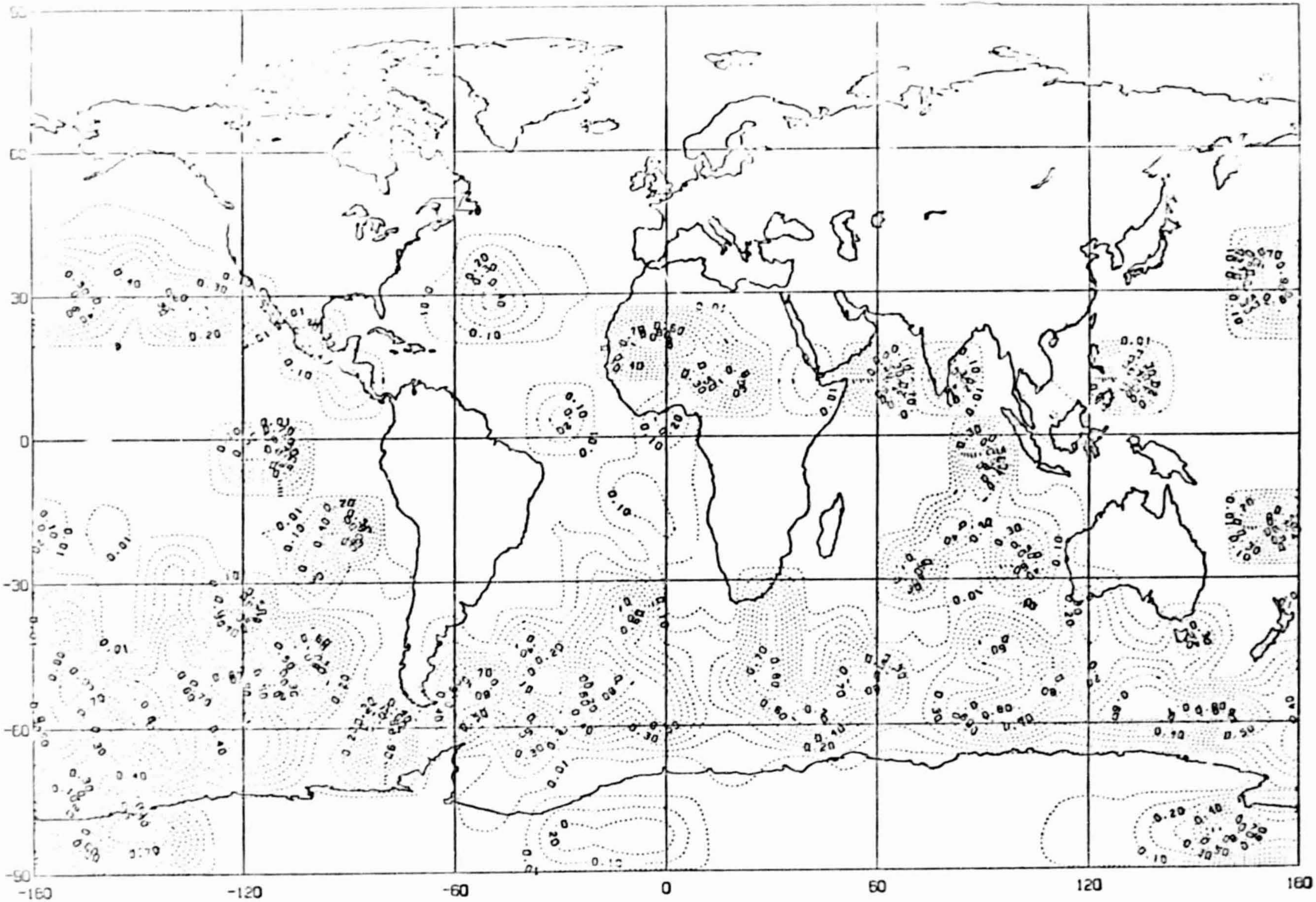
Over the continents, the sea level pressures (Fig. 4a) generally reflect the influence of the surface temperatures, with high pressure



