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AIR WEATHER SERVICE

DENSITY ALTITUDE MAPS
of
IRAN AND IRAQ

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by

Maj Walter F. Miller

USAFETAC

Past Weather-Our F...

MAY 1991

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13. Abstract: This report provides maps of Iran and Iraq with contours of mean monthly density altitude at the surface near the times of maximum and minimum temperatures. Surface values of temperature, vapor pressure, and pressure used to calculate DA were adjusted at each grid point using gridded terrain elevation from the Defense Mapping Agency (DMA) 100-meter Digital Terrain Database (DTED).

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PREFACE

This report documents the results of USAFETAC Project 90424, "Density Altitude Maps." Analysts were Major Walter F. Miller (DNO) and MSgt Gary Tryon (ECO). The original request (from OL-A, Detachment 21, 5 WS, Fort Stewart, GA) was for maps of Iran and Iraq with contours of mean monthly density altitude at the surface near the times of maximum and minimum temperature. Surface values of temperature, vapor pressure, and pressure used to calculate DA were adjusted at each grid point using gridded terrain elevation. The terrain used in this analysis was obtained from the Defense Mapping Agency (DMA) 100-meter Digital Terrain Database (DTED). The customer asked for and received a map scale of 1:3,000,000 in the initial report, but a much smaller scale is used in this, the final publication.

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1. INTRODUCTION

1.1 Product Description. As requested by the customer, two sets of planning maps are provided. The first set provides contoured mean surface DA at the time of *minimum* temperature, by month. The second set gives gridded monthly mean surface DA at the time of *maximum* temperature. The customer (Det 21, 5WS) asked for and received this data on 1:3,000,000-scale maps (21.9 inches x 27.7 inches), with contours at 1,000-foot intervals. These maps are reproduced in the appendix of this report, but to a much smaller scale. North-south map boundaries are 40 and 25° N; east-west boundaries, 63 and 42° E.

1.2 Density Altitude Defined. Density altitude (DA) is pressure altitude (PA) corrected for nonstandard temperature and dew-point variations. PA is the altitude indicated by an altimeter when it is set to the standard datum plane of 29.92 inches of mercury. When conditions are standard, PA and DA are the same. If temperature is above standard, DA is higher than PA. If temperature is below standard, DA is lower than PA. DA can also be expressed as the altitude in the ICAO standard atmosphere at which a given density occurs. The maps produced in this study show the altitude in the ICAO standard atmosphere at which surface density occurs. DA can be calculated from (List, 1984):

$$DA = 145{,}366\left[1 - \left(\frac{17.326 p_{stn}}{T_v}\right)^{0.235m}\right] \qquad (1)$$

where

DA = DA in feet

p_{stn} = station pressure in inches of mercury

T_v = virtual temperature in Rankine (459.4 +°F)

Virtual temperature can be obtained from (Duffield and Nastrom, 1983):

$$T_v = -0.288 + 1.8\,(T + 273.15)\left[\frac{(1 + 1.60779r)}{(1 + r)}\right] \qquad (2)$$

where

T = temperature in degrees C

r = mixing ratio (kg/kg)

Mixing ratio is calculated by (Duffield and Nastrom, 1983):

$$r = \frac{0.622\,e}{p_{stn} - e} \qquad (3)$$

where

p_{stn} = station pressure in millibars

e = vapor pressure in millibars

r = mixing ratio (kg/kg)

A modified Teten's formula (Murray, 1967) is used to calculate vapor pressure:

$$e = 6.11\,(mb) * exp\,\frac{(a\,T_d)}{(T_d + b)} \qquad (4)$$

where

T_d = dew point temperature in °C

e = vapor pressure in millibars

a = 17.269 when $T_d > 0°$ C and 21.874 when $T_d < 0°$ C

b = 237.3 when $T_d > 0°$ C and 265.5 when T_d 0° C

In this study, the surface values of temperature, vapor pressure, and pressure used to calculate DA were adjusted at each grid point using gridded terrain elevation.

1.3 Limitations. The original maps prepared with terrain data at 6-NM resolution were hard to read; as a result, data at 30-NM resolution was interpolated and smoothed to a 6-NM grid. Elevation errors of 100 to 700 meters and DA errors of 2,000 feet are found in areas of steep terrain; for this reason, the maps should be used for planning purposes only. Users should also note that DA in the vicinity of mountain peaks is significantly higher than the surface DAs shown on the maps.

1.4 Data. Enough data was available for 38 weather reporting stations either in the area of interest or within 1 degree of its boundaries. The terrain used for this analysis was taken from the 100-meter Defense Mapping Agency (DMA) Digital Terrain Database (DTED). Processing of the DTED database is described in Section 3.

1.5 Terrain Effects. The variables from which DA is calculated--temperature, moisture (mixing ratio that can be determined from dew-point temperature), and pressure--are influenced by terrain height, solar radiation, vegetation type, precipitation, and geography. Unfortunately, there has not been enough research to take all these factors into consideration; this study only considers the effects of terrain, as explained in the next paragraph. Other variables can only be accounted for by the representativeness of the observations from available weather stations.

1.6 Procedures. Monthly means of temperature, vapor pressure, and altimeter setting were calculated for each station using values at the time of each daily maximum and minimum temperature. These monthly mean values were then adjusted to sea level (zero meters elevation) using the relationships described in Section 3. The variables adjusted to sea level (temperature, vapor pressure, and altimeter setting) were then interpolated to a tenth of a degree latitude/longitude (6-NM) grid. This horizontal interpolation was performed using a cubic spline technique that fits a third-order equation in the x (E-W) and y (N-S) direction. It was now possible to obtain values for each grid point at sea level. The gridded sea-level meteorological data and the gridded terrain heights were then used to adjust temperature and vapor pressure to the terrain surface using standard meteorological relationships. Altimeter setting was adjusted to station (surface) pressure using the gridded elevation. Once these variables were obtained at the surface, Equation 1 could be used to calculate DA. These steps are described in greater detail in Section 3.

1.7 Quality Control. The following assumptions were necessary to complete this study:

·That DA at the time of the daily maximum temperature is close to the maximum DA for the day.

·That minimum DA has to be related to DA at the minimum temperature.

·That the results would not be seriously affected by the lack of available data for Iran and Iraq--that is, the number of limited duty stations and 3-hourly observations, and a period of record less than 10 years.

·That the cubic spline interpolation spreads the data accurately.

The error introduced by each of these assumptions will be discussed in Section 4, where support for the complex procedure used in producing our DA maps, as opposed to interpolating DA directly to a grid, is also supplied.

1.8 Maps. The DA maps are described in Section 5 and provided in the appendix. DA isopleths are labeled at 1,000-foot intervals. Because of the rugged terrain in Iran, smoothed terrain was used; this improves readability at the expense of some accuracy. To take full advantage of the high-resolution terrain data available from DMAAC, much larger maps would be required.

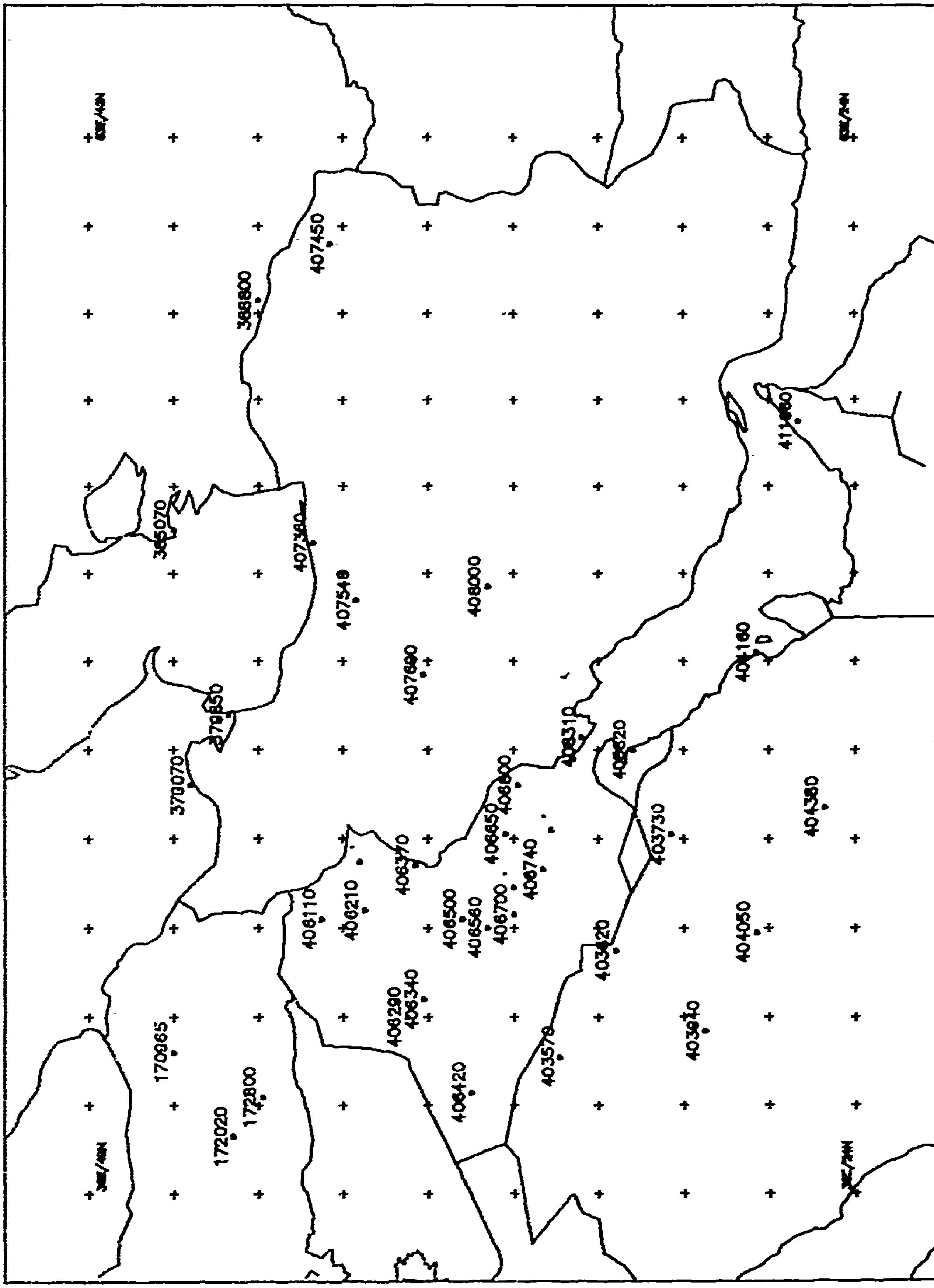

Figure 1. Stations Used in the Interpolation Scheme.

2. INPUT DATA

2.1 Surface Observations. Although USAFETAC maintains surface observations from 1973 to 1989, some stations reported only at 3-hourly intervals and others have failed to report for several years. Rodney (1986) concluded that 10 years of observational data was enough for a representative sample of climate in a region. Only 11 of the 38 stations used here, however, provided a full 10-year period of record (POR). Most stations had a 5-year POR, but stations with PORs as small as 4 years were included if they were in a data-sparse area. Table 1 lists the weather stations used; their locations are shown in Figure 1. Some stations, although off the maps, were included as inputs to the interpolation scheme to provide more accurate values at the boundaries. As can be seen in Figure 1, most of the stations are in the western half of the region, while the eastern half has very few. We evaluated 35 stations in the eastern portion and could find none with enough observations to be useful.

TABLE 1. List of Stations Used in the Interpolation Scheme.

Block Station	Name	Country	Lat	Lon	Elev (meters)	POR
170965	Erzurum	TU	39 57'N	41 10'E	1756	77-86
172020	Elazig	TU	38 36'N	39 17'E	882	77-86
172800	Diyarbakir	TU	37 03'N	40 11'E	677	77-86
379070	Fizuli	RS	39 36'N	47 09'E	430	73-77
379850	Lenkoran	RS	38 44'N	48 50'E	-11	73-77
385070	Krasnovodsk	RA	40 02'N	52 59'E	89	73-77
388800	Ashabad	RA	37 58'N	58 20'E	228	73-77
403570	Arar	SD	30 54'N	41 08'E	552	77-86
403620	Rafha	SD	29 38'N	43 29'E	447	77-86
403730	Hafr Al-Batin	SD	28 20'N	46 07'E	355	77-86
403940	Hail	SD	27 26'N	41 41'E	1013	77-86
404050	Gassim	SD	26 18'N	43 46'E	650	77-86
404160	Dhahran IAP	SD	26 16'N	50 09'E	17	77-86
404380	Riyadh	SD	24 43'N	46 43'E	612	77-86
405820	Kuwait IAP	KW	29 13'N	47 59'E	55	77-86
406110	Salahaddin	IQ	36 37'N	44 13'E	1088	77-80
406210	Kirkuk	IQ	35 28'N	44 24'E	331	73-80
406230	Sulaimaniya	IQ	35 33'N	45 27'E	853	73-80
406290	Ana	IQ	34 28'N	41 57'E	150	73-80
406340	Haditha	IQ	34 04'N	42 22'E	140	73-80
406370	Kanaqin	IQ	34 18'N	45 26'E	202	73-80
406420	Rutbah	IQ	33 02'N	40 17'E	615	73-80
406500	Baghdad	IQ	33 14'N	44 14'E	34	73-80
406560	Karbalaa	IQ	32 37'N	44 01'E	29	77-80
406650	Kut-al-Hai	IQ	32 10'N	46 03'E	15	73-80
406700	Najaf	IQ	31 59'N	44 19'E	32	73-80
406720	Diwaniya	IQ	31 59'N	44 59'E	20	73-80
406740	Semawa	IQ	31 18'N	45 16'E	6	73-80
406760	Nasiriya	IQ	31 05'N	46 14'E	3	73-80
406800	Amarah	IQ	31 51'N	47 10'E	9	73-80
406890	Basrah/Magal	IQ	30 34'N	47 47'E	2	73-80
407360	Babulsar	IR	36 43'N	52 39'E	-21	73-80
407450	Mashhad	IR	36 16'N	59 38'E	980	76-80
407540	Tehran/Mehrabad	IR	35 41'N	51 21'E	1191	73-80
407690	Arak	IR	34 06'N	49 42'E	1720	76-80
408000	Esfahan	IR	32 37'N	51 40'E	1590	76-80
408310	Abadan IAP	IR	30 22'N	48 15'E	11	73-80
411960	Sharjah IAP	ER	25 20'N	55 31'E	33	77-86

2.2 Variables Used. For this study, temperature, dew-point temperature, and altimeter setting were used to calculate DA (see Equation 1 and 1.6). If altimeter setting was not available, sea-level pressure was converted to altimeter setting as described in Section 3. Altimeter setting was chosen for three reasons:

- Station pressure is not reported in surface observations.

- Obtaining station pressure from altimeter setting o. .y requires one additional variable--elevation.

- The technique used in this study requires that pressure be adjusted to sea level (zero meters) for interpolation.

Vapor pressure was obtained from Equation 4 using the dew-point temperature. Monthly means of temperature, vapor pressure, and altimeter setting were calculated using the values at the times of the maximum and minimum temperature. Some variables are in metric units and some in English units, depending on which calculation was being done. The equations in this report are in the form given in the reference from which they were taken; therefore, all equations specify units required.

2.3 Terrain Data. Although USAFETAC has arranged to acquire worldwide DTED terrain data at 100-meter resolution from the Defense Mapping Agency (DMA), only a small subset of the DTED database was available to USAFETAC analysts for use in this study. Fortunately, the data that was available included Iran and Iraq. To conserve storage, only enough data are maintained at USAFETAC to recreate the actual data with less than 1 percent of interpolated values having errors greater than 300 feet. Terrain heights with 6-NM resolution were obtained from this dataset for the area of interest; as shown in Figure 2, using terrain data to this resolution would result in an unreadable, unusable product.

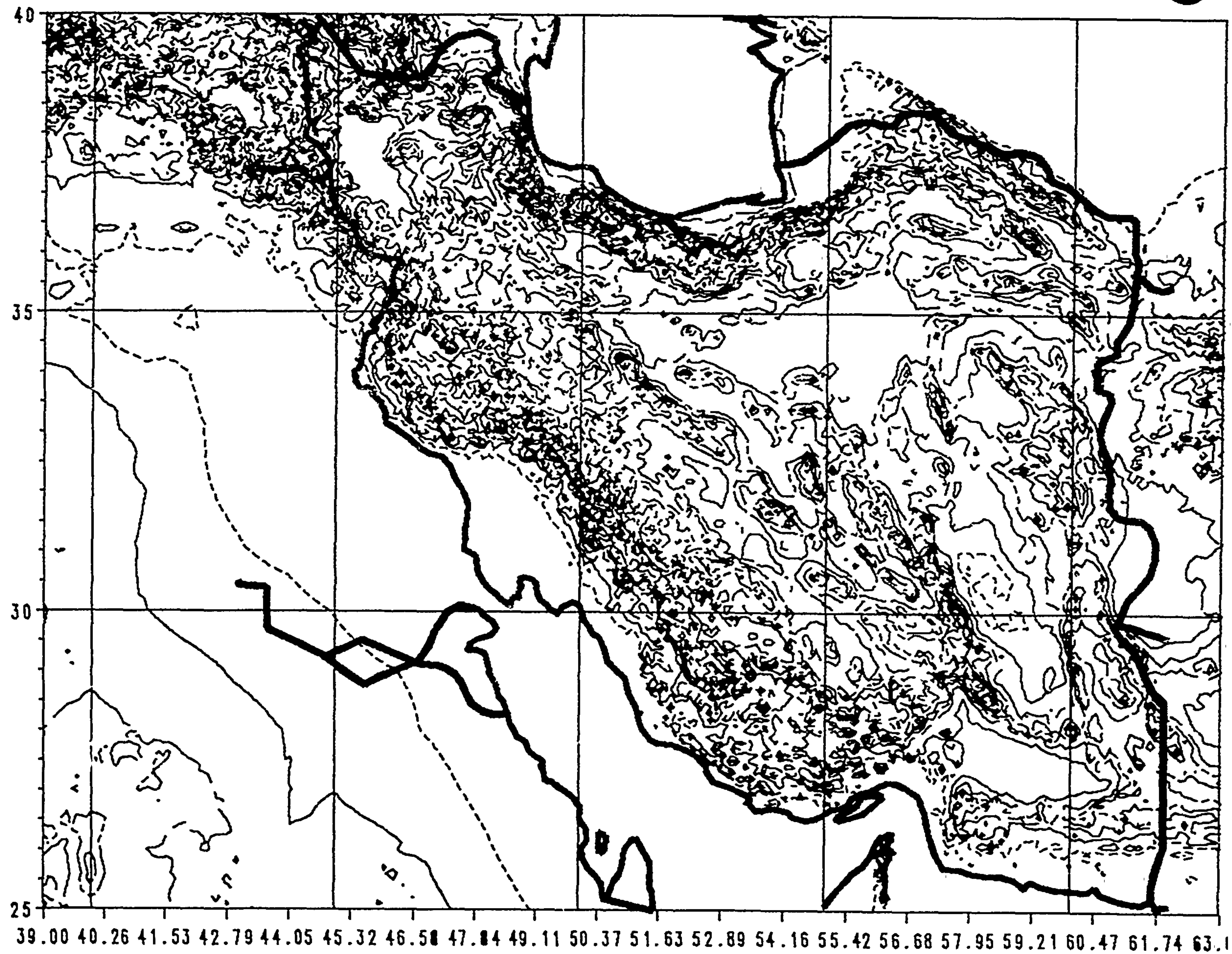

Figure 2. Elevations (meters) for Iran and Iraq Using the DTED Database with 6-NM Resolution.

