TECHNICAL REPORT
ES-17

AREAL DISTRIBUTION AND DIURNAL VARIATION OF WATER VAPOR NEAR THE GROUND IN THE CONTIGUOUS UNITED STATES

by

ARTHUR V. DODD, PhD.

EARTH SCIENCES DIVISION

NOVEMBER 1965

U. S. Army Materiel Command
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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FOREWORD

Humidity is an important consideration in military activities, with effects ranging from deterioration of materiel to human efficiency and comfort. The Earth Sciences Division and its predecessor organizations have received numerous requests for information on the occurrence of humidity in specific areas of the United States. Until recently, reliable data for answering these requests have not been available. In the past, humidity information has resulted from observations taken in varying ways with varying degrees of accuracy, and there have been many pitfalls in the adequate climatic treatment of the data.

The need for a basic study of humidity distributions was further brought out at the first International Symposium on Humidity and Moisture held in Washington, D. C., in 1963. Not one paper at the conference dealt with distributional aspects of humidity.

This study was possible because of the recent availability from the Air Weather Service, USAF, of unusually detailed summaries of observations at approximately 200 stations in the United States. The study is condensed from the author's doctoral dissertation at Boston University. It is published for military use at the suggestion of the Army Meteorological Research and Development Coordination Committee and members of the Army Research Office. Some of the maps in this report have been published in the Monthly Weather Review and a portion of this study has been presented at the 1965 Annual Meeting of the Association of American Geographers.

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ABSTRACT

Maps showing the distribution in the United States (except Hawaii and Alaska) of average monthly dew point and its standard deviation, average monthly vapor pressure, and types of diurnal variation and range of dew point are presented and discussed. The maps are based on hourly psychrometric observations at nearly 200 stations for lengths of record of about ten years. The principal features of the maps are evidence of different humidity controls in different areas of the country. The tendency toward east-west alignment of the isopleths in the East, the varied pattern approximating contours in the mountainous areas, and the north-south alignment of the isopleths near the West Coast reflect the differing controls.

Four types of diurnal variation of dew point are defined based on the time of occurrence of the average minimum dew point. Type I is indicative of moisture availability at the earth's surface with highest dew points during the day. Type IV is found in dry areas and has lowest dew points during the day. Types II and III are transitional with both a morning and afternoon minimum of dew point in the daily cycle.

Areas of the United States with differing humidity regimes are delineated in Part IV of the study. The areas, differentiated on the basis of average annual dew point and the range of average monthly dew points, reflect the dominant control of latitude in the East, altitude in the mountain states, and exposure on the West Coast. This final section serves to summarize the maps presented in the report.

AREAL DISTRIBUTION AND DIURNAL VARIATION OF WATER VAPOR NEAR THE GROUND IN THE CONTIGUOUS UNITED STATES

PART I

INTRODUCTION

MEASURES OF HUMIDITY AND TREATMENT OF BASIC DATA

1. Measures of humidity

There are a number of ways to express "the state of the atmosphere with respect to the water vapour it contains*." These include dew point, relative humidity, specific humidity, mixing ratio, saturation deficit, absolute humidity, and wet bulb temperature. Most authorities believe that dew point is the most useful humidity parameter for climatological purposes because it is expressed in the temperature scale, and is readily convertible to vapor pressure.** It is a relatively accurate measure of the amount of water vapor in the air. The dew point is defined as the temperature to which a given parcel of air must be cooled at constant pressure and water vapor content in order for saturation to occur (a relative humidity of 100 percent).

Vapor pressure, the partial pressure of the atmosphere exerted by the water vapor in it, is a fundamental expression of humidity. When this partial pressure over a flat water surface is in equilibrium with the pressure driving molecules of water (at the same temperature) into the air, the transfer of water molecules between the water and the air is in balance. The pressure of the water vapor is then called the saturation vapor pressure. It is controlled by one thing alone: the temperature. Dew point and vapor pressure are single-valued functions of each other.*** Maps of both mean monthly dew point and mean monthly vapor pressure are included in this study because differing disciplines are familiar with one or the other of these measures of humidity. There also are questions concerning the units to express the dew point and vapor pressure. Since the data were summarized in degrees Fahrenheit the dew point maps in this study are expressed in that scale. The vapor pressure maps are expressed in inches of Mercury because a contour interval of .05 inches of Mercury is a convenient and reasonable contour interval. Earlier United States

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* Definition of humidity in A Dictionary of Geography by W. G. Moore, Penguin Books, 1960.

** Byers, 1944, p. 157; Hare 1958, p. 24; Penman, 1955, p. 14; Petterssen, 1940, p. 26; to name a few.

*** For a given dew point there is only one saturation vapor pressure.

maps of mean monthly vapor pressure were also expressed in inches of Mercury. Because vapor pressures are commonly expressed in millibars or millimeters of Mercury, a conversion graph showing the relationship between the various units is included (Fig. 1). The figures on the graph will be referred to later in discussing a dew point averaging error.

Dew points can be measured directly in several ways. An infrared hygrometer is sensitive to the absorption by water vapor of a light beam of known wave length. A dew point hygrometer measures the temperature of a cooled polished surface at the moment dew forms. In its most advanced form this instrument utilizes a photoelectric cell to detect the formation of dew, and thermoelectric cooling to produce the cold surface (Ruskin, 1963, p. 59). Although these and other methods are gaining favor for dew point measurements, they are only now replacing the more familiar psychrometic measurements utilizing dry bulb and wet bulb thermometers. The dew point is determined from dry bulb and wet bulb readings by reference to tables or by use of a psychrometric slide rule, either of which use dry bulb and depression of the wet bulb as arguments.

Most other expressions of water vapor in the atmosphere can be derived from the vapor pressure. The relative humidity is the ratio of the actual vapor pressure to the saturation vapor pressure, expressed as a percentage. Saturation deficit is the difference between the saturation vapor pressure and the existing vapor pressure. Hare (1958, p. 22) characterizes relative humidity as "the meteorological equivalent of absolute humbug," and Penman (1955) refers to relative humidity as a "used, misused, confused, and abused" parameter. These indictments are based on the fact that a given percentage of relative humidity at different temperatures has quite a different significance, and therefore for most purposes it is not meaningful to treat relative humidity statistically. Absolute humidity and wet bulb temperature are other measures of humidity whose use is limited because they are not conservative measures* of the amount of moisture in the atmosphere.

Specific humidity and mixing ratio are conservative measures of humidity. Specific humidity is defined as the mass of water vapor per unit mass of moist air, while the mixing ratio is the unit mass of water vapor per unit mass of dry air. Frequently, mixing ratio and specific humidity are used interchangeably because the difference between them even at high humidities is less than the error of most humidity measurements. Both parameters are useful in air mass analysis because they are not changed except by the addition or subtraction of water vapor. Unfortunately, published summaries of mixing ratio or specific humidities are not

* A conservative measure is one whose values do not readily change. See Huschke (1959, p 129), Peterssen (1940, Chapter I).

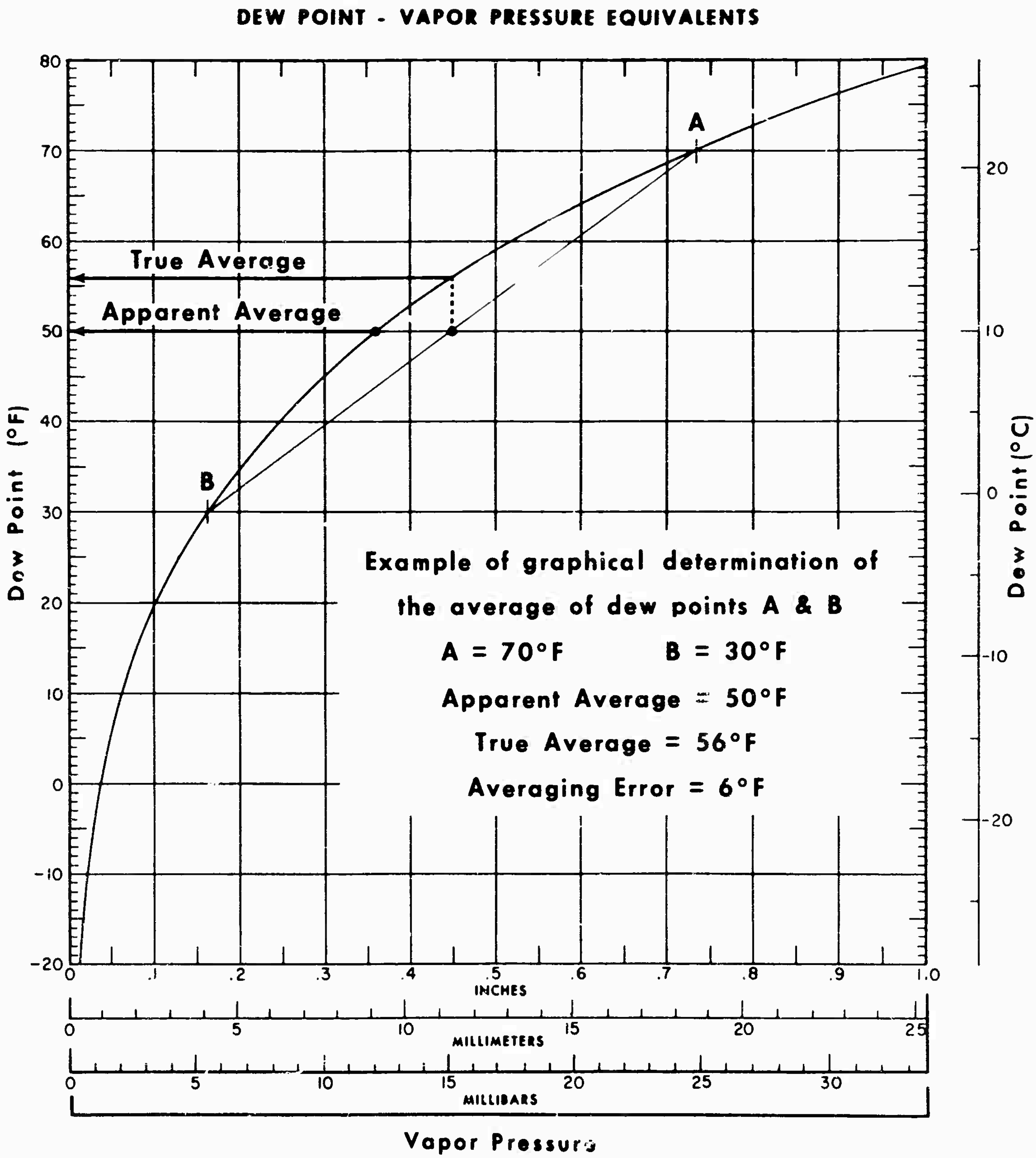

DEW POINT - VAPOR PRESSURE EQUIVALENTS
True Average
Apparent Average
A
B
Example of graphical determination of the average of dew points A & B
A = 70°F B = 30°F
Apparent Average = 50°F
True Average = 56°F
Averaging Error = 6°F
Dew Point (°F)
Dew Point (°C)
INCHES
MILLIMETERS
MILLIBARS
Vapor Pressure

Figure 1

common in the literature. They can be defined in terms of vapor pressure and atmospheric pressure, and summaries of the vapor pressure or dew point are more readily available.

2. Basic data

Summarized humidity tabulations are now available which permit a more meaningful and detailed analysis of the distribution of water vapor near the ground in the United States than had been accomplished by earlier investigators (Day, 1917; Dodd, and Hastings, 1958; Sellers, 1960; Shaw, 1928; and Tunnell, 1958). These new data also permit a more penetrating investigation of the diurnal variation of water vapor near the ground than was possible in earlier studies, since they include summaries of hourly humidity measurements.

The primary source of data for this study is psychrometric summaries for 191 stations in the contiguous United States prepared by the United States Air Force (United States Air Force, 1958-1962). The summaries provide a comprehensive monthly listing by 2-degree temperature classes of concurrent dry bulb and wet bulb temperatures each hour. Similar tabulations for eight 3-hour time groups for each month are also given. The time groups in Local Standard Time are 0000, 0100, 0200; 0300, 0400, 0500, 0600, 0700, 0800, etc. Although the data are broken down by 3-hour time groups, they are summaries of hourly observations.

In a separate section of the summaries statistical data for individual elements are provided. These include the average dew point and standard deviation for each month, and for each of the eight time periods. The average dew point determined from hourly observations has not previously been available for a large number of stations in the United States, and its availability now makes possible a more accurate representation of the distribution of average dew point. Inclusion of the standard deviation makes it possible to estimate the error inherent in averaging dew points directly. The standard deviation is also determined from hourly data.

The locations of the stations for which the Air Force summaries are available are shown in Figure 2. The locations, elevations, and periods of record of each station are enumerated in Table I. An identifying station number is shown on both the map and the table to facilitate cross reference. It will be noted from Table I that the period of record is not the same at all stations. Most stations have 10-year records, but 31 stations have longer records and 18 have shorter. The unity of the period of record is probably best illustrated by the fact that 164 of the 191 stations have records during the entire 6-year period, 1953 through 1958.

A second source of data for this study was unpublished average monthly dew point data from the files of the Hydrological Services Division

LOCATION OF STATIONS WITH PSYCHROMETRIC SUMMARIES

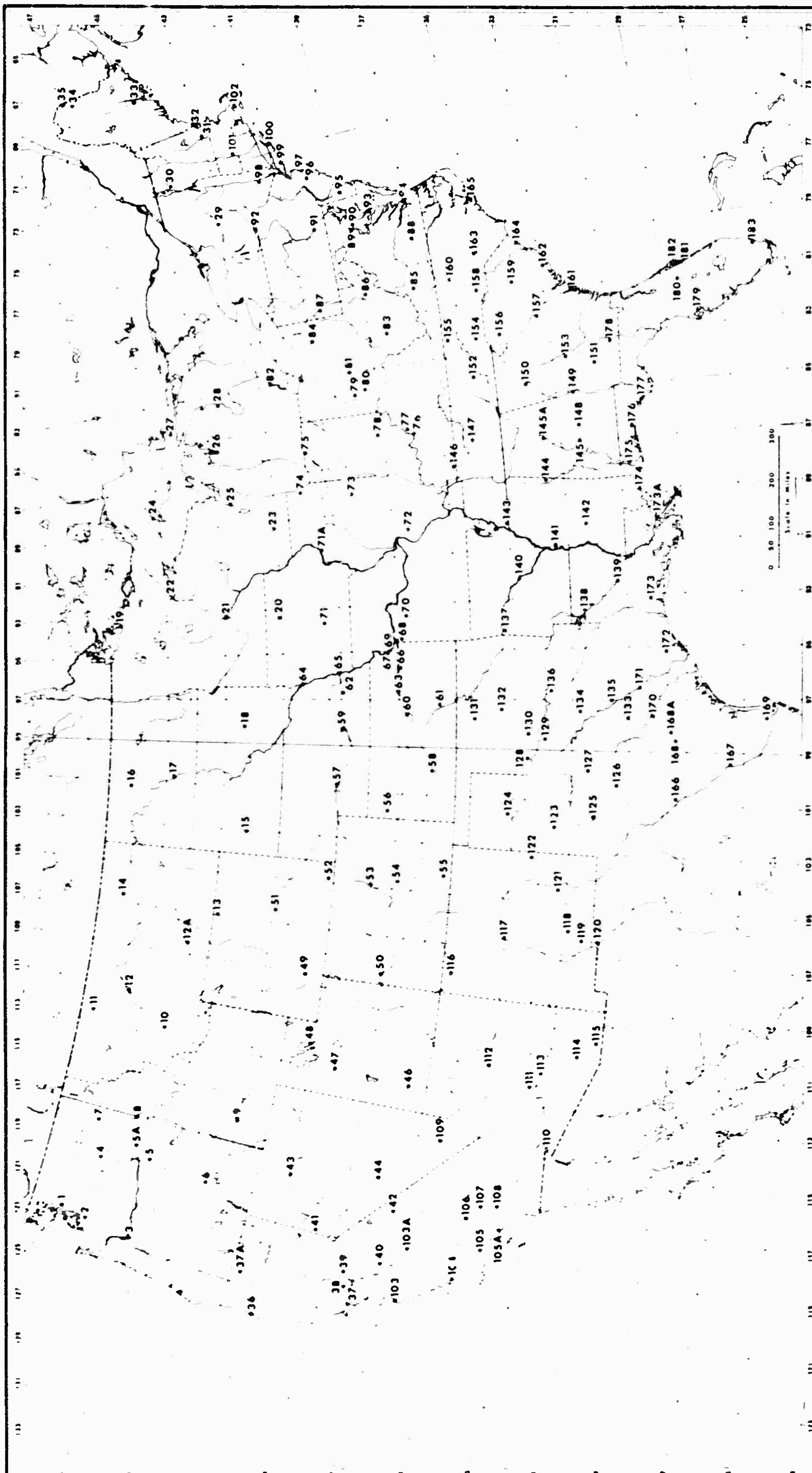


Figure 2

TABLE I

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

AAF - Army Air Field
AFB - Air Force Base
FAA - Federal Aviation Agency
MCAS - Marine Corps Air Station
NAF - Naval Air Field
NAS - Naval Air Station
AS - Army Station
WBAS - Weather Bureau Airport Station

STATION	NO.*	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
ALABAMA					
Birmingham WBAS	145A	630	33 34	86 45	Mar 53 - Feb 63
Montgomery AFB	148	184	32 23	86 21	Sep 49 - Aug 59
Mobile (Brookley AFB)	175	26	30 38	88 04	Feb 50 - Jan 60
Selma (Craig AFB)	145	207	32 21	86 59	Feb 50 - Jan 60
ARIZONA					
Chandler (Williams AFB)	113	1,351	33 18	111 40	Jan 46 - Feb 59 less Mar 46
Flagstaff WBAS	112	6,993	35 08	111 40	Nov 51 - Oct 61
Fort Huachuca AS	115	4,664	31 34	110 20	Oct 54 - Dec 61
Phoenix (Luke AFB)	111	1,093	33 32	112 23	Dec 41 - Nov 46, Apr 51 - Feb 59, less Mar 46
Tucson (Davis-Monthan AFB)	114	2,654	32 10	110 53	Oct 49 - Sep 59
Yuma WBAS	110	199	32 40	114 36	Feb 50 - Jan 60
ARKANSAS					
Fort Smith WBAS	137	463	35 20	94 22	Jan 49 - Dec 58
Little Rock WBAS	140	265	34 44	92 14	Aug 49 - Jul 59
CALIFORNIA					
Arcata FAA	36	217	40 59	124 06	Dec 49 - Nov 58
Bishop WBAS	42	1,165	37 22	118 22	Nov 51 - Oct 61
Edwards AFB	106	2,316	34 55	117 54	Jan 46 - Jul 59
Fairfield (Travis AFB)	38	72	38 16	121 56	Jan 46 - Jun 58
Fresno WBAS	103A	330	36 46	119 43	Jan 53 - Dec 62
Long Beach WBAS	105A	43	33 49	118 09	Jan 46 - Sep 57
Merced (Castle AFB)	40	178	37 22	120 34	Sep 49 - Aug 59
Montague FAA	37A	2,635	41 46	122 28	Jan 50 - Dec 54
Monterey NAF	103	164	36 35	121 52	Feb 48 - Mar 59
Oxnard AFB	105	94	34 15	119 05	Apr 44 - Jul 45, Dec 52 - Dec 60
Riverside (March AFB)	108	1,511	33 54	117 15	Oct 49 - Sep 59
Sacramento (Mather AFB)	39	92	38 34	121 18	Jan 52 - Dec 61
San Rafael (Hamilton AFB)	37	3	38 04	122 31	Feb 50 - Jan 60
Santa Maria WBAS	104	259	34 54	120 28	Jan 48 - Jul 58
Victorville (George AFB)	107	2,890	34 36	117 20	Jan 42 - Feb 46, May - Sep 48, Sep 50 - Feb 59
COLORADO					
Colorado Springs WBAS	54	6,173	38 49	104 42	Dec 50 - Nov 60
Denver (Lowry AFB)	53	5,396	39 43	104 54	Feb 50 - Jan 60
Grand Junction WBAS	50	4,839	39 06	108 32	Oct 51 - Sep 61
Trinidad FAA	55	5,743	37 16	104 20	Jan 49 - Dec 58
DELAWARE					
Dover AFB	95	38	39 08	75 27	Jan 46 - Aug 59, less Oct 46 - Jun 49, Oct 49 - Aug 50
DISTRICT OF COLUMBIA					
Andrews AFB	90	353	38 49	76 51	Jan 46 - Feb 59
Bolling AFB	89	29	38 50	77 01	Feb 51 - Jan 61

* Location of stations indicated by number on location map (Figure 2).

TABLE I (Cont.)

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

STATION	NO.	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
FLORIDA					
Cape Kennedy	182	12	28 28	80 29	Jun 50 - Feb 54, Apr 54, Apr 56 - Jul 60
Cocoa Beach (Patrick AFB)	181	9	28 14	80 36	Feb 50 - Jan 60
Miami WBAS	183	24	25 49	80 17	Jan 48 - Feb 59
Orlando (McCoy AFB)	180	105	28 27	81 18	Aug 44 - Feb 46, Sep - Oct 46, May 52 - Jul 60
Panama City (Tyndall AFB)	177	22	30 04	85 35	Jun 51 - May 61
Tampa (MacDill AFB)	179	12	27 51	82 30	Oct 49 - Sep 59
Valpariso (Eglin AFB)	176	91	30 29	86 31	Sep 49 - Aug 59
GEORGIA					
Albany (Turner AFB)	151	225	31 35	84 07	Sep 49 - Aug 59
Augusta WBAS	157	182	33 22	81 58	Nov 51 - Oct 61
Fort Benning (Lawson AAF)	149	242	32 21	85 00	Jan 46 - Jun 58 less Mar - Apr 46
Marietta (Dobbins AFB)	150	1,016	33 55	84 31	Feb 50 - Jan 60
Savannah (Hunter AFB)	161	70	32 01	81 08	Oct 49 - Sep 59
Valdosta (Moody AFB)	178	239	30 58	83 12	Mar 44 - Jan 60 less Mar 46, Jun 46 - Jun 51
Warner Robbins AFB	153	277	32 38	83 36	Sep 49 - Aug 59
IDAHO					
Lewiston WBAS	8	1,419	46 23	117 02	Nov 51 - Oct 61
Mountain Home AFB	9	2,992	43 03	115 51	May 49 - Dec 58 less Dec 49 - Mar 51
ILLINOIS					
Belleville (Scott AFB)	72	444	38 33	89 51	Feb 51 - Jan 61
Moline WBAS	71A	594	41 27	90 31	Jan 49 - Dec 58
Rantoul (Chanute AFB)	73	749	40 18	88 09	Jan 46 - Dec 59
O'Hare Int. Aprt.	74	667	41 59	87 54	Nov 48 - Oct 58
INDIANA					
Columbus (Bakalar AFB)	78	654	39 15	85 53	Feb 50 - Jan 60
South Bend WBAS	75	773	41 42	86 19	Feb 50 - Jan 60
IOWA					
Des Moines WBAS	71	963	41 32	93 39	Jan 52 - Dec 61
Mason City FAA	20	1,168	43 10	93 20	Nov 51 - Oct 61
Sioux City WBAS	64	1,113	42 24	96 23	Dec 50 - Nov 60
KANSAS					
Dodge City WBAS	58	2,592	37 46	99 58	Jan 49 - Dec 58
Fort Leavenworth (Sherman AFB)	67	786	39 22	94 55	Nov 42 - Oct 53 less Feb, Mar, and May 46
Fort Riley (Marshall AFB)	63	1,076	39 03	96 46	Aug 38 - Apr 50, Feb 56 - Feb 59, less Feb - Jun 46
Goodland WBAS	56	3,652	39 22	101 42	Nov 51 - Oct 61
Salina (Schilling AFB)	60	1,281	38 48	97 38	Jan 46 - Sep 59 less Dec 49 - Sep 52
Topeka (Forbes AFB)	66	1,091	38 57	95 40	Jan 46 - Sep 59 less Jul - Nov 57, Dec 49 - Jan 52
Wichita (McConnell AFB)	61	1,355	37 37	97 16	Dec 53 - Aug 62
KENTUCKY					
Fort Campbell AFB	146	564	36 40	87 30	Jul 43 - Sep 45 Jun 50 - Feb 59
Fort Knox (Godman AAF)	76	753	37 54	85 58	Jan 46 - Feb 59 less Mar, Apr 56
Louisville WBAS	77	488	38 11	85 44	Oct 52 - Sep 62

TABLE I (Cont.)