*MEAN SURFACE AIR TEMPERATURE (IN DEGREES CENTIGRADE)*

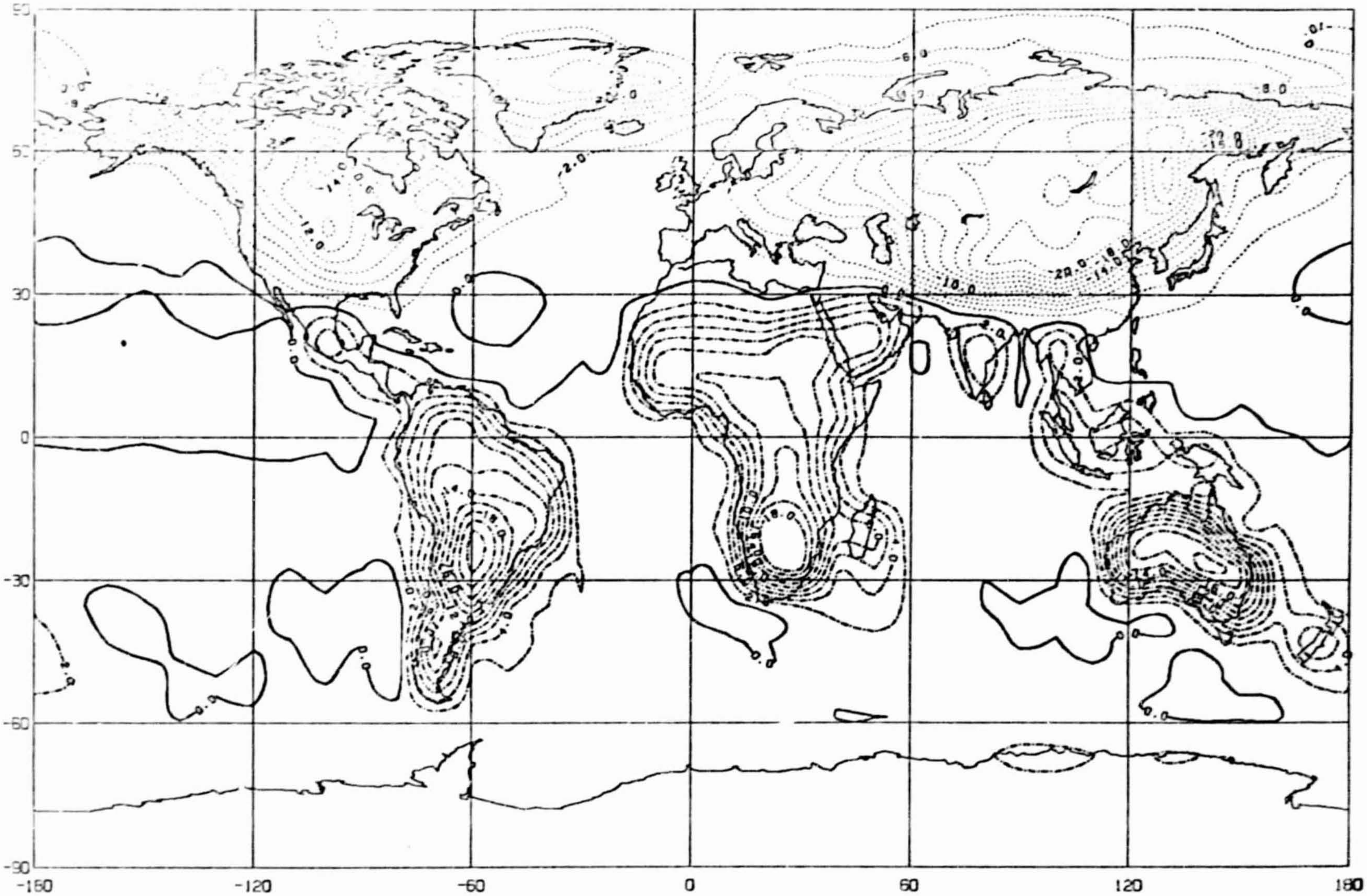
*The mean Difference for RUN002-RUN000*

Fig. 1a



SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: SFC.TEMP. RUNS 0 & 2

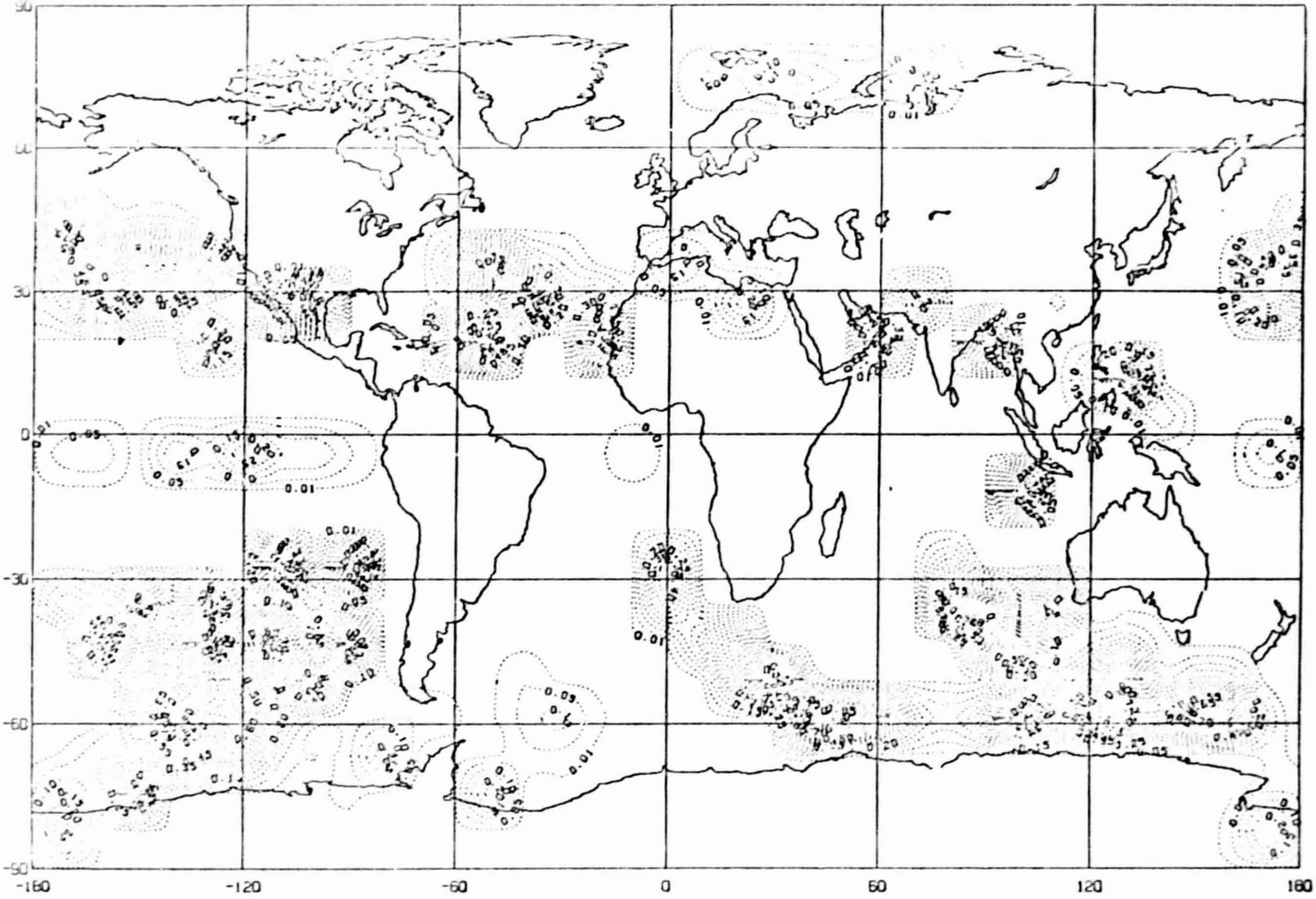
Fig. 1b



*Mean Thickness Temperature from 1000mb to 850mb in Kelvin*

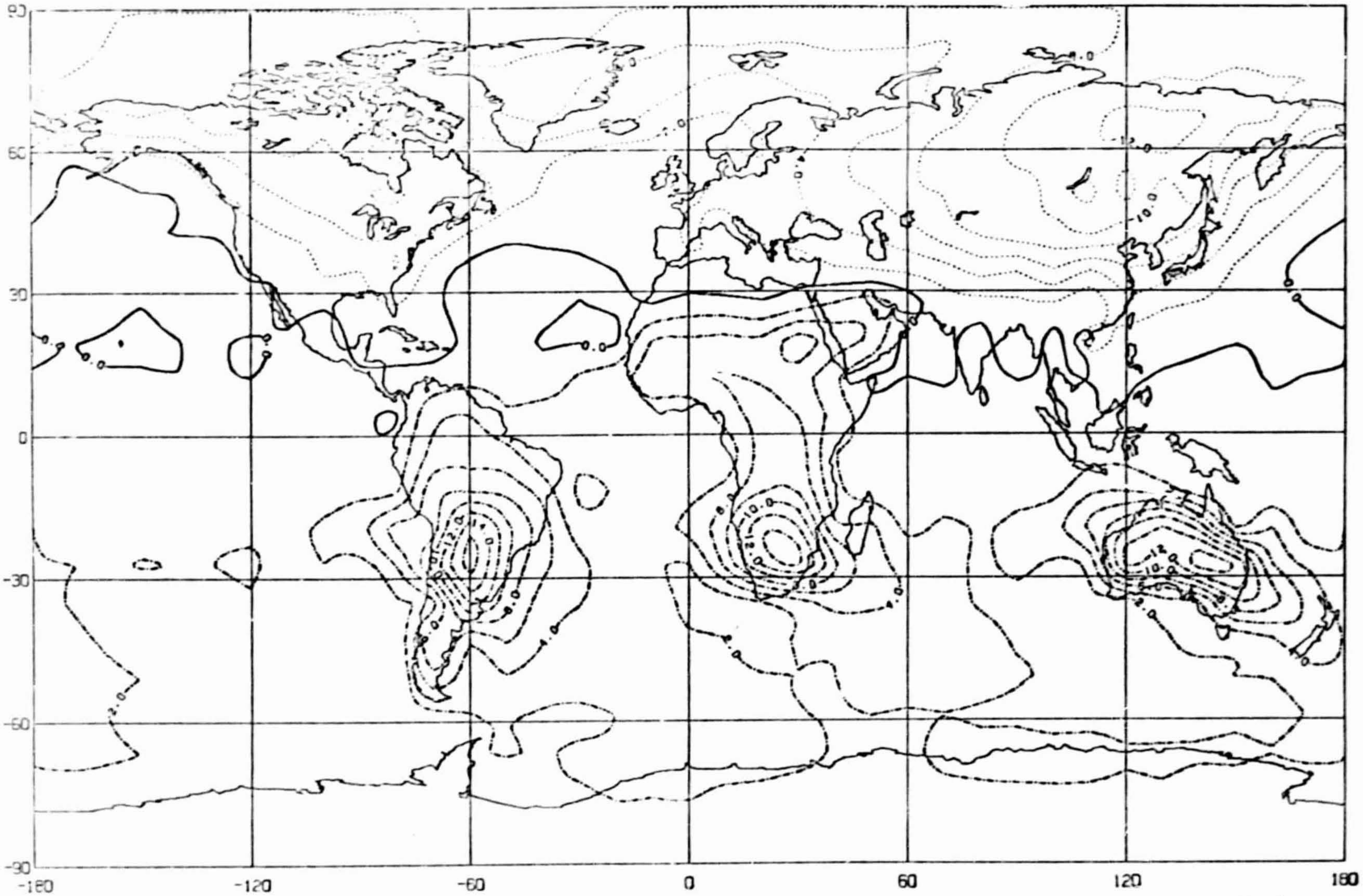
*The mean Difference for RUN002-RUN000*

Fig. 2a



SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: T1000/850.RUNS 0 & 2

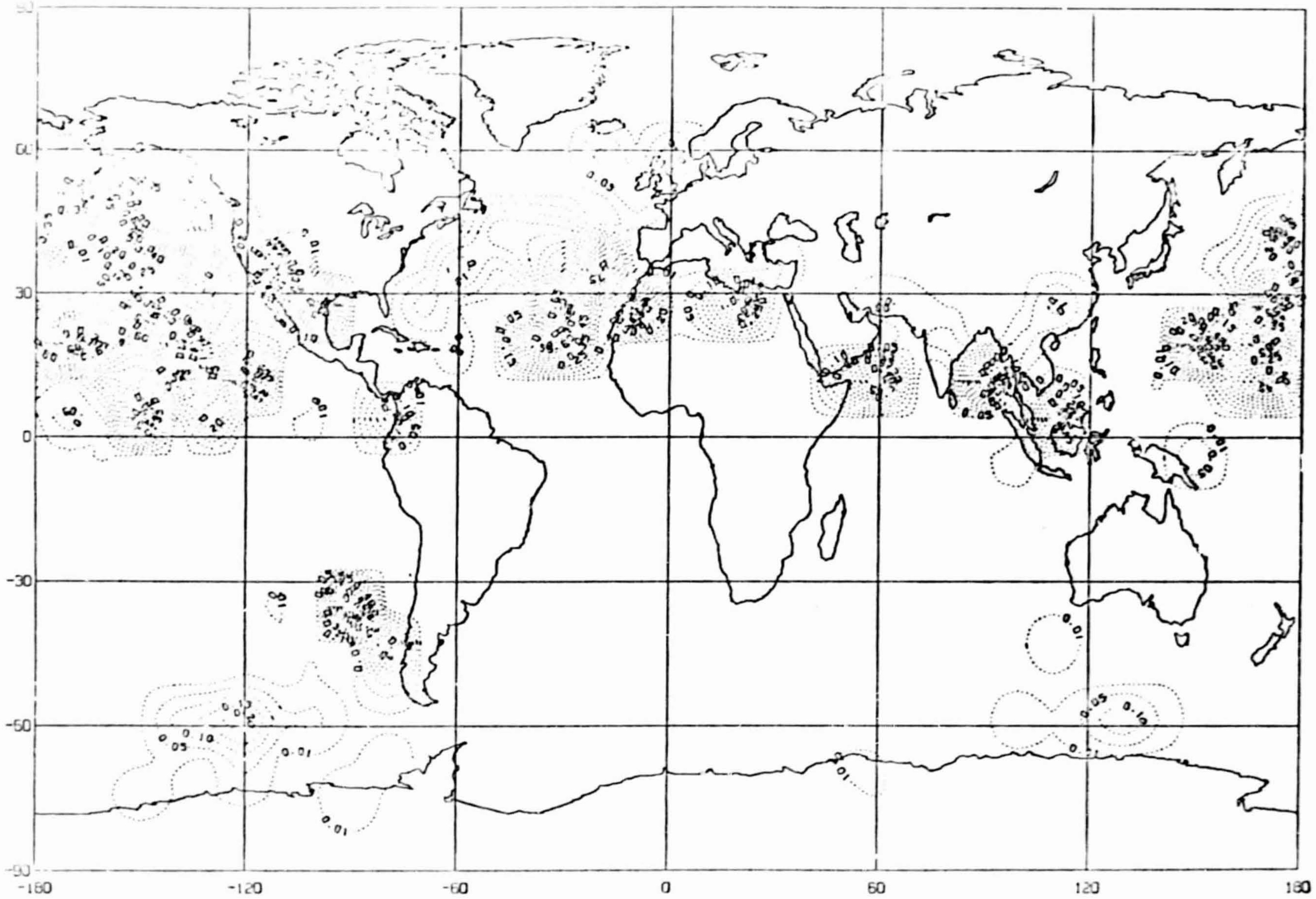
Fig. 2b



*Mean Thickness Temperature from 850mb to 700mb degrees (K)*

*The mean Difference for RUN002-RUN000*

Fig. 3a



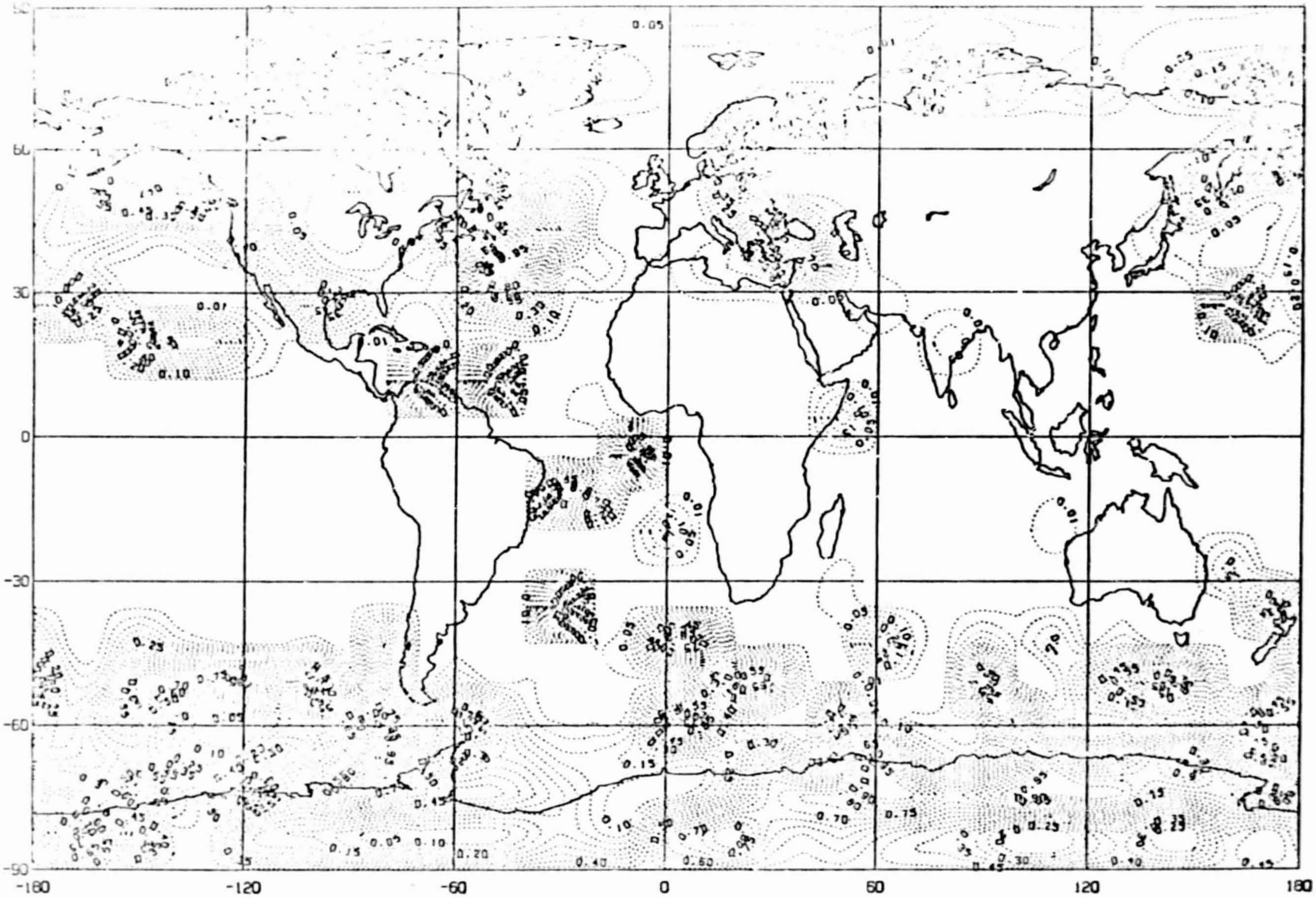
SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: T850/700.RUNS 0 & 2