3. PROCEDURES FOR DA CALCULATION

3.1 Gross Error Checks. Surface weather observations for each station were quality controlled for gross errors. The data had to pass the following tests:

·Temperature must be between 20° and 138° F.

·Dew-point temperature must be less than or equal to the temperature.

·Dew-point temperature must be between -30° and 93° F.

·If altimeter setting is used, it must be between 28 and 32 inches of mercury.

·If sea level pressure is used, it must be between 948 and 1050 mb.

·The difference between the maximum and minimum temperature must be less than 65° F.

·The difference between the altimeter setting for the minimum and maximum temperature is limited to half an inch of mercury; the sea-level pressure difference is limited to 20 mb.

If all these conditions were met, the surface weather observation was used in selecting the maximum and minimum temperature as described in 3.2. Extreme highs for temperature and dew-point temperature used in quality-controlling the data were obtained from MIL-STD-210C. The lower values were thought to be appropriate extremes for the Mideast.

3.2 Maximum and Minimum Values. The maximum and minimum temperatures for each day were selected, along with the dew-point temperature and altimeter setting (sea level pressure) that corresponded to the time of the maximum and minimum temperature. Because the data from some stations was limited, only minimum and maximum temperatures occurring within 3 hours of 0300 and 1200Z (respectively) were selected.

3.3 Vapor Pressure. Vapor pressure was calculated using the dew-point temperature at the time of the maximum and minimum temperature for each day (Equation 4). The monthly mean vapor pressure was then calculated for these two times. Another option would have been to calculate monthly mean dew-point temperatures at the time of maximum and minimum temperatures and use those values in Equation 4 to calculate the monthly mean vapor pressure. Tests showed that there was a difference as large as 0.5 mb when the monthly mean dew-point temperature was used; we therefore calculated monthly mean from daily vapor pressure at the time of the maximum and minimum temperature.

3.4 Pressure Conversion. Altimeter setting was chosen for interpolation to the horizontal grid because only terrain heights were needed to obtain surface pressure. Several stations used in this study, however, reported only sea level pressure; for them, we converted sea-level pressure to altimeter setting by reversing the sea-level computation process given in the Smithsonian Meteorological Tables (List, 1984). Mean surface temperature was calculated from daily minimum and maximum temperature. To calculate mean layer temperature, surface temperature was increased by 5° C for every 1,000 meters the station was above sea level (List, 1984). Since the mean layer temperature is valid half the distance between the surface and sea level, the lapse rate term can be added to the mean surface temperature if it is reduced by half; that is, (0.5(5° C)/1,000 meters or 1/400 °C m^{-1}). The mean temperature for the layer is used to solve the hypsometric equation for station pressure (Wallace and Hobbs, 1977):

$$p_{stn} = p_{sl} \exp \frac{(-g\ h)}{(R\ T_m)} \qquad (5)$$

where

p_{stn} = station pressure in mb

p_{sl} = sea-level pressure in mb

g = acceleration due to gravity in ms^{-2}

h = station elevation in meters

R = gas constant for dry air, 287 $m^2s^{-2}K^{-1}$

T_m = mean layer temperature in kelvin (see section 3.4), given by

$$T_m = 0.5\,(T_{max} + T_{min}) + h/400$$

T_{max} = maximum temperature for the day in kelvin

T_{min} = minimum temperature for the day in kelvin

Station pressure is than converted back to altimeter setting using Equation 6 (Duffield and Nastrom, 1983):

$$ALSTG = \left(1 + 8.42 \cdot 10^{-5}\, h\, p_{stn}^{\;-0.190284}\right)^{5.255} p_{stn} \frac{29.92}{1013.25} \qquad (6)$$

where

$ALSTG$ = altimeter setting in inches of mercury

p_{stn} = station pressure in mb

3.5 Monthly Mean. The monthly mean of temperature, vapor pressure, and altimeter setting is calculated using the temperature, vapor pressure, and altimeter setting at the time of maximum temperature for each day. This time must be within 3 hours of 1200Z, but it does not have to be the same time every day. This step is repeated for values at the time of the daily minimum temperature, which is within 3 hours of 0300Z. The standard lapse rate of 6.5° C per 1,000 meters is used to adjust the monthly mean temperature to sea level (List, 1984):

$$T_{sl} = T_{sfc} + 0.0065\,h \qquad (7)$$

where

h = station elevation in meters

T_{sl} = temperature at sea level in °C

T_{sfc} = temperature at the surface in °C

Hann's empirical formula as described by List, 1984, is used to adjust the monthly mean vapor pressure to sea level; altimeter setting is already adjusted to a constant level.

$$e_{sl} = e_{sfc}\, exp\left(\frac{h}{6{,}300}\right) \tag{8}$$

where

e_{sl} = vapor pressure at sea level in mb

e_{sfc} = vapor pressure at the surface in mb

3.6 Interpolation. Sea-level temperature, sea-level vapor pressure, and altimeter setting at irregularly spaced stations are interpolated to a regularly spaced, horizontal (sea-level) grid using a cubic spline technique. The grid consists of points every tenth of a degree in latitude and longitude. Examples of interpolated data for July are provided in Figures 3 through 5. A cubic spline produces a surface similar to "one that would be formed if a stiff, thin metal plate were forced through or near the given data points" (SAS, 1990). Mathematically, a cubic spline fits a third-order polynomial to the data in both horizontal directions. Values for each grid point can be determined from the third-order equations. Thus, data for 38 irregularly spaced points are spread to each point on the tenth of a degree grid at sea level. Extension of data in the vertical and computation of DA is a subsequent processing step and is described in 3.8, below.

3.7 Smoothed Terrain. As this report was being published, USAFETAC was still in the process of acquiring DTED data from DMA. To maintain a DTED database for the entire world, USAFETAC would have had to find room to store 6,300 magnetic tapes. A method was developed, however, to store just enough data to reproduce the original terrain with less than 1 percent of the errors greater than 300 feet. From this reduced data set, we obtained 6-NM resolution terrain for the area of interest. Initial studies using this data showed that there was too much detail --see Figure 2. To provide smoother fields, 30-nm terrain data was interpolated using the same cubic spline technique as for the meteorological variables. During interpolation, the data was smoothed; the smoothed terrain field is shown in Figure 6. A comparison of Figures 2 and 6 shows the detail lost; the smoothed map, however, is much more readable.

3.8 DA Calculations. After interpolation, we had monthly mean sea-level temperature, monthly mean sea-level vapor pressure, monthly mean altimeter setting, and elevation for each grid point. There are six grids for each month; one set of three (sea-level temperature, sea-level vapor pressure, and altimeter setting) for the time of maximum temperature and another set of three for the time of minimum temperature. The procedure for calculating DA from gridded fields was repeated for each month and for each set of grids. Equations 7 and 8 are solved for surface temperature and vapor pressure using the smoothed, gridded terrain heights. Station pressure is obtained from altimeter setting using the relationship from Duffield and Nastrom, 1983 (Equation 9); finally, DA was calculated with Equation 1.

$$p_{stn} = (ALSTG^{\,0.19026} - 4.306 \cdot 10^{-5}\, h)^{5.2561} \tag{9}$$

where

$ALSTG$ = altimeter setting in inches of mercury

p_{stn} = station pressure in inches of mercury

h = gridded terrain elevation

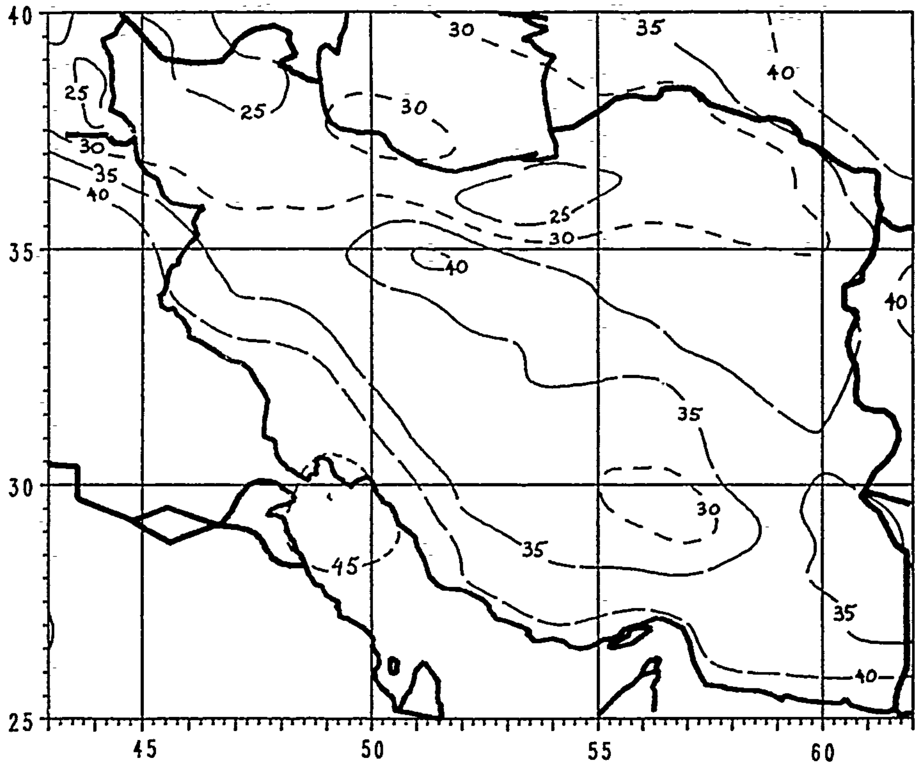

Figure 3. Interpolated Mean Monthly Sea-Level Temperature (°C), July.

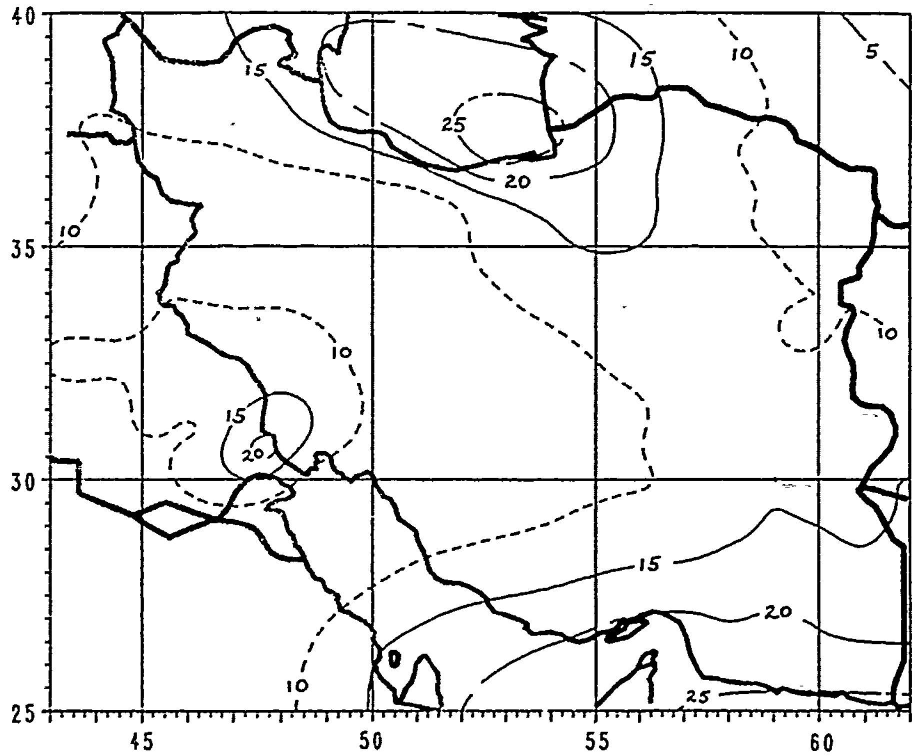

Figure 4. Interpolated Mean Monthly Sea-Level Vapor Pressure (mb) at the Time of Maximum Temperature, July.

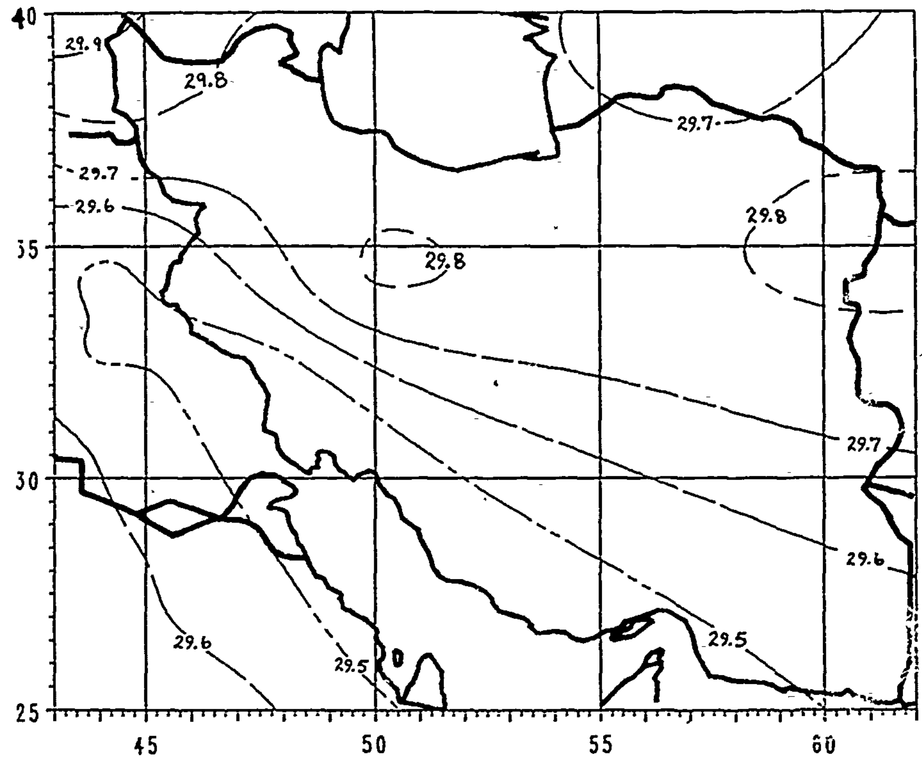

Figure 5. Interpolated Mean Monthly Altimeter Settings (in Hg) at the Time of Maximum Temperature, July.

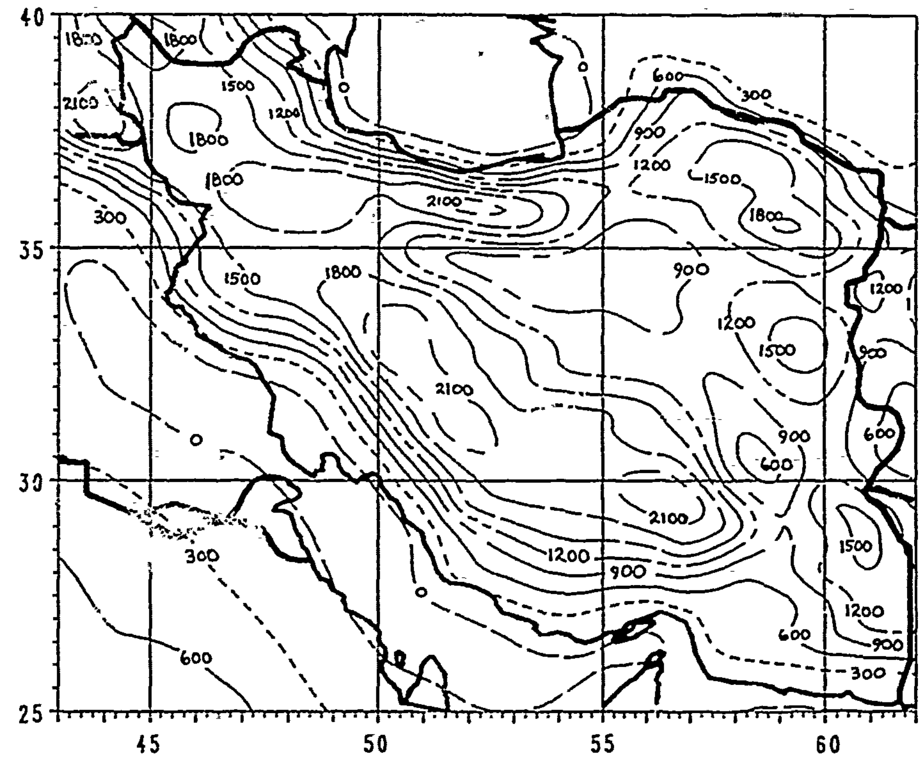

Figure 6. Elevations (meters) from Smoothed Terrain Data for Iran and Iraq.