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

STATION	NO.	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
LOUISIANA					
Alexandria (England AFB)	139	89	30 19	92 33	Sep 43 - Jun 60 less Dec 45 - Mar 52
Lake Charles WBAS	173	32	30 13	93 09	Oct 49 - Sep 59
New Orleans NAS	173A	5	29 50	90 01	Jan 58 - Jan 63
Shreveport (Barksdale AFB)	138	138	32 30	93 41	Oct 49 - Sep 59
MAINE					
Bangor (Dow AFB)	33	162	44 48	68 49	Nov 44 - Sep 54 less Apr 45 - Feb 48, Nov 49 - Feb 51
Limestone (Loring AFB)	35	175	46 57	67 53	Sep 50 - Sep 59
Presque Isle AFB	34	486	46 41	68 03	Jan 47 - Aug 59 less Jul 48 - Feb 51
MARYLAND					
Patuxent River NAS	93	45	38 17	76 25	Jan 49 - Dec 58
MASSACHUSETTS					
Chicopee Falls (Westover AFB)	101	247	42 12	72 32	Jan 46 - Jun 58
Falmouth (Otis AFB)	102	137	41 39	70 32	Sep 49 - Aug 59
MICHIGAN					
Houghton (Calumet FAA)	24	1,079	47 10	88 30	Jan 49 - Dec 58
Kinross (Kincheloe AFB)	27	803	46 15	84 28	Apr 53 - Dec 60
Mount Clemens (Selfridge AFB)	82	610	42 36	82 50	Sep 49 - Aug 59
Oscoda (Wurtsmith AFB)	28	618	44 28	83 22	Nov 44 - Dec 45 Dec 50 - Aug 59
Traverse City FAA	26	630	44 44	85 35	Nov 51 - Oct 61
MINNESOTA					
Duluth WBAS	22	1,417	46 50	92 11	Dec 50 - Nov 60
Minneapolis WBAS	21	838	44 53	93 15	Dec 50 - Nov 60
International Falls WBAS	19	1,126	48 36	93 24	Jan 49 - Dec 58
MISSISSIPPI					
Biloxi (Keesler AFB)	174	26	30 24	88 55	Feb 50 - Jan 60
Columbus AFB	144	224	33 38	88 27	Mar 42 - Feb 46, Apr - Jun 46, Nov 53 - Jul 62
Greenville AFB	141	139	33 29	90 59	Feb 42 - Aug 59 less Apr - Jul 45, Feb 46 - Mar 53
Jackson WBAS	142	332	32 20	90 13	Jan 49 - Dec 58
MISSOURI					
Grandview (Gebaur AFB)	68	1,133	38 50	94 35	Apr 54 - Feb 61
Kansas City WBAS	69	750	39 07	94 35	Jun 52 - May 62
Knobnoster (Whiteman AFB)	70	838	38 44	93 34	Apr 43 - Sep 46 Jun 54 - Nov 60
MONTANA					
Billings WBAS	12A	3,583	45 48	108 32	Jan 53 - Dec 62
Butte WBAS	10	5,529	45 58	112 30	Jan 50 - Dec 60 less Jan - Dec 55
Cut Bank FAA	11	3,838	48 37	112 22	Nov 51 - Oct 61
Glasgow WBAS	14	2,298	48 13	106 37	Oct 49 - Sep 59
Great Falls (Malmstrom AFB)	12	3,465	47 31	111 10	Jan 46 - Dec 58
NEBRASKA					
Grand Island WBAS	59	1,856	40 58	98 19	Oct 52 - Sep 62
Lincoln AFB	62	1,169	40 51	96 46	Oct 49 - Sep 59
North Platte WBAS	57	2,787	41 08	100 42	Jan 49 - Dec 58
Omaha (Offutt AFB)	65	1,023	41 07	95 54	Sep 49 - Aug 59

TABLE I (Cont.)

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

STATION	NO.	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
NEVADA					
Las Vegas (Nellis AFB)	109	1,881	36 15	115 02	Mar 42 - Sep 44 Jan 49 - Aug 61
Reno (Stead AFB)	41	5,023	39 40	119 52	Jan 43 - Jan 60 less Dec 45 - Jul 52
Tonopah FAA	44	5,422	38 04	117 08	Nov 51 - Oct 61
Winnemucca WBAS	43	4,339	40 54	117 46	Nov 51 - Oct 61
NEW HAMPSHIRE					
Manchester (Grenier AFB)	31	243	42 56	71 26	Nov 47 - Jan 60 less Nov 49 - Feb 51, Nov - Dec 55
Portsmouth (Pease AFB)	32	88	43 05	70 49	Apr 56 - Mar 61
NEW JERSEY					
Belmar (Sig. C.)	97	165	40 11	74 04	Jan 55 - Jul 61
Trenton (McGuire AFB)	96	147	40 00	74 36	Sep 49 - Aug 59
NEW MEXICO					
Alamagordo (Holloman AFB)	118	4,070	32 51	106 05	Feb 50 - Jan 60
Albuquerque WBAS	117	5,314	35 03	106 37	Sep 49 - Aug 59
Clovis (Cannon AFB)	122	4,301	34 23	103 19	Feb 43 - Oct 46
Farmington WBAS	116	5,509	36 45	108 15	Feb 53 - Oct 61
Roswell (Walker AFB)	121	3,643	33 18	104 32	Sep 49 - Aug 59
White Sands (Missile Range)	119	4,238	32 22	106 29	Feb 51 - Jan 61
NEW YORK					
Binghamton WBAS	92	832	42 05	76 06	Jan 49 - Dec 58
Hempstead (Mitchel AFB)	99	125	40 44	73 36	Jan 46 - Feb 59
Newburgh (Stewart AFB)	98	465	41 31	74 06	Feb 50 - Jan 60
Rome (Griffis AFB)	29	476	43 14	75 25	Sep 49 - Aug 59
Suffolk County AFB	100	57	40 49	72 38	Aug 43 - Nov 45
NORTH CAROLINA					
Asheville FAA	154	2,185	35 26	82 32	Jan 48 - Dec 54
Charlotte WBAS	158	769	35 14	82 32	Jul 52 - Jun 62
Cherry Point MCAS	165	35	34 54	76 53	Jan 49 - Dec 58
Fort Bragg (Pope AFB)	163	199	35 11	79 01	Jan 46 - Feb 59
Greensboro WBAS	160	902	36 05	79 57	Jan 49 - Dec 58
NORTH DAKOTA					
Bismarck WBAS	17	1,660	46 46	100 45	Jan 49 - Dec 58
Minot FAA	16	1,714	48 15	101 17	Sep 49 - Aug 59
OHIO					
Akron WBAS	84	1,052	40 55	81 26	Dec 51 - Nov 61
Columbus (Lockbourne AFB)	81	744	39 49	82 56	Oct 47 - Sep 59 less Oct 49 - Feb 51
Dayton (Wright-Patterson AFB)	79	822	39 49	84 02	Jan 46 - Jun 58
Wilmington AFB	80	1,054	39 26	83 48	Aug 43 - Sep 49 Mar 53 - Feb 59
OKLAHOMA					
Altus AFB	128	1,357	34 39	99 16	Sep 53 - May 61
Enid (Vance AFB)	131	1,287	36 20	97 54	Feb 50 - Jan 60
Fort Sill AAF	130	1,194	34 39	98 24	Jan 46 - Feb 59
Oklahoma City (Tinker AFB)	132	1,260	35 25	97 24	Sep 49 - Aug 59

TABLE I (Cont.)

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

STATION	NO.	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
OREGON					
Burns WBAS	6	4,162	43 35	119 03	Nov 51 - Oct 61
Pendleton WBAS	5	1,494	45 41	118 51	Nov 51 - Oct 61
Portland WBAS	3	26	45 36	122 36	Dec 50 - Nov 60
PENNSYLVANIA					
Middletown (Olmsted AFB)	91	306	40 12	76 46	Feb 50 - Jan 60
Pittsburgh WBAS	87	1,151	40 30	80 13	Jan 49 - Dec 58
SOUTH CAROLINA					
Charleston WBAS	162	46	32 54	80 02	Feb 50 - Jan 60
Greenville AFB	156	976	34 46	82 23	Feb 49 - Jan 60
Myrtle Beach AFB	164	35	33 41	78 56	Jan 46 - Jun 47 Jan 49 - Feb 59
Sumter (Shaw AFB)	159	263	33 59	80 29	Jan 46 - Feb 59
SOUTH DAKOTA					
Huron WBAS	18	1,289	44 23	98 13	Jan 49 - Dec 58
Rapid City (Ellsworth AFB)	15	3,215	44 09	103 06	Sep 49 - Aug 59
TENNESSEE					
Bristol	155	1,566	36 30	82 21	Dec 51 - Nov 61
Knoxville WBAS	152	974	35 49	83 59	Jan 49 - Dec 58
Memphis WBAS	143	282	35 03	89 59	Jan 49 - Dec 58
Smyrna (Stewart AFB)	147	522	36 00	86 32	Dec 50 - Nov 60
TEXAS					
Abilene (Dyess AFB)	127	1,777	32 26	99 51	Oct 49 - Sep 59
Amarillo (English Field WBAS)	124	3,604	35 14	101 42	Sep 49 - Aug 59
Austin (Bergstrom AFB)	170	507	30 12	97 40	Sep 49 - Aug 59
Big Spring (Webb AFB)	125	2,572	32 14	101 30	Feb 50 - Jan 60
Bryan AFB	171	275	30 40	96 33	Mar 43 - May 58 less Jan 46 - Sep 51
Del Rio (Laughlin AFB)	166	1,072	29 22	100 47	Sep 49 - Aug 59
El Paso (Biggs AFB)	120	3,923	31 50	106 24	Sep 46 - Jan 59 less Apr 47 - Jan 48
Fort Worth (Carswell AFB)	134	617	32 46	97 27	Sep 49 - Aug 59
Harlingen AFB	169	38	26 14	97 40	Mar 42 - Jan 46 Jul 52 - Jul 58
Houston (Ellington AFB)	172	39	29 37	95 10	Jul 41 - Feb 46 Jan 50 - Feb 59
Laredo (Mun. Aprt)	167	512	27 32	99 29	Dec 50 - Nov 60
Lubbock (Reese AFB)	123	3,330	33 36	102 02	Feb 50 - Jan 60
Killeen (Gray AFB)	133	1,021	31 04	97 49	Dec 50 - Nov 60
San Angelo (Goodfellow AFB)	126	1,878	31 24	100 24	Sep 48 - Aug 58
San Antonio (Kelley AFB)	168	682	29 23	98 34	Sep 49 - Aug 59
San Antonio (Randolph AFB)	168	743	29 32	98 17	Sep 49 - Aug 59
Sherman (Perrin AFB)	136	763	33 43	96 40	Feb 50 - Jan 60
Waco (Connally AFB)	135	475	31 38	97 04	Dec 48 - Feb 59
Wichita Falls (Kell Field WBAS)	129	1,039	33 59	98 31	Sep 49 - Aug 59
UTAH					
Cedar City FAA	46	5,616	37 42	113 06	Nov 51 - Oct 61
Ogden (Hill AFB)	48	4,785	41 07	111 58	Feb 50 - Jan 60
Tooele AAF	47	4,356	40 11	112 56	Feb 51 - Jan 61

TABLE I (Cont.)

STATION LOCATIONS, ELEVATIONS, AND PERIODS OF RECORDS

STATION	NO.	ELEV. ft.	LAT. °N	LONG. °W	PERIOD OF RECORD
VERMONT					
Burlington WBAS	30	349	44 28	73 09	Feb 50 - Jan 60
VIRGINIA					
Blackstone FAA	88	438	37 04	77 57	Jan 49 - Dec 58
Hampton (Langley AFB)	94	20	37 05	76 21	Jan 46 - Feb 59
Roanoke WBAS	85	1,193	37 19	79 58	Jan 49 - Dec 58
WASHINGTON					
Everett (Paine AFB)	1	596	47 54	122 17	Feb 50 - Jan 60
Moses Lake (Larson AFB)	4	1,183	47 11	119 20	Apr 49 - Dec 58
Spokane (Fairchild AFB)	7	2,437	47 37	117 39	Sep 49 - Aug 59
Tacoma (McChord AFB)	2	350	47 09	122 29	Jan 46 - Feb 59
Walla Walla WBAS	5A	1,206	46 06	118 17	Jan 48 - Dec 54
WEST VIRGINIA					
Charleston WBAS	83	989	38 22	81 36	Feb 49 - Dec 58
Elkins WBAS	86	1,973	38 53	79 51	Dec 51 - Nov 61
WISCONSIN					
Green Bay WBAS	25	699	44 29	88 08	Sep 49 - Dec 58
Madison WBAS	23	866	43 08	89 20	Dec 50 - Nov 60
WYOMING					
Casper WBAS	51	5,323	42 55	106 28	Jan 49 - Dec 58
Cheyenne WBAS	52	6,144	41 09	104 49	Feb 51 - Jan 61
Rock Springs WBAS	49	6,745	41 36	109 04	Nov 51 - Oct 61
Sheridan WBAS	13	3,946	44 46	106 58	Nov 51 - Oct 61

of the United States Weather Bureau. The unpublished data for 213 stations for the period 1946-1955 proved a valuable supplementary source of information. They consist of averages determined from observations taken every six hours, so they are not strictly comparable to the averages from the Air Force hourly data and they are not suitable for delimiting diurnal variations.

The dew point averages for these 213 stations, including a number of stations for which there were no Air Force summaries, were plotted on separate monthly maps and isodrosotherms (lines of equal dew point) were drawn. This supplemental analysis served two purposes: 1) it confirmed the analysis in areas where there was ample coverage from the Air Force summaries; and 2) it supplemented the analysis in areas where the coverage was not adequate. In general, there was good agreement between the average monthly dew point maps prepared from the Air Force and the Weather Bureau summaries, even though the data were for different periods of records, and from observations taken at different times. The Weather Bureau summaries were needed most in mountainous areas where dew point gradients are largest.

3. Treatment of basic data

a. The dew point averaging error

There is an error inherent in directly averaging dew points because the relationship between dew point and vapor pressure is nonlinear. This error is demonstrated graphically in Figure 1. The "apparent" average of dew point A (30°F) and dew point B (70°F) is shown as 50°F, but the "true" average, the average of the vapor pressures converted to a dew point, is 56°F.* Errors introduced by averaging sets of dew points are further illustrated in Table II. Notice that the dew point errors increase as the range between the dew points increases, and that the errors are greater at a given range with lower dew points. Averaging dew points always results in a lower average than averaging the equivalent vapor pressures and converting back to dew point.

Because the dew point averaging error is dependent mainly on the range between dew points to be averaged, it was possible to develop a nomograph for estimating this error (Fig. 3). The construction of the nomograph is discussed elsewhere (Dodd, 1964, pp 66-70). The use of the nomograph can be illustrated by considering a station where the average of the hourly dew points during a given month is 57°F and the standard

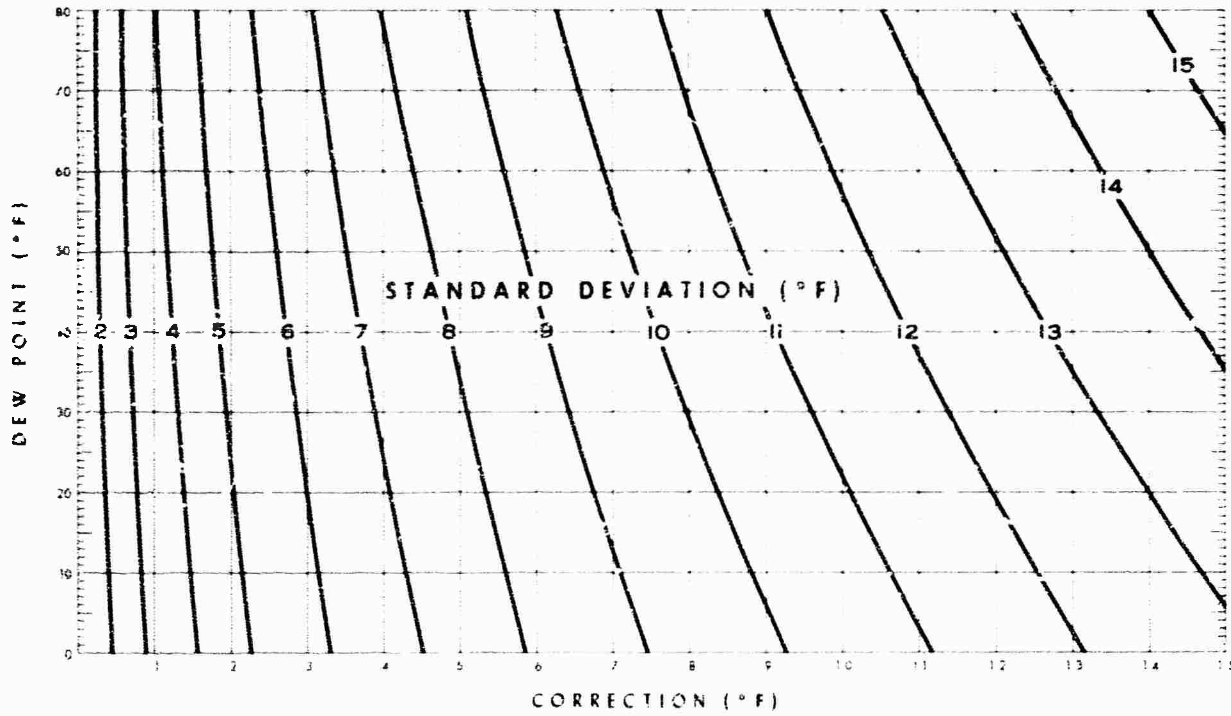
* The average of the vapor pressures is designated as the "true" average because vapor pressure is a more fundamental measure of the water vapor present. For a more complete discussion see Dodd, 1964.

TABLE II

DIFFERENCES BETWEEN "TRUE" AVERAGE DEW POINTS AND "APPARENT" AVERAGE DEW POINTS FOR SELECTED SETS OF DEW POINTS

A dew point sets (°F)	B apparent average	C true average	D difference "C" - "B"
70 30	50	56.0	6.0
70 40	55	58.4	3.4
70 50	60	61.5	1.5
70 60	65	65.4	0.4
50 10	30	36.6	6.6
50 20	35	38.8	3.8
50 30	40	41.7	1.7
50 40	45	45.4	0.4
30 -10	10	18.0	8.0
30 0	15	19.8	4.8
30 10	20	22.2	2.2
30 20	25	25.5	0.5

DEW POINT CORRECTION NOMOGRAPH



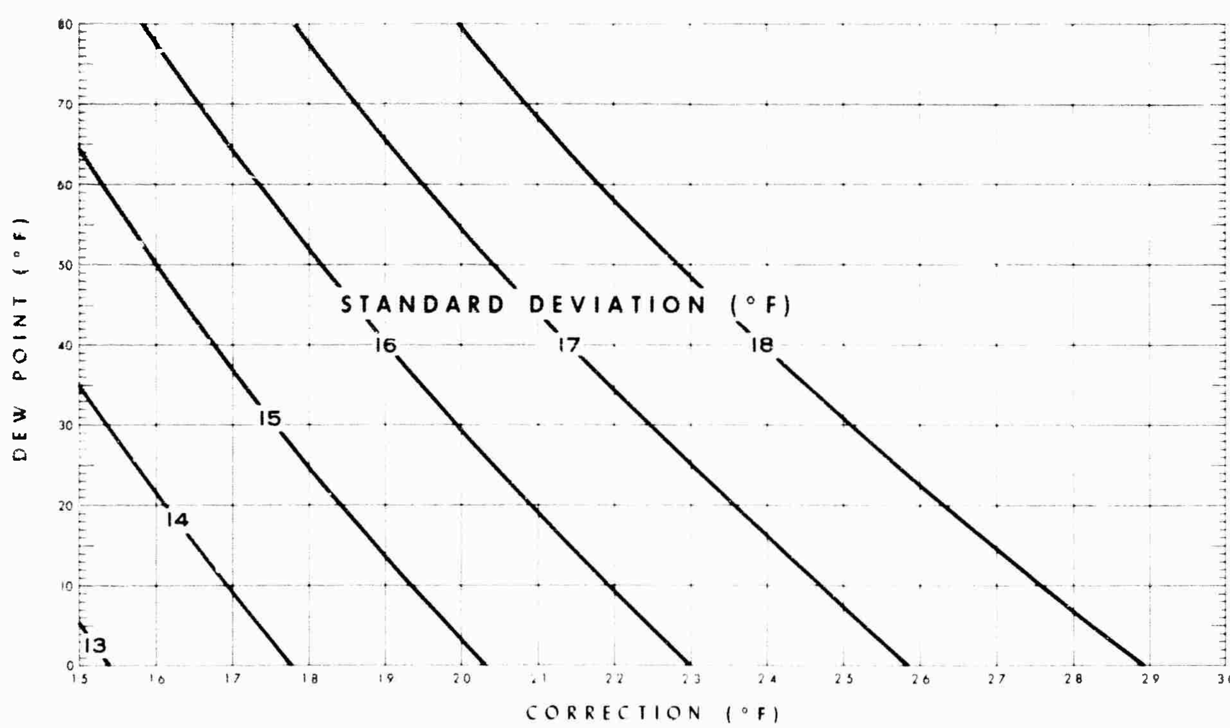


Figure 3

deviation is 12F°. From Figure 3 it can be seen that a correction of 1F° should be applied to the dew point to allow for the dew point averaging error; thus the corrected dew point is 58°F.