Fig. 3b

*Sea level pressure in (millibars)*

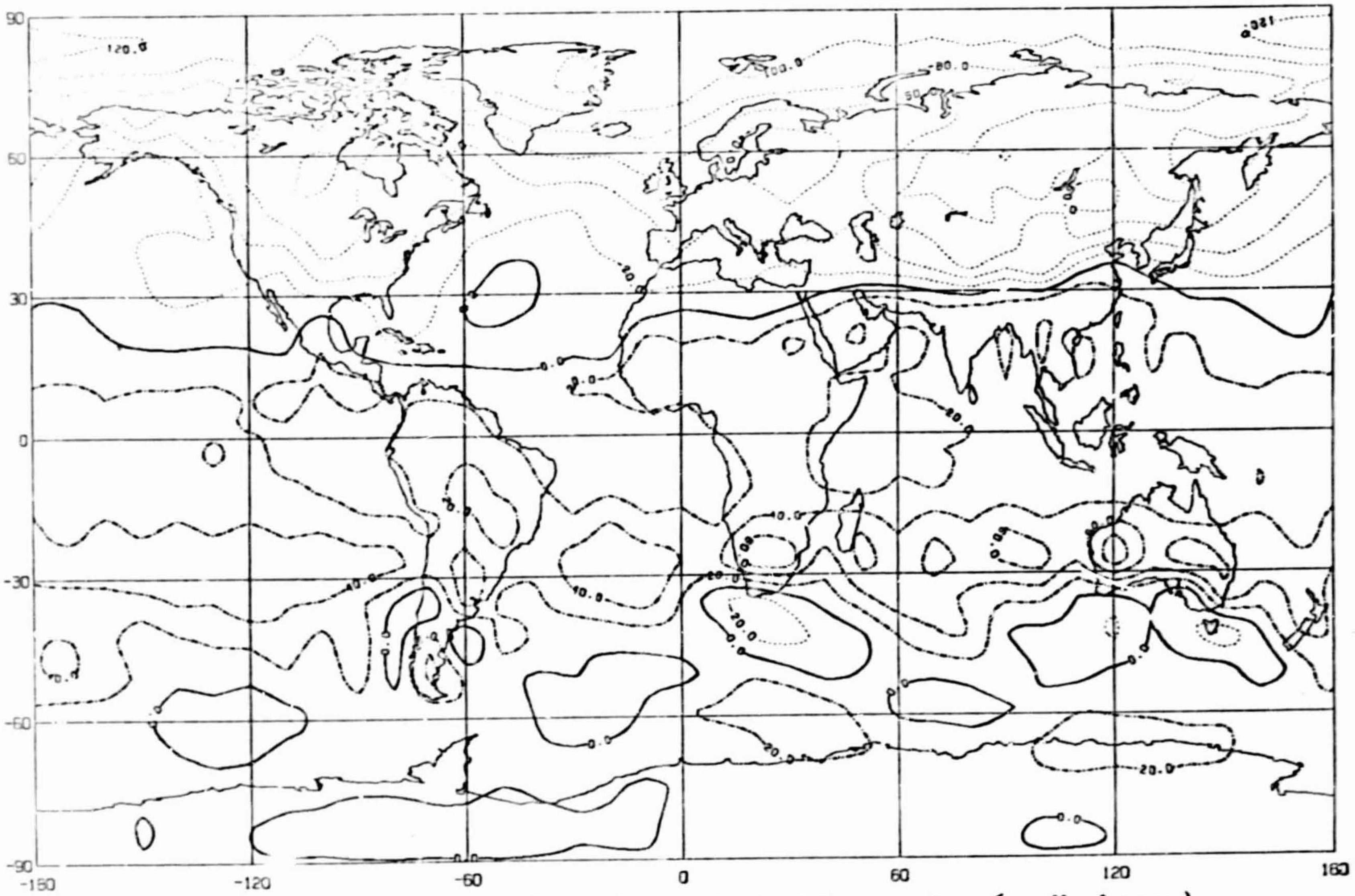
*The mean Difference for RUN002-RUN000*

Fig. 4a



SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: SLP, RUNS 0 & 2

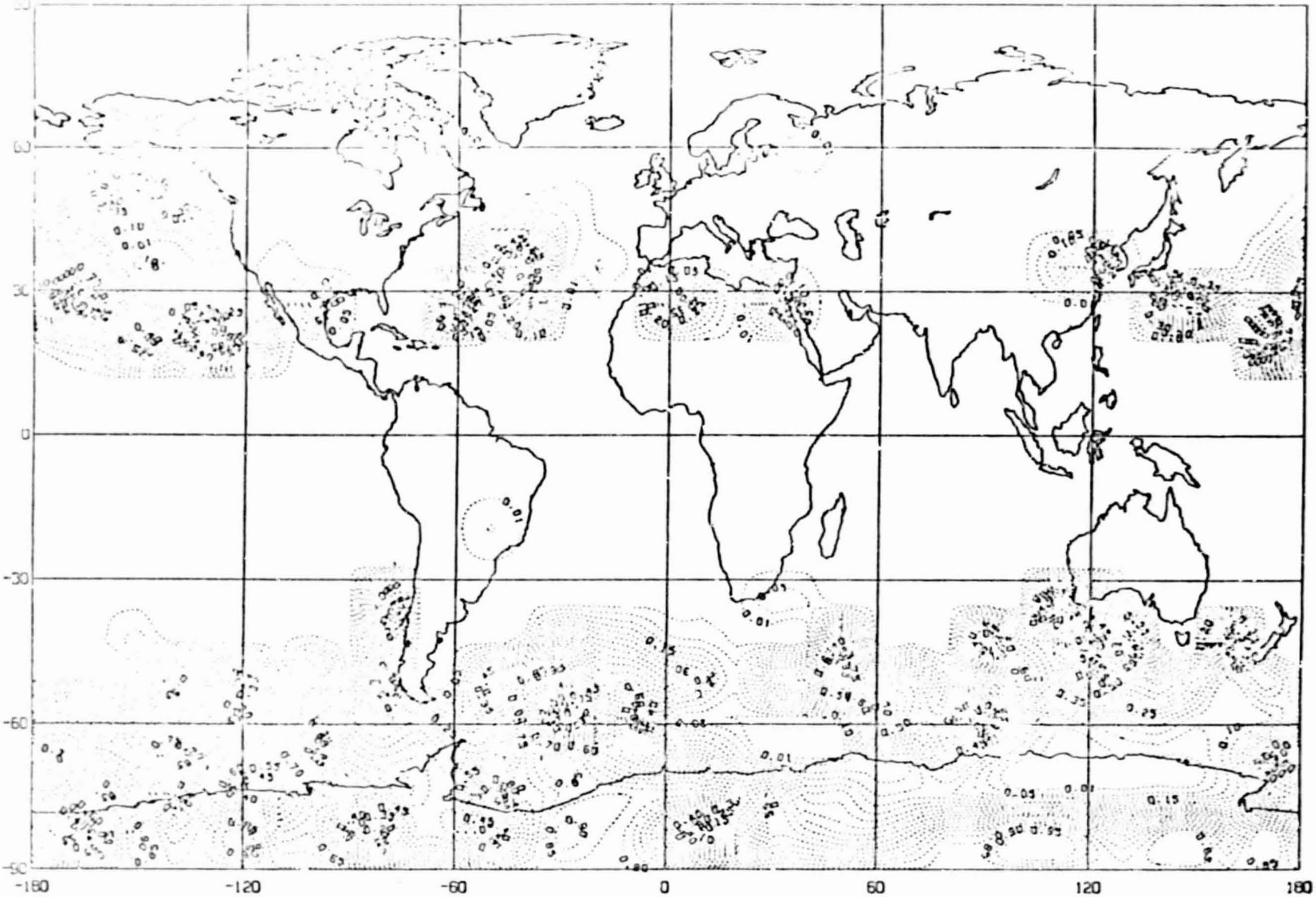
Fig. 4b



700 Millibar Geopotential Height in ( Meters)

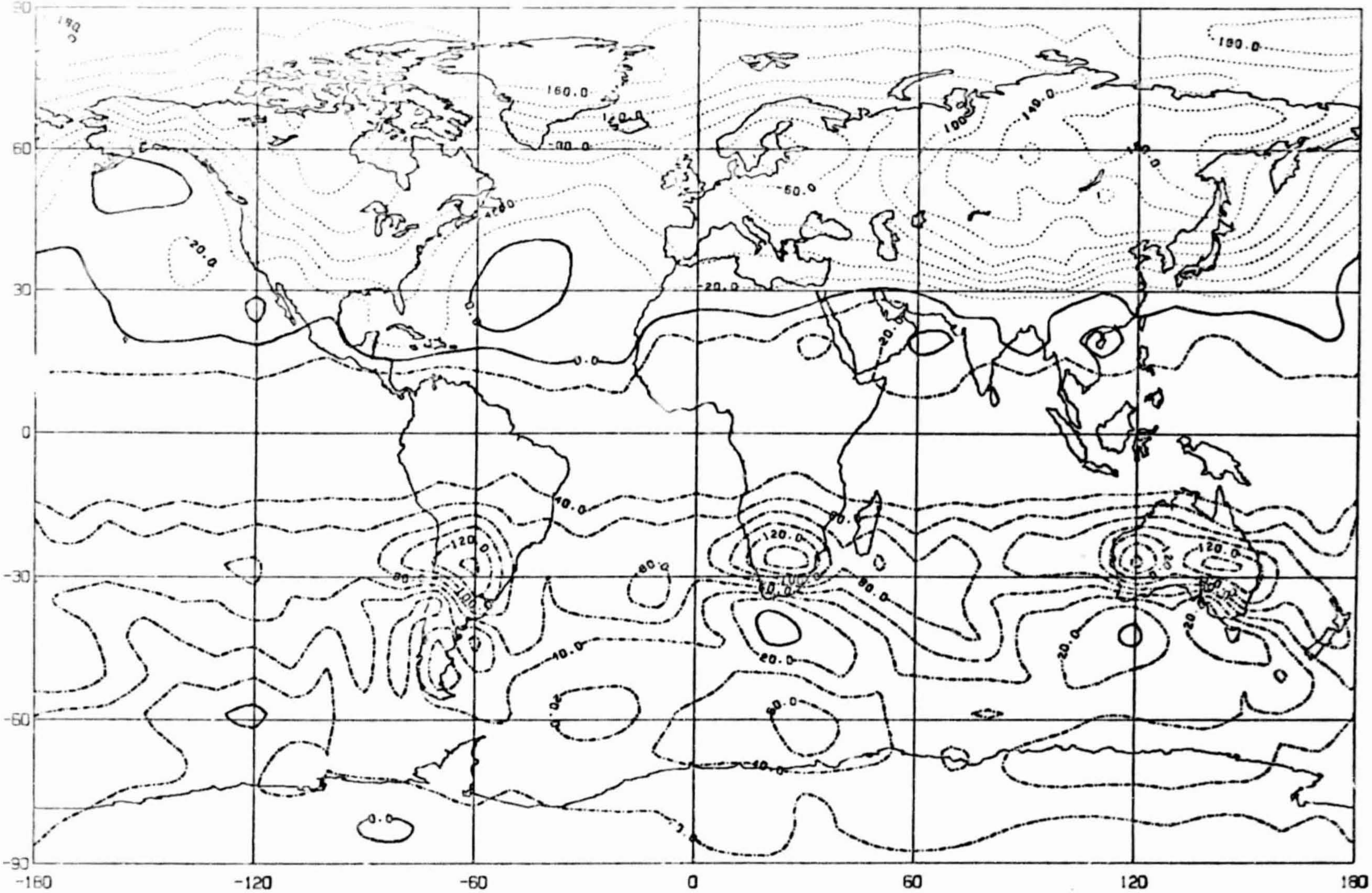
The mean Difference for RUN002-RUN000

Fig. 5a



SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: Z700, RUNS 0 & 2

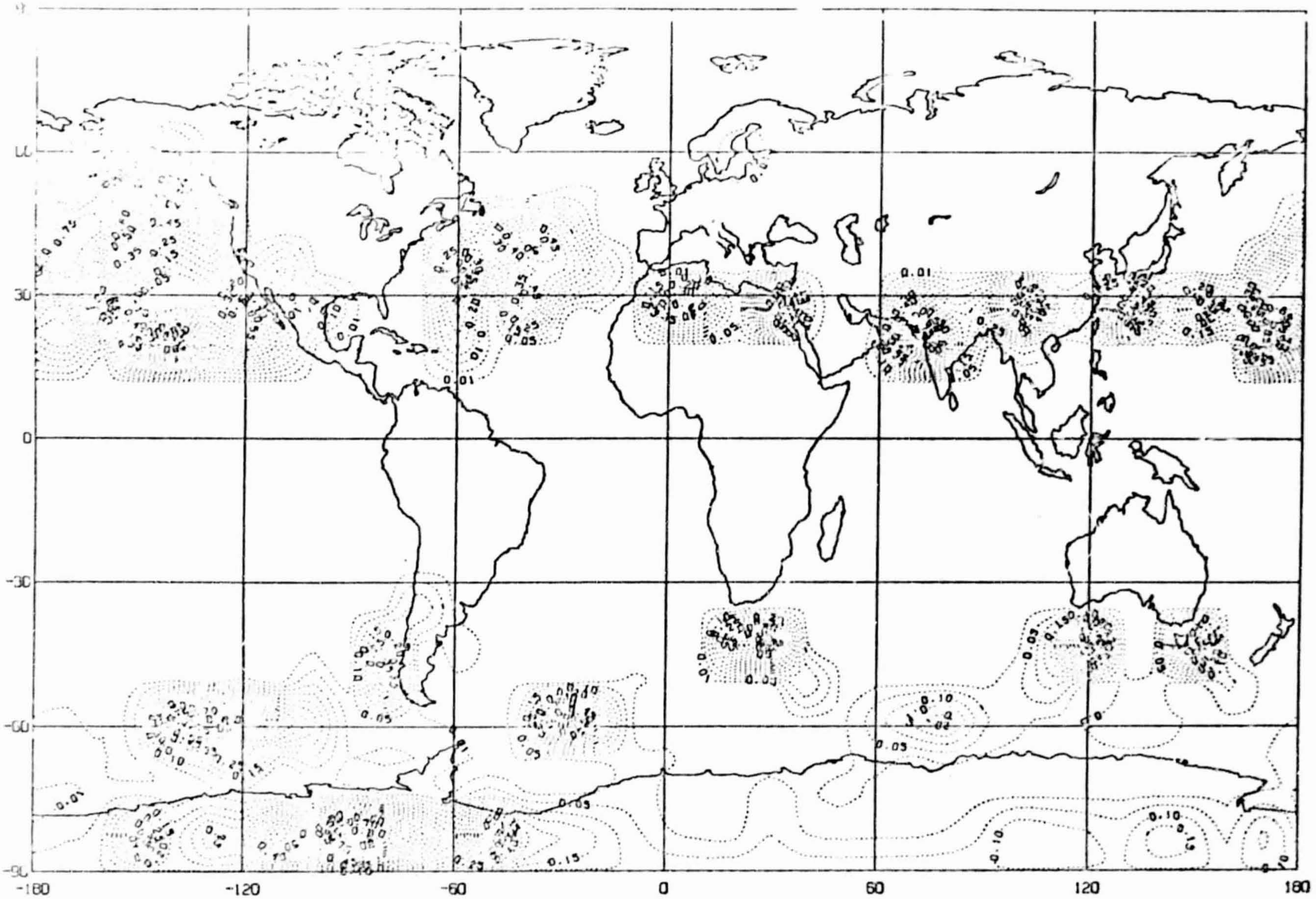
Fig 5a



500 Millibar Geopotential Height (in Meters)

The mean Difference for RUN002-RUN000

Fig. 6a



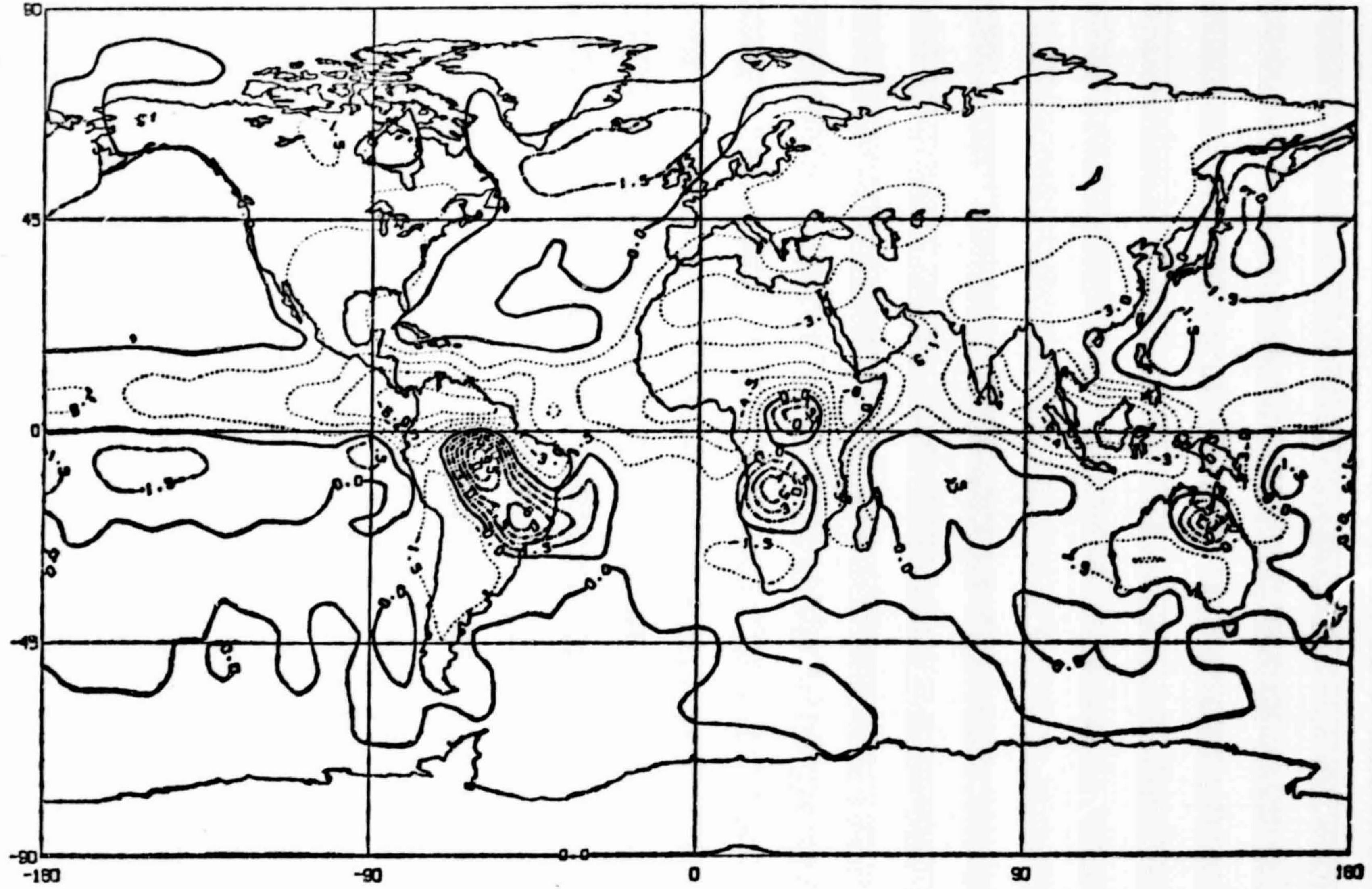
SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: Z500, RUNS 0 & 2

Fig. 6b

over cold land and low pressure over warm land. However, this continental effect is weakest and least significant (Fig. 4b) over North America. The mass excesses over the cold continents and mass deficits over the warm continents are associated with mass deficits and excesses, respectively, over the adjacent subtropical oceans, notably in the eastern North Pacific and the Southern Hemisphere, indicating a mass exchange between the cold (warm) continents and the relatively warm (cold) adjacent ocean areas. In addition, significantly lower pressures are found in the regions of the Norwegian Sea and the Aleutian Islands in run 002 than in 000, again indicating a monsoonal mass exchange between the cold continents and the relatively warm oceans.

The hydrostatic effects of the cold and warm continents on the geopotential heights of the 700 mb and 500 mb isobaric surfaces appear clearly in Figures 5 and 6, respectively, where the surfaces are elevated over warm land and depressed over cold land, producing stronger subtropical westerlies in both hemispheres in the flat continents model than on the water planet. In both hemispheres the continents generate significant but small amplitude waves in the contours of the mid-tropospheric (700 and 500 mb) isobaric surfaces.