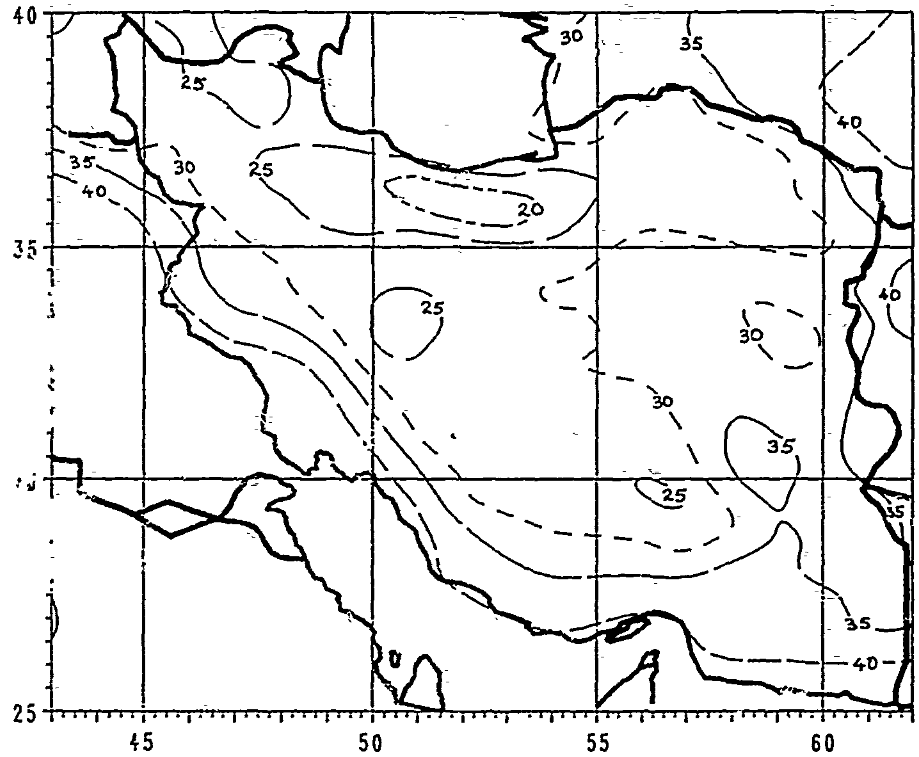

Figure 7. Interpolated Mean Monthly Maximum Sea-Level Temperature (°C), July; 12 Stations Removed.

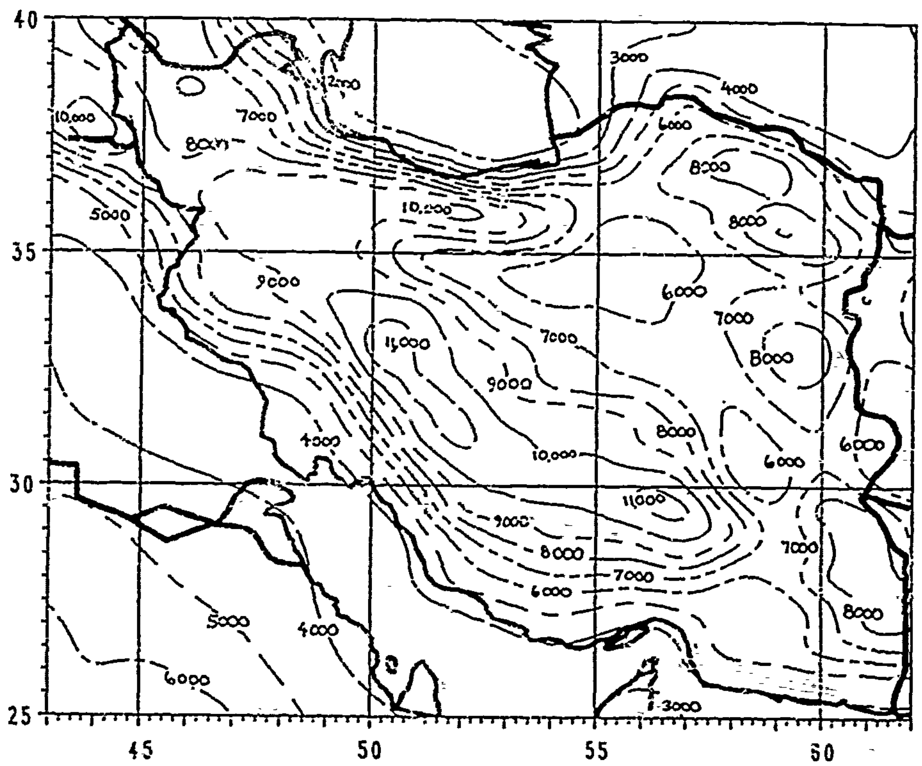

Figure 8. Mean Monthly Surface Density Altidude (feet) at the Time of Maximum Temperature, July; Terrain Effects Included.

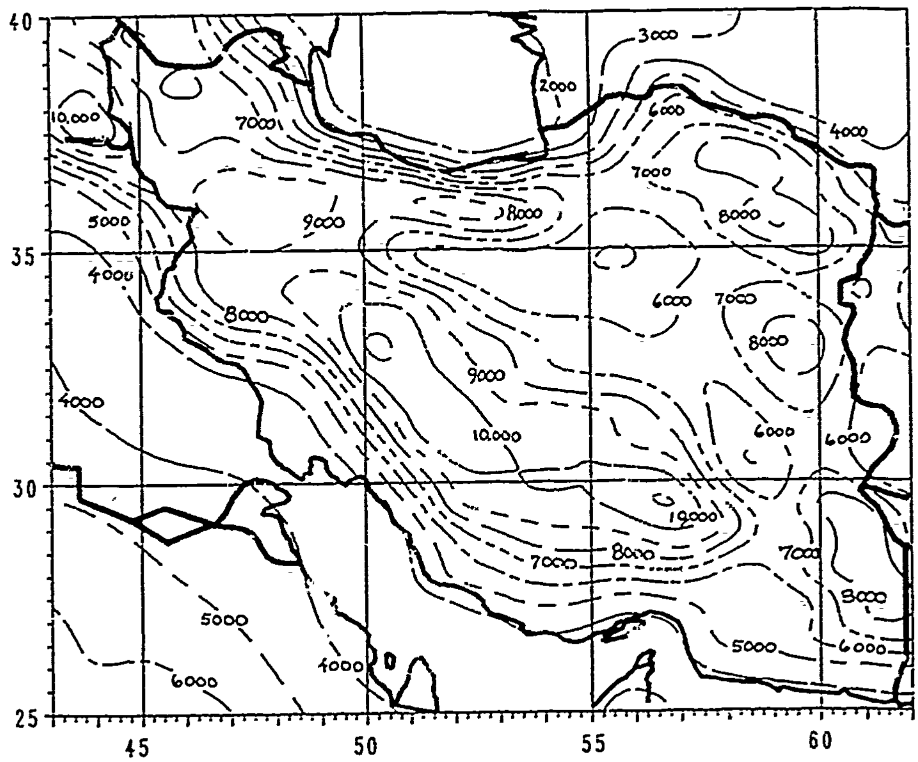

Figure 9. Mean Monthly Surface Density Altitude (feet) at the Time of Maximum Temperature, July; Terrain Effects included, but with 12 Stations Removed.

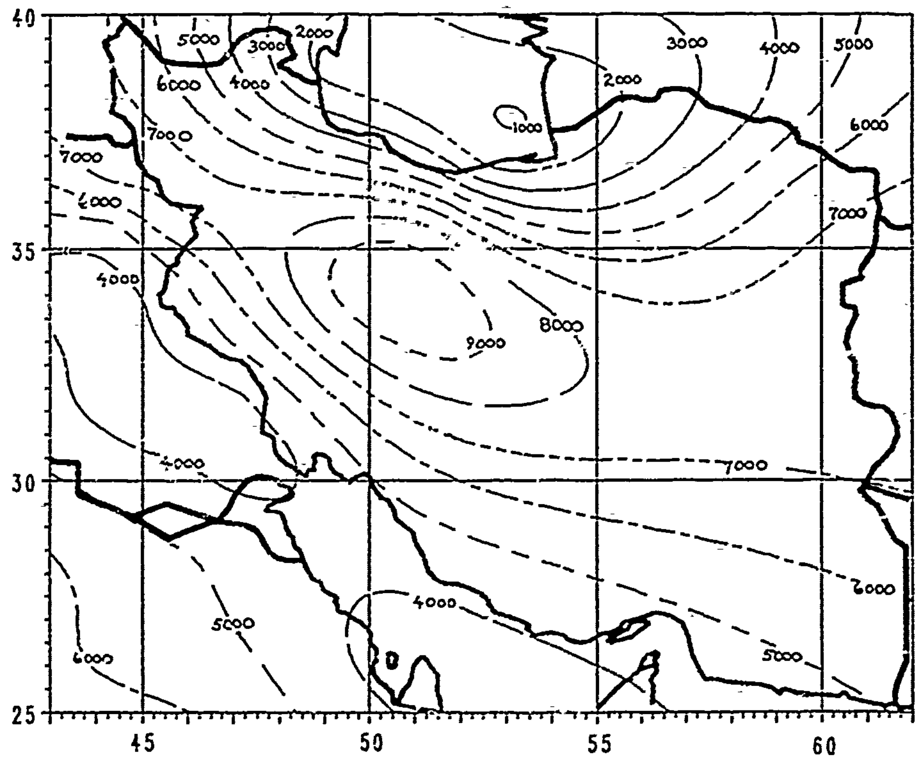

Figure 10. Interpolated Mean Monthly Surface Density Altitude (feet) at the Time of Maximum Temperature, July; Terrain Effects Not Included.

4. QUALITY CONTROL

4.1 Accuracies of Maximum and Minimum Temperatures were checked against published values in USAFETAC/DS-89/035, *Station Climatic Summaries Asia*. More than half the stations used could be verified by this method. Errors were on the order of 2 to 3° F. Even though only 4 years of data were available for some stations, results from these small samples seemed to be representative of the climatological mean.

4.2 DA at Maximum Temperature. Our gridding method used data valid at the time of the daily maximum and minimum temperature to calculate DA. This method agrees with the customer's request for DA at the time of the maximum and minimum temperature. Our first quality control check was to determine the size of the difference between the monthly mean maximum DA and the monthly mean DA at the time of maximum daily temperature. For the six stations evaluated, the monthly mean maximum DA was no more than 100 feet higher than the monthly means using the maximum temperature. An error of similar size (opposite sign) is associated with the monthly mean minimum DA and the monthly mean DA at the time of the minimum temperature.

4.3 Mean DA From Mean Values. The next concern was if the DA calculated from the monthly mean values of temperature, vapor pressure, and altimeter setting was close to the monthly mean maximum and minimum DA. The error between the monthly mean DA and the calculated mean was 100 feet. Our results showed excellent agreement with DA calculated from the values at the time of maximum or minimum temperature and the calculated monthly mean from these values. The errors were less than 20 feet.

4.4 Three-Hourly Data. Next, we ran a test using four stations to compare monthly mean DA at the time of maximum or minimum temperature from hourly and 3-hourly data. The difference between the monthly means changed by less than 100 feet (maximum, lower; minimum, higher).

4.5 Interpolation Error. Because data from several stations was used to determine the value at each grid point, a small error was expected. If no data was present, the size of the error was unknown. Because of the limited number of stations in the region, the error at a large number of grid points was unknown. In an attempt at estimation, 12 stations with data were removed from the interpolation. Table 2 shows the difference between interpolated values using all stations and the interpolated value missing the 12 stations (All - Void) for sea-level temperature, sea-level vapor pressure, altimeter setting, and DA. As might be expected, the errors were larger at the eastern locations (the last three stations). Figure 7 showed the interpolated maximum sea level temperature for July. A comparison of Figures 3 and 7 shows that the basic pattern remains, but that some of the small-scale features are lost. These differences are even smaller for the monthly mean DA at the time of maximum temperature in July--see Figures 8 and 9.

4.6 Terrain Error. The largest source of error was the elevation assigned to each grid point. Because of terrain resolution and smoothing, there were differences of up to 700 meters in the comparison. Elevation errors this large can result in DA errors on the order of a 2,000 feet. When the gridded elevation was close to station elevation, the DA was within several hundred feet. This error, however, was a compromise between accurate data and readable data.

4.7 Spreading DA. One might ask, "Why go through the complex procedure of taking elevation into account when creating gridded fields of DA?" A comparison of Figures 10 (interpolated DA) and 8 (terrain effects included) shows the large errors that result from ignoring terrain. These errors were quantified using the data void test results. Table 2 shows the difference between the mean monthly DA at the time of the maximum temperature and the interpolated DA (Spread DA). The mean monthly DA calculated with terrain (but with 12 missing stations) is also compared to the station value (Table 2, Terrain DA). The greatest errors occur in area with the highest terrain.

Data was taken from DA at the time of maximum temperature for July. Spread DA is the difference between station DA and interpolated DA without taking terrain into acount, and with 12 stations removed. Terrain DA is the difference between station DA and DA calculated with terrain, but with 12 stations removed.

TABLE 2. Differences Between Selected Interpolated Variables: Spread DA and Terrain DA (feet).

BLKSTN	T_{sl} (°C)	e_{sl} (mb)	ALSTG (in hg)	Spread DA (feet)	Terrain DA (feet)
385070	3.6	-3.9	-0.05	-331	791
403620	0.5	0.4	-0.01	345	212
403730	-0.1	0.1	0.03	456	130
406110	0.7	0.6	-0.10	-536	292
406210	0.5	0.8	0.03	1,089	186
406700	-0.3	-2.6	0.00	96	96
406890	-2.4	8.1	-0.01	163	20
407540	12.0	-9.8	0.10	-4,615	1,118
407690	7.8	-6.2	0.26	-5,630	153
408000	7.2	-8.7	0.19	-5,117	715

4.8 Total Error. Based on the error analysis above and ignoring the smoothing of terrain height, the DAs provided are accurate to within 1,000 feet. The errors along the western half of the study area are less than 500 feet because of the higher data density. Smoothing of terrain can result in another 1,000-foot error. The DA at the tops of large mountains is not considered in this analysis.

5. MAPS

5.1 Description. Twenty-four maps of mean DA for Iran and Iraq are provided in the appendix. The map area, specified by the customer, is bounded by 25 and 40° N latitude and 43 and 62° E longitude. There is a map for each month at the time of maximum and minimum temperature. Contours are drawn every 1,000 feet, with zero feet as the base. Table 3 provides DA values for Baghdad, Iraq; Tehran, Iran; and Dhahran, Saudia Arabia, for use as reference points. Geopolitical boundaries of the area (bold lines) are also plotted. Our software does not close off southern Iraq at the Persian Gulf coast. Latitude and longitude lines are provided at 5-degree increments to help users locate points.

5.2 Map Data Summary. Minimum DAs are found in Iraq, Saudi Arabia, and Russia, but DA increases rapidly along the border of Iran, reaching its largest values on the central plateau. During the winter, the DA at the minimum temperature along the Persian Gulf is near -1,000 feet, increasing to several thousand feet during the summer. DA at the maximum temperature is near zero during the winter, increasing to almost 4,000 feet during the summer. In the high plateau of Iran, DA at the minimum temperature is near 5,000 feet during the winter and 7,000 feet during the summer. DA at the maximum temperature is more than 8,000 feet during the winter, increasing to more than 11,000 feet during the summer.

TABLE 3. DA (feet) for Key Reference Points.

	Baghdad		Tehran		Dhahran	
Month	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
January	-1876	-363	2706	5741	-682	560
February	-1451	201	3173	6170	-471	808
March	-905	776	3885	6926	80	2004
April	-170	1570	4763	7784	798	2121
May	-64	2421	5370	8387	1489	2873
June	1180	3114	6135	9196	2064	3419
July	1548	3526	6554	9573	2350	3703
August	1360	3374	6343	9302	2241	3546
September	789	2910	5775	8768	1714	3153
October	-137	1995	4790	7879	1039	2417
November	-1194	765	3741	6791	280	1541
December	-1602	-68	3190	6140	-466	793

6. SUMMARY

6.1 Terrain Effects. Mean DA for Iran and Iraq is provided for each month at the time of maximum and minimum temperature. Instead of interpolating mean DA for all 38 available stations, terrain elevation and standard meteorological relationships were used to provide DA on a grid. This technique required converting temperature and vapor pressure to a common surface (sea level) before interpolating them to a latitude-longitude grid with a resolution of 0.1 degree. These interpolated values were than adjusted back to the gridded elevation. From these, adjusted values of temperature, vapor pressure, and pressure, DA were calculated. Much more detail, along with tighter gradients of DA were produced by this method than by merely interpolating mean monthly DA.

6.2 Quality. An error analysis showed that the DAs provided have errors of less than 500 feet in the western half of the region, increasing to 1,000 feet in the east. Additional error is added by using smooth terrain instead of the full 6-NM resolution; however, the smooth terrain was justified in that its use resulted in a readable product.

APPENDIX

The 24 maps in the appendix provide contoured values of density altitude (DA) in Iraq and Iran at minimum and maximum temperature for each month of the year. Values of DA were calculated as described in the text of this report. Contours were drawn with SAS software, a copyright-protected product of the SAS Institute, Cary, NC Contours are in 1,000-foot intervals. Since SAS software was incapable of labeling contours, the labels were applied by hand.