Because mean monthly dew point and its standard deviation are both given in the Air Force summaries, it is possible to use the dew point correction nomograph to correct for the dew point averaging error. It was found that at most stations there is an annual regime of averaging errors with largest corrections in winter and smallest corrections in summer. The largest corrections, over 2.5F°, occur in the northern tier of the central states in the winter months, and the smallest corrections, less than 0.2F°, are found in the southeastern states in the summer months. In July many stations along the Gulf of Mexico coast have corrections of less than 0.1F°.

b. Machine tabulation of data

Data from the Air Force summaries were punched on EAM cards and tabulated to facilitate analysis. A sample tabulation is shown in Table III. Included in the tabulation are the height of the station, the month, the average monthly dew point and standard deviation, the tri-hourly average dew points for the eight time groups, and the difference between the tri-hourly average and the monthly average for each of the time groups.

Several steps were necessary before the final tabulation could be prepared. Errors in the original data, in copying the data, and in punching the data were found by machine methods. The average of the eight time groups was obtained and checked against the average in the summary. If they did not agree, the reason was ascertained and the correction made. It was found that some stations with fewer observations at night than during the day had different average dew points when the eight time groups were averaged than when the average of all the observations was taken. These data were eliminated from the study if the error introduced was large.

Before the data were checked for errors, the averaging correction to the mean monthly dew points for each station was punched on the EAM card. The print out of these corrections was checked at the same time the averages were checked. The final tabulations, including the corrections in the monthly and the tri-hourly averages, were then run. A sample of this final tabulation is shown in Table III.

A deck of punched cards with dew point-saturation vapor pressure equivalents (from the Smithsonian Meteorological Tables) was used in converting the average dew points to vapor pressures. This tabulation was used in preparing the average monthly vapor pressure maps. Referring to the sample station (Table III), it will be seen that columns 14 to 21 show

TABLE III

SAMPLE DEW POINT TABULATION SHEET

GRAND ISLAND, NEBRASKA

COLUMN

1. Station designator - 59
2. Height in feet - 1856
3. Month (01 = January, etc.)
4. Average monthly dew point (150 = 15.0°F)
5. Standard deviation of average monthly dew point (131 = 13.1°F)
6. Average dew point for first time group (0000, 0100, 0200 LST)
7. second (0300, 0400, 0500 LST)
8. third (0600, 0700, 0800 LST)
9. fourth (0900, 1000, 1100 LST)
10. fifth (1200, 1300, 1400 LST)
11. sixth (1500, 1600, 1700 LST)
12. seventh (1800, 1900, 2000 LST)
13. eighth (2100, 2200, 2300 LST)
14. Column 4 minus column 6
15. 7
16. 8
17. 9
18. 10
19. 11
20. 12
21. 13

See page 17 for explanation

TIME OF SUNRISE — TIME OF SUNSET

COLUMN

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0059	1856	01	150	131	136	125	116	142	174	185	168	152	14	25	34	08	24-	35-	18-	02-
0059	1856	02	196	120	184	174	168	196	217	222	211	196	12	22	28	00	21-	26-	15-	00
0059	1856	03	249	106	240	232	227	248	264	267	264	253	09	17	22	01	15-	18-	15-	04-
0059	1856	04	349	105	347	339	342	352	352	349	354	356	02	10	07	03-	03-	00	05-	07-
0059	1856	05	481	96	477	469	475	483	484	482	488	490	04	12	06	02-	03-	01-	07-	09-
0059	1856	06	578	71	576	567	574	582	581	576	583	587	02	11	04	04-	03-	02	05-	09-
0059	1856	07	617	55	615	608	616	624	617	610	619	624	02	09	01	07-	00	07	02-	07-
0059	1856	08	607	67	604	599	603	616	611	600	611	609	03	08	04	09-	04-	07	04-	02-
0059	1856	09	493	97	493	488	490	502	495	486	497	494	00	05	03	09-	02-	07	04-	01-
0059	1856	10	377	113	374	366	367	386	383	377	384	381	03	11	10	09-	06-	00	07-	04-
0059	1856	11	255	105	246	238	236	261	271	270	263	252	09	17	19	06-	16-	15-	08-	03
0059	1856	12	193	103	182	174	170	195	215	214	200	190	11	19	23	02-	22-	21-	07-	03

the range and pattern of the average daily variation of the dew point. The dew point changes during the day are indicated by the underlined values. The maximum points are underlined by dashed lines; the minimum points by a solid line. At the sample station, Grand Island, there is a single minimum and maximum during the colder months and a double minimum and maximum during the warmer months. This is a common pattern of diurnal variation and is apparent to the analyst with no further processing of the data.

If columns 14 to 21 are considered as representing a 24-hour day, the time of sunrise and sunset can be plotted and the times of maximum and minimum dew points can be related to the solar regime. At Grand Island the minimum dew point occurs before or near sunrise in every month.

c. Altitudinal considerations

The question of whether the data should be reduced to sea level had to be resolved at the time the machine tabulation of the data was planned. European investigators (Shaw, 1928; Tunnell, 1958; Száva-Kováts, 1938) have chosen to reduce the data to sea level or only to consider stations near sea level, whereas the American investigators (Day, 1917; Dodd and Hastings, 1958; Sellers, 1960; Landsberg, 1964) have chosen to present the data for the levels at which they were observed. There are two reasons why reduction of the data to sea level does not serve the purpose of this study. First, the theoretical humidity distribution at sea level is a fictitious distribution. It does not represent conditions at the earth's surface where man lives. A second reason is that there is no certainty that this can be done accurately in all mountainous areas of the United States. Tunnell (1958) found that in mountainous areas where persistent wintertime inversions disturbed the normal vapor pressure decrease with altitude, the formula for reduction to sea level does not apply. Since winter inversions are common in the west, and particularly in the Great Basin, generalized formulae for the reduction of dew point or vapor pressure to sea level could not be applied.

Isodrosotherms and isovapors were drawn on the maps in the Appendix after careful consideration of available data for the mountainous areas. There are Air Force summaries for four stations in the United States above 6,000 feet: Flagstaff, Arizona; Colorado Springs, Colorado; Cheyenne, Wyoming; and Rock Springs, Wyoming. There are additional high stations with data from the unpublished Weather Bureau summaries. The only high station in the East, Mt. Washington, has a record summarized by the Weather Bureau.

To augment the data for the mountainous areas of the United States, graphs were prepared which showed the lapse rate of dew point in the various high sections of the country. Dew points at intermediate levels between the station heights can be read from the graphs. Such values are an aid in interpolating the placement of the isodrosotherms. Several of the graphs are shown in Figure 4 to illustrate the nature of dew point decrease with altitude. They also show the difficulty in reducing dew points to sea level. The decrease in dew point with elevation is fairly constant throughout the year from Concord to Mt. Washington, New Hampshire; from Burbank to Sandberg, California; and from Sacramento to Blue Canyon, California. (See Fig. 5 for station locations.) At the other three sites there is a seasonal difference in the rate of dew point change with elevation. The increase in dew point with elevation between Reno, Nevada, and Blue Canyon, Calfiornia, is caused because the increase of dew point towards the Pacific Ocean is greater than the decrease which would be expected from the lower (Reno) to the higher (Blue Canyon) station. In July, and to some extent in September, the increase in dew point with elevation between the two stations is reversed, and a more normal decrease in dew point with elevation is found. This occurs because in summer the primary source of water vapor is from the southeast in the Reno-Blue Canyon area. The seasonal variation of dew point gradients between nearby stations can be a useful climatic tool since it illustrates the source of water vapor being advected into the area.

DEW POINT CHANGE WITH ELEVATION

SIX SELECTED AREAS OF THE UNITED STATES

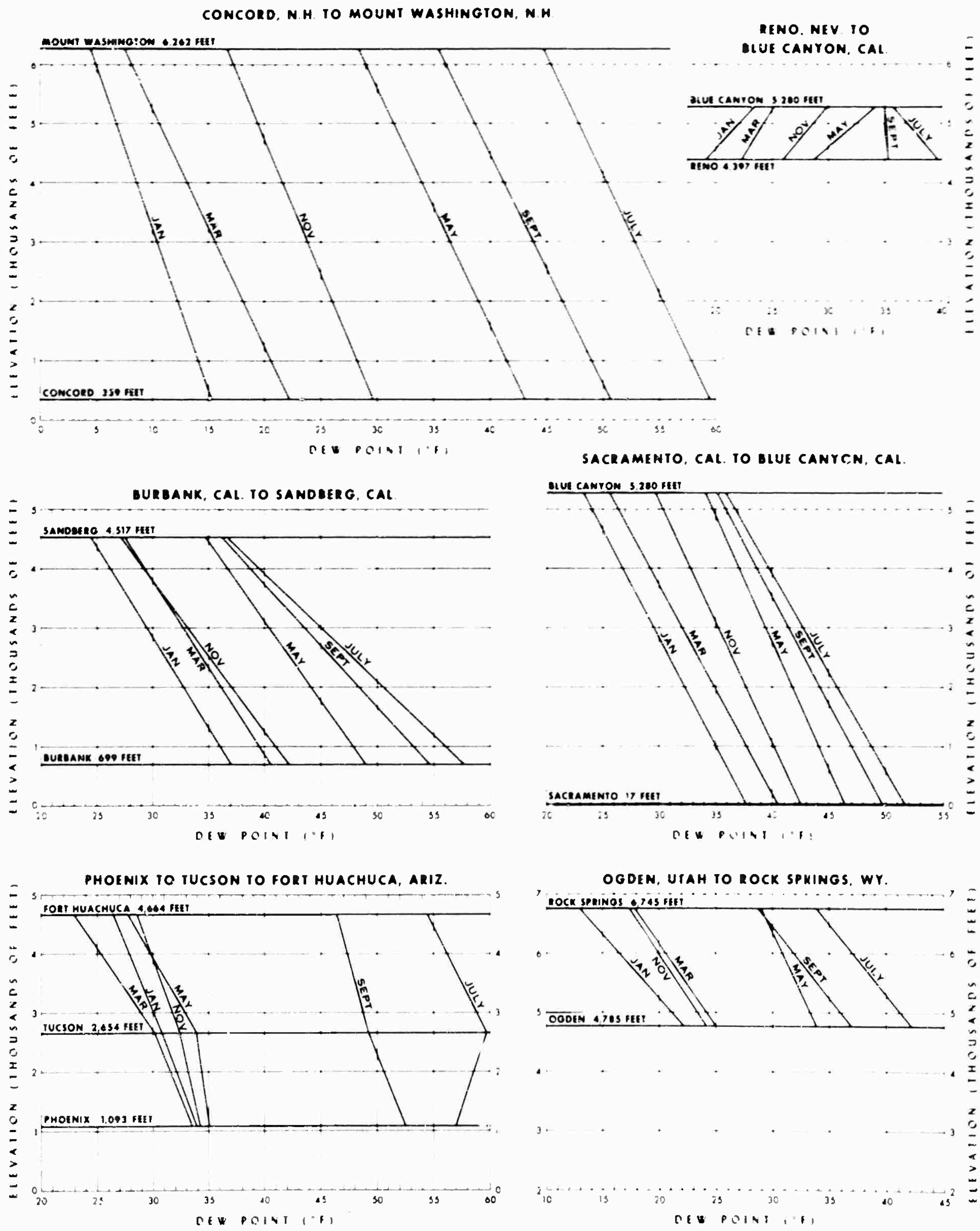


Figure 4

LOCATION OF STATIONS SELECTED TO ILLUSTRATE DEW POINT CHANGE WITH ELEVATION

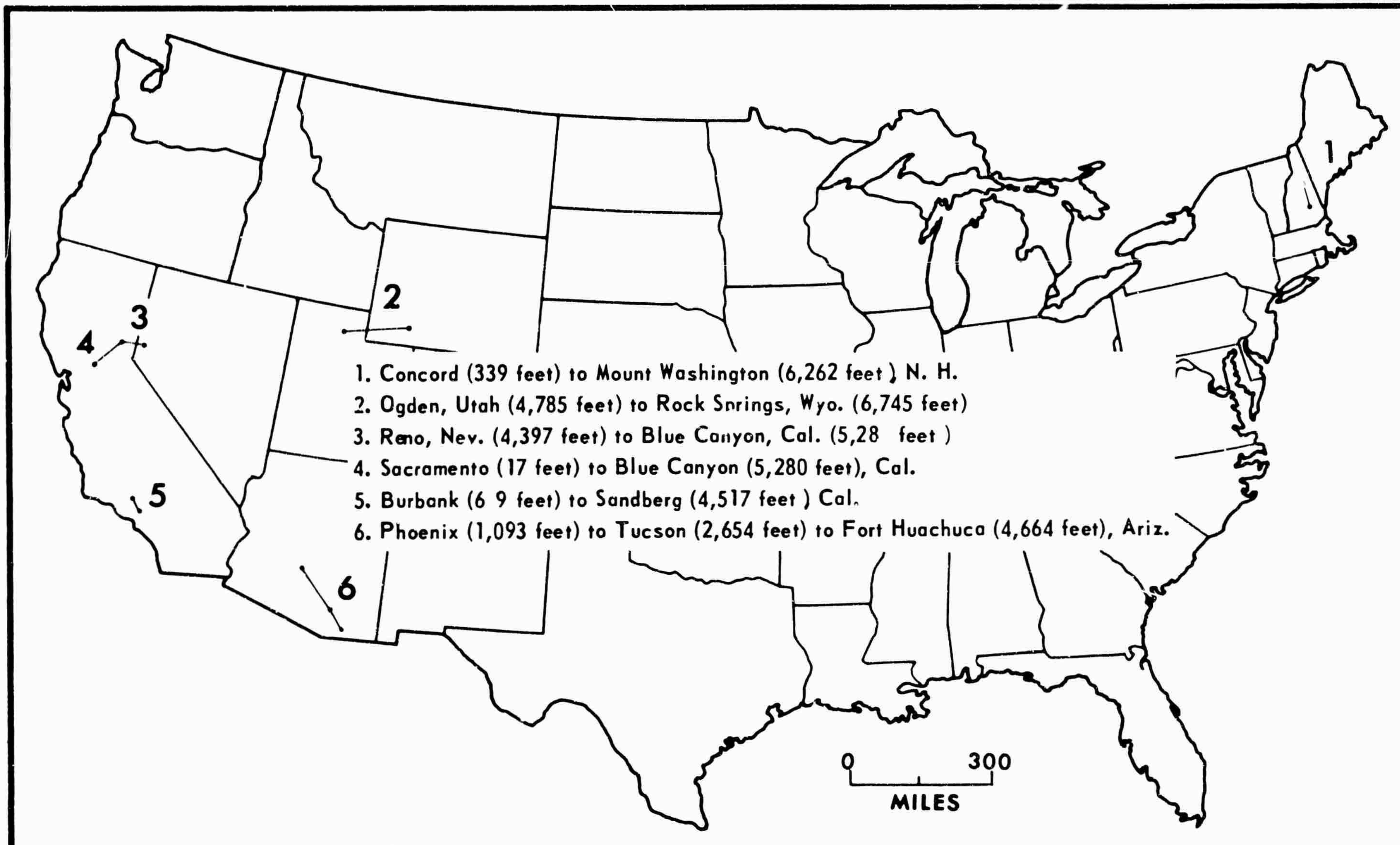


Figure 5

PART II

DISTRIBUTION OF DEW POINT AND VAPOR PRESSURE

1. Background information

Figures 13 to 24 in the Appendix are maps of average dew points in the contiguous United States with inset maps of standard deviation of dew point. Figures 25 to 36 show average monthly vapor pressure. Figures 37 to 48 show diurnal variation types and will be discussed in Part III.

a. Preparation of dew point and vapor pressure maps

The original work maps were prepared at a scale of one to seven million using as a base a U. S. Geological Survey polyconic map with nine elevation classes indicated in color, and contour lines at 500-foot intervals to 2,000 feet, and 1,000-foot intervals above 2,000 feet. The base map was selected mainly because the detailed hypsometry facilitated drawing of isopleths in the mountains. The map scale is appropriate for the station network available.

The basic data were plotted on overlays to the base map, and the isodrosotherms were originally drawn on acetate placed over both the base and data overlay on a light table. This technique assures proper consideration of the data and the hypsometry in the analysis. Lines for each month were drawn and then checked for continuity from month to month. Little smoothing was necessary east of the 100th meridian. In the mountains considerable judgment and smoothing was necessary in drawing the lines, even with the graphic aids used to determine the dew point change with altitude.

Isodrosotherms in mountainous areas reflect the effect of elevation on dew point as much as the station data. In areas where the dew point or vapor pressure gradient is very steep (for example, on the western slopes of the high Sierra Nevadas, and in the high Rockies of western Colorado) it was not possible to represent it accurately. In these cases the contours were drawn at a wider interval than that at which they actually occur. This was preferable to eliminating isodrosotherms or isovapors or crowding the lines where the data do not indicate exactly where the gradient is steepest.

b. Dew point and vapor pressure controls

Figure 6 was generalized from the dew-point maps in the Appendix to illustrate the seasonal variation in average dew points in the United States, and thus serve as a reference point for a discussion of the primary controls of water vapor in the air near the ground. These primary controls are temperature, exposure to sources of water vapor, and elevation. Not evident in Figure 6 are the effects of local controls on water vapor in the air near the ground. Insofar as possible, these local differences must be eliminated in this macroscale analysis.

(1) Temperature

Temperature is the major control determining the amount of water vapor in the atmosphere. Commonly, but not always, an increase in average monthly temperature is accompanied by an increase in average monthly dew point. The possible amount of water vapor in the atmosphere increases with temperature as illustrated in Figure 1, and the amount which normally is present also usually increases as the average temperature increases. Thus, as seasonal warming progresses northward over the country, dew points and vapor pressures rise. This is illustrated in Figure 6 by the northward progression of the area with average dew points above 60°F from the tip of southern Florida in January to near the northern limit of the United States east of the Rockies in July.

The primary reason for the dependence of dew point upon temperature east of the Rocky Mountains is that the warm tropical air masses moving northward from the Gulf and Caribbean are also the moist air masses. The tropics are a source not only of heat, but also of water vapor. Maritime Pacific air is also a source of moisture, normally the only source on the Pacific Coast, but it is not as warm as maritime tropical (mT) air from the Gulf of Mexico and it does not have as high dew points.

Just as warm air masses are a source of moisture, cold air masses are characterized by their dryness. As polar continental (cP) air masses move southward from Canada into the United States they are warmed in their lower layers. This warming causes instability, convection, and mixing of the air, and encourages evaporation. This, in turn, favors an increase in the water vapor content of the air as it moves southward. The continental interior is not as effective a supplier of water vapor as the warm waters to the south, however, and the cP air is relatively dry.

In the Southwest hot and dry continental tropical (cT) air from Mexico causes an increase in temperature without the normal increase in dew point, because of the lack of a source of moisture to be evaporated into the air. As soon as the southern flow into the Southwest has a maritime source, dew points rise. This is well illustrated by the cT/mT front which crosses the Southwest in the early summer.

(2) Relationship to sources of water vapor

A second control of dew point is distance from and exposure to major sources of water vapor, particularly the oceans. This is

AREAS WITH AVERAGE DEW POINTS ABOVE 40°F AND 60°F JANUARY, APRIL, JULY AND OCTOBER

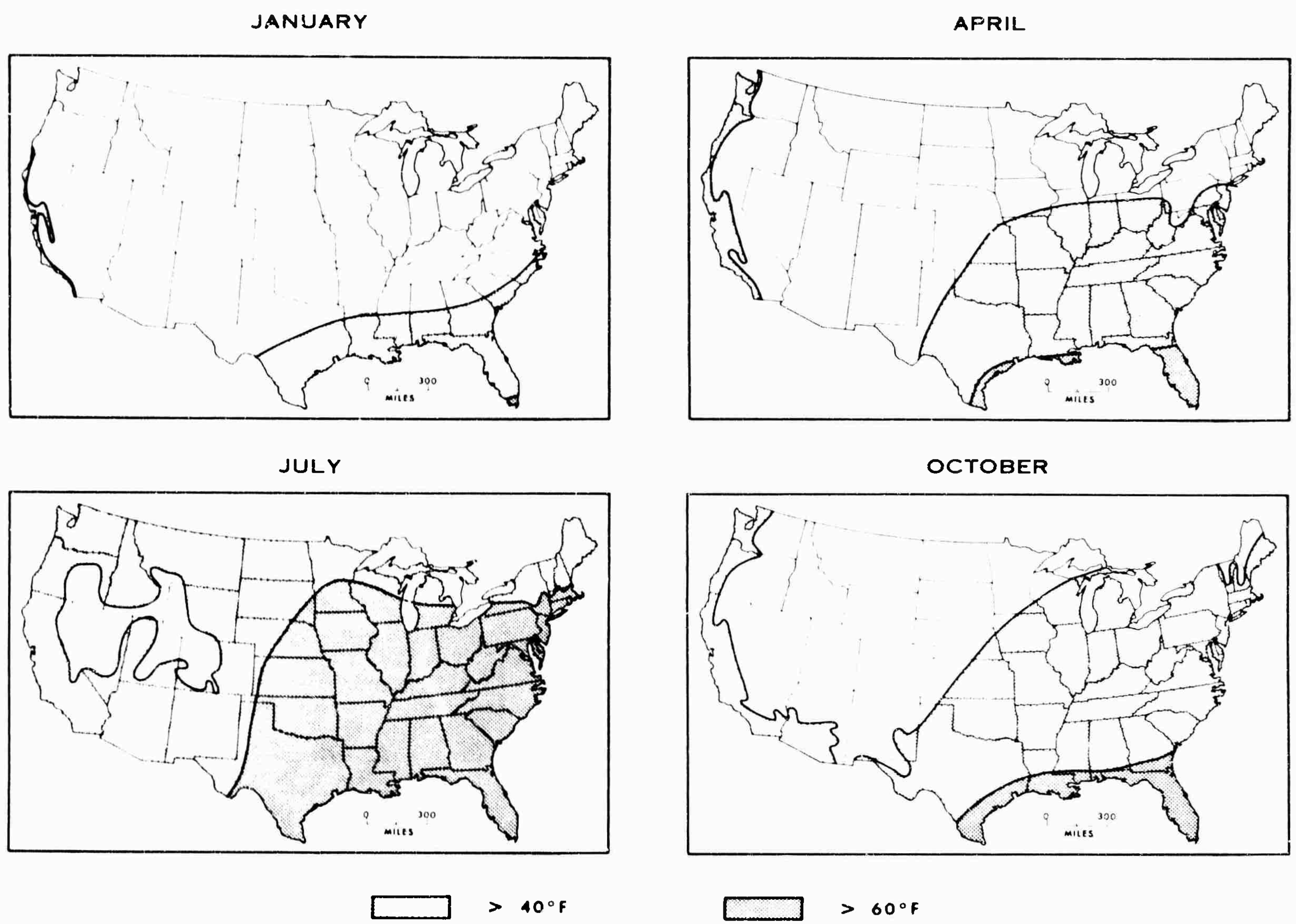


Figure 6

illustrated in Figure 6 by the seasonal penetration inland from the Pacific Coast and southeast coast of the United States of the areas with dew points above 40° and 60°F. It is difficult to separate the temperature control and proximity to water control east of the Rockies, for both controls cause a decrease in dew points towards the north. On the West Coast dew points are more completely controlled by exposure to the Pacific. During part of the year average temperatures increase inland from the coast, but dew points do not.