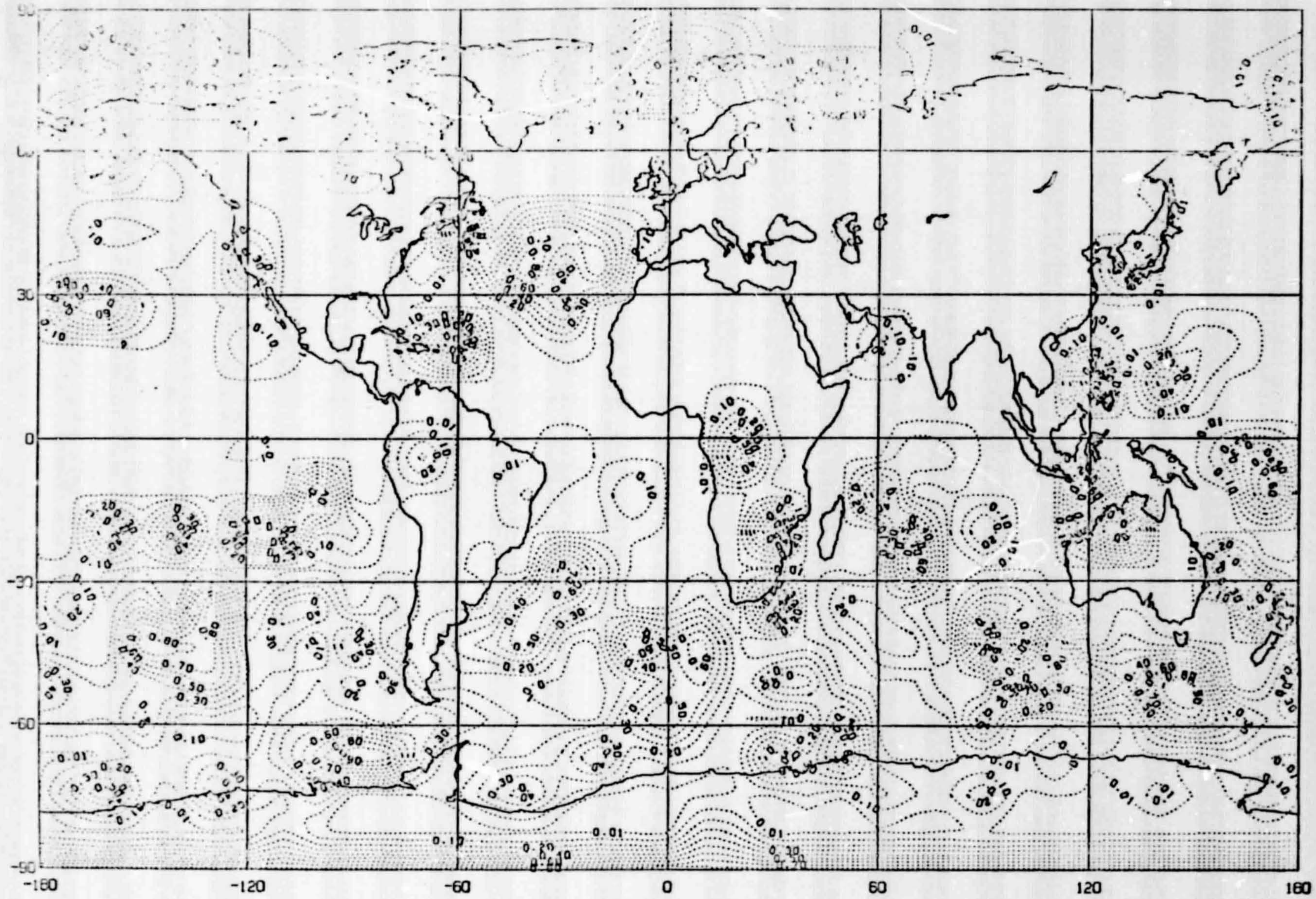
The effect of the flat, dry continents on the mean daily precipitation, illustrated in Figure 7 (in mm day$^{-1}$), is clearly not a simple function of the temperature. Although the main regions of increased rainfall (dashed difference isohyets) are found over the warm continents in the tropics and Southern Hemisphere, and areas of decreased precipitation (dotted isohyets) do appear over the cold continents of the Northern Hemisphere, significant areas of reduced rainfall are also found in the tropics, both over land and ocean, while enhanced precipitation appears over the North Atlantic and Northwest Pacific. The influence of the continents is thus not merely one of either suppressing or augmenting convection through the static stability, but a more complex dynamical effect



PRECIPITATION IN (MM/DAY)

The mean Difference for RUN002-RUN000

Fig. 7a



SIGNIFICANCE LEVELS OF DIFFERENCE OF MEANS: PRECIP. RUNS 0 & 2

Fig. 7b

operating through the wind field on the large scale divergence, vertical motion, and moisture transport. Particularly noteworthy are the (unrealistic) dry zone north (rather than south) of the Equator in the eastern Pacific Ocean, which extends over South America in the flat continents model. More realistic features are the dry Horn of east Africa (Somalia) and the relatively dry Sahara. In the equatorial Atlantic and Pacific Ocean regions, the continents appear to "rob" precipitation from the wet oceanic bands at $5^{\circ}$ N (see Dorman and Bourke, 1979, 1981), which are more realistically simulated by the water planet model than by the flat continents model (Spar, 1981).

## Spherical harmonic analysis

Further insight into the quantitative synoptic effects of the continents on the model-generated climatology may be gained through the use of spherical harmonic analysis (Christidis and Spar, 1981). Amplitudes (A) and phase angles (b) are shown in Tables 1-3 for the ten leading spherical harmonics of degree n and order m for runs 000 and 002 for three fields: mean temperature of the layer 1000-850 mb, sea-level pressure, and 500 mb geopotential height. The longitudinal wave number is m, while n-m denotes the number of nodal parallels of the harmonic function. Zonally symmetric harmonics are those for which $m = 0$. The water planet, of course, exhibits a high degree of zonal symmetry.

From Table 1 it is seen that the two zonally symmetric components, representing the temperature differences between the poles and Equator (2,0) and between the hemispheres (1,0) are dominant in both the water planet and flat continents model, and indeed are of even larger amplitude in the

**Table 1. Amplitudes (A) and phase angles (b) of the first ten spherical harmonics of the temperature (°C) of the layer 1000-850 mb, for runs 000 ("water planet") and 002 (flat continents").**

| | 000 | | | 002 | |
|---|---|---|---|---|---|
| n,m | A(°C) | b(°) | n,m | A(°C) | b(°) |
| 2,0 | 35.6 | 180 | 2,0 | 46.0 | 180 |
| 1,0 | 6.0 | 180 | 1,0 | 17.7 | 180 |
| 7,0 | 4.0 | 180 | 3,2 | 5.5 | 38 |
| 5,0 | 3.5 | 180 | 4,4 | 5.0 | 124 |
| 3,0 | 3.0 | 180 | 8,0 | 4.7 | 180 |
| 8,0 | 3.0 | 180 | 1,1 | 4.4 | 344 |
| 4,0 | 2.2 | 180 | 4,2 | 4.1 | 359 |
| 15,0 | 2.2 | 0 | 7,0 | 3.9 | 180 |
| 17,0 | 1.9 | 0 | 3,3 | 3.7 | 104 |
| 14,0 | 1.8 | 0 | 3,1 | 3.5 | 246 |

Table 2. Same as Table 1, but for sea-level pressure (mb)

| | 000 | | | 002 | |
|---|---|---|---|---|---|
| n,m | A(mb) | b(°) | n,m | A(mb) | b(°C) |
| 4,0 | 9.0 | 180 | 4,0 | 10.0 | 180 |
| 2,0 | 6.8 | 180 | 2,0 | 5.8 | 180 |
| 8,0 | 3.4 | 0 | 1,1 | 5.3 | 155 |
| 6,0 | 3.4 | 0 | 3,2 | 5.2 | 230 |
| 1,0 | 2.9 | 180 | 4,4 | 4.2 | 305 |
| 3,0 | 2.4 | 180 | 5,4 | 3.6 | 136 |
| 5,0 | 2.0 | 0 | 3,3 | 3.6 | 286 |
| 10,0 | 1.2 | 0 | 2,2 | 3.6 | 154 |
| 18,0 | 1.1 | 180 | 2,1 | 3.3 | 96 |
| 7,0 | 1.0 | 0 | 3,0 | 3.2 | 180 |

Table 3. Same as Table 1, but for 500 mb geopotential height (m).

| | 000 | | | 002 | |
|---|---|---|---|---|---|
| n,m | A(m) | b(°) | n,m | A(m) | b(°) |
| 2,0 | 786 | 180 | 2,0 | 886 | 180 |
| 1,0 | 132 | 180 | 1,0 | 293 | 180 |
| 4,0 | 78 | 180 | 4,0 | 96 | 180 |
| 7,0 | 37 | 180 | 8,0 | 55 | 180 |
| 3,0 | 36 | 180 | 7,0 | 49 | 180 |
| 8,0 | 31 | 180 | 6,0 | 49 | 0 |
| 6,0 | 27 | 0 | 3,0 | 34 | 180 |
| 15,0 | 20 | 0 | 15,0 | 25 | 0 |
| 10,0 | 14 | 0 | 4,2 | 24 | 20 |
| 9,0 | 13 | 180 | 7,1 | 23 | 85 |

latter in January. The longitudinal variations resulting from the continents are represented by harmonics of smaller amplitude with longitudinal wave numbers (m) equal to 1, 2, 3, and 4. The third largest harmonic, (3,2), for example, reflects the zonal pattern of two warm and two cold regions associated with the two cold continents and the warm intervening oceans of the Northern Hemisphere, but with a reversal of phase in the Southern Hemisphere.

The sea-level pressure patterns are also dominated by the same two zonally symmetric components (4,0 and 2,0) in both the water planet and flat continents January climatologies, as can be seen in Table 2. (The 4,0 harmonic with a phase of $180^{\circ}$ corresponds to an equatorial low pressure belt, two subtropical or mid-latitude highs, and Arctic and Antarctic lows.) The zonal structure associated with the continents is again represented by harmonics with longitudinal wave numbers 1, 2, 3 and 4. For example, the third harmonic, (1, 1), indicates the dominance of the Asiatic anticyclone, while the smaller 3,3 harmonic reflects the 3-cell structure in the Southern Hemisphere.

At the 500 mb level, as shown in Table 3, the contour pattern of the flat continents model, like that of the water planet, is predominantly zonal. This is indicated by the fact that the first 8 harmonics are all zonally symmetric, and are the same (although listed in slightly different order) for both models. It is not until we come to the relatively weak 4,2 harmonic, reflecting two small amplitude long wave troughs and ridges in the Northern Hemisphere, that the effect of the continents on the 500 mb contour pattern is apparent in the harmonic analysis.