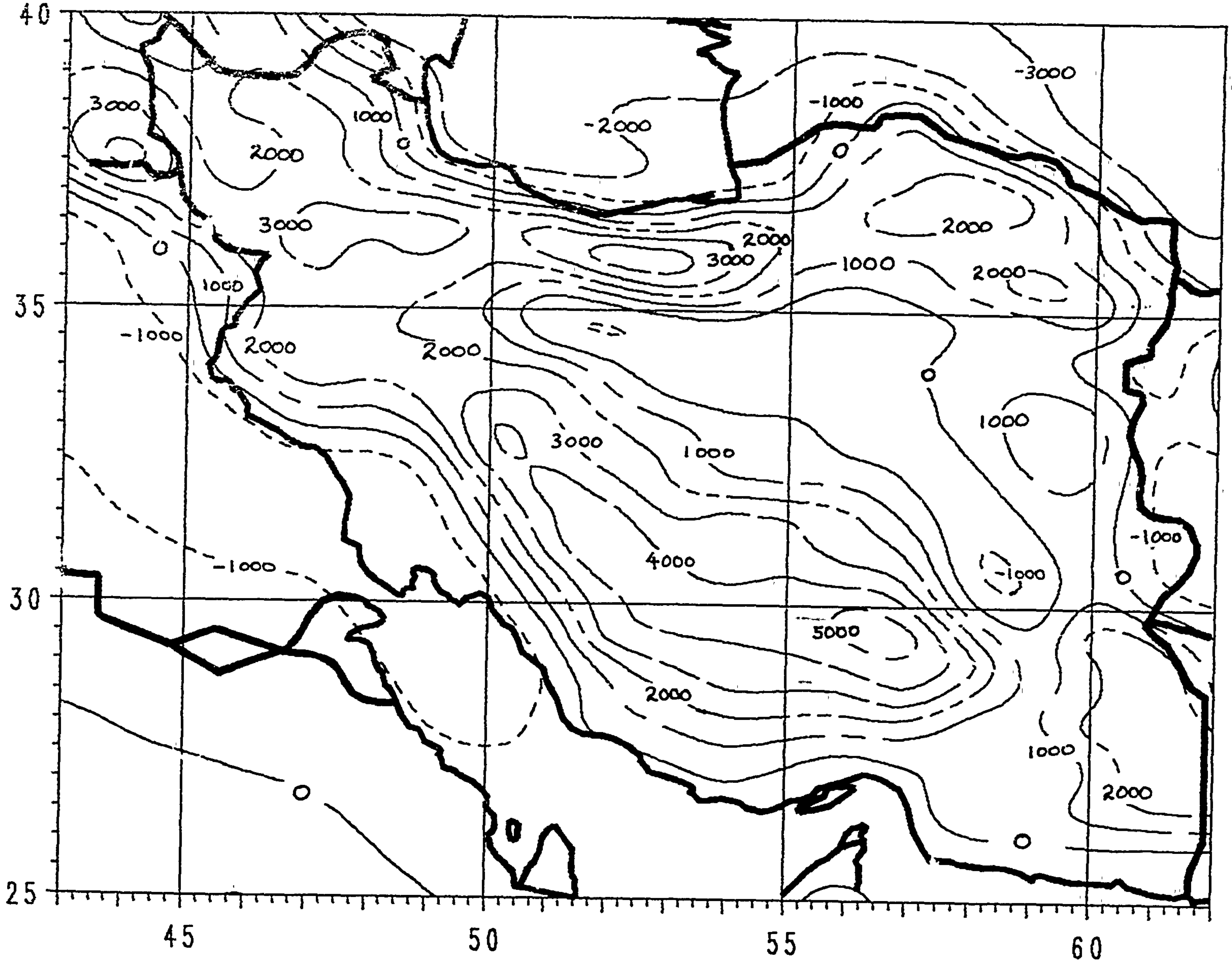

Figure A-1. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, January.

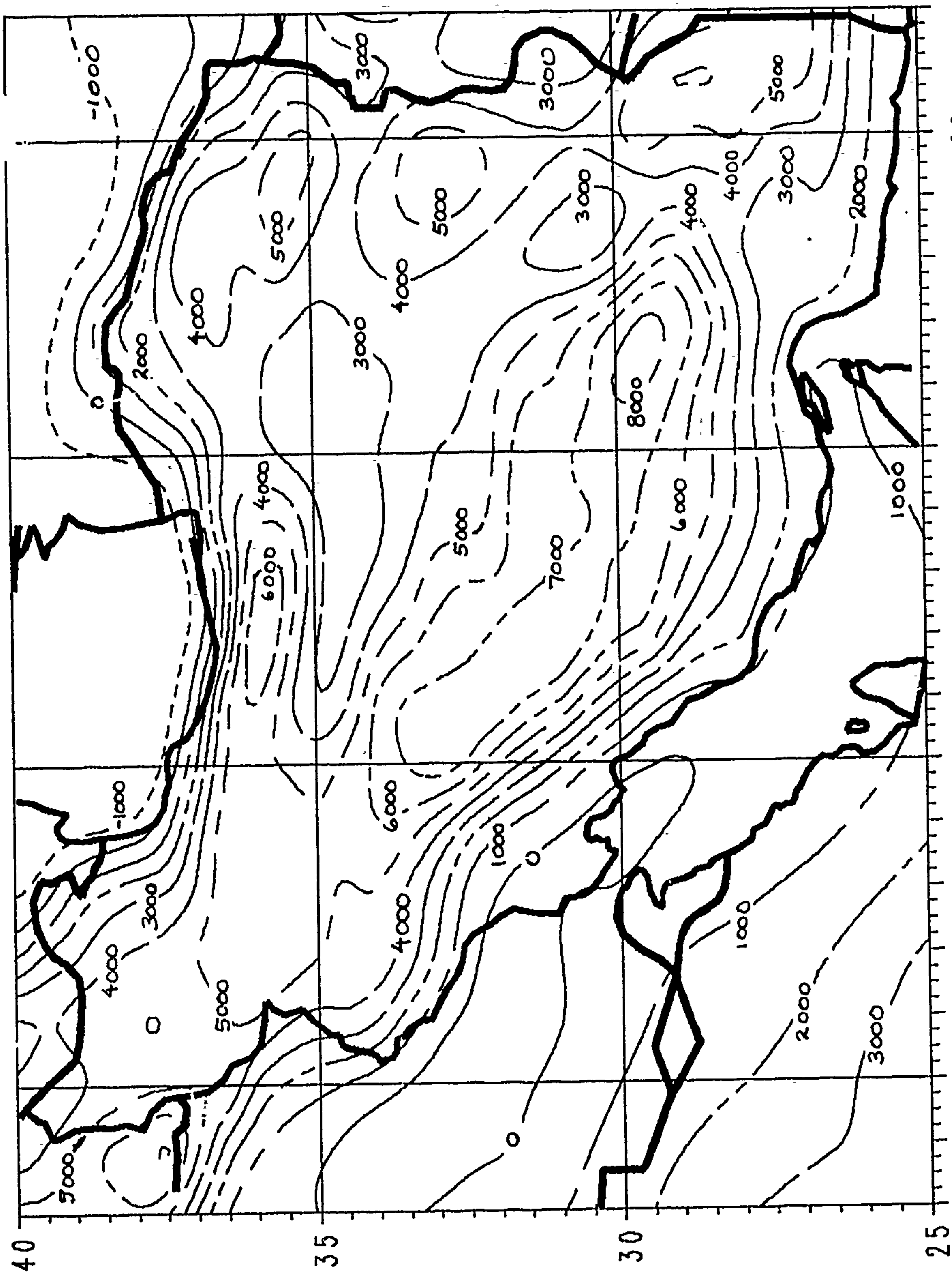

Figure A-2. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, January.

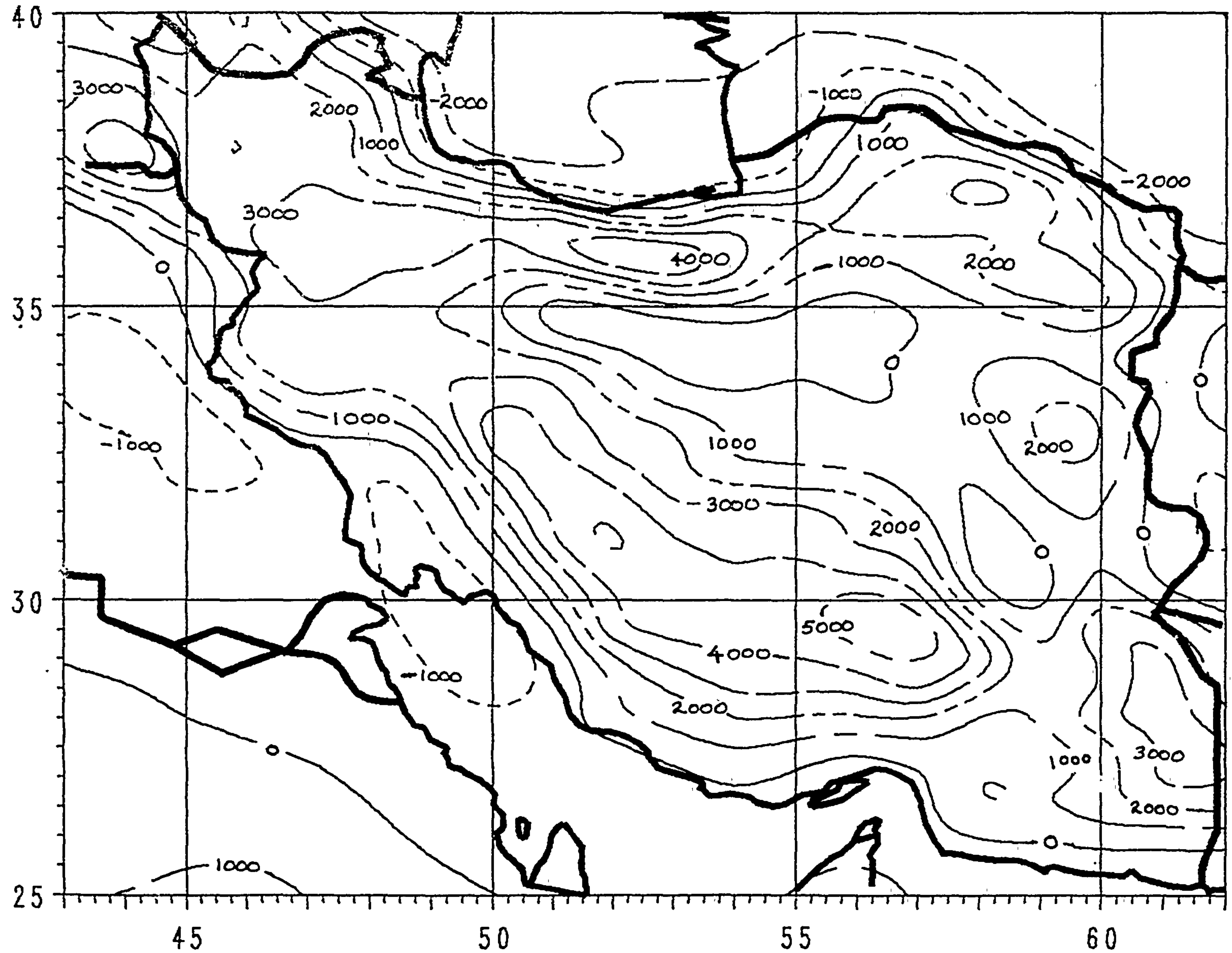

Figure A-3. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, February.

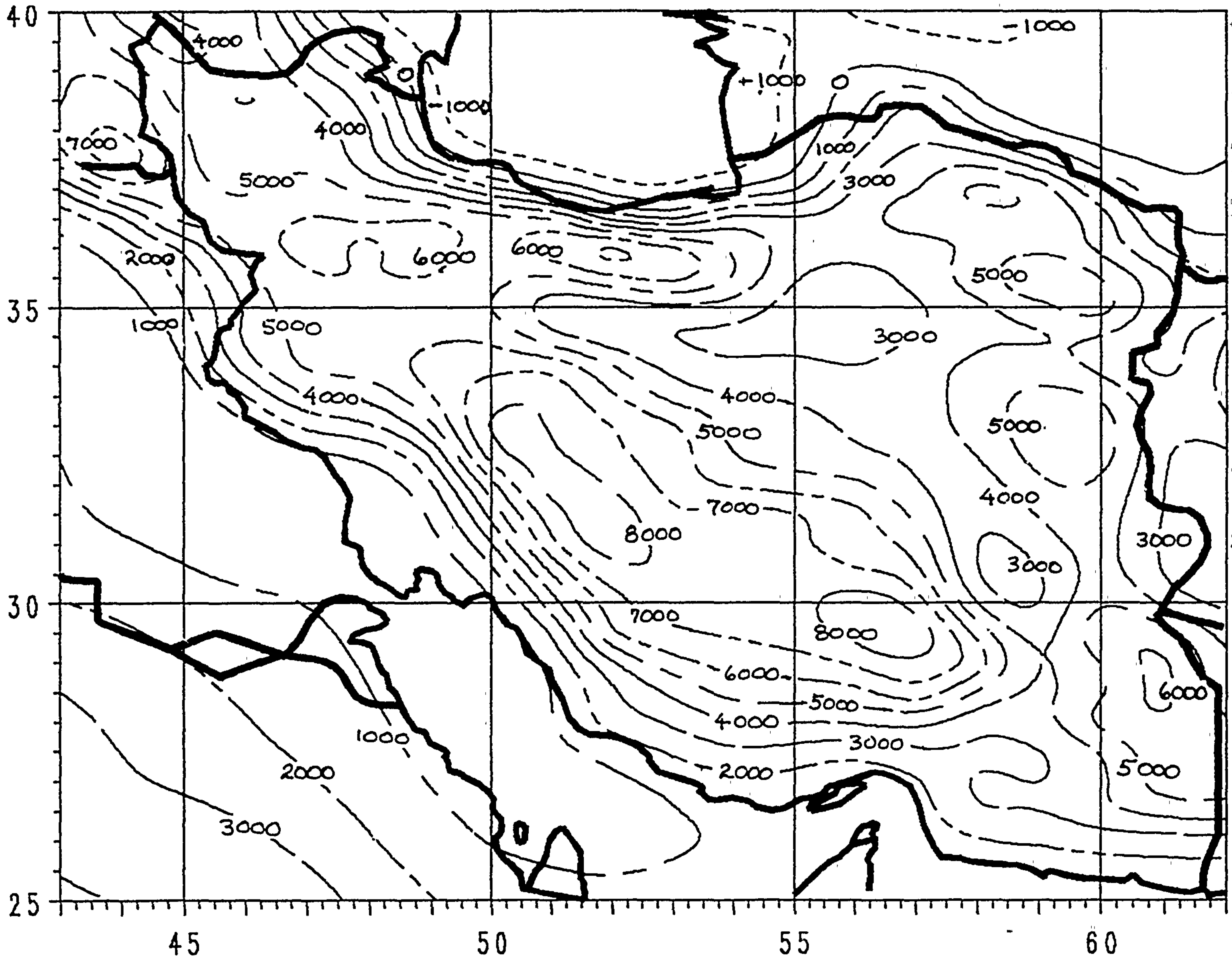

Figure A-4. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, February.

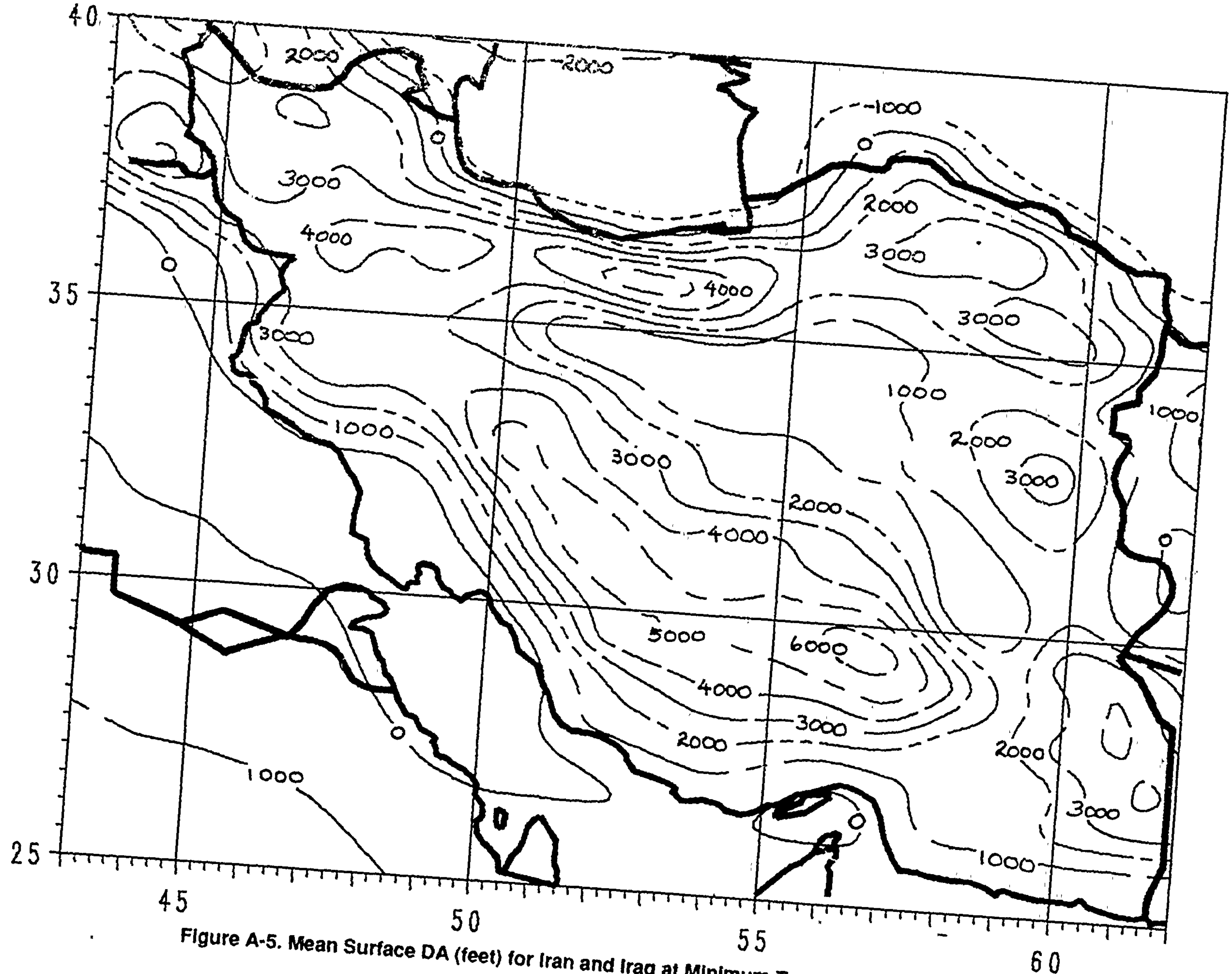

Figure A-5. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, March.