The maps in Figure 6 are too generalized to show the effect of the oceans on the gradient of dew points on the immediate coast. It would be expected that dew points would decrease away from the coast, and this is the usual situation, but there is a seasonal nature to this variation in areas where sea surface temperatures vary relative to temperatures over land. Where the sea surface temperature is lower than the temperature over land, dew points over the land may be higher than over the adjacent sea and the usual dew point gradient is reversed. Sea surface temperatures are lower than coastal temperatures in New England in the spring and average dew points decrease from the land to the sea. For example, the average dew point on Nantucket is lower than on the nearby mainland in April.

(3) Elevation

A third control of dew point is elevation. As already discussed, this is the control which most complicates the analysis. There is a general decrease in dew point with elevation, but it is not regular in all seasons and areas. Because of these seasonal and areal variations, humidity distributions in mountainous areas are bound to be complicated and difficult to map. The effect of elevation on dew point is evident on the July map in Figure 6 where average dew points below 40°F are found in the high areas of the West.

(4) Local controls

Local differences in humidity occur which also complicate the analysis. Causes of local differences in humidity are height of instruments above the ground; nearness to sources of moisture; urban effects; mountain and valley effects, etc. Although these local variations in humidity are on a small scale, they must be considered in judging the representativeness of the observations for macro-scale analysis. In general, the local controls of humidity affect the diurnal variation of dew point more than its average value. As the data were analyzed, many questions arose concerning the representativeness of the humidity measurements. Considerable correspondence with the officer-in-charge at the stations in question was necessary to ascertain the representativeness of the humidity observations. A list of this correspondence is included in the Bibliography.

c. Dew point and vapor pressure isopleth intervals

As stated earlier, dew points and vapor pressures are single-valued functions of each other and the dew point and vapor pressure maps show the distribution of the same climatic element. Since isodrosotherms and isovapors both indicate the distributions of water vapor near the ground, only the dew point maps will be discussed in detail. This analysis also applies to the vapor pressure maps.

The vapor pressure maps are included in the Appendix because certain disciplines (i.e., physiology, meteorology) commonly use this unit, although the vapor pressure maps show essentially the same thing as the dew point maps. There are differences in the sets of maps, however, which must be noted. The contour interval for the dew point maps is 5F° while the contour interval for the vapor pressure maps is 0.5 inches of Mercury. These two intervals are not equal because the relationship between dew point and vapor pressure is not linear. Low dew points represent very small vapor pressures, and the difference between 0°F and 5°F dew points is small in terms of vapor pressure (0.01169 inches of Mercury). In contrast, changes in high dew points represent a large change in vapor pressure. The difference between a dew point of 70° and 75°F (0.13590 inches of Mercury) is nearly twelve times as large. Dew point-vapor pressure equivalents are shown in Table IV. In areas characterized by low dew points there is a more detailed analysis on the dew point maps (the contour interval is smaller) than on the vapor pressure maps. Conversely, when dew points are high there is a more detailed analysis on the vapor pressure maps. The contour intervals are approximately equal between 40° and 45°F (0.25 and 0.30 inches of Mercury) so that the vapor pressure analysis is more detailed above these values and the dew point analysis is more detailed below. A check of the maps in the Appendix will show that the 40° and 45°F isodrosotherms correspond very closely with the 0.25 and 0.30 inches of Mercury isovapors.

It is necessary to mention one additional aspect of the contour intervals. When dew point and vapor pressure maps are interpreted it is essential to consider the effect of the size of the contour interval. For example, if the average dew points in a valley range from 36° to 39°F in a given month, and from 39° to 41°F in another month, it will appear from the presence of the 40°F isodrosotherm on the second map that there is a larger dew point gradient. Similarly, in mountain areas there may be three isodrosotherms in an area where the difference of dew points is only 12°F, while in another month there may be two isodrosotherms where the difference with elevation is 13°F. This is an inherent limitation of the contour interval, and it must be kept in mind as the maps are examined.

d. Factors affecting standard deviation of dew point

A number of factors must be considered in the interpretation of the standard deviation patterns shown in inset maps to Figures 13 to 24

TABLE IV
VAPOR PRESSURE-DEW POINT
CONVERSIONS*

inches of mercury		degrees Fahrenheit	degrees Fahrenheit		inches of mercury
.05	-	2.4	0	-	0.04477
.10	-	17.9	5	-	.05646
.15	-	27.5	10	-	.07080
.20	-	34.6	15	-	.08832
.25	-	40.3	20	-	.10960
.30	-	45.0.	25	-	.13534
.35	-	49.1	30	-	.16631
.40	-	52.7	35	-	.20342
.45	-	55.9	40	-	.24767
.50	-	58.9	45	-	.30023
.55	-	61.5	50	-	.36240
.60	-	64.0	55	-	.43564
.65	-	66.3	60	-	.52160
.70	-	68.4	65	-	.62209
.75	-	70.4	70	-	.73916
.80	-	72.4	75	-	.87506
.85	-	74.1	80	-	1.0323
.90	-	75.8			
.95	-	77.5			
1.0	-	79.1			

* Values from Smithsonian Meteorological Tables, 6th Revised Edition.

in the Appendix. Air masses from different sources have markedly different water vapor contents, and areas characterized by many changes in air mass will have large standard deviations of dew points. A second factor which increases the standard deviation of the dew point is the diurnal range in dew point (shown on inset maps to Figures 37 to 48 in the Appendix and discussed in the next section). In some areas diurnal ranges in dew point are as large as 10F° in some months, while in other areas diurnal variations are very small. Obviously, standard deviations of the dew point distributions will be larger where the diurnal variations are larger.

A third factor affecting the standard deviations of the dew point distribution is the dew point itself. The differing amount of water vapor involved in a dew point change of 5°F at different levels has already been illustrated. If twelve times as much water vapor is involved in a change in dew point from 70° to 75°F than from 0° to 5°F it is apparent that this is less likely to occur. Other things being equal it would be expected that larger standard deviations would be associated with lower dew points.

Local factors would also be expected to affect the variation of the dew points; however, local difference did not cause any problems in drawing the isopleths shown on the inset maps. Either the variability of the dew point is not changed much by the exposure of the instruments, or the isopleth interval of 2°F on the standard deviation maps is too large to reflect local influences.

2. Discussion of dew point maps

Consideration of the distribution of dew points in the contiguous United States is limited to discussion of the main features of the mean monthly dew point maps. For a more detailed discussion of the maps the reader is referred to the basic study (Dodd, 1964) where analysis of the dew point maps is organized into discussion of dew point changes in three broad geographic areas in which different climatic controls dominate. On the Pacific Coast exposure to the Pacific Ocean is the primary control as indicated by the parallelism of the isodrosotherms to the coast. In the mountain states altitudinal controls have more effect as indicated by the hypsometric pattern of the isodrosotherms. East of the Rocky Mountains latitudinal or temperature controls dominate as indicated by the east-west trend of the isodrosotherms.

a. January (Fig. 13)

Throughout the country January average dew points are lower than in any other month. In northern North Dakota and Minnesota dew points average below zero, and at high elevations in the Rocky Mountains and on the summit of Mt. Washington average dew points are below 5°F. There is no attempt to draw the isodrosotherms for all the high elevations of the mountains in the West, for this would imply an unwarranted accuracy to the maps.

The curvature of the isodrosotherms near the Gulf of Mexico and in the lower Mississippi Valley indicates that even at the peak of winter, advection of moist air from the Gulf is an important aspect of the climate. The influence of the southern waters on the dew points is the result of the periodic invasion of mT air into the country in the southerly circulation associated with the migration of low pressure areas across the country. Many of these lows regenerate or form east of the Rockies and move east and northeast drawing warm moist air into the southlands. Northerly circulation in the rear quadrant of the lows replaces this moist air with colder, drier air, but the colder air masses are greatly modified in the South. The northward extension of the isodrosotherms along the Atlantic Coast is caused by the moderating influence of the Atlantic Ocean increasing dew points near the coast. This moderating influence is at a maximum earlier in the winter but it is still evident in January.

The southward curvature of the isodrosotherms in the Northern Plains shows clearly the advection of cold dry air into the country from Canada. The moderating effect of the Great Lakes, warmer than the land at this time of year and characterized by higher dew points, is apparent in the northward extension of the 10°, 15°, and 20° isodrosotherms. The altitudinal effect of the Appalachians is evident in the southward dip of the 20°, 25°, and 30°F isodrosotherms.

A large area centered in northwestern Nebraska is characterized by little dew point gradient. In this area the factors which cause changes in dew point are in balance. Cold dry air advection to the northeast, increasing altitude to the southwest, and lower latitude with increasing dew point to the south all contribute to the lack of dew point gradient in the area.

On the west coast average dew points are above 40°F, and dew points are lower inland with the isodrosotherms alignment parallel to the coast and closely spaced. The water vapor gradient is particularly steep from the Central Valley of California to the crest of the Sierra Nevadas. The values of the isodrosotherms change with the seasons, but the pattern of the lines in these areas shows little variation from month to month.

b. <u>February (Fig. 14)</u>

The February map differs little from the January map; each isodrosotherm is displaced slightly northward and there no longer are any average monthly dew points below 0°F. The effect of the Great Lakes is a little less pronounced in February than in January. The curvature of the isodrosotherms indicating cold air advection does not extend as far south and conversely the curvature indicating warm air advection over the eastern United States is displaced northward. As in January, there is a null area between the High Rockies and the area of maximum cold dry air advection. In February this area is within the 15°F line.

c. March (Fig. 15)

In March the increase in average dew points is very marked in the North, but is small in the South and in the West. In Minnesota and North Dakota the isodrosotherms indicate a full 10°F increase in dew point; the increase is proportionately less farther south and is very small in Florida. In fact, dew points in Florida average only slightly higher than in January. On the west coast the distribution of dew points has not changed much since January and in the Southwest dew points average slightly lower than in January and February. The null area which extends from Nebraska through northwest Wyoming into Montana is inclosed by the 20°F isodrosotherm in March. The Great Lakes have little effect on the distribution of the isodrosotherms in March.

d. April (Fig. 16)

In April the entire country has higher average dew points than in March with increases of over 10°F in the North, and over 5°F in the South. Dew points are nearing summer levels in southern Florida, where they average over 65°F, and they average lowest in the high Rocky Mountains--below 20°F.

Each month since January there has been an increasing tendency for north-south orientation of the isodrosotherms to the west of the 100th meridian. The 30°F line in April is aligned almost north-south along the 103rd meridian in New Mexico and Colorado, separating the more humid air to the east from drier conditions of the Rocky Mountain states. The curvature of the lines is indicative of the northward advection of moist air almost to the Canadian border. In January lowest dew points were found in Minnesota and North Dakota, but by April the lowest dew points are clearly in the High Rockies, an indication that maritime tropical air has more influence in the Northern Plains than in the High Rockies.

e. May (Fig. 17)

May is characterized by continued increases in average dew points throughout almost all the country. Only in southwestern Arizona and southern California are no increases in dew point indicated, and this is a consequence of the isopleth interval, for stations in these areas have one or two degrees F increases in average monthly dew points. Again in this month the dry mountain states are separated from the more humid Mississippi drainage area by a north-south trending isodrosotherm along the 103rd meridian, this time the 40°F line. The 65°F line is now well inland from the Gulf of Mexico and the eastern two-thirds of the country has dew points which average 5 to 10°F higher than in April.

f. June (Fig. 18)

Possibly a good definition of a summer month is a month in which the Gulf of Mexico littoral has average dew points above 70°F. This is indicative that mT air is well established in the Southeast. Average dew points above 55°F as far north as the Great Lakes indicate the extent of influence from the south. The influence of mT air is now becoming evident farther west also, as evidenced by the western migration of the 40°F isodrosotherm from the 103rd meridian to the 105th meridian in the central United States and farther west to the south and to the north.

In June the lowest dew points are found in the High Rockies and in the Great Basin. The influence of the Pacific as a source of water vapor is indicated by dew points over 50°F on the southern California coast. This influence does not extend beyond the Sierra Nevadas, and the Great Basin, far removed from moisture sources in the East and protected from the West, has very low moisture content of the air. The areas of the Rockies with similar dew points are several thousand feet higher.

g. July (Fig. 19)

Average dew points are highest in July in most of the United States. With the exception of the higher areas of New England, dew points average above 55°F east of the 100th meridian, and a large area of the south has dew points above 70°F. No station has an average dew point of 75°F, however, although Galveston, New Orleans, and Cape Kennedy all have averages of over 74°F. Very likely there are localities along the Gulf of Mexico or Atlantic Coasts with average July or August dew points greater than 75°F, but observations are not available from the places and they cannot be allowed for on the map.

In July there are only three isodrosotherms between the Gulf of Mexico and the Canadian border. This small dew point gradient is a deceptive measure of the water vapor gradient, for a difference of 5°F in the high dew points which occur in July is equivalent to a much larger difference in dew points in the winter months. This is apparent on the mean vapor pressure map for July (Fig. 30) where there are seven isovapors between the Gulf Coast and the Canadian border.

Again in July the lowest average dew points in the United States are found in the Great Basin and in the High Rockies. The largest increases in dew point between June and July are found in the Southwest where some stations have dew points almost 20°F higher in July than in June (e.g., Tucson, 41°F in June, 60°F in July). This increase in dew point is caused by the westward penetration of mT air from the Gulf of Mexico which had already been noted farther east in June. This westward penetration of mT air is a regular feature of the climate of the Southwest and has been discussed in the literature (Jurwitz, 1953; Bryson and Lowry, 1955; Ohman and Pratt, 1956).

The variations in the annual range of average monthly dew points can be obtained from comparison of the January and July (January and August in the Southwest) maps. Largest ranges are found in North Dakota and Minnesota where average dew points range from below 0°F in January to above 55°F in July. Ranges are small in the West--only about 10°F in some areas of the Pacific Coast, but increase to over 20°F in the Great Basin and to over 30°F on the Mexican border where relatively humid air is found in the late summer.

Annual ranges of average monthly dew points on the East Coast increase from about 15°F in southern Florida to over 40°F on the New England coast. In general the pattern of annual ranges in dew points in the United States is similar to the pattern of temperature ranges (Visher, 1954, p. 138).

h. <u>August (Fig. 20)</u>

There is little difference between the July and August average dew point maps. In most of the country dew points average slightly lower in August. Exceptions are found in the northern plains where, near the Canadian border, August dew points are as much as 5°F lower than July dew points, and in the Southwest where August dew points are slightly higher than in July. August is the only month in which a 60°F isodrosotherm is found in the West. These relatively high dew points are caused by the westward penetration of air from the Gulf of Mexico noted in July.

i. <u>September (Fig. 21)</u>

The 70°F isodrosotherm is still found along the Gulf Coast in September, but the dew point gradient northward is now larger with average dew points below 45°F found in North Dakota (compared with dew points between 55°F and 60°F in July). As would be expected average dew points are lower throughout the country in September than in July and August, but they are higher than in May, and in the Southwest they are higher than in June (e.g., Yuma, Arizona--June 42°F; September 54°F).

j. <u>October (Fig. 22)</u>

By October the transition from summer to winter conditions is apparent throughout the country. The 70°F isodrosotherm is only found in southern Florida and the gradient in dew points northward is now 30°F as compared with a 15°F gradient in July.

At this time of year the Great Lakes and the Atlantic Ocean are warmer than the land and have a modifying influence on dew points. This effect is well illustrated by comparison of the 40°F isodrosotherms in April and in October. In April the 40°F isodrosotherm remains south of the Great Lakes and is only slightly farther north on the Atlantic coast than in the Mississippi River Valley. In October this line of equal dew points has a larger north-south variation, extending north of Lake Huron and Lake Michigan and through northwest Maine. It crosses the Mississippi at latitude 44°N and reaches the Atlantic coast somewhere north of 47°N.

k. November (Fig. 23)

The moderating effect of large bodies of water evident in October is even more marked in November. Each isodrosotherm is found farther north on the Atlantic coast than in the central United States; this displacement increases at the higher latitudes. For example, the 50°F line is one degree of latitude farther north at the Atlantic coast than at the 93rd meridian; the 45°F line is extended 2° farther north; the 35° line is about 5° farther north on the Atlantic coast; and the 30°F isodrosotherm crosses the 93rd meridian at the 41st parallel, is then extended sharply northward through the Great Lakes, and reaches the Atlantic in Canada near the Strait of Belle Isle (not on map).

In the western United States the decreases in dew points from September to October and October to November average about 5°F on the coast and inland with little latitudinal variation. Decreases in dew point from October to November are larger along the Mexican border from El Paso to Yuma. At El Paso the dew point in November is 14°F lower than in October, indicating an end to the influence of the mT air from the Gulf of Mexico so prominent in the late summer and early fall.

l. December (Fig. 24)

December average dew points are not as low as those in January. February dew points also average slightly higher than January dew points on the Gulf of Mexico Coast and in the Great Basin. The winter pattern of isodrosotherms is now established with curvature of the lines in the North Central States indicating dry cold air advection, and the reverse curvature in the south resulting from the advection of air from the Gulf of Mexico.

3. Discussion of standard deviation inset maps

The inset standard deviation maps to Figures 13 to 24 have several distinguishing features. In the West the distribution of standard deviation is characterized by values on the coast of less than 8°F in winter and less than 4°F in summer. Inland, standard deviations are higher in every month. East of the Rockies in most months there is an increase in standard deviation northward, but there are exceptions to this. In January standard deviations are larger on the Gulf Coast than inland, although they are highest farther north. In the spring and fall standard deviations are slightly lower in the north and south than in the center of the country. No explanation for this is offered, but the similarity of the alignment of the standard deviation isopleths in April and October would indicate some rather general controls of dew point variability.

At most stations there is a seasonal variation in standard deviation, with winter standard deviations 2 to 5 times as large as in summer. For example, in the Northern Plains near the Canadian border January standard deviations are larger than 10°F while July standard deviations are less than 6°F. In southern Florida January standard deviations are about 10°F while in July they are about 2°F. The Southwest is the one section of the country not characterized by a large difference in standard deviation from summer to winter. Standard deviations range from 8°F to 12°F throughout the year, and some stations have their highest deviations in the summer.

There is an interesting progression of standard deviations of the dew point distributions on the April, May, June, and July maps which is apparently caused by air mass changes. In April the highest variability of dew points in the country is found in an area extending from the Rio Grande to near Kansas City. In this area standard deviations are over 13°F at some stations. In May, the area of maximum standard deviations has moved westward, and includes most of New Mexico. In June this area has expanded and covers most of the southwest. This causes a strong gradient of standard deviations in southern California. In July the area of maximum standard deviations of dew point distributions is confined to the lower Colorado River basin and the southern portion of the Great Basin.

This westward migration of the area of maximum standard deviations is associated with the increase in dew points experienced at stations in the Southwest in the summer. It is not a characteristic of the mT air which migrates westward during the summer, but of change from cT to mT air. The mT air mass is characterized by small variation in dew point, whereas the cT air mass has more variability in water vapor content. Yuma, Arizona, the station most continuously under the influence of continental tropical air, is the only station in the country with standard deviations of the dew point distributions of over 10°F in each month.

PART III

DIURNAL VARIATION OF DEW POINT

The diurnal variation in the amount of water vapor near the ground is a function of the physical processes which add and subtract water vapor at the earth's surface. Water vapor is added to the air by evaporation and transpiration. Water vapor is depleted during the day mainly by turbulent mixing with drier air aloft, and at night by the condensation of dew. The physical elements which control evaporation, transpiration, turbulent mixing, and formation of dew, then, are the principal elements which control the diurnal variation of water vapor near the ground.

There are variations in water vapor near the ground due to other than diurnal processes. The best example is the change in dew point or vapor pressure which occurs with change in air mass. Since there is no evidence of diurnal periodicity of air mass changes on a macro-scale (eliminating land and sea breezes), air mass change is not considered a control of diurnal variation of water vapor in the air.

1. Controls of diurnal variation of dew point.

Incoming radiant energy and moisture availability at the earth's surface are the two major controls that determine the daily march in dew point. Other controls are locally important, but these two exert an influence on the daily march of dew point at all stations. Moist surface conditions may be at the site of the observations or moisture may be brought into the locality by prevailing surface winds; the best example is a sea breeze. Thus wind is a third control of the dew point regime at some sites. Cloudiness is an indirect control in that it limits the amount of incoming radiation during the day and decreases both the amount of evaporation and the amount of turbulent mixing due to surface heating. Cloud cover also hinders nighttime cooling and formation of dew. The net effect of cloudiness is to limit moisture exchange at the earth's surface and thus decrease daily variation in dew point near the ground. Its effect on the times of maximum and minimum dew points cannot be determined, however, for it limits both the processes which add water vapor and those that deplete water vapor near the surface.

As discussed in Chapter II, Conrad (1936) and P. Karapiperis (1951) identified definite types of diurnal variation of vapor pressure and established that they resulted from the interaction of evaporation and turbulent mixing. Karapiperis showed that there is a seasonal change in diurnal variation types at Blue Hill, Massachusetts. It will be demonstrated in this chapter that there is also areal order to the types of diurnal variation of dew point or vapor pressure.

Since solar radiation is a dominant control of daily march of dew point, and since it has definite areal and temporal variation, it is not surprising that there exists some degree of order to the types of daily march of dew point. Normally, after sunrise, incoming radiant energy increases evaporation and transpiration of water vapor into the atmosphere and increases the dew point. In areas where incoming radiation is intense, turbulent mixing resulting from strong surface heating tends to offset the increase in water vapor due to evapotranspiration, and, later in the morning or early in the afternoon, decreases the amount of water vapor near the ground.

It was found that in the United States the expected increase in dew point after sunrise occurred at all stations with representative exposure of psychrometers. The only stations where this did not occur each month had instruments exposed high above the ground surface away from moisture exchanges taking place after sunrise.* An increase after sunrise is the one universal feature of the diurnal variation or daily march of dew point.