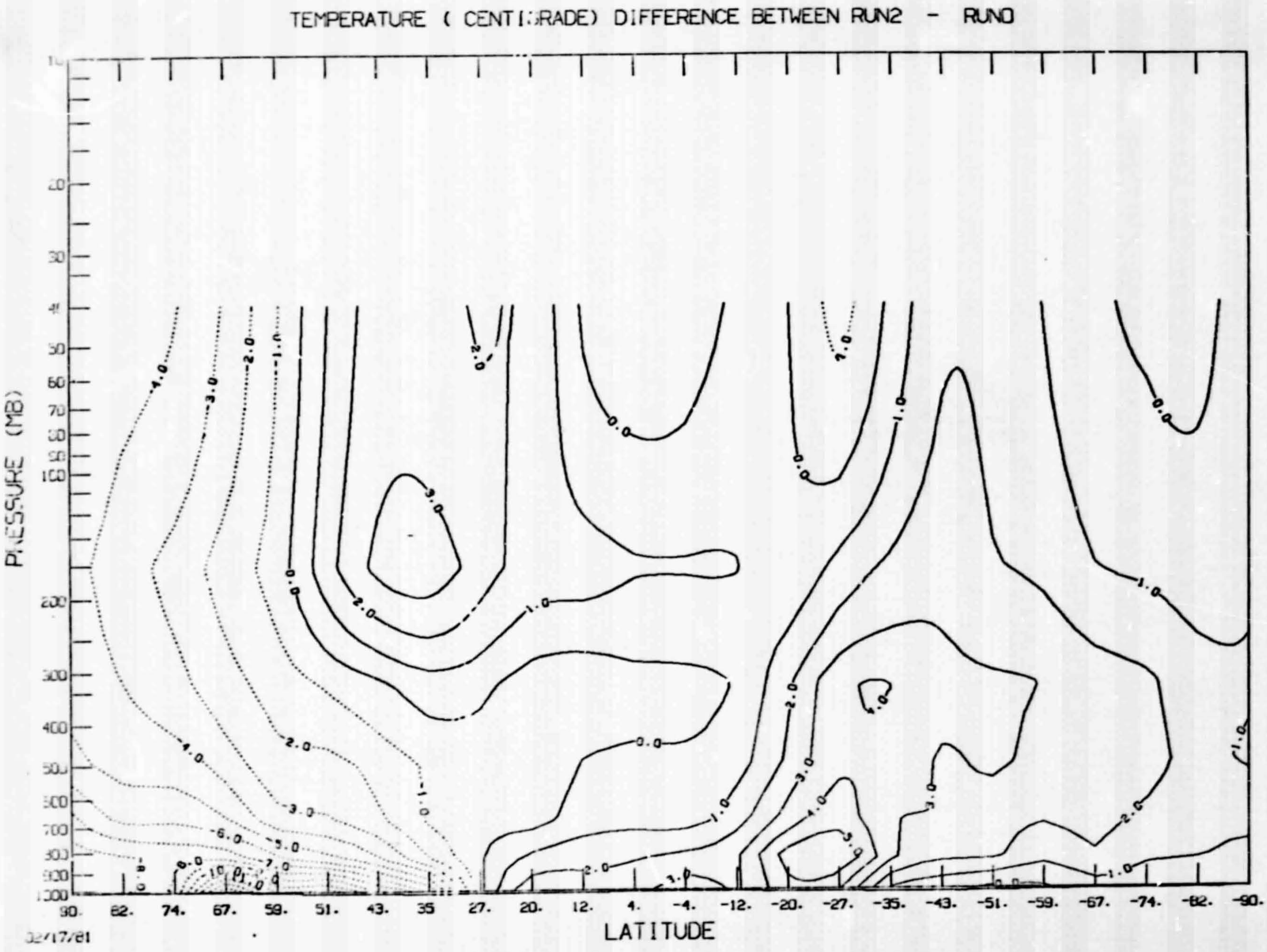
## Meridional cross-sections

Some effects of the flat continents on the mean meridional structures of certain zonally-averaged properties of the model-generated January climate are illustrated in Figures 8 - 11, showing (a) the mean difference between runs 002 and 000, and (b) the significance levels of the differences between the means.

The temperature difference cross-section (Fig. 8) shows that the Southern (summer) Hemisphere is significantly warmer with the continents, not only near the surface and in the latitude band of the continents, but at higher altitudes and latitudes as well. In the Northern Hemisphere, the cooling effect of the continents extends into the stratosphere at high latitudes. However, in middle and subtropical latitudes, the cold troposphere over the continental regions of the Northern Hemisphere is surmounted by warmer temperatures in the upper troposphere and lower stratosphere than on the water planet.

The influence of the continents on the mean zonal circulation is shown in the meridional cross-section in Figure 9. Here it can be seen that, through the thermal wind, the effect of the cold continents of the Northern Hemisphere and the warm continents of the tropics and Southern Hemisphere is to strenghten the westerlies significantly (solid difference isotachs) south of latitude 25° S and north of latitude 25° N, while enhancing the easterlies or diminishing the westerlies (dotted difference isotachs) in the tropics, notably near 16° S, by as much as 18 $\mathrm{ms}^{-1}$.

The mean meridional circulation difference between runs 002 and 000 shown in Fig. 10 indicates stronger southerly (weaker northerly) winds by solid isotachs and stronger northerly (weaker southerly) winds by dotted isotachs. The effect of the continents here is to shift the ICZ and the axis of the Hadley circulation cell from 4° N in the water planet model (see Spar et al., 1981) to about 16° S in the flat continents model, due to the heating of the continents in the tropical regions of the Southern Hemisphere. The vertical velocity difference cross-section (Fig. 11) also