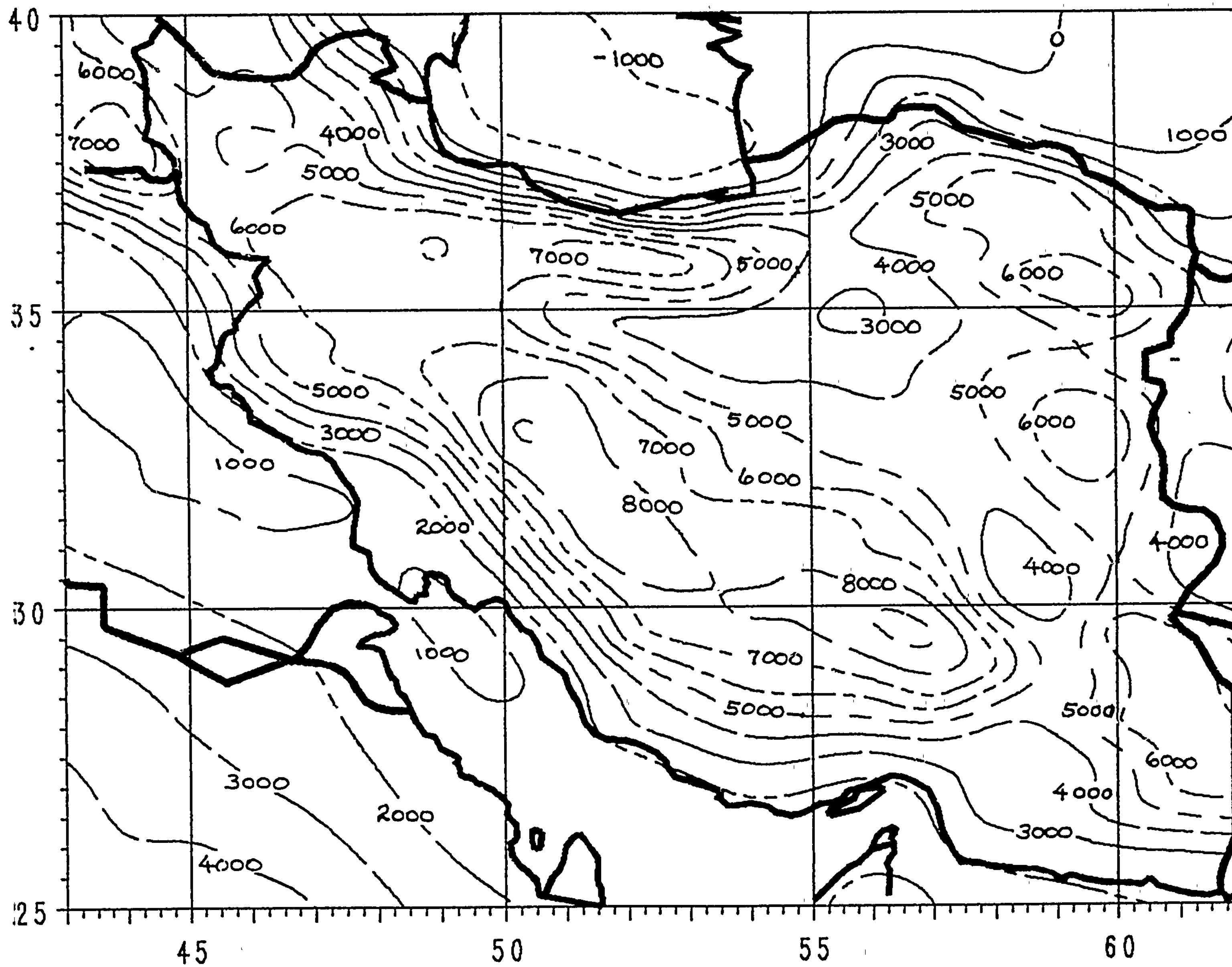

Figure A-6. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, March.

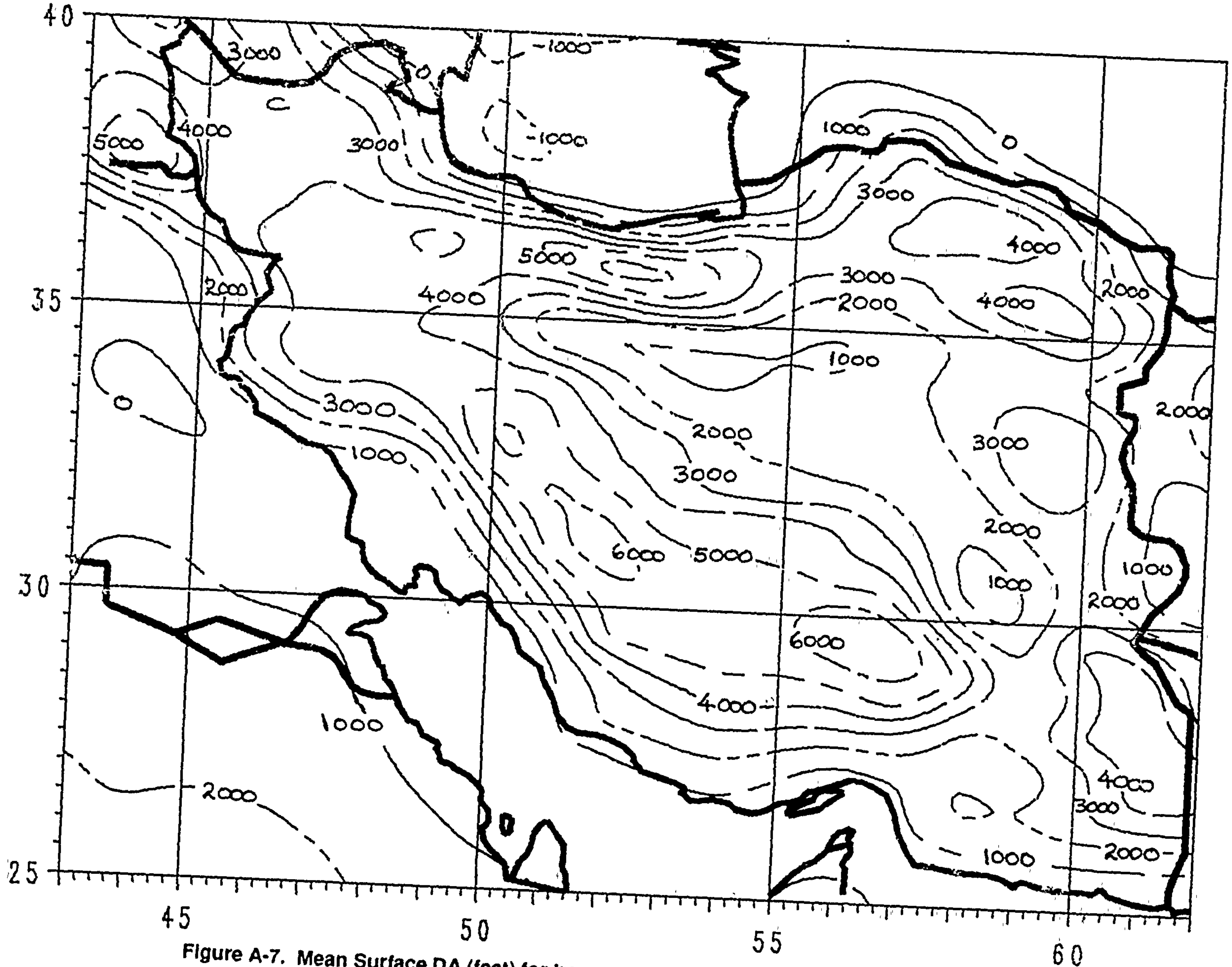

Figure A-7. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, April.

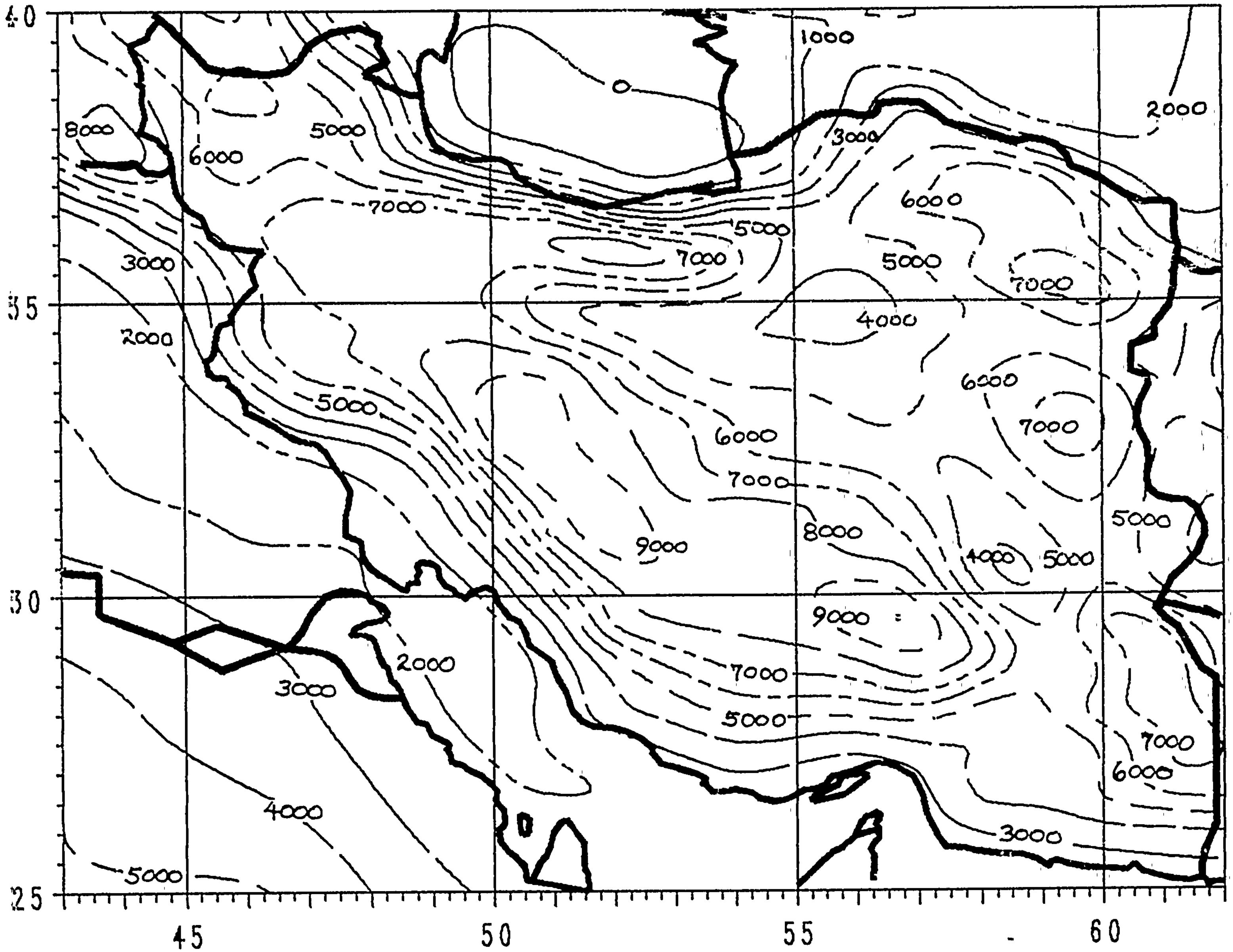

Figure A-8. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, April.

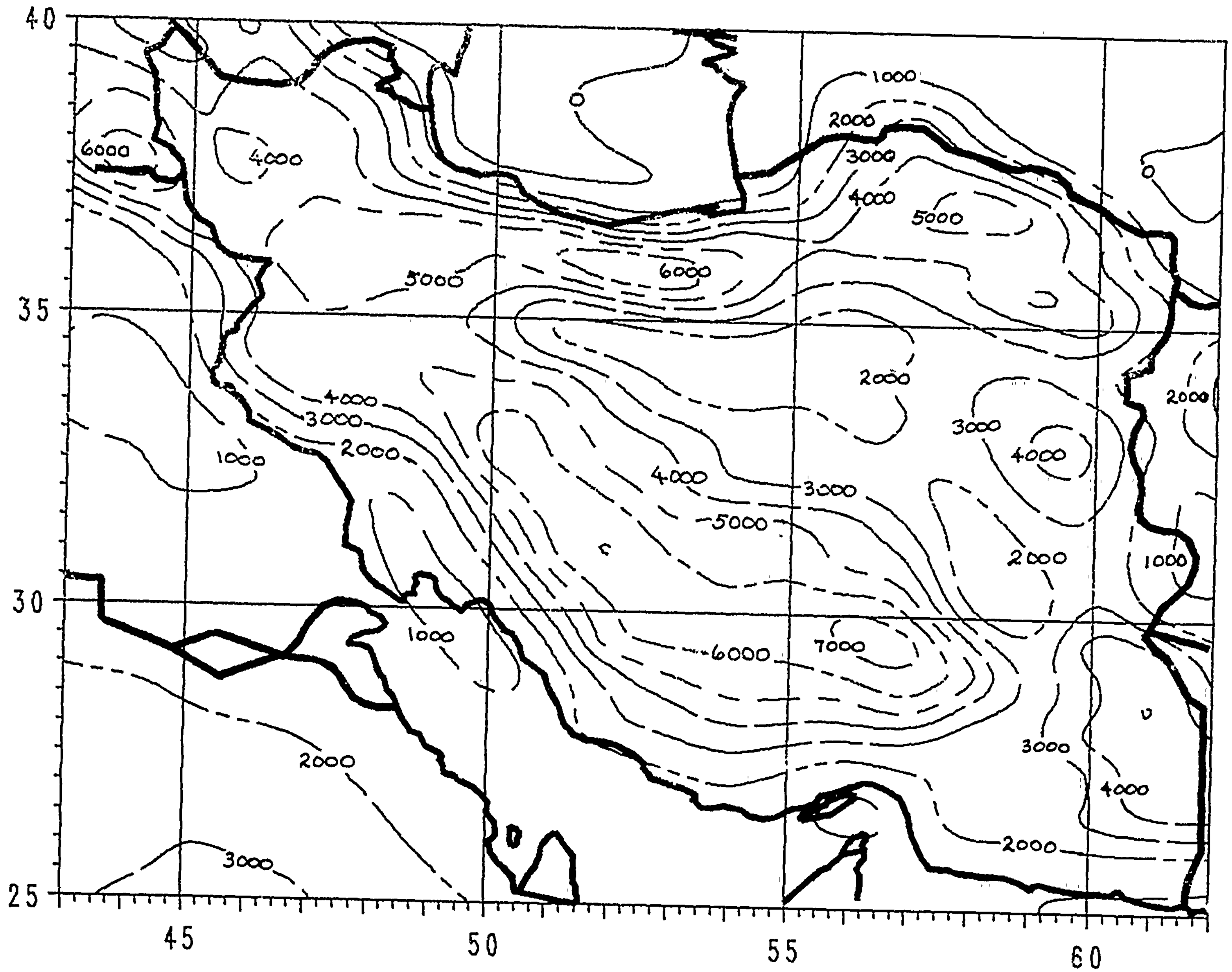

Figure A-9. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, May.

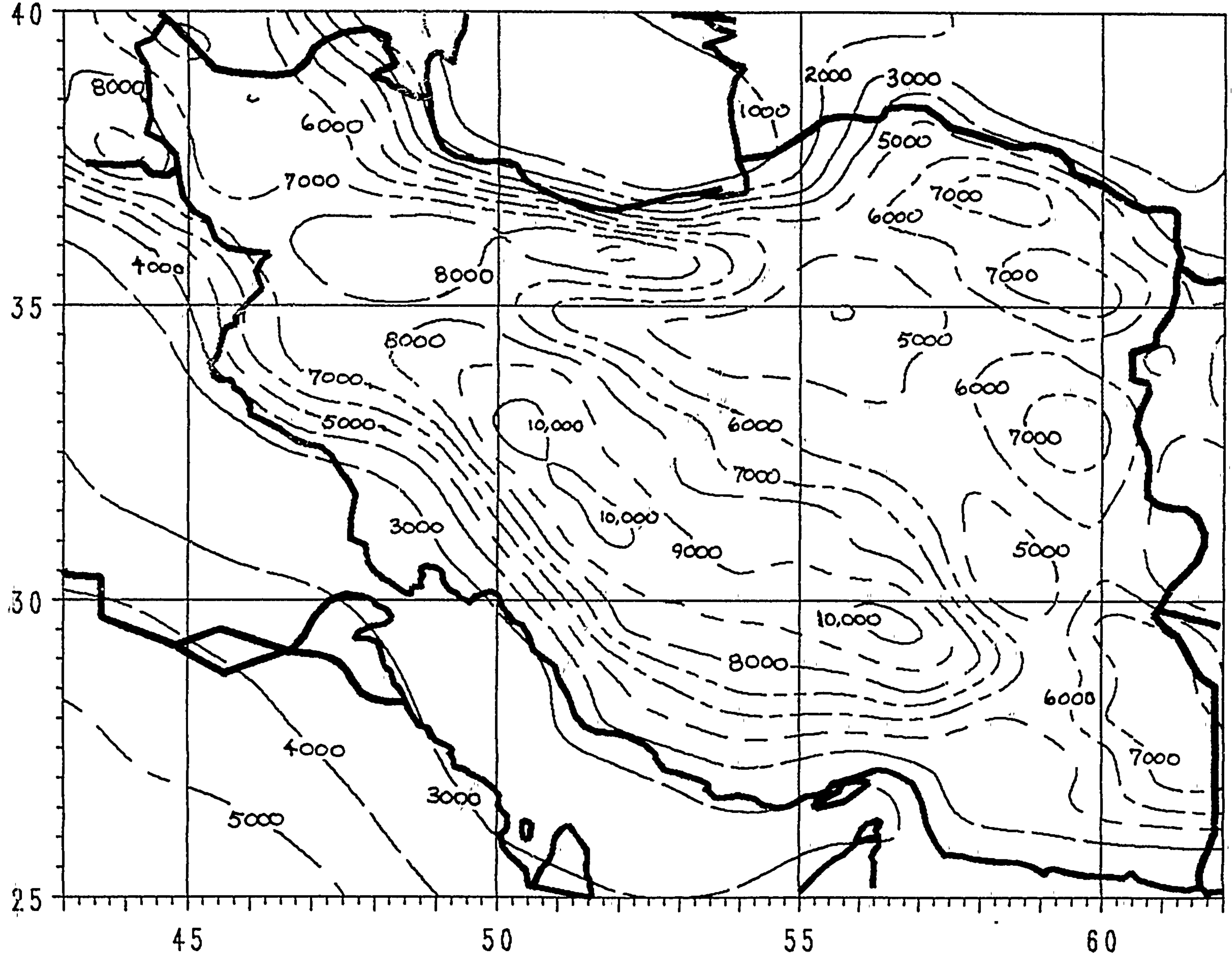

Figure A-10. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, May.