The second major control of the daily march of dew point is the availability of water at the earth's surface for evaporation or transpiration into the air. In dry regions the amount of water vapor available for evaporation is limited. Strong incoming radiation and strong winds are usually present during the day and favor turbulent mixing. Under these conditions daytime dew points are lowered during high sun hours. In dry regions the representativeness of the observation site is particularly important, for where moisture is available (as in irrigated areas) transfer of water vapor into the atmosphere through evaporation (and transpiration if there is a plant cover) is rapid, and dew points near sources of moisture may be considerably higher than in the more representative dry areas. Care must be exercised in accepting data for dry sites without first considering the exposure of the instrument. For example, upon inquiry, it was found that the observations at one station in Arizona were taken over a "grassy lawn" which was irrigated (McFadden, 1963). At this station the summer minimum dew point in the daily cycle occurred in the morning, whereas other nearby stations had minima in the afternoon. The higher afternoon dew points at this station resulted from evaporation and transpiration from the irrigated lawn. It was the diurnal variation of dew point that revealed the unrepresentative nature of the site better than the dew point average itself because the station had average dew

* Examples are Kansas City (psychrometer 39 feet above the ground on a roof) and Colorado Spring (psychrometer 35 feet above the ground, also on a roof). At Kansas City and Colorado Springs in several months of the year the average hourly dew points continue to decrease after sunrise. At these stations and others with instruments well above the ground, the daily range in dew point is smaller than at the more representative exposures near the ground.

points only slightly higher than nearby stations. Data from unrepresentative stations had to be disregarded when the diurnal variation maps were drawn.

In areas where surface moisture is more generally available, as in the northeastern United States, there is apt to be an increase in dew points during the day. In northern humid sections of the country there is considerable precipitation and cloudiness, and less incoming radiant energy than in the drier areas. Not only is more moisture available for evapotranspiration, but there is on the average less surface heating and turbulent mixing. Thus the daily march of dew points in the more humid parts of the United States is characterized by an afternoon maximum. This is particularly true during the low sun months when there is less surface heating and turbulent mixing.

In mountainous areas, particularly in the West, stations experience mountain and valley breezes and a vigorous vertical flux of moisture, both of which modify significantly the diurnal variation of humidity. Rathschuler (1949) has shown that valleys may have different diurnal variations of dew points than nearby ridges or summits because of the upward flux of water vapor during the day as the ground is heated. Valley stations have a decrease in dew points during the day while summits have an increase. Most stations in the mountainous areas of the West are representative of the valley situation.

There are exchanges between the surface air and soil which do not involve condensation or evaporation (Ramdas, 1938). Buettner (1958, p. 159), in classifying processes which bring water to the earth's surface identified the moisture exchange discussed by Ramdas as adsorption.* Adsorption is dependent on soil properties, principally the percentages of fine particles, and may occur when soil is relatively dry. Adsorption of water vapor into the soil from the air occurs at night while during the day the water vapor is again released to the air. Adsorption, therefore, tends to decrease the nighttime and increase the daytime vapor pressure.

2. Types of diurnal variation of dew point

It follows from the discussion of dew point controls that the occurrence of a minimum dew point in the early morning is characteristic of humid climates, while the occurrence of the minimum dew point during the day is characteristic of dry climates. Because the morning and afternoon minima in the daily cycle of average dew points are so widespread, they

* Adsorption: water vapor taken into solid or liquid hygroscopic surfaces whose temperatures are higher than the dew point of the adjacent air.

are the basis for the four classifications adopted in this study. The Type I diurnal variation regime is identified by a single dew point minimum before sunrise and a maximum dew point during the day. In the Type II diurnal variation regime the minimum before sunrise is still the primary minimum, but there is also a secondary minimum in the afternoon. Type III also has a double cycle of dew points, but in this type the primary minimum is in the afternoon and the pre-sunrise minimum is less marked. In Type IV there is a single afternoon minimum dew point. Type IV is almost a mirror image of Type I. In each type the afternoon decrease in dew point is more prominent.

Conrad (1936) and Karapiperis (1951) also classified types of diurnal variation of dew point, or vapor pressure, according to the times of occurrence of minimum dew points. The classification here was expanded from theirs, and recognizes a progression from a regime in which there is water available for evaporation into the air as the ground is heated and the temperature rises, to a regime in which intense radiant heating and resultant turbulent mixing cause a sharp decrease in surface dew points during the day. Thus the four types of daily march of dew points identified here indicate the moisture exchange taking place between the earth's surface and the air near the ground. Discussion of each of the four types will be covered in the following paragraphs. Analysis of the areal distribution of these types for each month will follow.

a. Type I (Humid)

Type I is the most widespread of the diurnal variation types. In it the dew point varies almost directly with the temperature with lowest average dew points in the morning before sunrise, and in almost all cases, highest average dew points in the afternoon. Conrad referred to Type I as "oceanic" implying an insular or coastal location. Since it also occurs in places far removed from oceans it is referred to here as the humid type. Type I is indicative of a ready availability of water at the surface for evaporation into the air during the day. Type I also indicates that the incoming radiant energy during the day is not sufficient to cause a daytime decrease in dew point due to turbulent mass exchange. It is not surprising that Type I is most widespread during low sun months.

Examples of Type I daily march of dew point are given in Figure 7. These examples were selected to illustrate the variations which exist within this type defined by the unifying characteristics of an early morning minimum average dew point and a daytime maximum. Bangor, Maine, has a Type I variation each month of the year. In January the range of the tri-hourly average dew points is 6.1°F, varying from a minimum of 12.7°F in the time group near sunrise (0600, 0700, and 0800 LST), to 18.8°F in the early afternoon time group (1200, 1300 and 1400 LST). In July the range is smaller, 3.4°F, and the length of time with the dew points near

TYPE I - DAILY MARCH OF DEW POINT

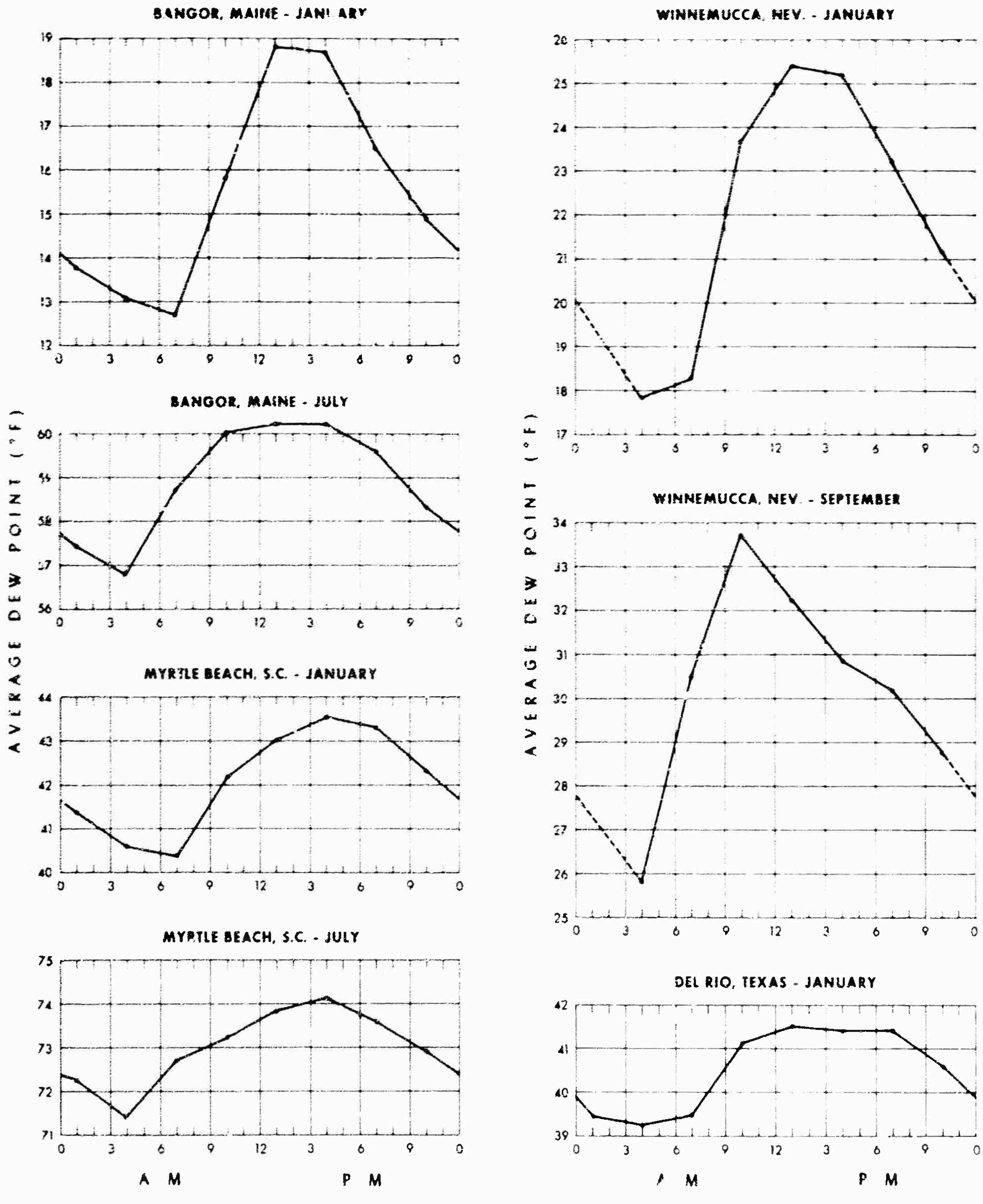


Figure 7

the maximum is longer.* The significance and distribution of the tri-hourly daily ranges is further discussed later in this chapter, and maps showing the tri-hourly daily range distribution are included as insets to the types of diurnal variation maps (Figs. 37 - 48, Appendix).

Myrtle Beach, South Carolina, also has a humid dew point regime each month of the year. This is clearly due to its coastal location because stations farther inland have Type I regimes only in the winter months. Most coastal stations in the United States have this type regime throughout the year because the highest dew points occur when the sea breeze is strongest in the afternoon. Conrad's "Oceanic" term is applicable at the coastal stations. Dew point ranges at Myrtle Beach are less than at Bangor, but it must be remembered that the 6°F range at Bangor in January represents a small variation in vapor pressure because of the low dew points at Bangor in winter.

Winnemucca, Nevada, like Bangor has a large tri-hourly daily range in the January daily march of dew point and this range represents more variation in vapor pressure since the average dew points are higher at Winnemucca. Types II and III occur at Winnemucca from March through August and Type I occurs from September through February. The September regime at Winnemucca differs from the January regime in that the maximum dew point occurs in the morning instead of in the afternoon. In dry climates maximum dew points typically occur in the morning a few hours after sunrise. The reason for this is not completely understood, but after sunrise rapid evaporation accompanying the intense solar radiation must contribute to the morning maximum dew point. The Winnemucca graphs in Figure 7 illustrate this rapid increase in average dew point after sunrise. (On the Winnemucca graphs, the average dew point for the first three-hour time group was missing, as indicated by the dashed lines.)

The range in tri-hourly average dew points at Del Rio, Texas, is small. Near the boundaries of the diurnal variation types the range of dew points is usually smaller than in the core areas. Del Rio is near the boundary with Type II and is one of the more southerly stations with a Type I variation in January (Fig. 37).

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* For convenience the difference between the highest and lowest tri-hourly average dew points will be referred to as the tri-hourly daily range. This is not the average daily range since it is derived from hourly observations summarized in three-hourly time groups. It was possible to compare the dew point daily ranges from hourly summaries at 16 stations (from 1961, 1962, and 1963 Weather Bureau records) with the ranges from tri-hourly summaries from the same stations available for this study. It was found that the dew point ranges from the hourly summaries were about 1°F larger. The line of regression for this relationship is $y = 1.02 + 1.04x$ with a standard error of estimate of 1.1°F, where x is the daily range from tri-hourly averages, and y is the daily range from hourly averages.

From inspection of Figure 7 it is apparent that there are differences in range and configuration of the Type I daily march of dew point, and similar differences will be demonstrated for the other type regimes. They do have unifying features, however, that have physical meaning.

b. Type II (Modified Humid)

Type II has a double daily variation, with the primary minimum dew point occurring in the morning at the time of the minimum temperature and a secondary minimum dew point occurring during the day. This is the type that Conrad referred to as "continental." In Type II the temperature control of Type I is still dominant and a primary minimum is found in the morning. However, the effects of turbulent mixing distributing water vapor from near the earth's surface upward is apparent in a secondary minimum in the dew point regime in the afternoon. The highest dew points in the double cycle occur in the morning after sunrise and in the late afternoon or evening after the secondary minimum. These maxima may be about equal or either one of them may be larger. In the more humid eastern part of the country there is a tendency for the primary maximum to occur in the evening, while in the drier west the highest dew points usually occur in the morning. There are enough exceptions to these differences in times of maximum dew points that they cannot be generalized.

The range between the lowest and highest tri-hourly average dew point in Type II usually is smaller than in Type I because the average dew point fluctuates through a double cycle each twenty-four hours.

Selected examples of the Type II daily march of dew point illustrate the variations in this type (Fig. 8). Note the variations in the times of the maximum dew points. Portsmouth, New Hampshire, and Green Bay, Wisconsin, are near the northern extent of the Type II regime in July (Fig. 43). At Portsmouth the tri-hourly daily range in dew point in July is less than 2°F, and the afternoon minimum is only a few tenths of a degree lower than the morning and evening maxima. This is almost a Type I variation. In contrast, at Green Bay the range is greater than 3°F and there is a definite primary maximum in the evening.

At Portsmouth and Green Bay Type II occurs in the summer, but in some areas it is a transitional type occurring in the spring and fall. Examples are given for Winnemucca, Nevada, in March; and Reno, Nevada, in September. At these western stations the dew point regimes in these months are similar with the primary minimum before sunrise and the primary maximum in the morning.

Laredo, Texas, is near the southern limit of Type II diurnal variation of dew point. Laredo has a small tri-hourly daily range with minima before sunrise and in the afternoon. The maxima occur after midnight and after sunrise.

TYPE II - DAILY MARCH OF DEW POINT

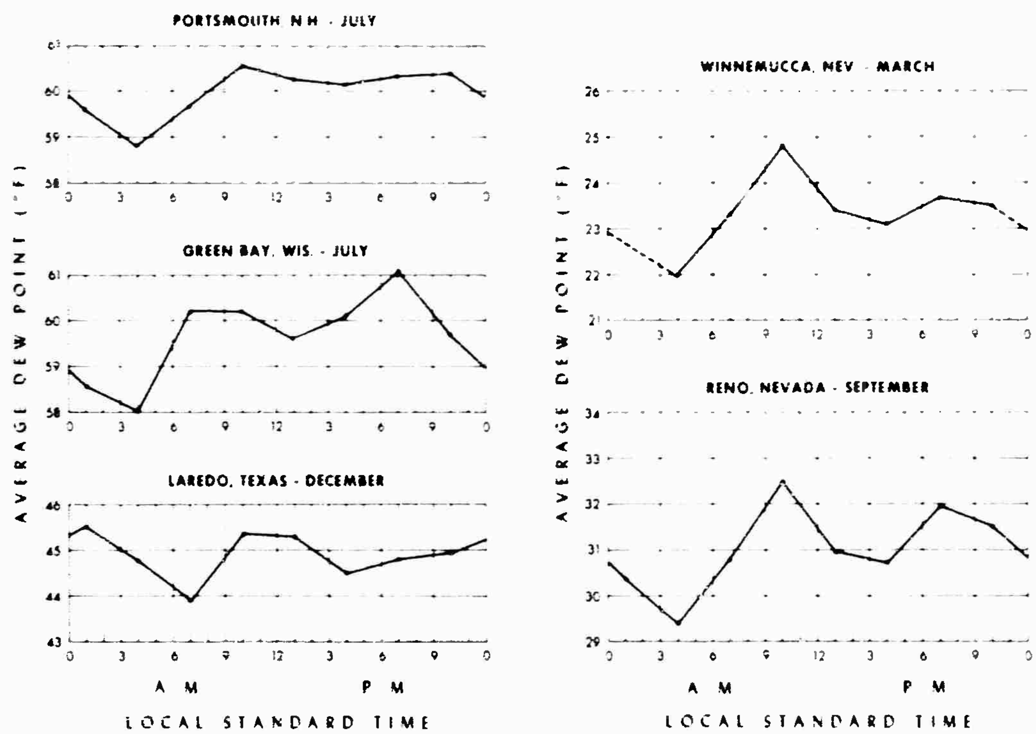

Figure 8

TYPE III - DAILY MARCH OF DEW POINT

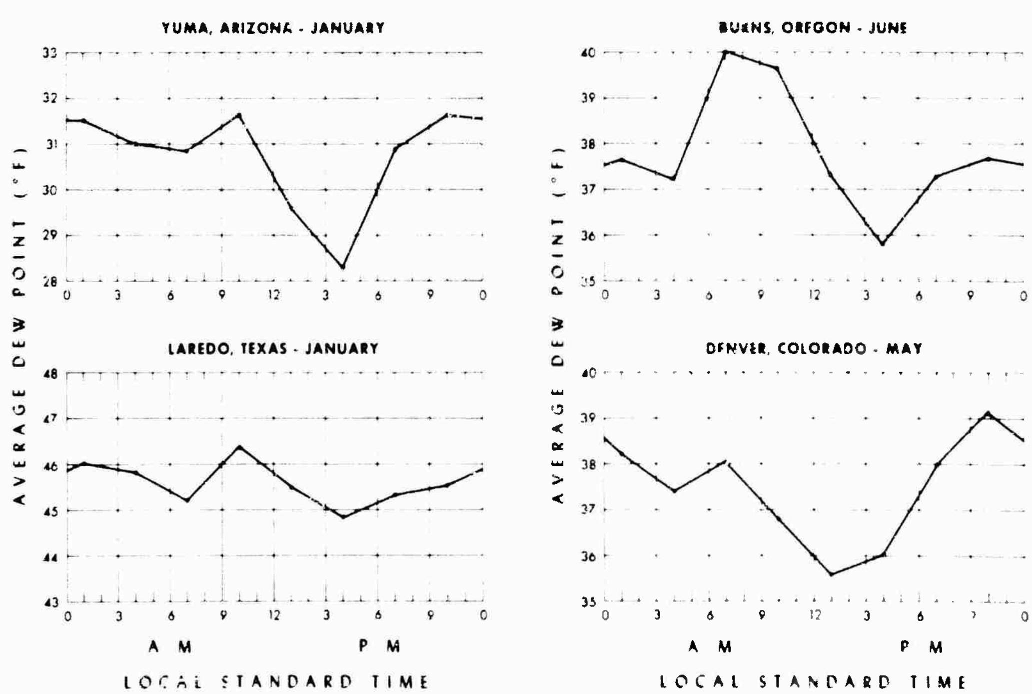

Figure 9

A feature of the Type II regime not found in the other types is the uniformity of the daily ranges of dew point. At most stations ranges are between 1° and 3°F, and no station has a range over 5°F.

c. Type III (Dry)

Like Type II, Type III has a double daily variation of dew point. The primary minimum occurs during the day, indicating that strong solar heating, increased turbulent mass exchange and dry ground dominate the control of the daily march of dew point. Temperature control is still evident in the secondary minimum of dew point before sunrise.

Type III daily march of dew point is confined to an area of the Southwest during the winter months that has a Type IV regime most of the year. Yuma, Arizona, has a Type III dew point variation in November, December, and January. In November and December the secondary minimum in the early morning is hardly marked enough to justify the Type III classification, but in January the secondary morning minimum is distinct (Fig. 9) and the morning and evening maxima are about equal. The Type III dew point regime at Laredo, Texas, in January is similar to the Yuma regime in that the two maxima are of the same order, but the range is much smaller at Laredo.

One of the more northerly stations to have a Type III daily march of dew point is Burns, Oregon. Burns has a distinct morning maximum and afternoon minimum with a large range in June. In contrast Denver, Colorado, has a Type III regime in May with an evening maximum dew point.

d. Subtype II-III (Transitional)

In Type II diurnal variation of dew point the primary minimum dew point occurs before sunrise, while in Type III the primary minimum dew point is in the afternoon. There are cases in which these two minima of dew point are equal, and these cases are treated independently because they do not belong in either Type II or Type III. The areal extent of conditions where the two dew point minima are equal is too limited to consider this occurrence as defining a type of dew point diurnal variation. It was useful, however, to delimit this transitional subtype in determining the boundaries between Type II and Type III.

Example of Subtype II-III variations are shown in Figure 10 to illustrate the variations which occur in this transitional type. At Winnemucca, Nevada, in April, the pairs of minima and maxima dew points are both about equal, resulting in a balanced double curve with the tri-hourly daily range between the high and low values of 3°F, a larger range than is typical of this transitional subtype. In May and June Winnemucca has Type III regimes of dew point variation during the day, but in July there is again transitional variation, this time with a pronounced morning maxima and a larger range.

The Des Moines, Iowa, and Hempstead, New York, curves in Figure 10 are examples of transitional daily marches of dew point with small ranges and a maximum dew point in the evening.

e. Type IV (Very Dry)

Type IV is characterized by its uniformity with a minimum dew point in the afternoon and a maximum dew point in the morning after sunrise. It is also characterized by a large tri-hourly daily range in dew point except near its boundary with Type III. Type IV is the desert and steppe type in Conrad's classification. No station in the contiguous United States has a Type IV dew point regime in January, but the area with this daily march in dew point increases from a small portion of the Southwest in February to its maximum extent covering about one-fifth of the country in July and August.

Examples of Type IV dew point regimes in Figure 10 are selected to show the variation in tri-hourly daily ranges from an extremely large range at Yuma, Arizona, in June to a small range at Fort Sill, Oklahoma, near the northeastern limit of the area with Type IV conditions in August.

There are a few stations which had daily march of dew points which fitted the Type IV classification better than any other class, but should not be considered as having Type IV regimes. In two cases these abnormal Type IV regimes could be attributed to the exposure of the instruments many feet above the ground, where the morning minimum dew point did not occur (Kansas City and Colorado Springs, discussed above). The Type IV variation in dew points at Kansas City would be a Type III regime if there were slightly more evaporation after sunrise to cause a secondary morning minimum before sunrise. Four stations within 75 miles of Kansas City have Type II or Type III regimes, an indication of the abnormal regime at Kansas City.

Similar effects on dew point variation were also found in the Washington, D. C., area. At Andrews Air Force Base outside Washington Type I or Type II dew point regimes occur throughout the year, while at nearby Bolling Air Force Base Type IV regimes occur from July through October. The Andrews psychrometric observations were made in an instrument shelter located five feet above the ground, while the Bolling observations were made in an instrument shelter on top of the Base Operations building approximately 18 feet above the ground (Holtzscheiter, 1963). The differences in diurnal variation regimes can be ascribed to differences in exposure of instruments.

3. Areal Distribution of Diurnal Variation Types

Inspection of Figures 13 to 24 in the Appendix reveals systematic changes in the areal distribution of dew point types in the United States.