TEMPERATURE ( CENTIGRADE) DIFFERENCE BETWEEN RUN2 - RUN0

Fig. 8a

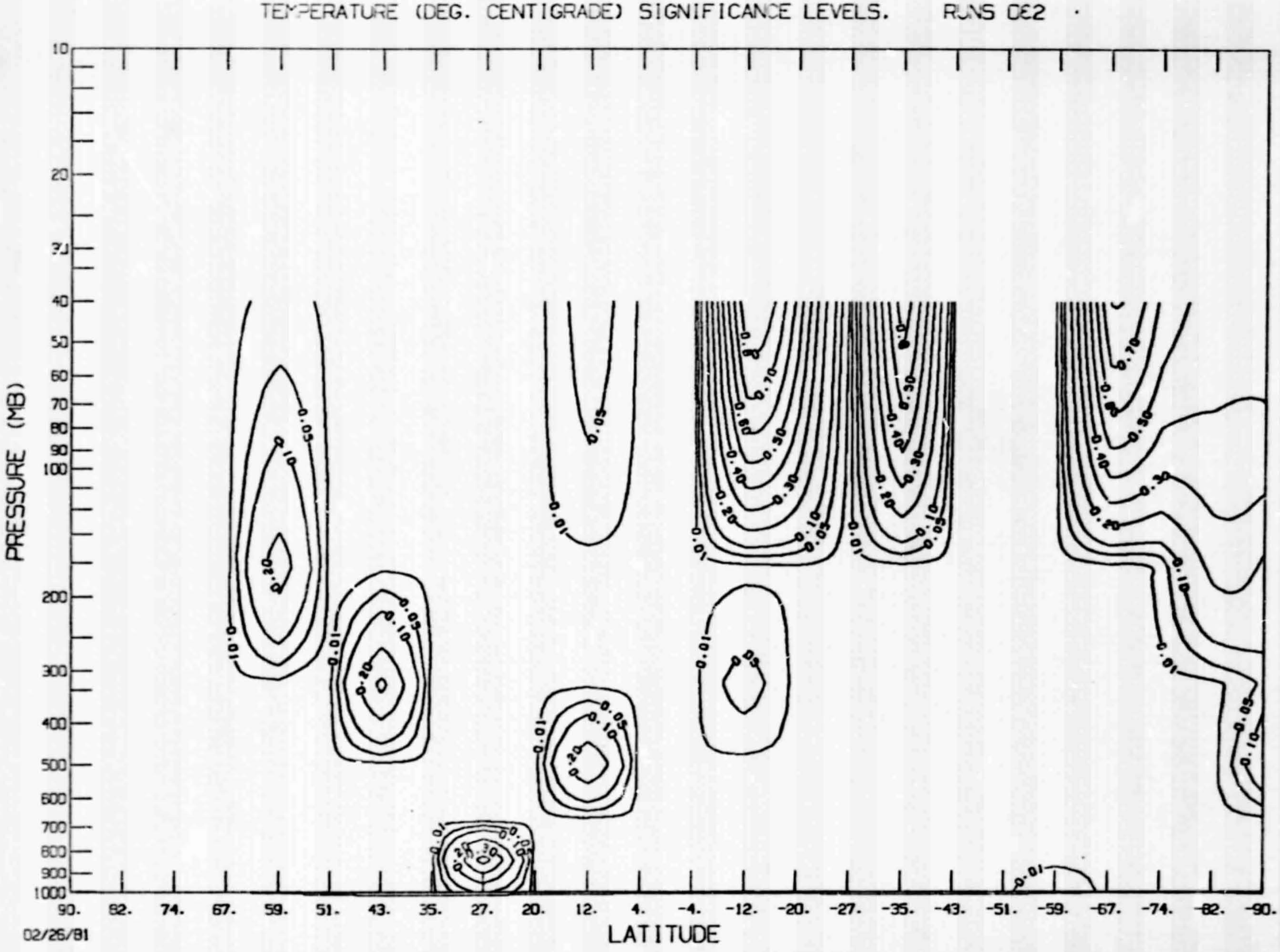
 TEMPERATURE (DEG. CENTIGRADE) SIGNIFICANCE LEVELS.     RUNS CE2

Fig. 8b

******************************FLAT*CONTINENTS*****************************************SPAR.WU.COHEN:RUN#2

ZONAL WIND (TENTHS OF M/SEC) DIFFERENCE BETWEEN RUN2 AND RUN3

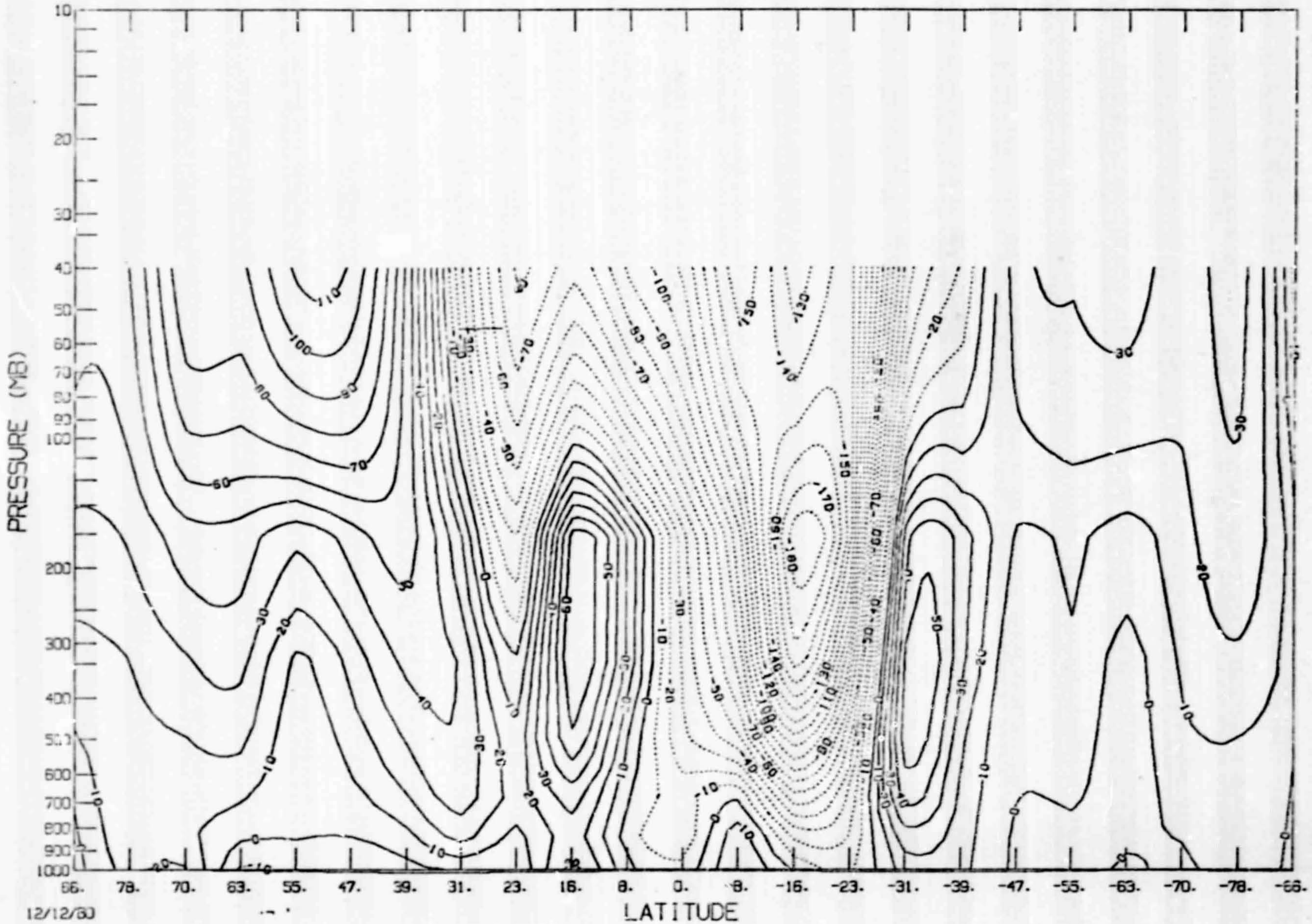
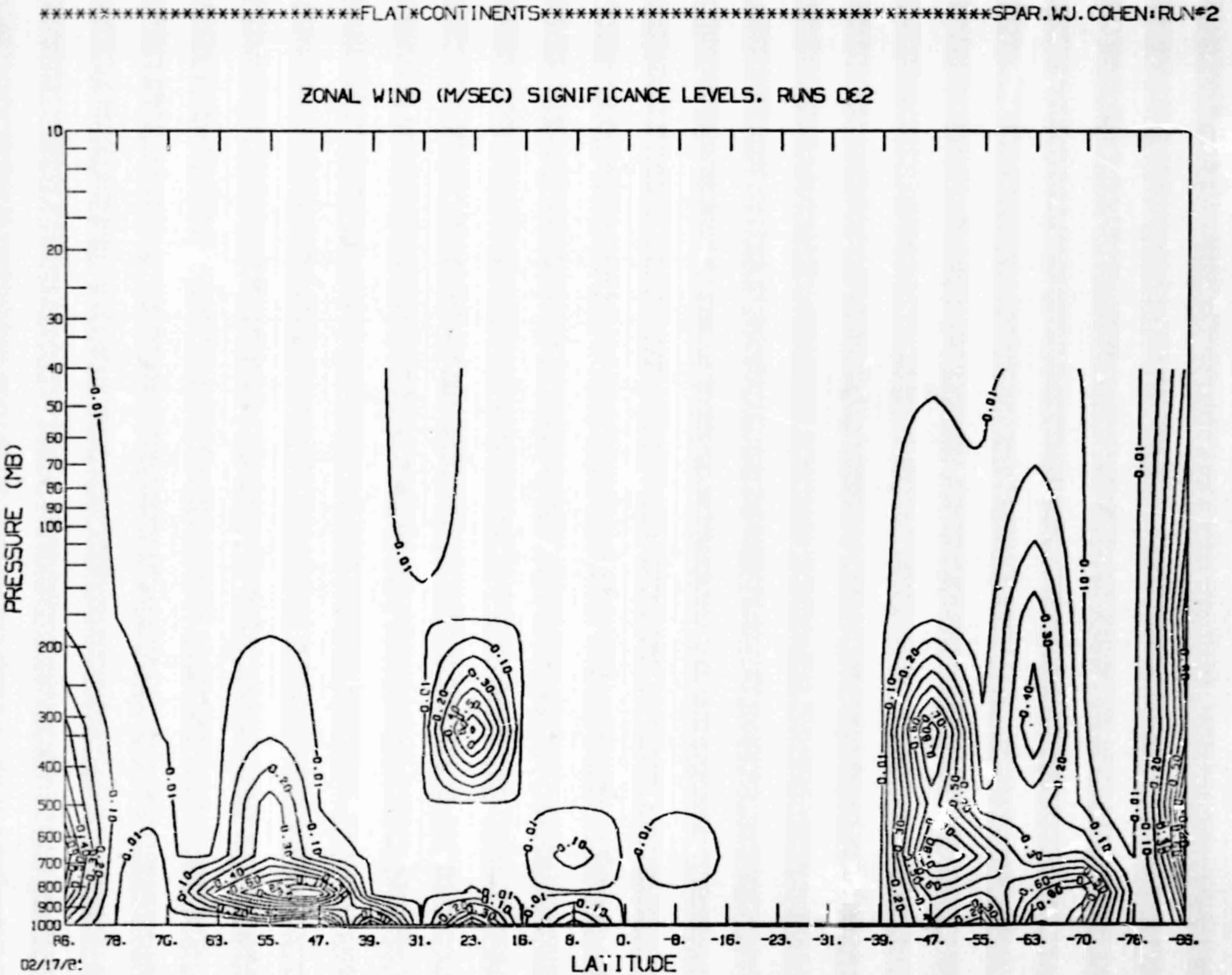


Fig. 9a

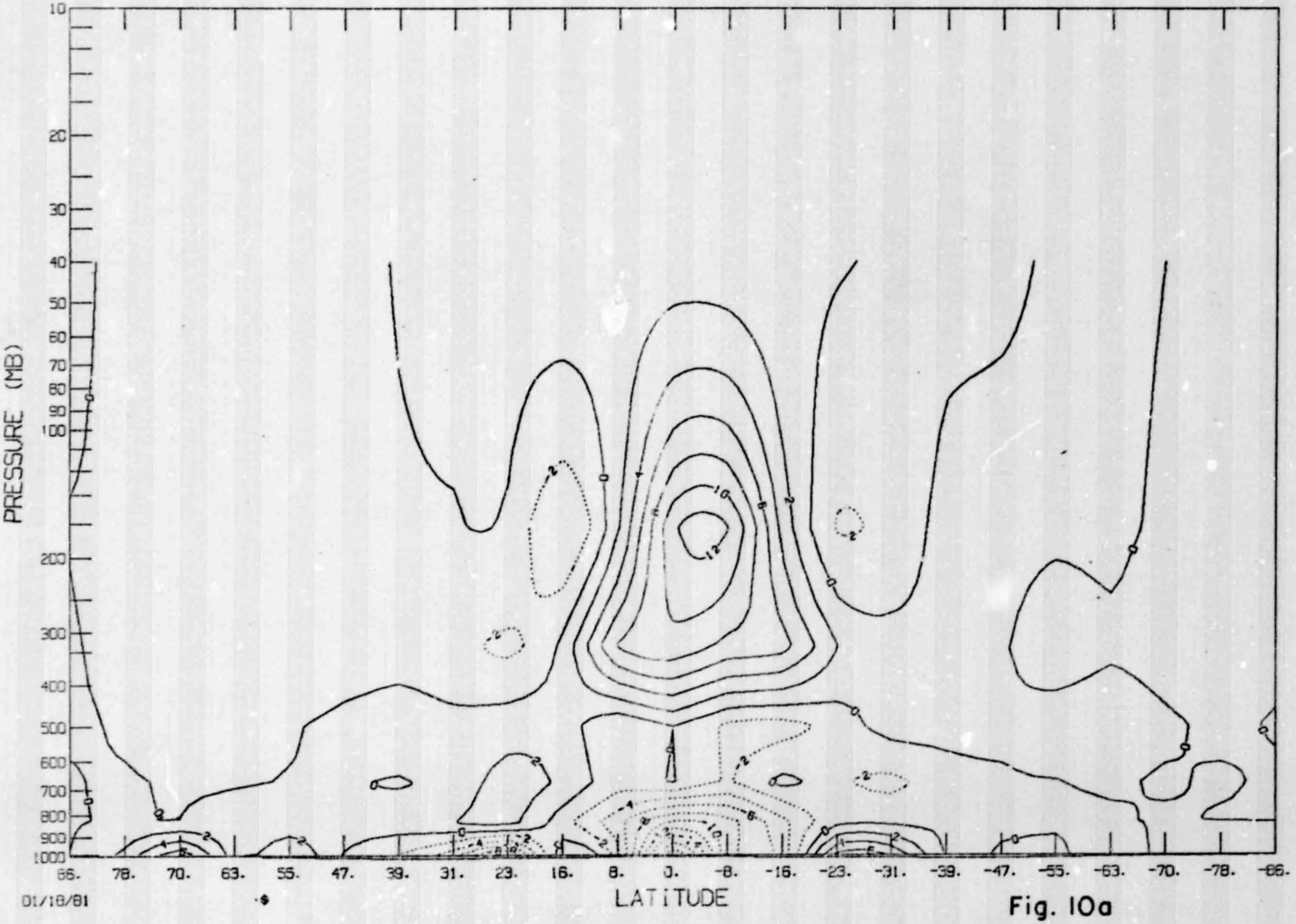


*************************FLAT*CONTINENTS**************************************SPAR.WJ.COHEN:RUN#2
ZONAL WIND (M/SEC) SIGNIFICANCE LEVELS. RUNS 0&2
PRESSURE (MB)
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
86.
78.
70.
63.
55.
47.
39.
31.
23.
16.
8.
0.
-8.
-16.
-23.
-31.
-39.
-47.
-55.
-63.
-70.
-78.
-86.
LATITUDE
02/17/8:
0.01
0.10
0.20
0.30
0.40
0.60
0.70
0.80