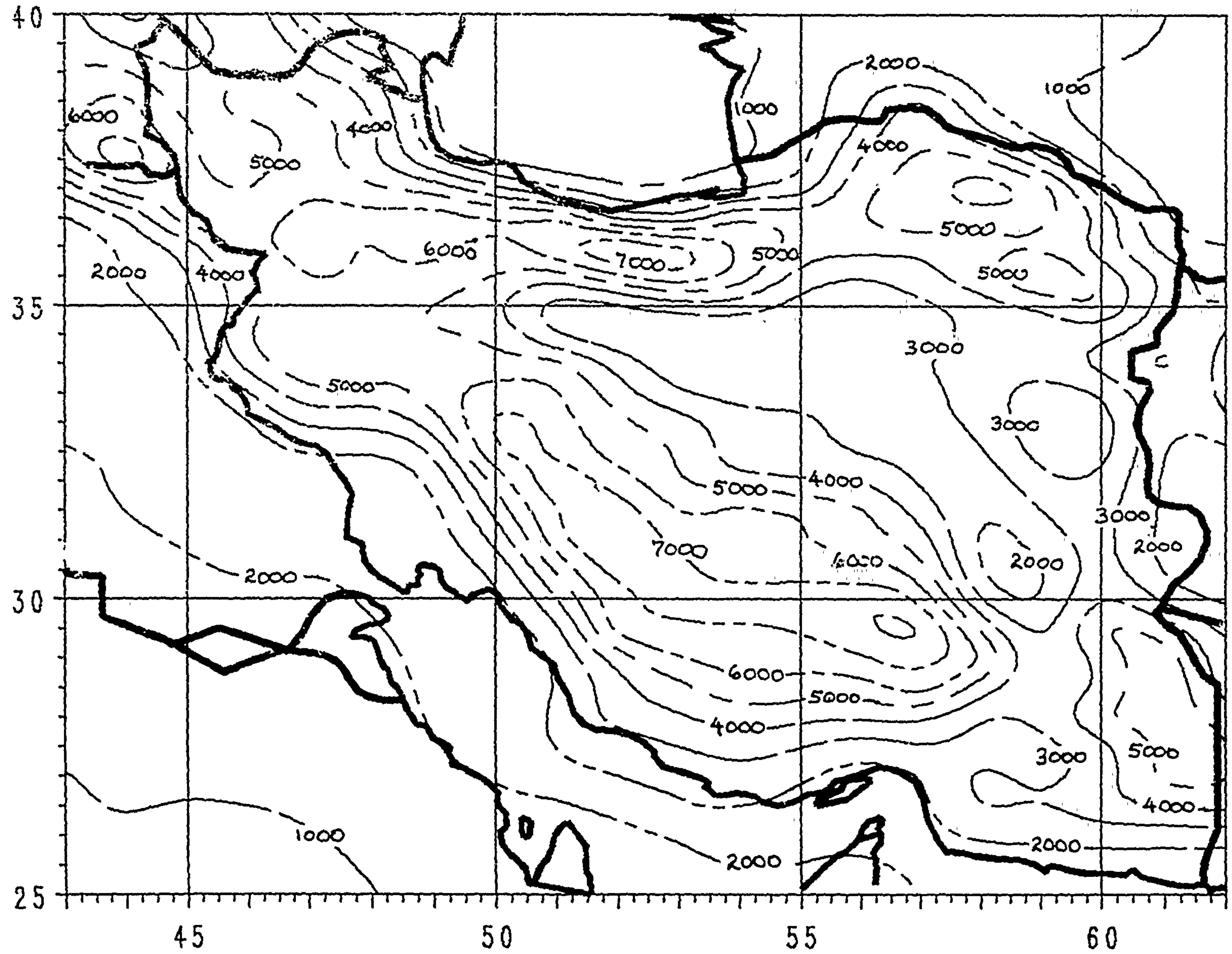

Figure A-11. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, June.

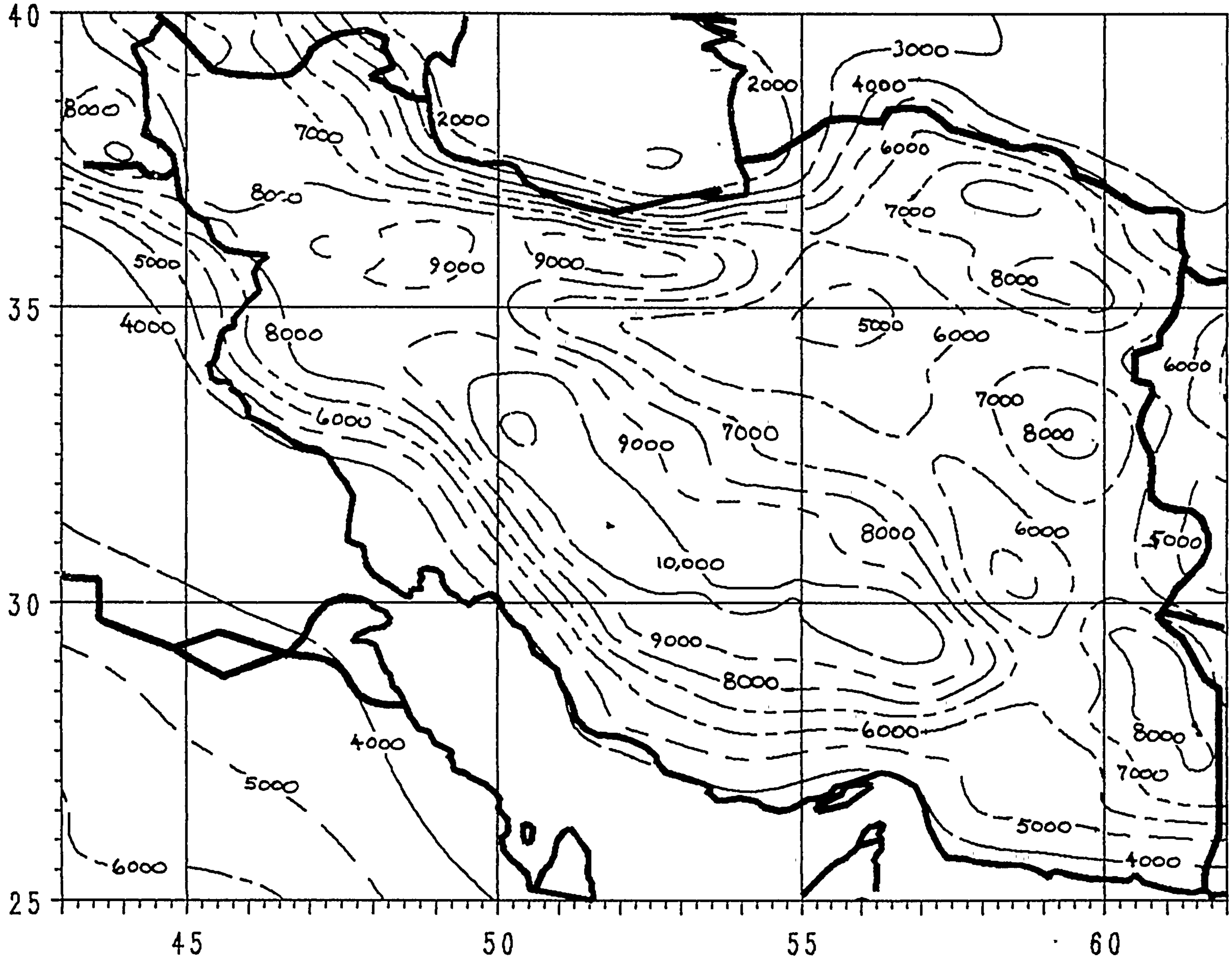

Figure A-12. Mean Surface DA (feet) for Iran and Iraq at MaximumTemperature for June.

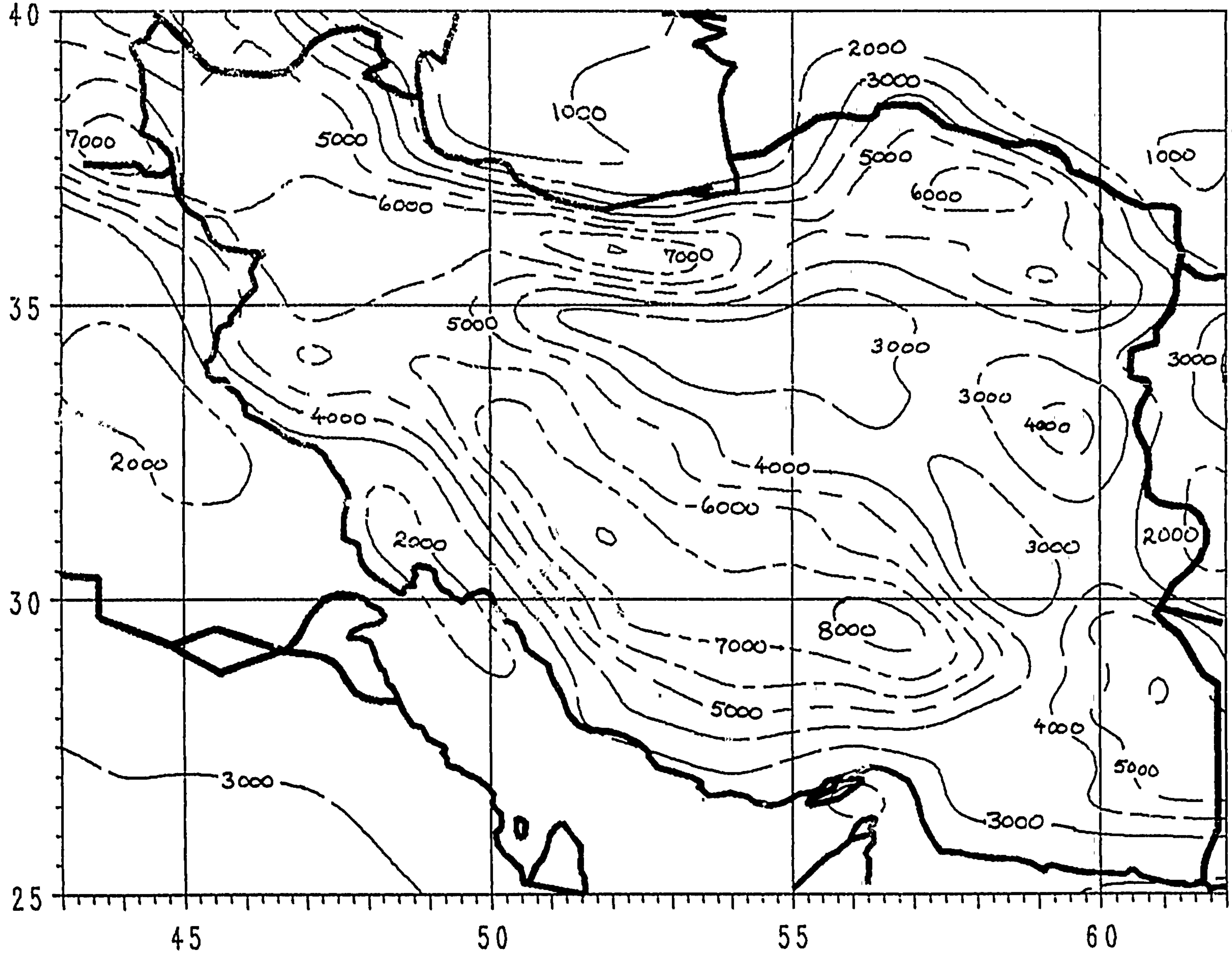

Figure A-13. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, July.

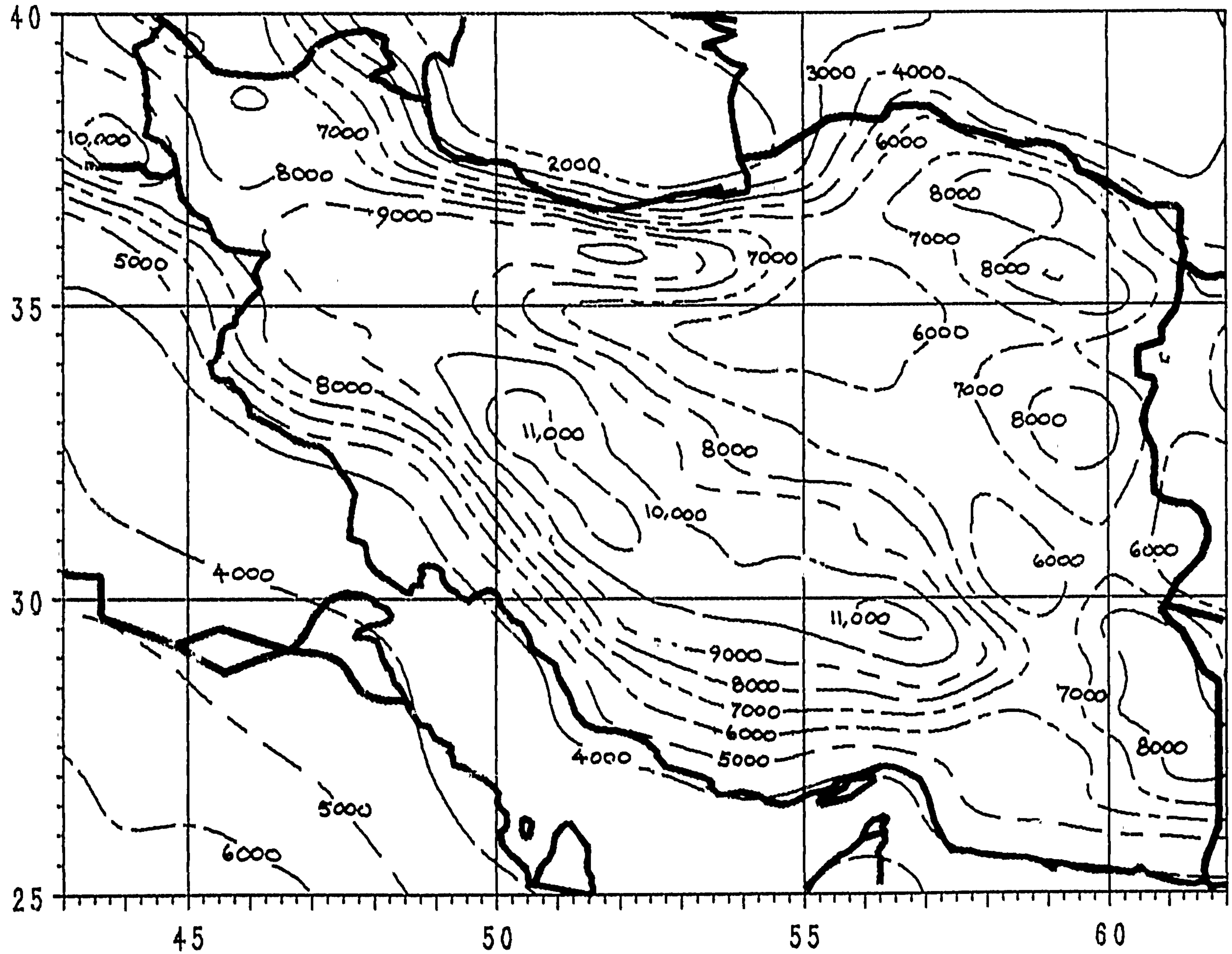

Figure A-14. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, July.

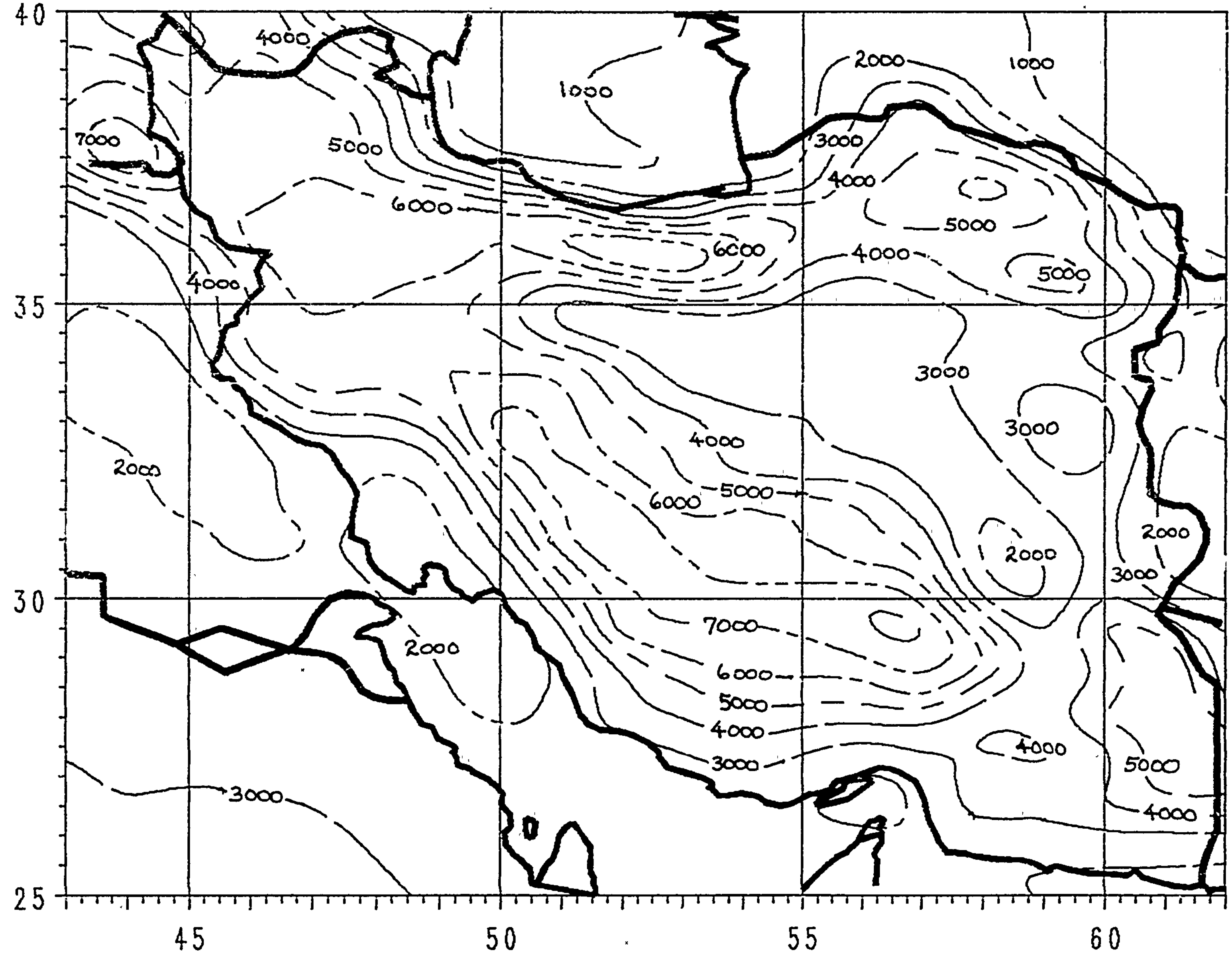

Figure A-15. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, August.