TYPE II-III - DAILY MARCH OF DEW POINT

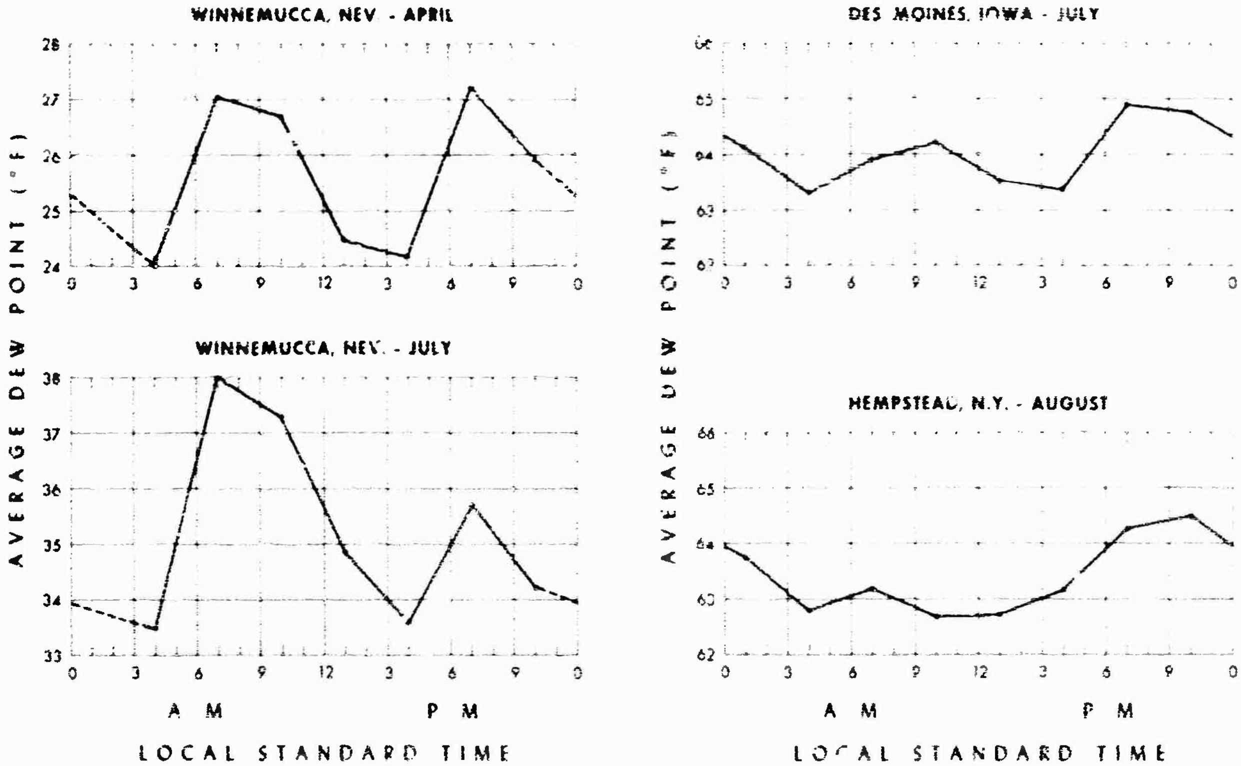

Figure 10

TYPE IV - DAILY MARCH OF DEW POINT

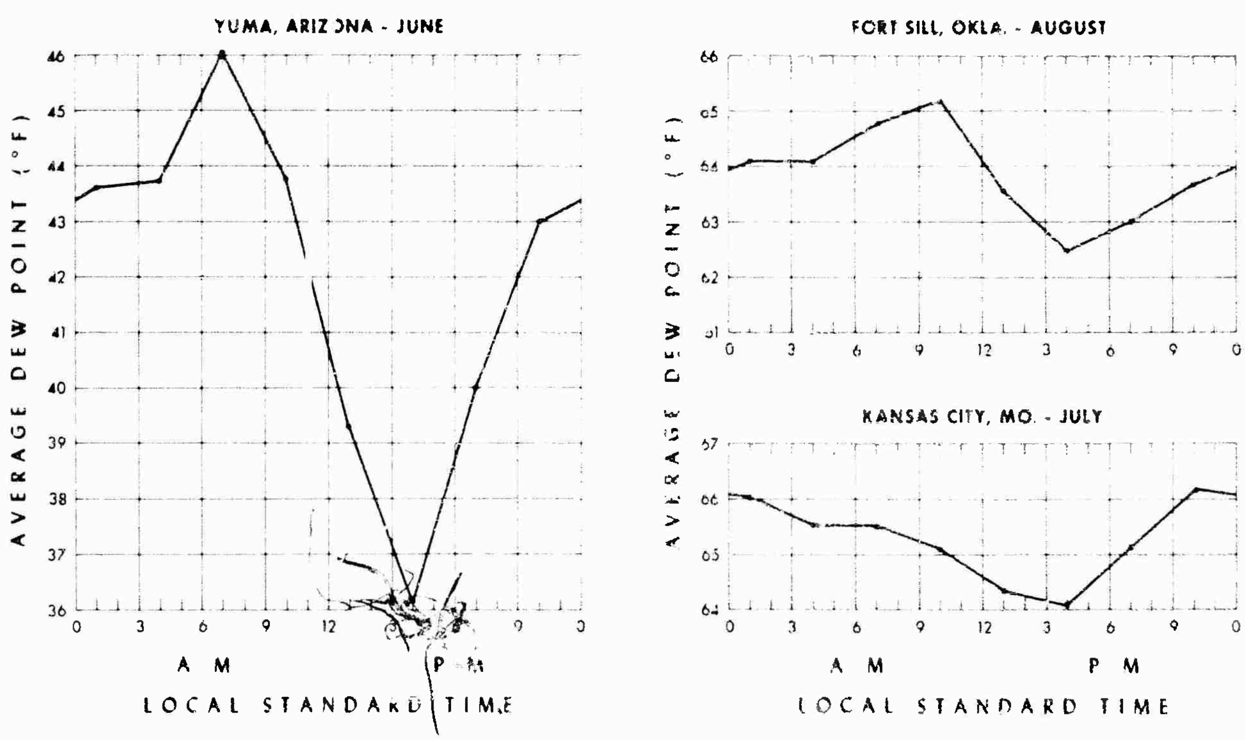

Figure 11

Types I and II, in which the early morning minimum of dew point is pronounced, are found in almost all the country in the winter and are widespread throughout the year. Types III and IV cover more than half the country during the summer months. In the following pages the distribution and characteristics of the four types will be discussed.

a. Type I (Humid)

In January Type I is found throughout all of the contiguous United States except portions of the Sonoran and Mojave Deserts, noncoastal southern Texas, and southern Florida. In these limited areas the solar radiation is intense enough to cause the turbulent mass exchange which mixes drier air from aloft with the surface air and decreases the dew point in the afternoon. Temperature* and moisture availability at the surface are the primary controls of a Type I diurnal variation. The occurrence of this type over such an extensive area of the country in the winter may be partially due to water-vapor exchanges similar to those which Ramdas has demonstrated and Buettner has referred to as adsorption In the drier parts of the country the occurrence of Type I daily march of dew points might be explained by this moisture exchange which does not require a wet surface.

The areal extent of Type I diurnal variation of dew point decreases each month from February to July. In July, August, and September, Type I is found only near moisture sources. In October most of the northern half of the country again has a Type I diurnal variation and by December it has reached its maximum extent.

Coastal areas of the United States are more subject to Type I conditions than interior areas and many coastal stations have this type throughout the year. The west coast, with prevailing onshore winds, has a dew point minimum before sunrise and a daytime maximum, usually in the afternoon, every month of the year. The east coast, with less tendency for prevailing onshore winds, has Type I dew point variations in the summer where the afternoon sea breezes are pronounced and cause an influx of air with higher dew point. Only three stations on the eastern seaboard have Type I diurnal variations throughout the year. They are Myrtle Beach, South Carolina; Cocoa Beach, Florida; and Cape Kennedy, Florida. Since they are the only stations directly on the coast with records of diurnal variation of dew point, they indicate the occurrence of the humid diurnal variation regime from South Carolina southward. The weather stations a few miles inland at Charleston, South Carolina; Savannah, Georgia; and Orlando, Florida; have Type I conditions only in the winter and indicate the limited extent inland of the sea breeze effect.

* Temperature is the direct control, but incoming radiant energy is the ultimate control.

None of the coastal stations north of Cape Hatteras have a Type I diurnal variation in July and August. Instead they have the Type II variation indicated on the maps for the Middle Atlantic and southern New England coasts during those months. Bangor, Maine, has a Type I variation throughout the year and is the basis for the mapping of the Maine coast as Type I each month.

The more extensive summer occurrence of Type I conditions on the Atlantic Coast south of Cape Hatteras is caused by a combination of factors. In the summer the sea surface temperatures along the coast decrease from over 75°F south of Cape Hatteras to below 60°F north of Cape Cod (United States Navy Hydrographic Office, 1944). In the south, sea surface temperatures are about 10°F higher than the average dew points at coastal locations, while in the north the sea surface temperatures are only slightly higher than average dew points at coastal locations. The net result of this is that a sea breeze north of Cape Hatteras normally will have little effect on the dew point, while farther south onshore winds during the day cause a rise in dew points. These relationships between dew point and sea surface temperature on the East Coast are corroborated in some detail by Nicholas and Sissenwine (1949). They found that north of Cape Hatteras the difference during summer months between the coastal dew points and adjacent sea surface temperatures varied from 1° to 4°F. South of Cape Hatteras the differences were from 7° to 10°F.

The Type I sea breeze variation in dew point is more difficult to delimit on the Gulf of Mexico coast. In the Eastern Gulf, Valparaiso, Florida, and Biloxi, Mississippi, have Type I distributions throughout the year. Stations as far west as New Orleans show the effects of sea breezes raising the dew point in the afternoon. Data from coastal stations in Texas were not available and it is not known whether a Type I variation in the summer would be found there. A few miles inland at Lake Charles and Houston there is no indication of an increase in dew point in the afternoon in the warmer months. Based on the data from these stations no Type I sea breeze variation is shown for the warmer months on the Texas Gulf coast.

Tri-hourly daily range is a good indicator of whether the station is in the core of the area represented by the type, or whether it is near the periphery of the type. In winter the daily range of dew points is greatest in the North Central States, northern New England, and the Great Basin. In these three areas 7° to 8°F variations between the maximum dew points in the afternoon and the minimum dew points in the morning occur in February. The dew point ranges decrease from these values to variations of less than 3°F in the Southeast, and less than 2°F on the boundaries of the areas with Type II diurnal variation of dew point. Usually the daily range becomes smaller at a given station in the month before the changeover from Type I to Type II regimes. By April daily ranges at all stations in the Type I areas are less than 5°F. The only other large diurnal ranges during Type I conditions are found on the West Coast where the variation in diurnal range between stations may be large (San Rafael, 9°F range in July; Monterey, 2°F range in July).

b. Type II (Modified Humid)

Type II daily march in dew point increases in the spring months from a more limited areal extent in December and January. In February, Type II conditions are found in a narrow band across the southern margin of the country from coast to coast. This band is found progressively farther north in March, April, and May.* In the West Type II reaches the Canadian border by April. In May this modified humid diurnal regime extends in the north from Montana to the Great Lakes, is restricted to a narrow band in the center of the country, and then is found in an east-west band to the Atlantic Coast.

Most of the country northeast of a diagonal line from Montana to Florida has Type II conditions in the summer months and Types III and IV are found southwest of this line. The boundary between Type II and Type III is the dividing line between the dominance of humid and arid controls. Whether this line has use as an aridity index has not been investigated, but it is at least a rough indicator of the area in which arid conditions prevail.

The migration southward of Type II conditions in the fall is more rapid than its northward progression in the spring. It is still extensive in October and November, but it is restricted to the Sonoran and Mojave Deserts, southern Texas, and southern Florida in December.

c. Type III (Dry)

Yuma, Arizona, is the only station in the country with Type III diurnal variation of dew point in December. By February Type III is found in southern Florida, southern Texas, and in the Sonoran and Mojave Deserts. Like Type II the area with Type III conditions expands and extends northward in the West in the spring months. By May it occurs as far north as the Canadian border in eastern Washington, Idaho and western Montana.

Type III conditions do not extend far inland from the Gulf of Mexico in the spring, varying little in its northern margin from March through

* The boundary between Type II and Type III is difficult to delimit in March and April. See footnote on page 65.

June in the East.* Type III daily march of dew point does occur farther north in July and August when solar radiation is at a maximum and the earth's surface is drier.

In summer Type III daily march of dew point is found in the Southeast away from the coast, in a central section of the Great Plains, the northern Rockies, and in most of the Columbia Plateau and Great Basin.

The boundaries between Types II, III, and IV in the arid mountain areas were delimited strictly on the basis of the data available and judged to be representative. As already discussed there is more likelihood of unrepresentative data in arid areas near moisture sources and care was taken to eliminate unrepresentative data. Little consideration could be given to differences in diurnal variation types which might be caused by terrain. A valley-summit reversal in diurnal variation discussed by Rathschuler could not be taken into account in drawing boundaries. However, since most of the stations in mountainous areas are in valleys the maps generally show the valley regimes.

Tri-hourly daily range of dew points in the areas with Type III diurnal variations is characteristically larger than the range in areas with Type II conditions. This is particularly evident near the boundary with Type IV conditions where some stations have ranges of over 5°F.

d. Type IV (Very Dry)

In November, December, and January, no station in the United States has the very dry type of diurnal variation in dew point. In February Yuma, Arizona, has a Type IV regime. In March it is found in the area around Yuma and in a larger area in western Texas from the Panhandle to the Rio Grande.

From April through September Type IV is found in an area which includes much of Texas, most of New Mexico, all of Arizona, southeastern California, southern Nevada, and portions of Colorado, Utah, and Wyoming which occupy the drainage areas of the Colorado and Green Rivers below 7,000 feet. In October there is a limited area in West Texas with Type IV conditions.

* In March and April stations in the East with Type II and III variations were so interspersed that the boundary between them is almost arbitrary. This is attributed to the small daily ranges of dew point at these stations. Most stations have ranges of less than 2°F and the difference between a Type II and a Type III station is small. Ranges are also small in summer and fall, but the boundary can be better delimited from the data. The March and April boundaries are indicated by a dash line.

In the summer there are two additional areas with Type IV diurnal variations of dew points: one occurs in eastern Washington and Oregon and western Idaho and is centered on the Snake River Valley; the other is in the southern San Joaquin Valley of California. Data from Spokane, Washington, Lewiston and Mountain Home, Idaho, and Burns, Oregon, substantiate the presence of the Type IV regime in the northern area, and the daily march of dew point at Fresno, California, indicates the occurrence of this regime in the southern San Joaquin Valley.

In March, April, September, and October the tri-hourly daily ranges of Type IV dew points are between 2° and 4°F except at Yuma, Arizona, and Laredo, Texas, where they are larger. From May to August a number of the stations with Type IV diurnal variations in dew points have daily ranges in dew point of over 6°F and some of these stations (Grand Junction, Colorado, Rock Springs and Casper, Wyoming, and Lewiston, Idaho) justify the northern extension of Type IV conditions shown on the maps.

It is a point of interest that areas in the United States with Type IV daily march of dew point are not the areas with the lowest dew points. Dew points average lowest in the summer months in the Great Basin, but most stations in the Great Basin exhibit a primary or secondary minimum of dew point before sunrise and cannot be classified as Type IV stations. For example, in Figure 7, the diurnal regime at Winnemucca is shown for September. There is a definite minimum dew point at the time of the minimum temperature and since there is a single maximum dew point the station is classified as Type I. Its dry characteristics are indicated by the morning rather than afternoon maximum. Since the nearest stations to Winnemucca had a secondary afternoon maximum, this area is shown on the map as Type II in September.

A possible explanation of the lack of Type IV in much of the Great Basin is that the low moisture content of the air and relatively high elevation allow strong outgoing radiation at night with resultant large diurnal variation in temperature. The low minimum temperatures in the morning cause the low dew points then.

All stations in the Great Basin share one feature of the Type IV diurnal regimes in July and August. They have marked decreases in average dew points between midmorning and mid afternoon in the summer months. This decrease in dew point is an indicator of dry surface conditions and of turbulent mixing with drier air aloft. Great Basin stations, particularly Winnemucca and Tonopah, Nevada, have daytime decreases in dew points of the same order as those found at Type IV stations. However, they do not fit the original Type IV requirements since they have a secondary minimum (or, in the case of Winnemucca in September, a primary minimum) in the morning. Thus most of the Great Basin is shown as Type III on the July and August maps (Fig. 43 and 44).

PART IV

HUMIDITY AREAS IN THE UNITED STATES

It is possible to reach a fuller comprehension of the areal order of humidity distribution if the individual isopleth maps in the Appendix are considered collectively and areas with some degree of unity are delimited. This areal differentiation also serves as a summary of the patterns found on the maps.

Seven dew point areas are differentiated in Figure 12 on the basis of the annual average dew point determined from the values on each of the 12 maps, and the range between the highest and lowest average monthly dew point at each station (referred to as the annual range). That the alignment of the areas differentiated in Figure 12 is responsive to changes in humidity controls is evident in the north-south trend of the boundaries in the three western areas which are dominated by Pacific maritime air masses, as opposed to the east-west trending boundaries delimiting the four eastern areas, more under the influence of dry cold air from the north and warm humid air from the south. The seven areas are discussed in the following paragraphs.

1. Pacific Coast and Mountains (Area I)

The most significant characteristic of the Pacific Coast and Mountains Area is the influence of the Pacific Ocean which greatly overshadows latitudinal control. The alignment of the isodrosotherms parallel to the coast on the dew point maps indicates the maritime control, and the small gradient in dew point between stations on the south coast and north coast illustrates the lack of latitudinal control: between Long Beach, California, and Portland, Oregon, the gradient of the average annual dew point is only 6°F. The inland extent of the maritime influence is evidenced by a rather abrupt change in annual dew point values across the north-south mountain ranges where altitudinal control of dew point is dominant. Average annual dew points in the Pacific Coast and Mountains Area vary from 35°F on the eastern border of the area to 50°F along the southern California coast. All stations within Area I have annual ranges of less than 20°F. Some stations have ranges of less than 12°F. The only other area of the country with such small ranges is the southern third of Florida where average dew points are much higher. Another indicator of the predominant maritime control in Area I is the small standard deviations of dew points evident on the insets to the dew point maps.

2. Western Interior (Area II)

The Western Interior is differentiated from the Pacific Coast and Mountains in that it has lower average annual dew points and, with the