Fig. 9b

THIS IS THE 00RUN (WATER SPHERE) WITH MEAN GLOBAL TEMP . SPEC..HUMIDITY........SPAR.COHEN.WU:RUN#0

V WIND (TENTHS OF M/SEC) DIFFERENCE BETWEEN RUN2 AND RUN0



01/18/81

Fig. 10a

***************************FLAT*CONTINENTS*************************************SPAR.WU.COHEN:RUN*2

MERIDIONAL WIND (M/SEC) SIGNIFICANCE LEVELS. RUNS D&2

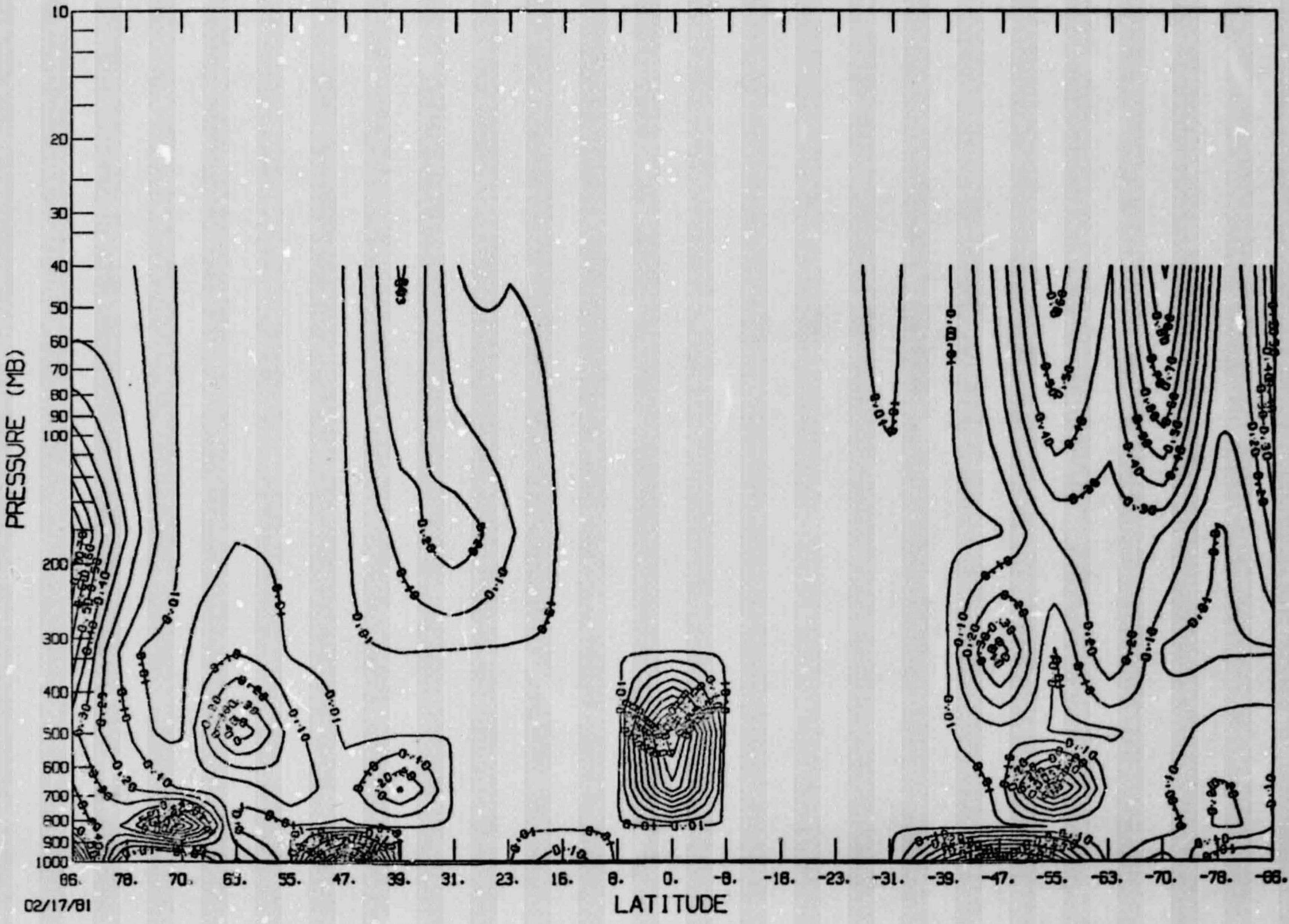


Fig. 10b

*****RUN003*SPIN UP WITH ISOTHERMAL ATMOSPHERE INCLUDING MOUNTIAN*ZERO GROUND WETNESS SPAR.COHEN.W

VERTICAL VELOCITY (10**-5 M/SEC) MEAN DIFFERENCE OF RUN2-RUNO

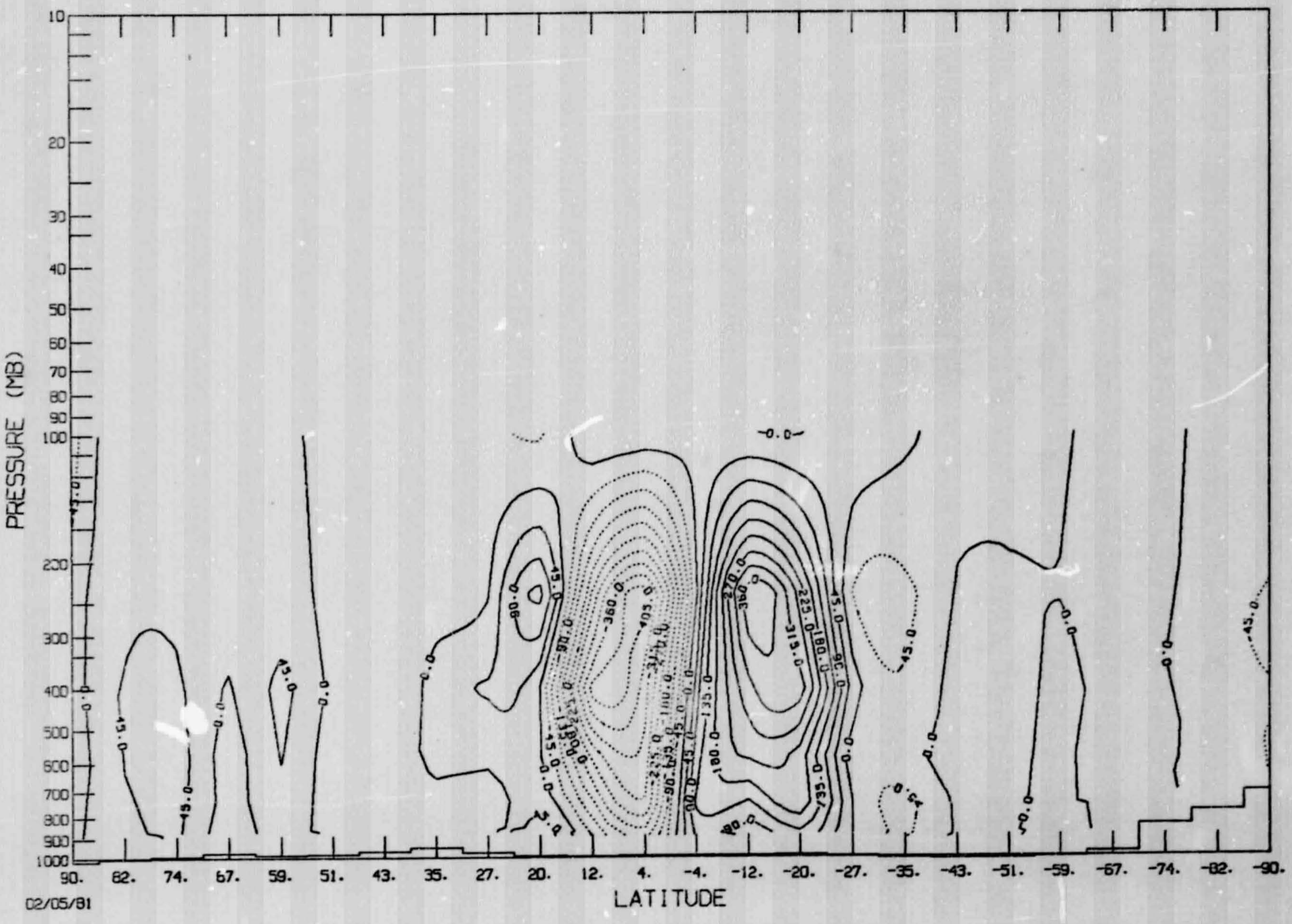


Fig. 11a

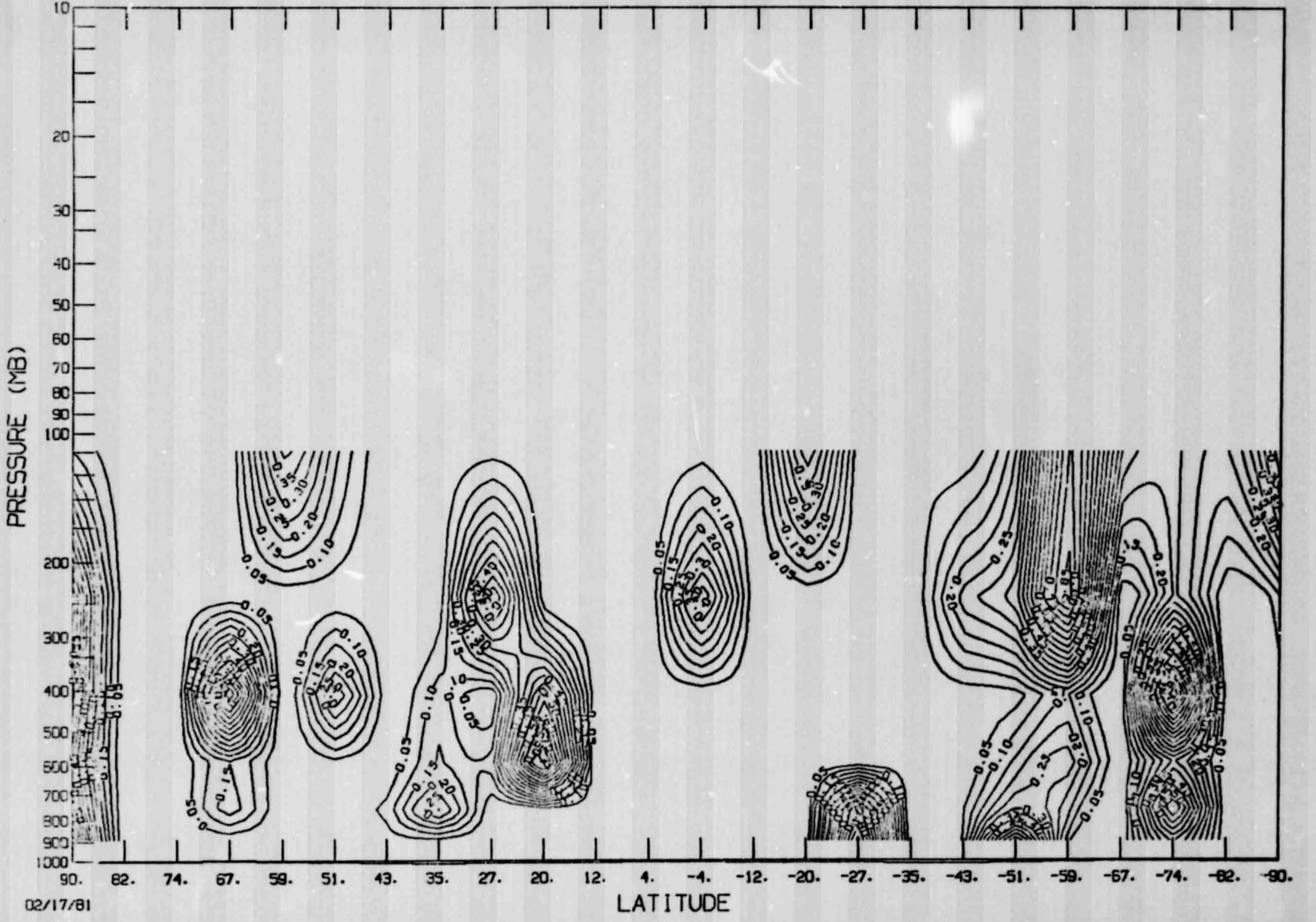

VERTICAL VELOCITY (10**-5 M/SEC) SIGNIFICANCE LEVELS. RUNS D&2
PRESSURE (MB)
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
90.
82.
74.
67.
59.
51.
43.
35.
27.
20.
12.
4.
-4.
-12.
-20.
-27.
-35.
-43.
-51.
-59.
-67.
-74.
-82.
-90.
LATITUDE
02/17/81
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40

Fig. 11b

shows a similar southward shift of the Hadley cell, with the ascending branch of the cell moving from $4^{\circ}$ N in the water planet model (Spar et al., 1981) into the Southern Hemisphere in the flat continents computation. (Cohen (1981) has shown that there are, in fact, two ascending branches in the flat continents run, one at $4^{\circ}$ N and one at $12^{\circ}$ S.)

## Summary

The continents exert a strong influence on the model-generated January climate directly and locally through their role as regional heat sources and sinks, resulting in a transformation from zonal symmetry to longitudinal cellular structure. They also affect the climate indirectly and remotely through more complex dynamical processes. Thus, for example, as expected, the continents are cold (warm) in the winter (summer) hemisphere, the surface pressures tend to be high (low) over the cold (warm) continents, and the mid-tropospheric isobaric surfaces are lower (higher) over cold (warm) land. On the other hand, the mass exchanges between the cold (warm) continents and the warm (cold) oceans produce significant pressure effects over the oceans as well as over the land.

Further evidence of the remote influence of the continents on the global climate is found in the distribution of precipitation and in the meridional cross-sections, which illustrate, on the one hand, the desiccating effects of heated continents on the precipitation over the equatorial oceans, and, on the other, a shift of the Hadley circulation cell into the summer hemisphere.

The effect of the continents on the mid-tropospheric (e.g., 500 mb) circulation, while statistically significant, is synoptically small, as indicated by the contour maps and the spherical harmonic analysis, both of which show a predominantly zonal circulation in the flat continents model climatology which is very similar to that of the water planet.

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