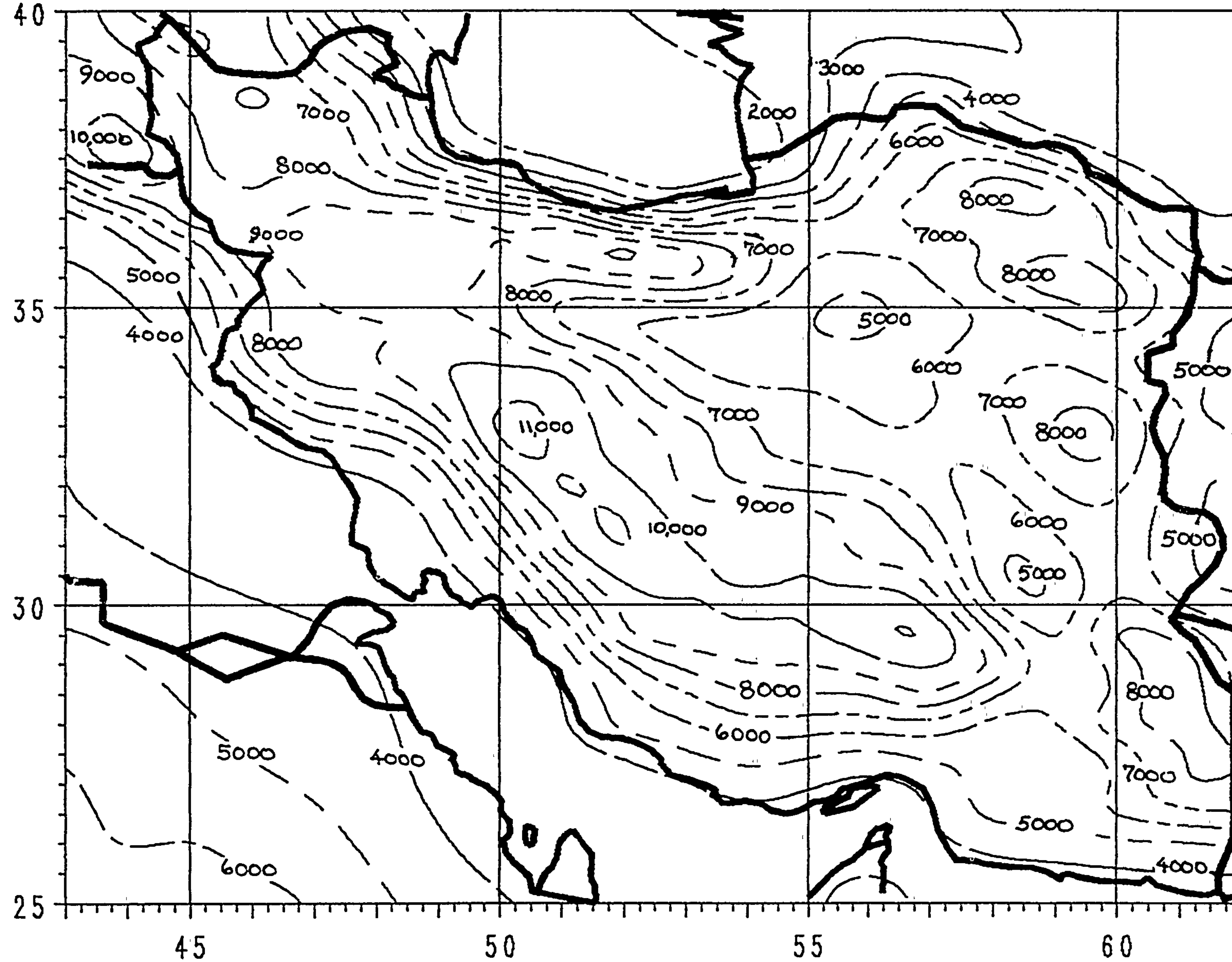

Figure A-16. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, August.

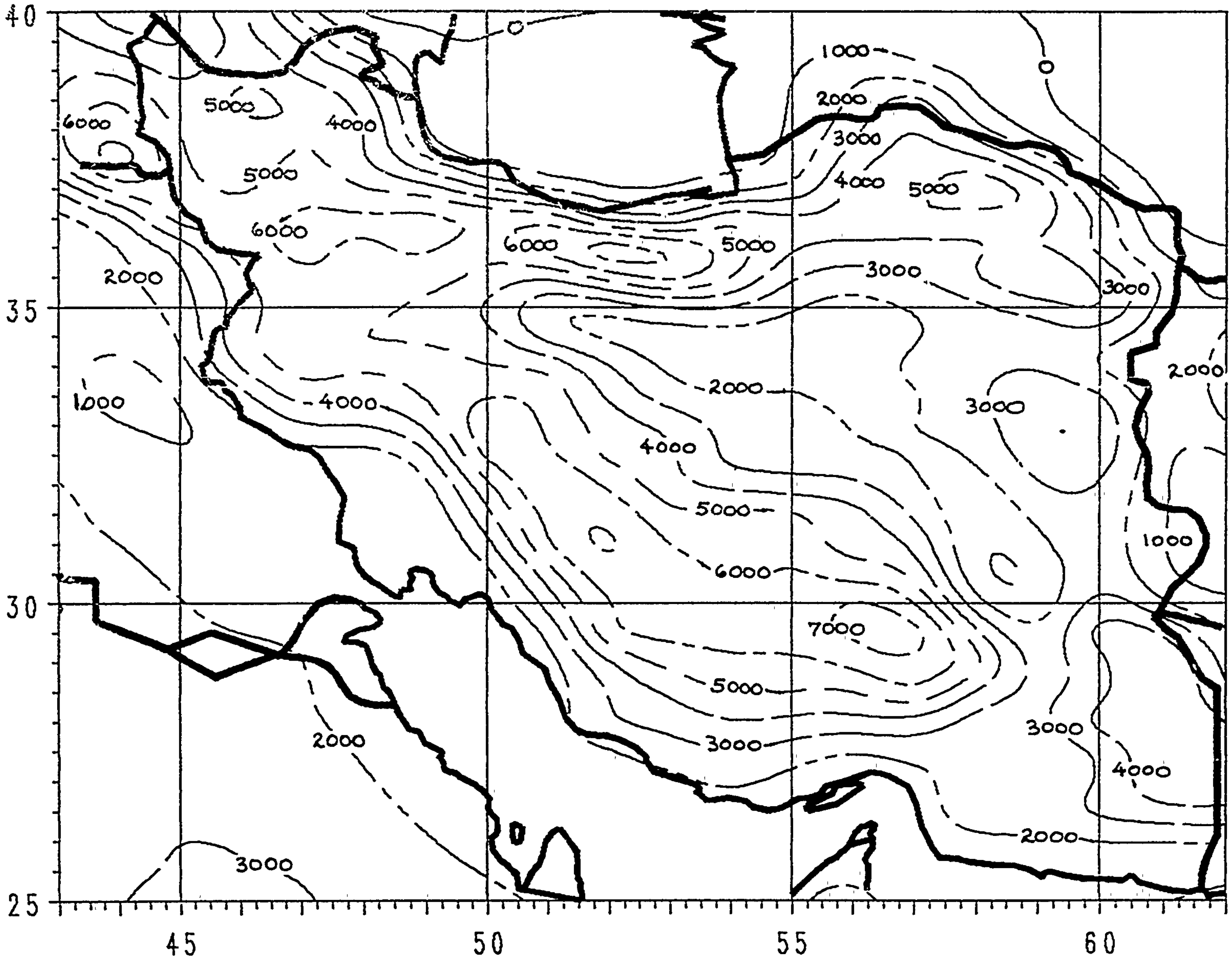

Figure A-17. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, September.

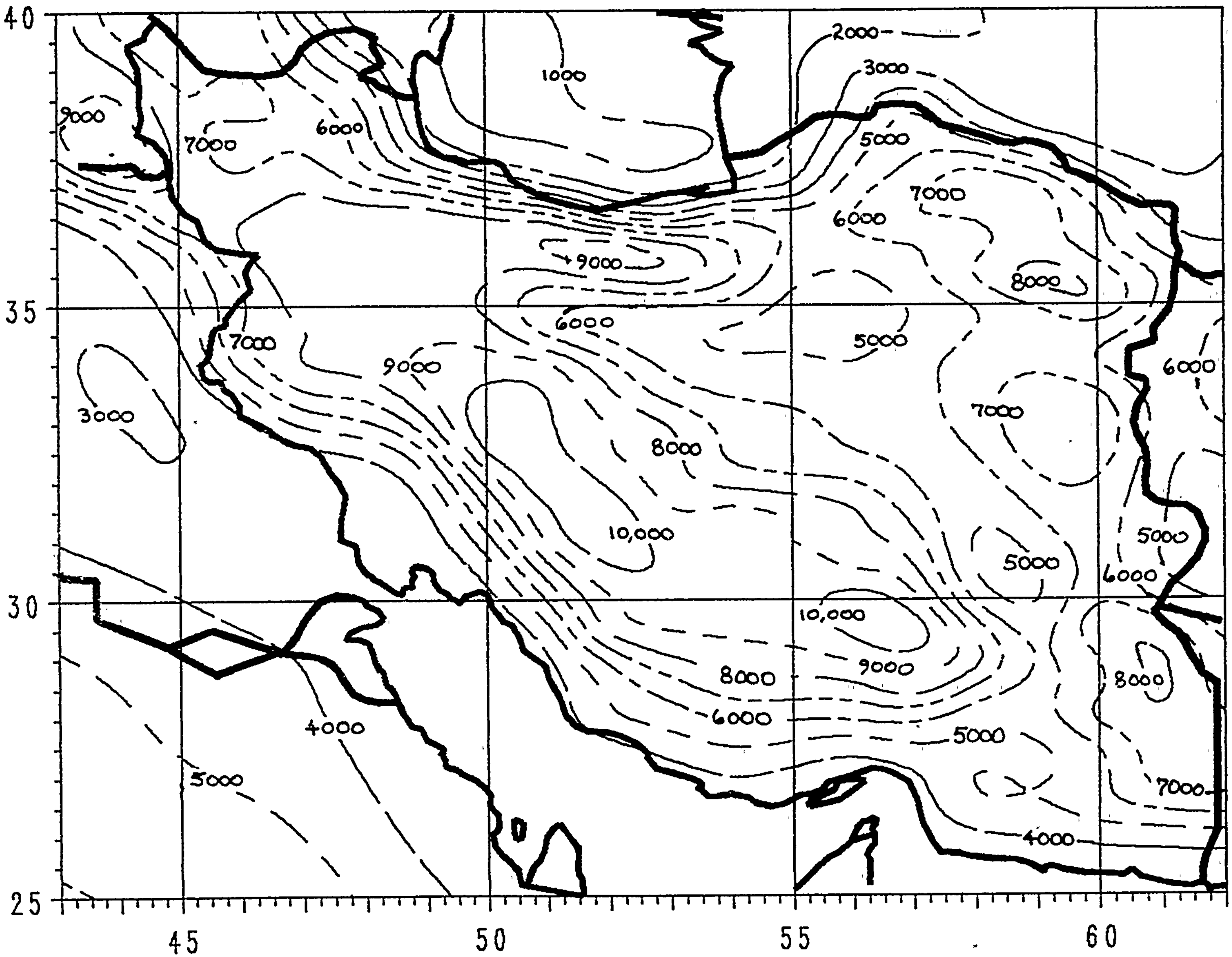

Figure A-18. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, September.

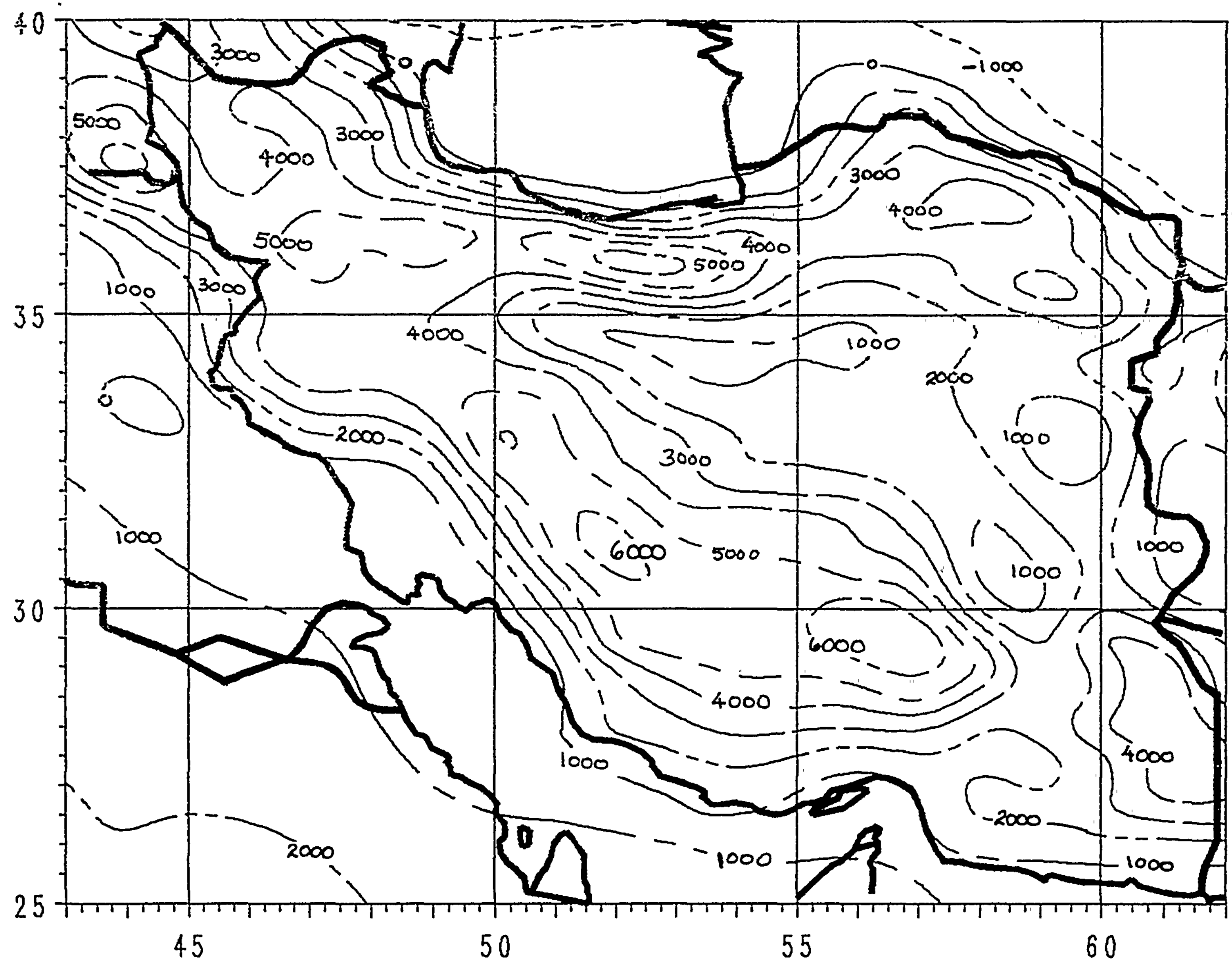

Figure A-19. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, October.