DEW POINT AREAS IN THE CONT

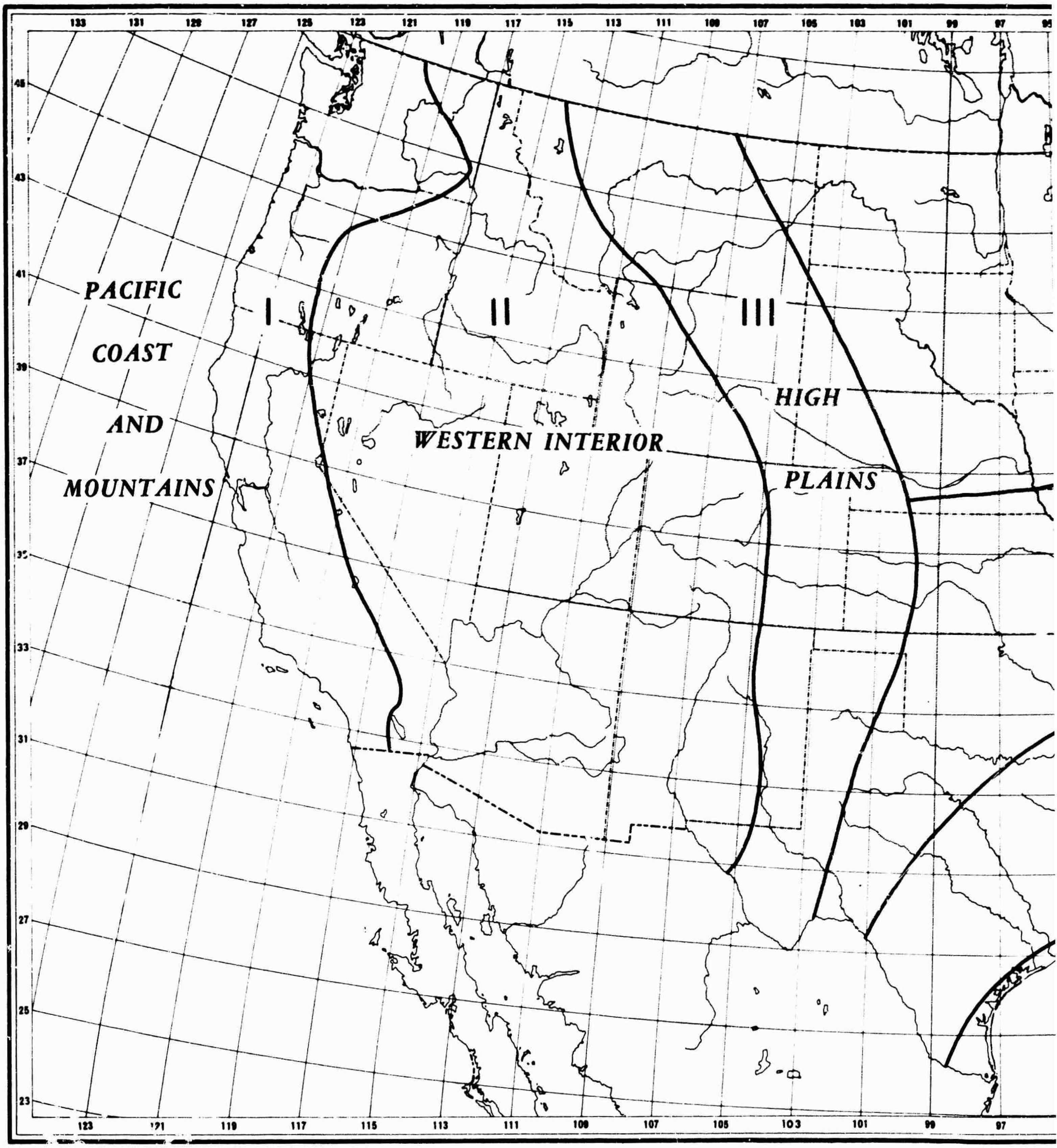

Figure 12

A

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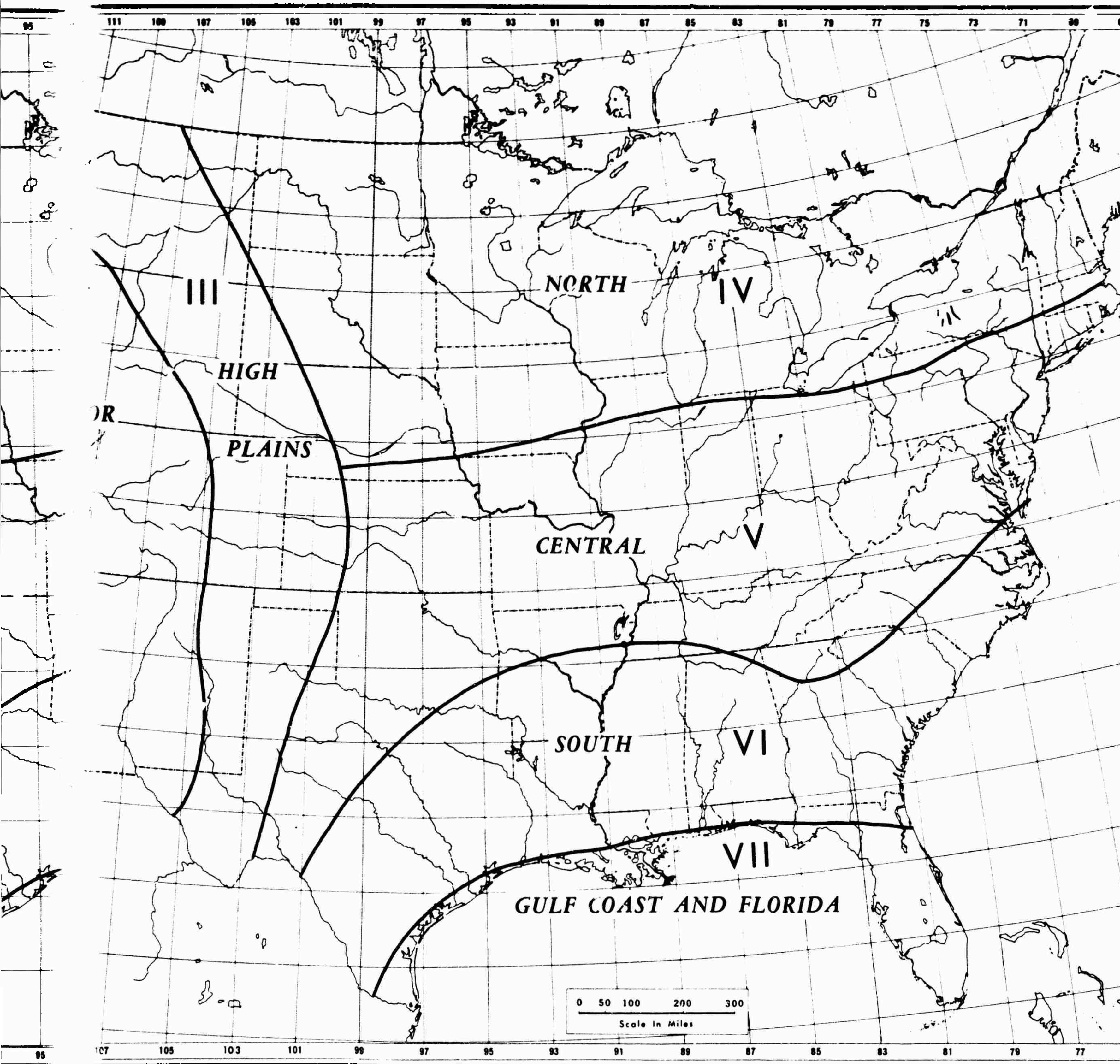
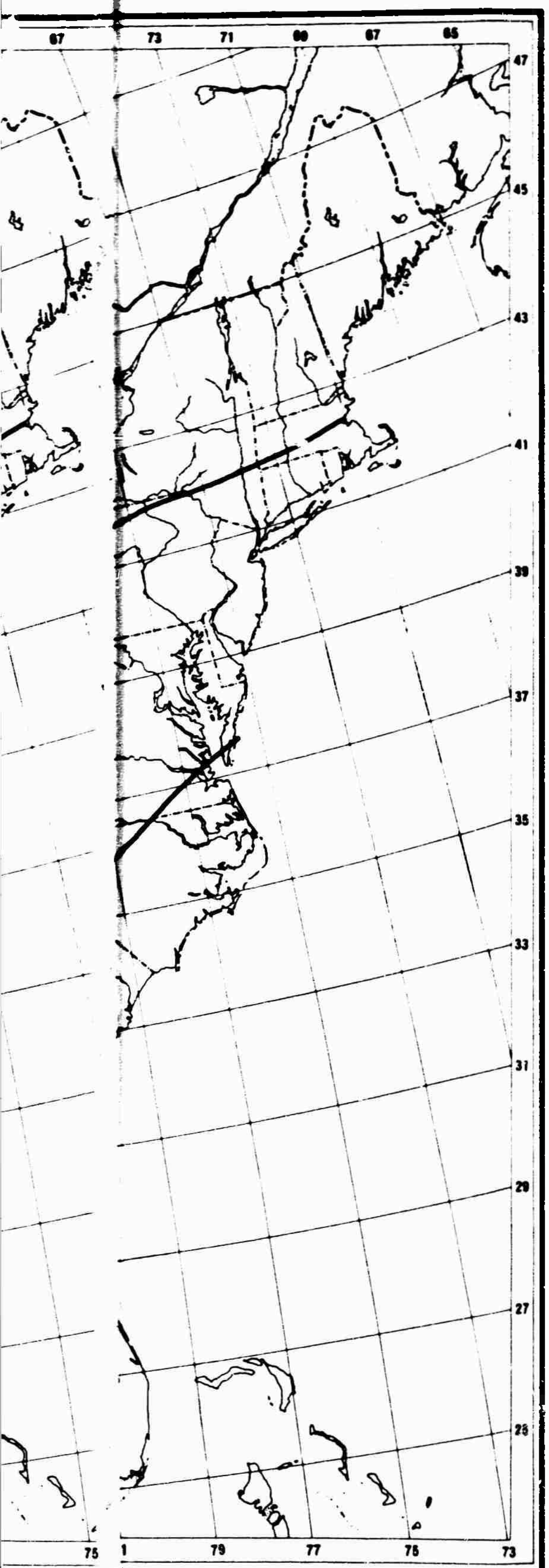


Figure 12

B

TED STATES



DEW POINT AREAS IN THE CONTIGUOUS UNITED STATES

Area I.	PACIFIC COAST AND MOUNTAINS		
	Average annual dew point.............	35°-50°F	
	Annual range of average dew points...	10°-20°F	
Area II.	WESTERN INTERIOR		
	Average annual dew point.............	20°-40°F	
	Annual range of average dew points...	15°-35°F	
Area III.	HIGH PLAINS		
	Average annual dew point.............	25°-40°F	
	Annual range of average dew points...	30°-40°F	
Area IV.	NORTH		
	Average annual dew point.............	25°-40°F	
	Annual range of average dew points...	40°-55°F	
Area V.	CENTRAL		
	Average annual dew point.............	40°-50°F	
	Annual range of average dew points...	35°-45°F	
Area VI.	SOUTH		
	Average annual dew point.............	50°-60°F	
	Annual range of average dew points...	25°-35°F	

C

exception of the portions of the Great Basin to the lee of the Sierra Nevada, it also experiences larger annual ranges in dew point. In western Nevada the annual range of dew points is less than 20°F, but the area is differentiated from Area I on the basis that the average annual dew points are less than 25°F; lower than in maritime Area I. Elsewhere in Area II average annual dew points are below 35°F except in the relatively low area near the junction of the Gila and the Colorado Rivers. Yuma, Phoenix, and Tucson, Arizona, all have average annual dew points near 40°F. Lowest average annual dew points in the Western Interior Area occur in the high Rocky Mountains and are estimated to be between 15° and 20°F. Another distinguishing feature of Area II is the hypsometric pattern of the isodrosotherms and isovapors on the maps due to the altitudinal control. Latitudinal variation in average annual dew point is slightly greater in this area than on the West Coast, but it is still small in comparison to latitudinal variation farther east. Locations in the south have average annual dew points about 10°F higher than at comparable elevations in the north.

Standard deviations of dew points in Area II are larger than in Area I. The monthly regime of standard deviations is unique in that summer standard deviations are about as large as winter standard deviations. In much of the country winter standard deviations are 2 to 5 times as large as the summer values. Summer standard deviations of over 10°F in the southern part of Area II are the highest in the country at that season.

3. High Plains (Area III)

The High Plains are differentiated from the Western Interior solely on the basis of the increase in the annual ranges of average monthly dew points. In the north the ranges from west to east across Area III vary from 30° to 45°F, while in the south the variation is from 30° to 40°F. The High Plains will be recognized here as a transitional area influenced both by circulation from the Pacific Ocean, and from the Gulf of Mexico and Caribbean Sea. Changes occur in the alignment of the isodrosotherms between 100°W and 105°W from a near east-west orientation in winter to a north-south orientation in summer. This realignment of the isopleths is caused by the seasonal change in the relative influence of air masses from the south and from the west. A reversal of the alignment of the isodrosotherms occurs only in Area III, demonstrating its transitional nature. However, this was not a criteria for delimiting the area.

4. North (Area IV)

Area IV, the farthest north of the areas with east-west trending boundaries, is characterized by relatively low average annual dew point, and by a very large range between the highest and lowest average monthly dew points. Average annual dew points in Area IV vary from 28°F along the Canadian border of Minnesota, North Dakota, and Montana to 40°F along the southern boundary of the area; approximately the same annual averages are found in Areas II and III. The annual ranges of average monthly dew points in Area IV, however, vary from 40°F in southern New England along the boundary with Area V, to 45°F along this boundary farther west, to 55°F in North Dakota. In winter average dew points below 0°F in North Dakota and Minnesota are the lowest average dew points in the country. In summer the average dew points of over 60°F on the southern boundary of Area IV are higher than values in the three western areas. Large standard deviations of dew point and large daily ranges of dew point are associated with the low winter values, but these measures of dew point variability are considerably smaller in summer.

5. Central (Area V)

Gradients of average annual dew points and of the annual range of average monthly dew points are larger in the East than in the West. From the Canadian border to the Gulf of Mexico there is a regular increase in average annual dew point and an equally regular decrease in the range between highest and lowest average monthly dew points. In the Central Area, extending from the mid-Atlantic coast, south of the Great Lakes, to the Big Bend country of Texas, average annual dew points vary from 40°F on the boundaries with Areas III and IV to 50°F on the boundary with Area VI. The range of the average annual dew points in the Central Area increases from 35°F on the boundary with Area VI to 40°F on the boundary with Area IV in New England, to 45°F on this boundary farther west. It is surprising to find as large and diverse an area as Area V with average annual dew points and the range of monthly averages within the 10°F class limits.

6. South (Area VI)

The increase in average annual dew point and decrease in range of average mon ly dew points southward is again evident in the criteria for delimiting Area VI. Average annual dew points are between 50° and 60°F, and the range in the monthly averages varies from 15° to 25°F. The increased influence of advection of mT air off the warm southern waters is more and more apparent in the higher average dew points and decrease in the range of average monthly dew points near the Gulf Coast.

7. Gulf Coast and Florida (Area VII)

Area VII is winter vacation country. High annual average dew points, greater than 60°F, indicate the relative freedom of the area from influx of cold air with low dew points. Ranges in average monthly dew points vary from 14°F at Key West to 25°F on the northern Gulf Coast. Enough seasonality in the dew points is evident to differentiate this area from a completely tropical area. For example, the range in average monthly dew points at Guantanamo Bay, Cuba, is 8°F, and the range on Guam is 4°F.

8. Acknowledgments

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I am indebted to the staff of the Technical Library for obtaining source materials often difficult to locate. I also am indebted to Mrs. Leonora Kundla for transferring the basic data to punched cards, and to the staff of the Computer Branch for machine summarization of data. Mr. Willard Morse helped in the preparation of the data for punching.