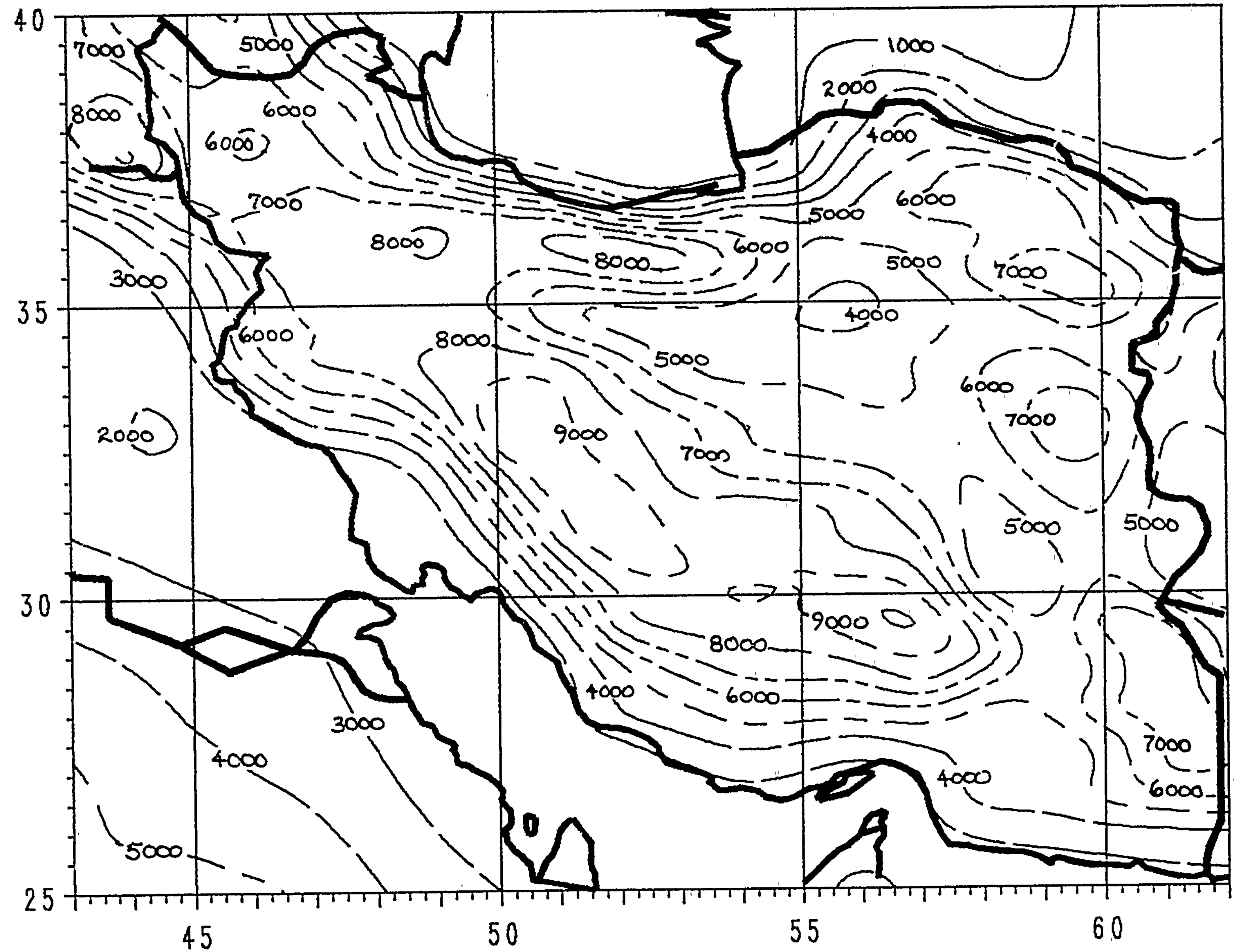

Figure A-20. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, October.

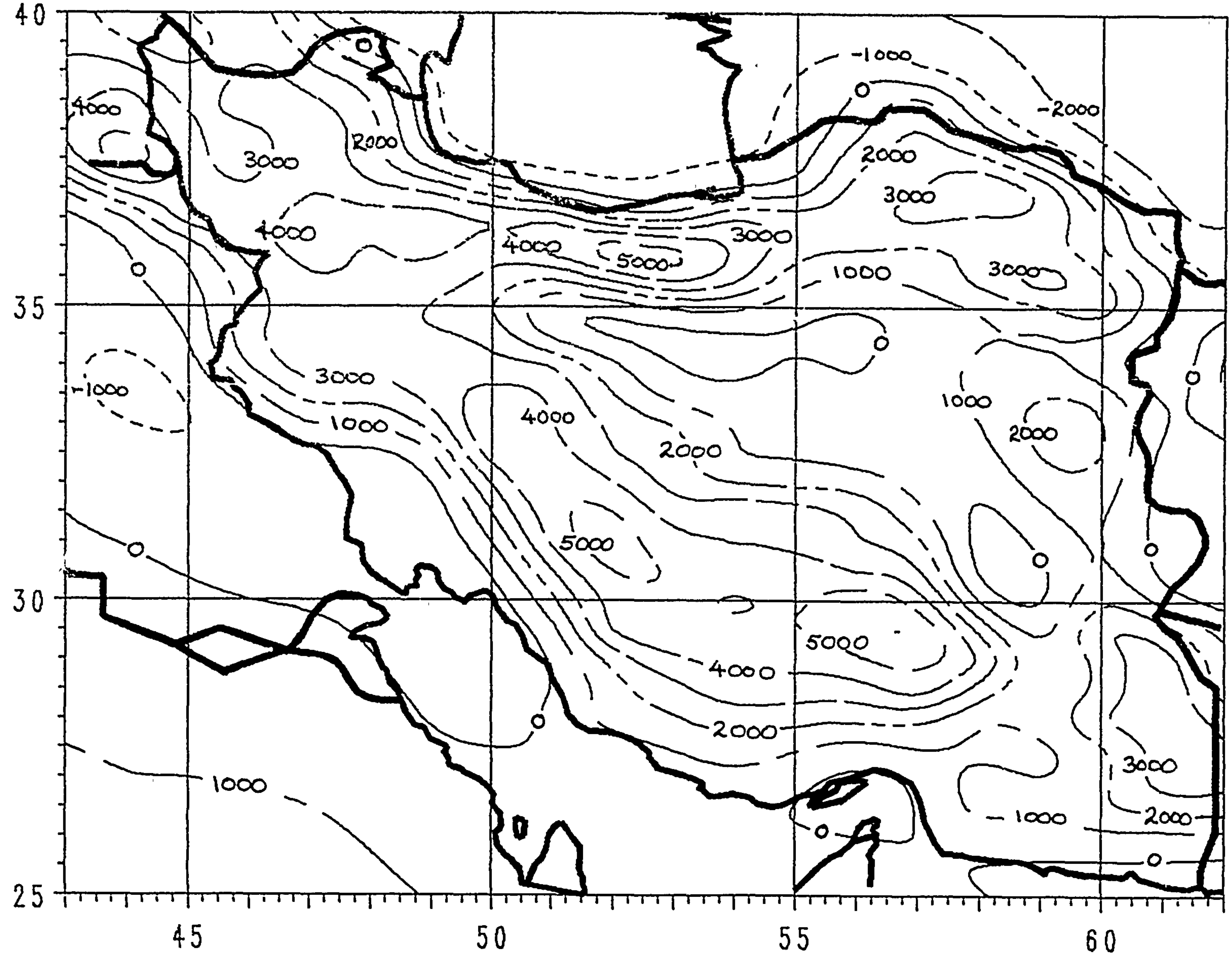

Figure A-21. Mean Surface DA (feet) for Iran and Iraq at Minimum-Temperature, November.

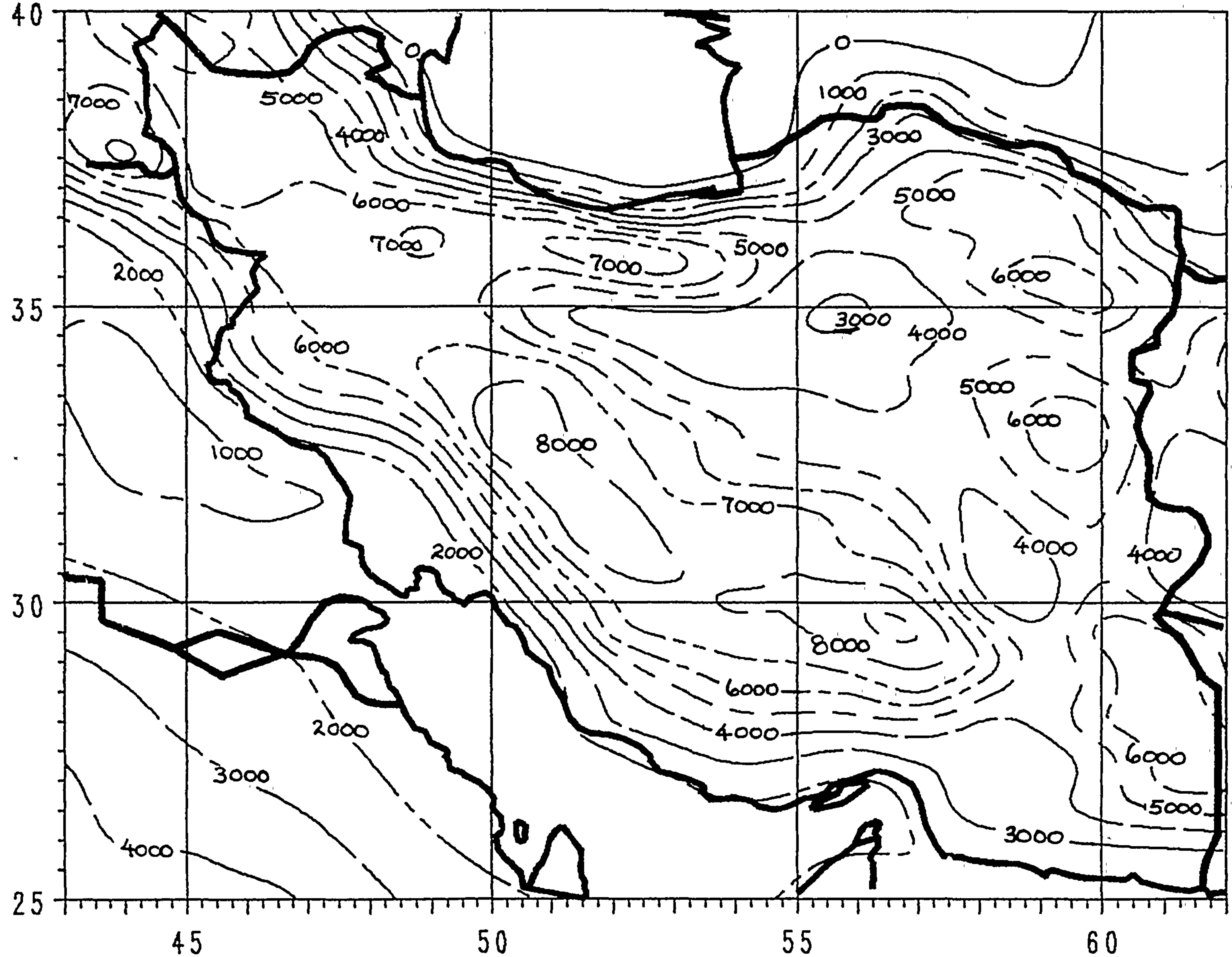

Figure A-22. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, November.

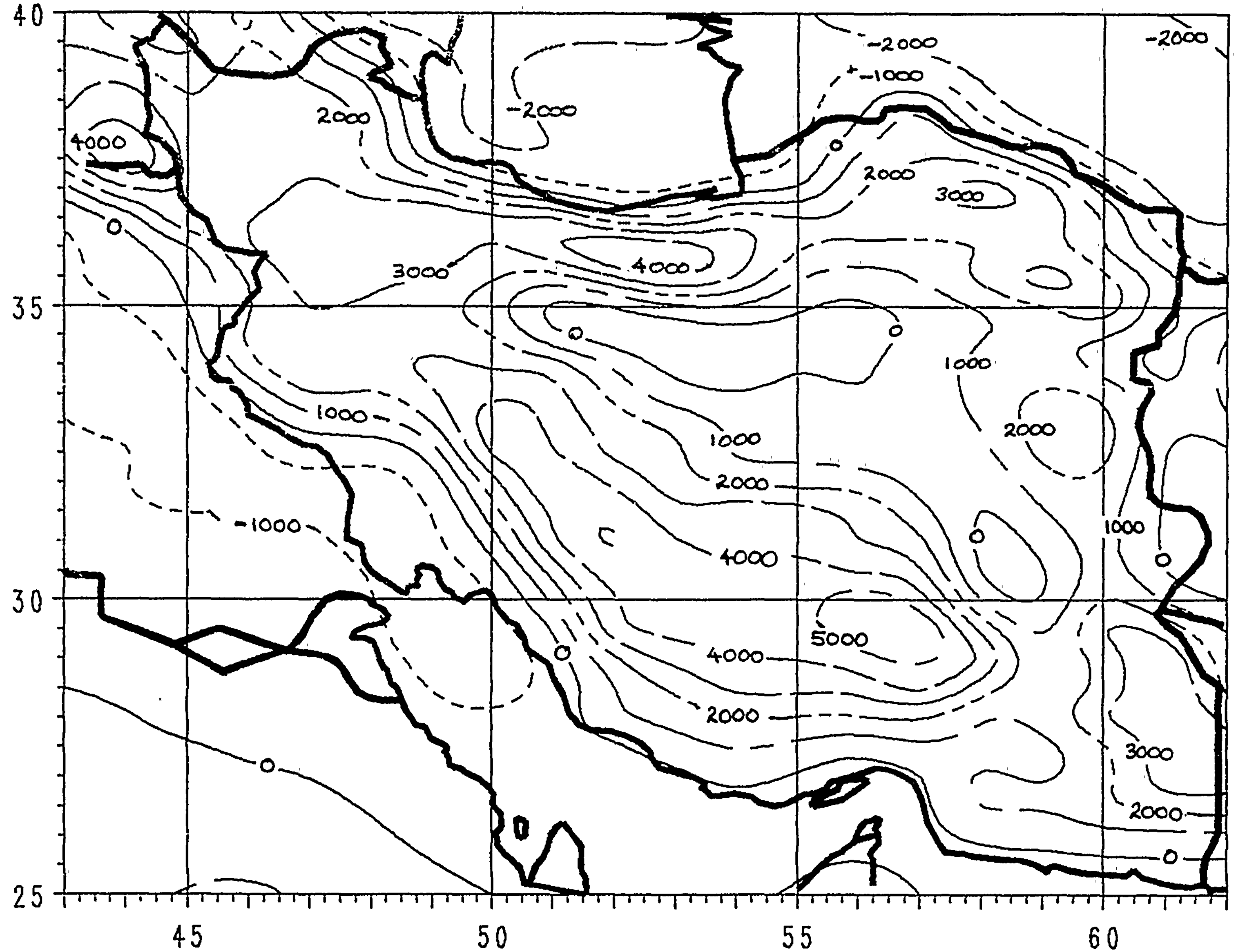

Figure A-23. Mean Surface DA (feet) for Iran and Iraq at Minimum Temperature, December.

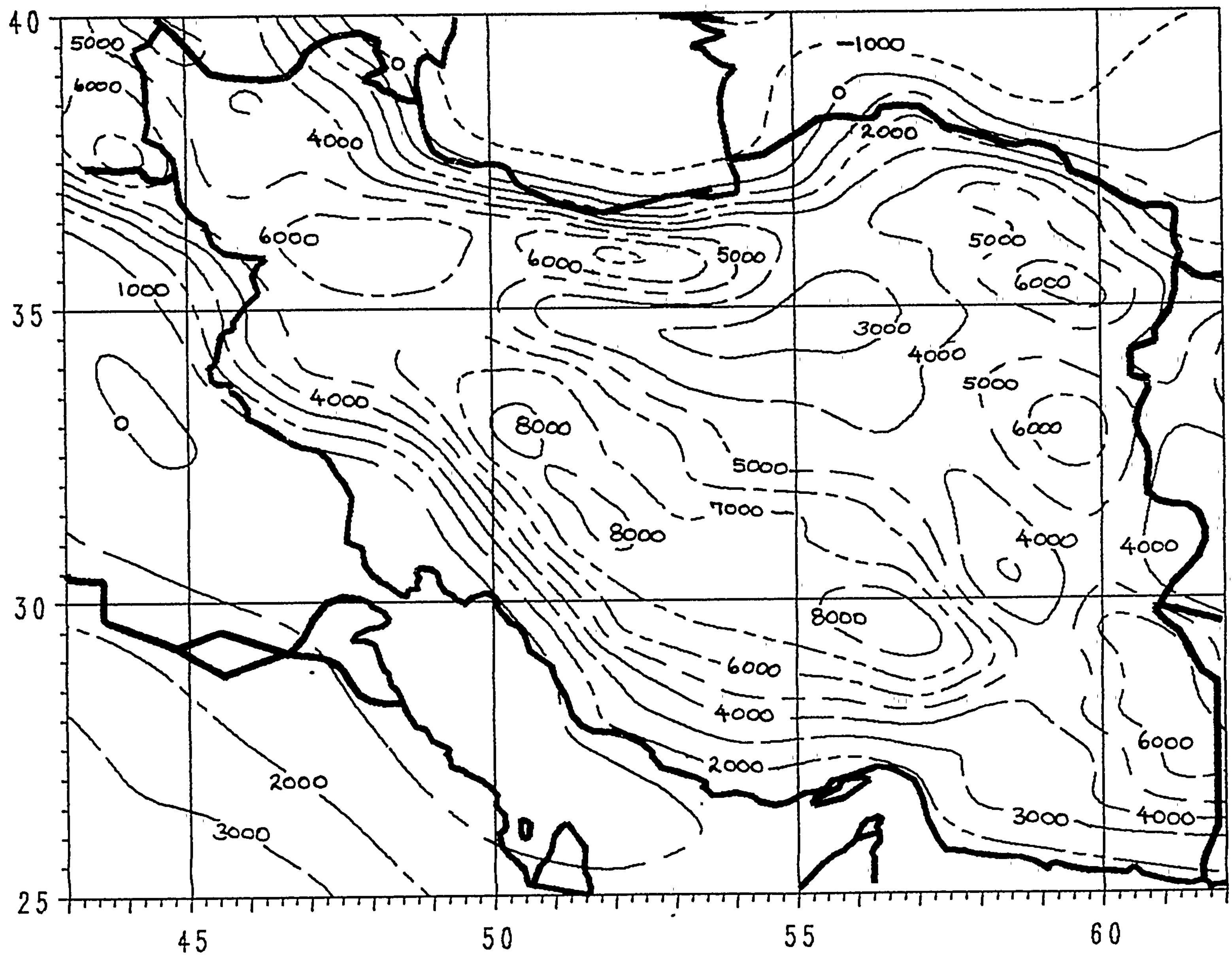

Figure A-24. Mean Surface DA (feet) for Iran and Iraq at Maximum Temperature, December.

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SPECIALIZED TERMS AND ACRINABs

ACRINAB	acronym, initialism, abbreviation
ALSTG	altimeter setting
C	Celsius
DA	Density altitude
DMA	Defense Mapping Agency
DTED	Digital Terrain Elevation Database
e	vapor pressure
ER	United Arab Emirates
e_{sl}	sea level vapor pressure
e_{sfc}	surface vapor pressure
F	Fahrenheit
g	gravity
h	station elevation
IQ	Iraq
IR	Iran
KW	Kuwait
mb	millibar
p	pressure
P_{sl}	sea-level pressure
p_{stn}	station pressure
POR	period of record
R	gas constant for dry air
r	mixing ratio
RA	USSR--ASIA
RS	USSR--Europe
T	Temperature
T_d	Dew-point temperature
T_m	Mean layer temperature
T_{max}	Maximum temperature
T_{min}	Minimum temperature
T_{sl}	Sea-level temperature
T_{sfc}	Surface temperature
T_v	Virtual temperature

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