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APPENDIX

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

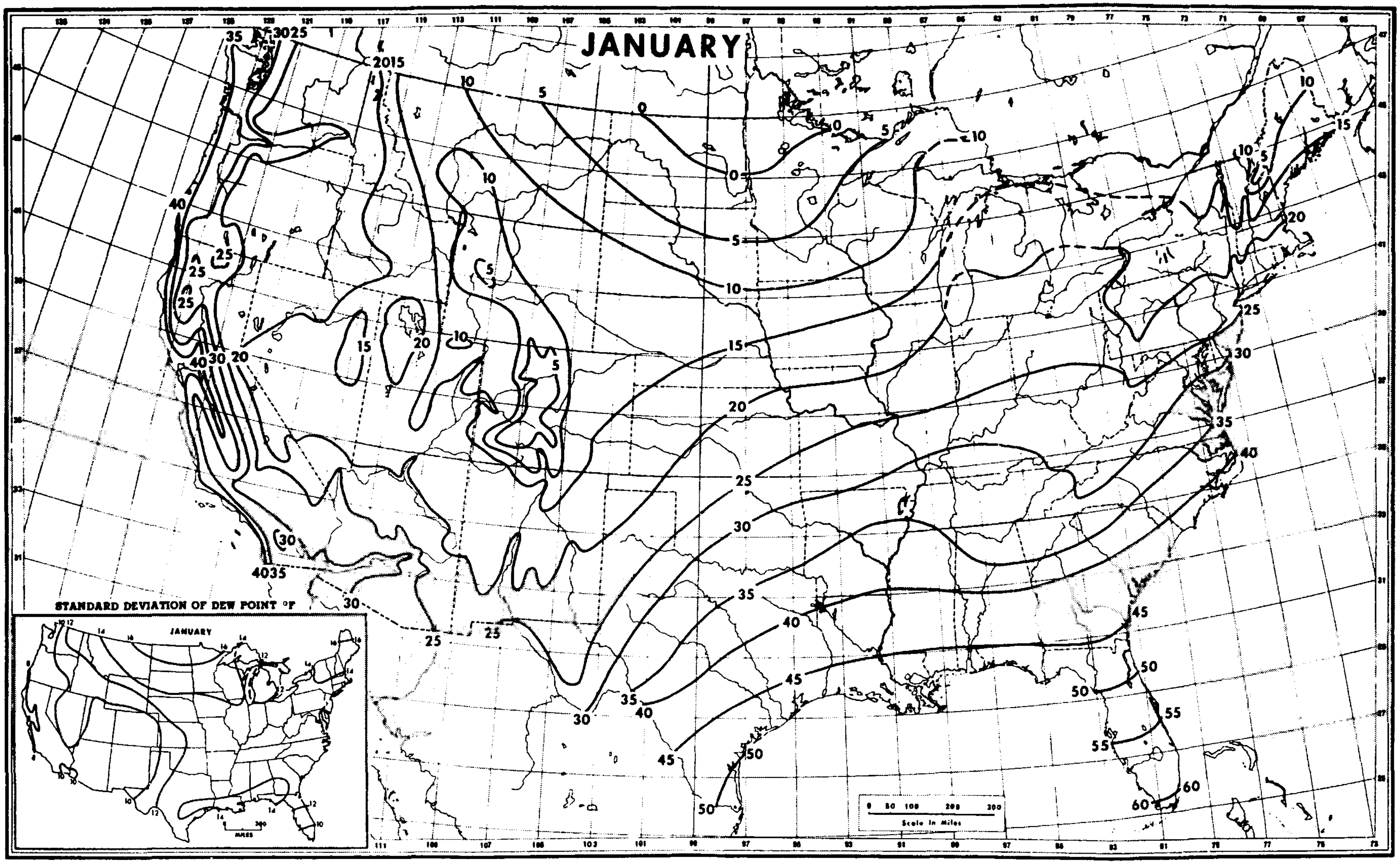


Figure 13

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

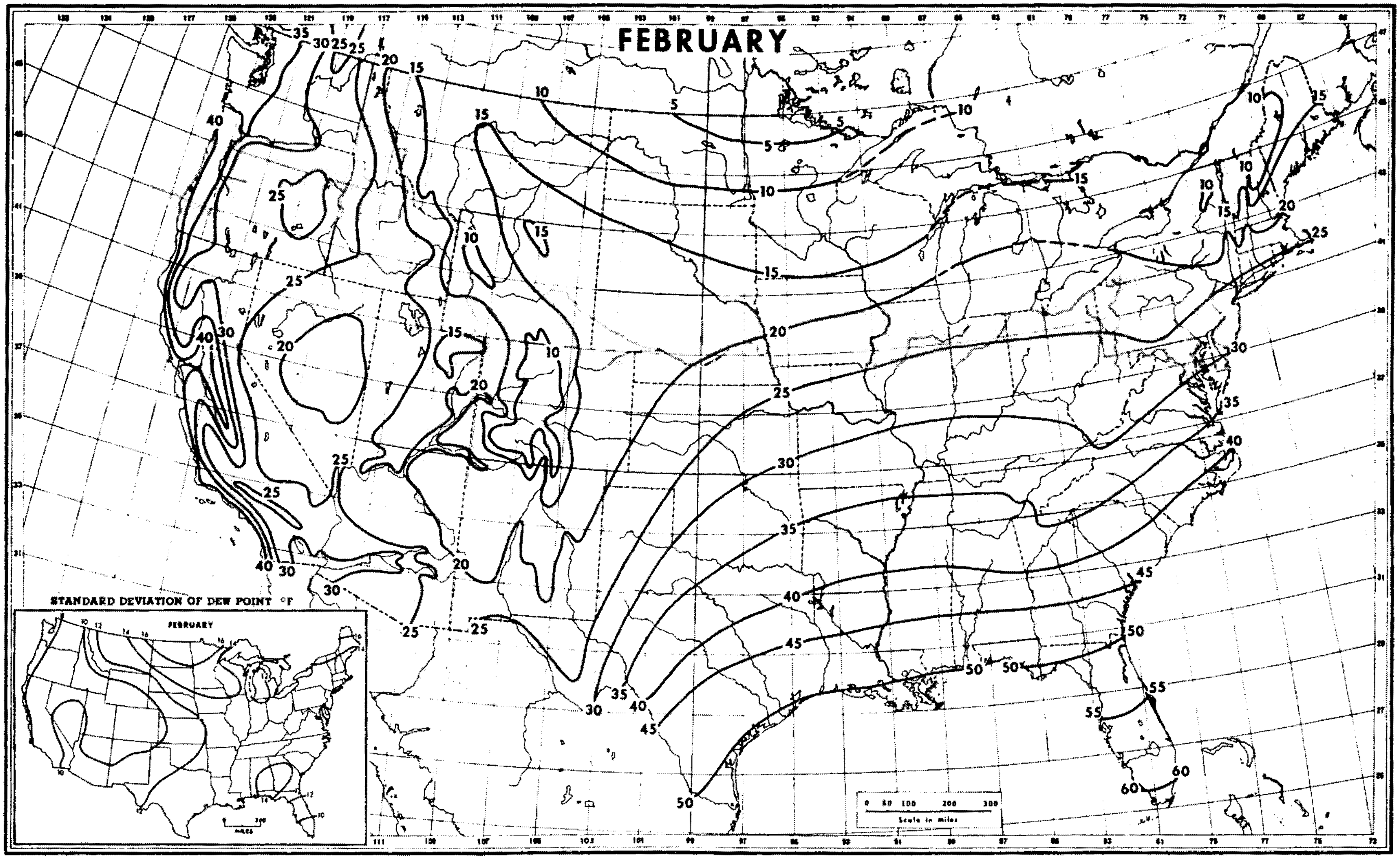


Figure 14

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

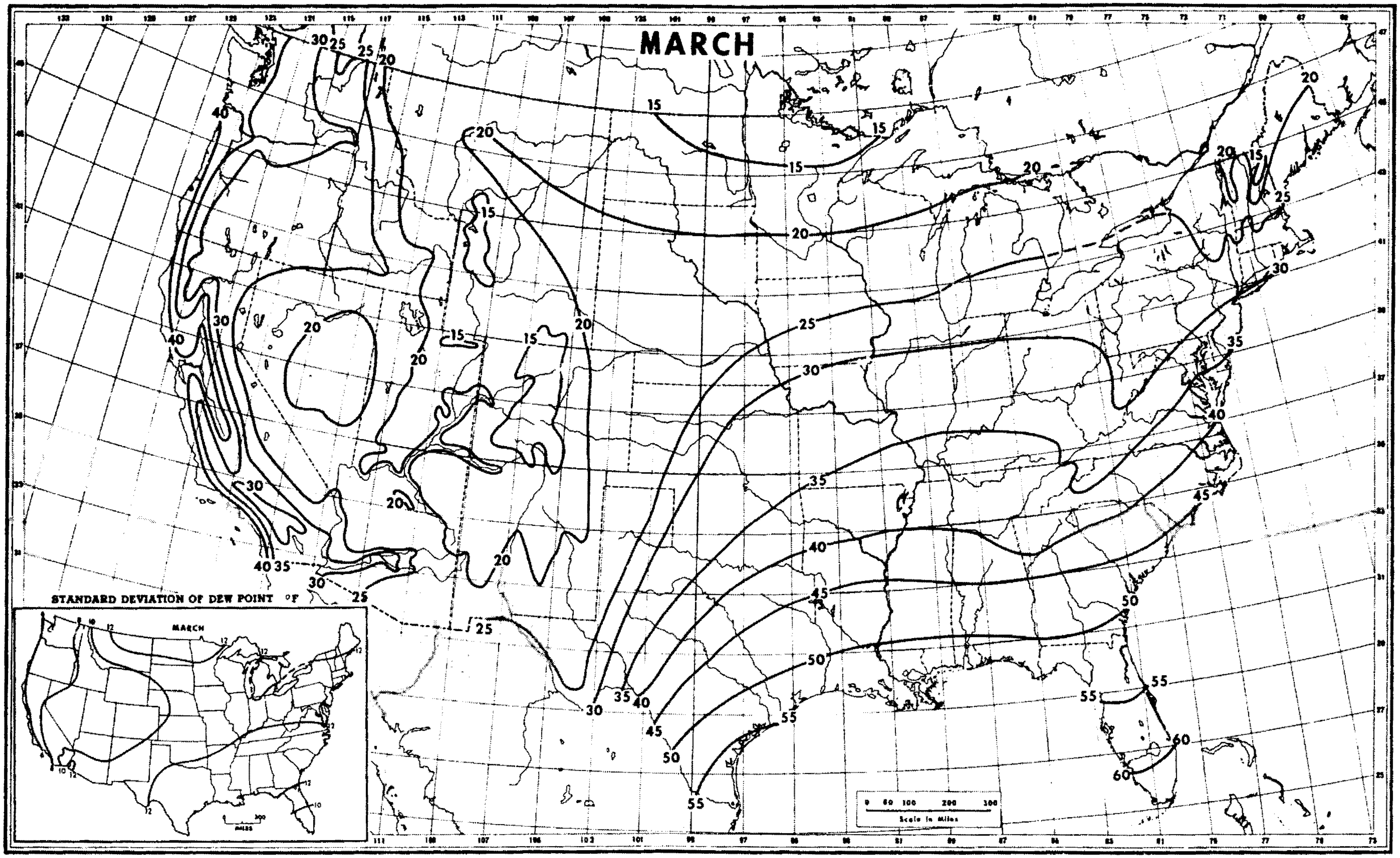


Figure 15

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

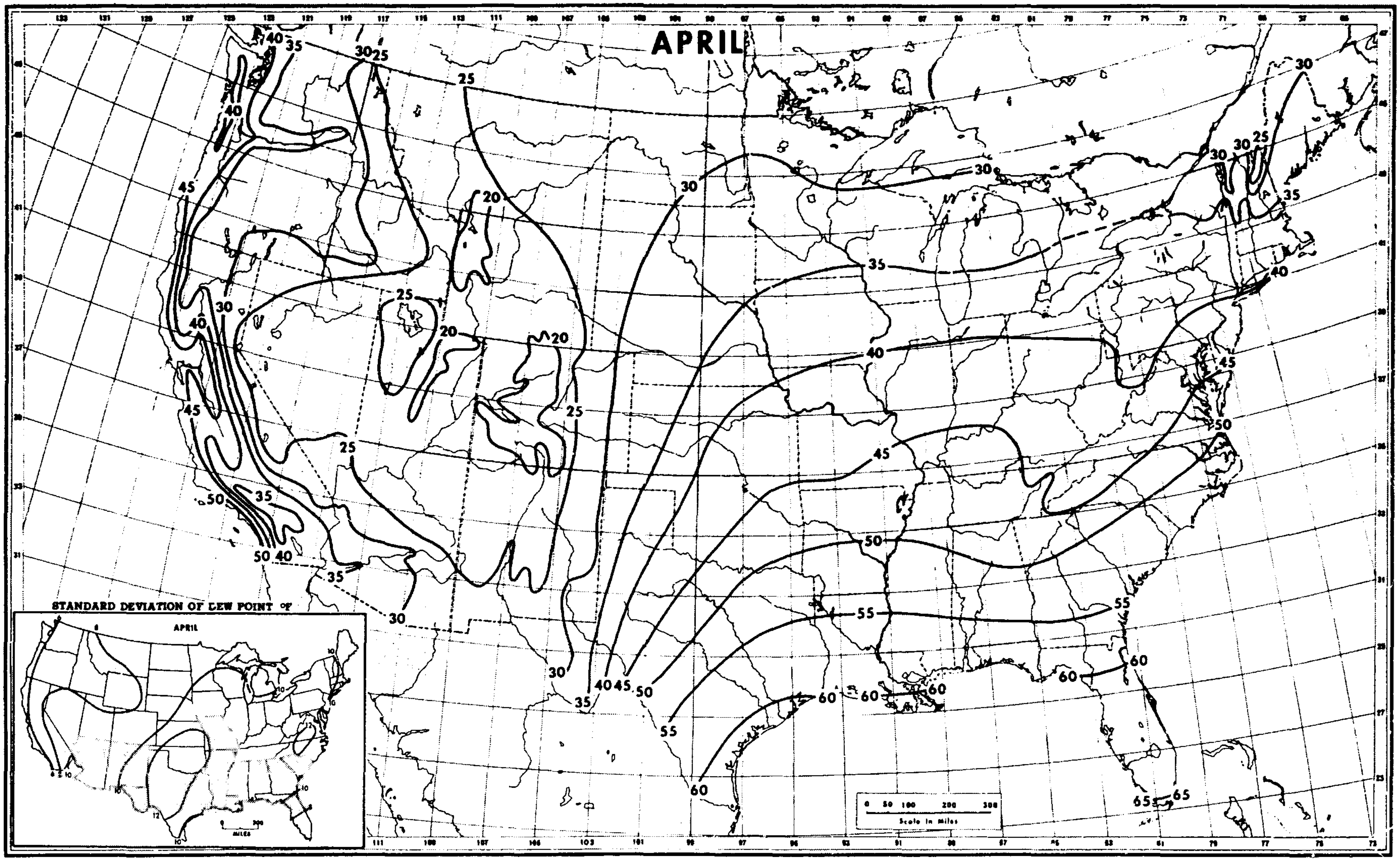


Figure 16

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

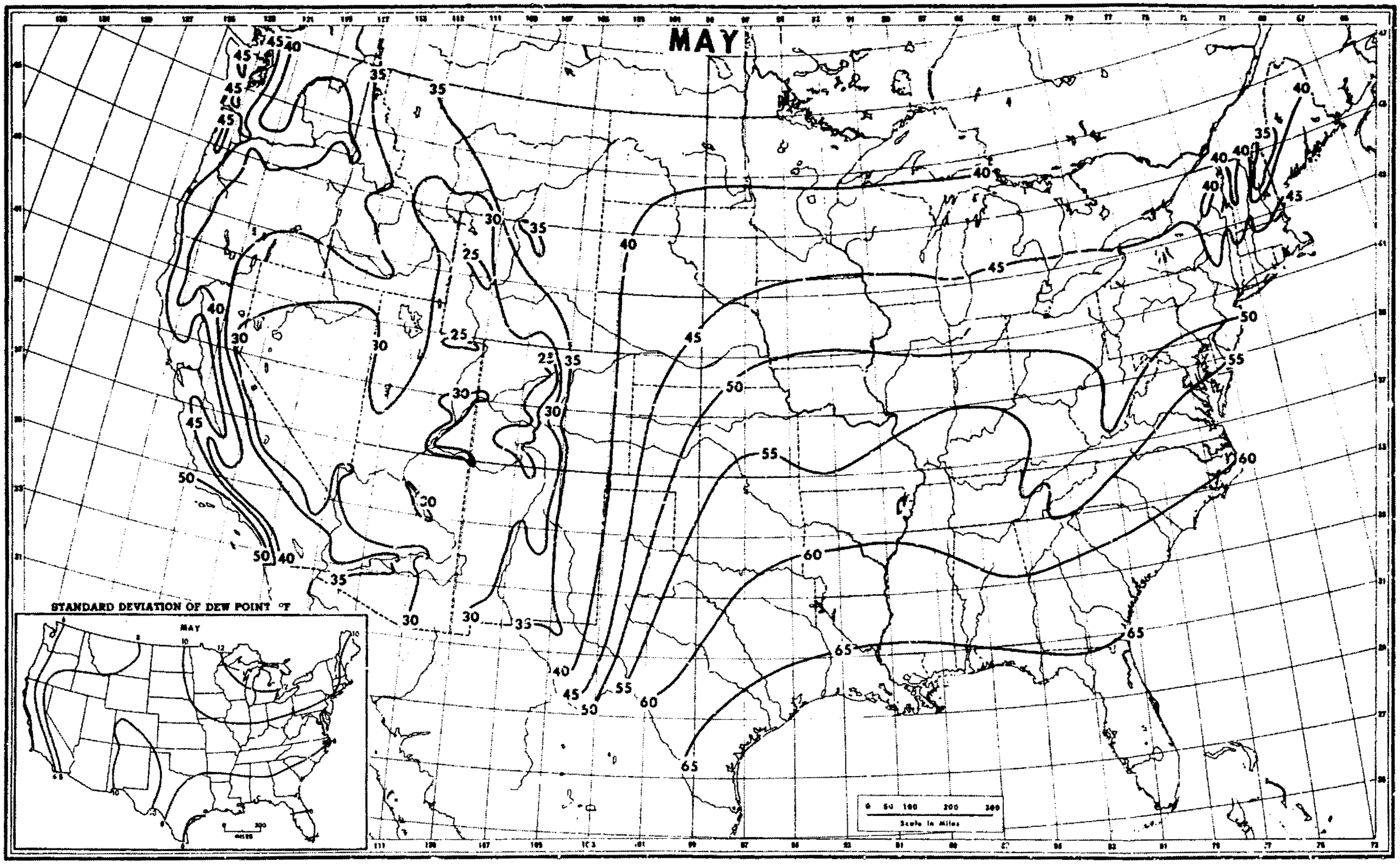


Figure 17

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

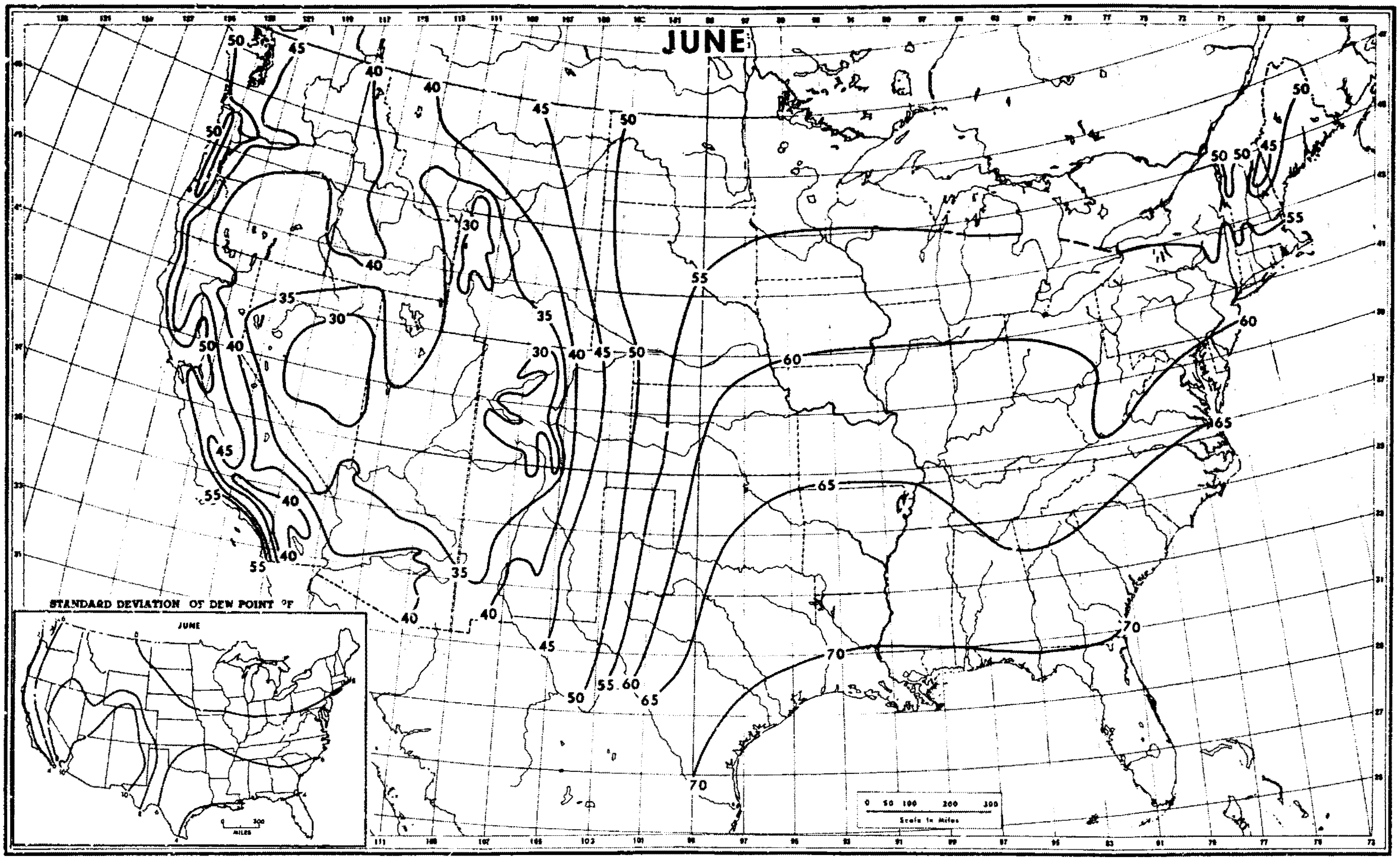


Figure 18

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

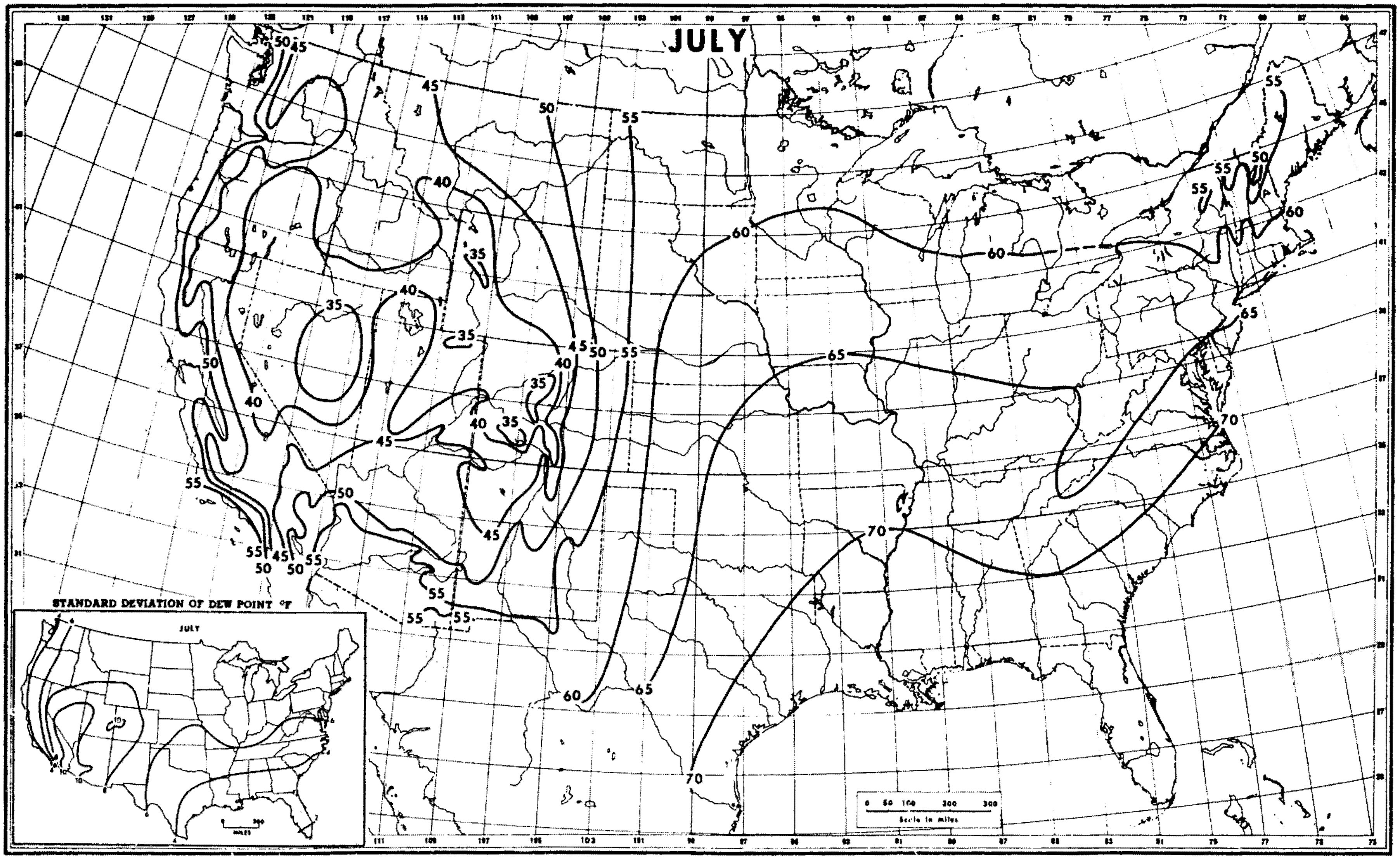


Figure 19

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

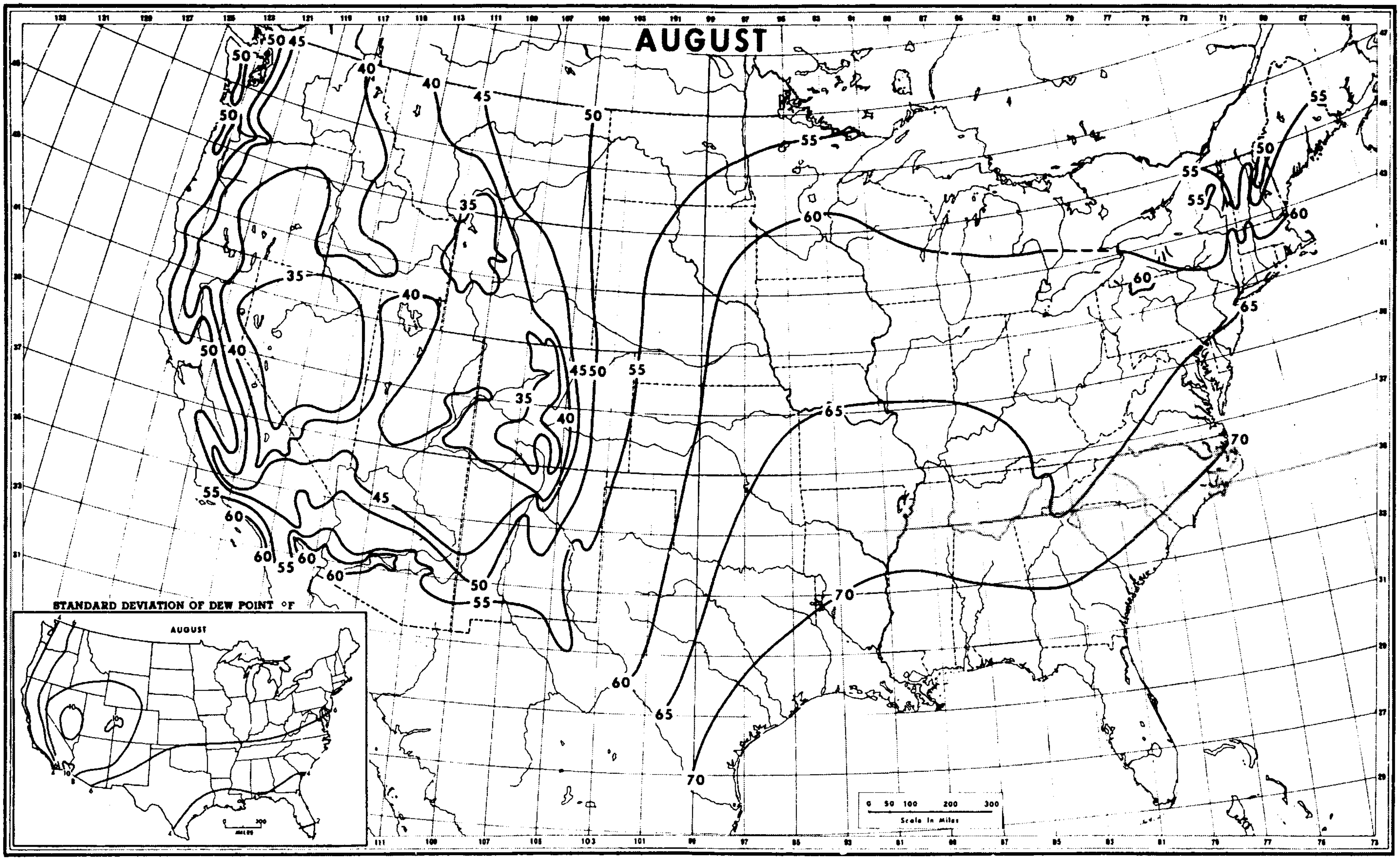


Figure 20

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

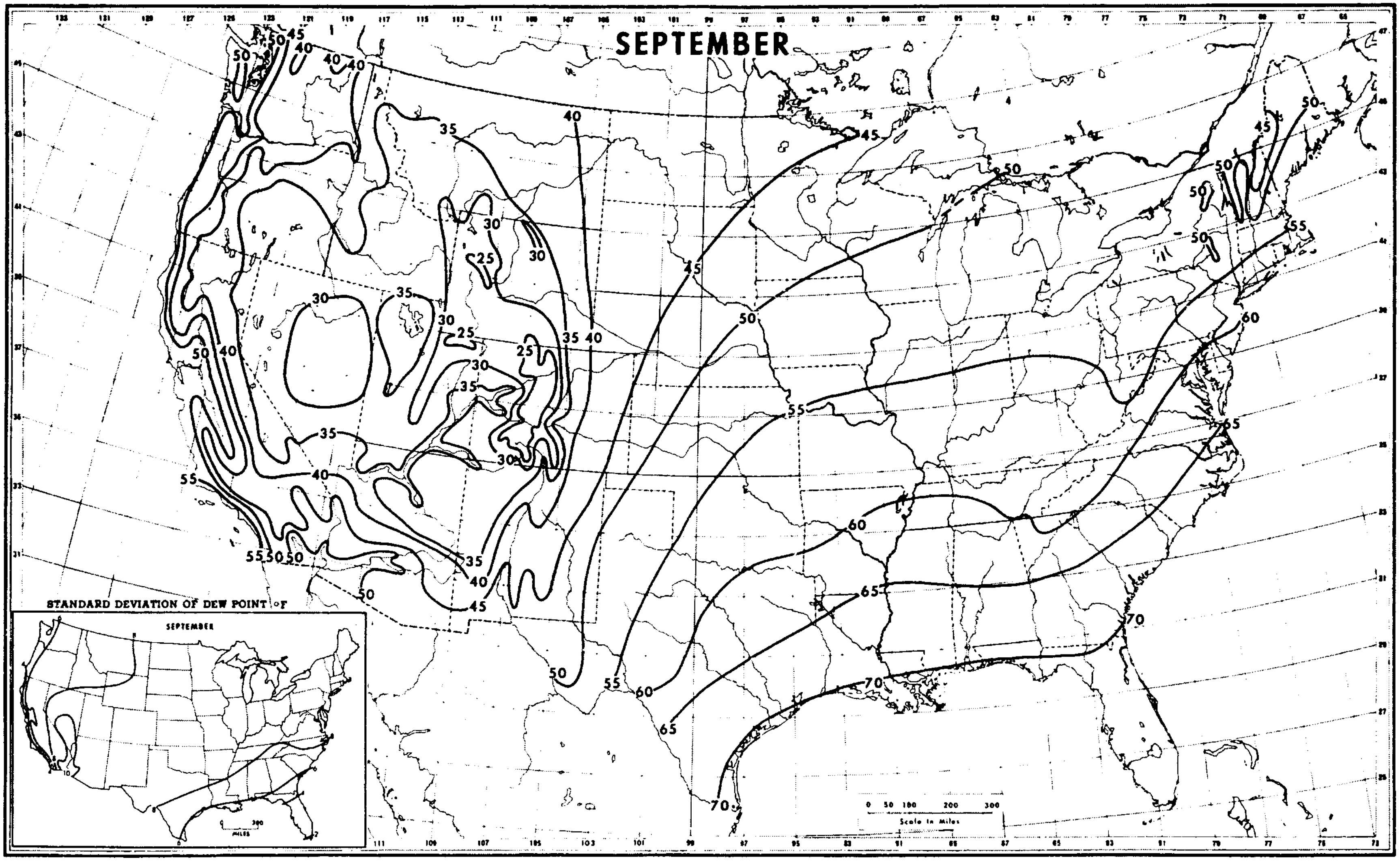


Figure 21

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

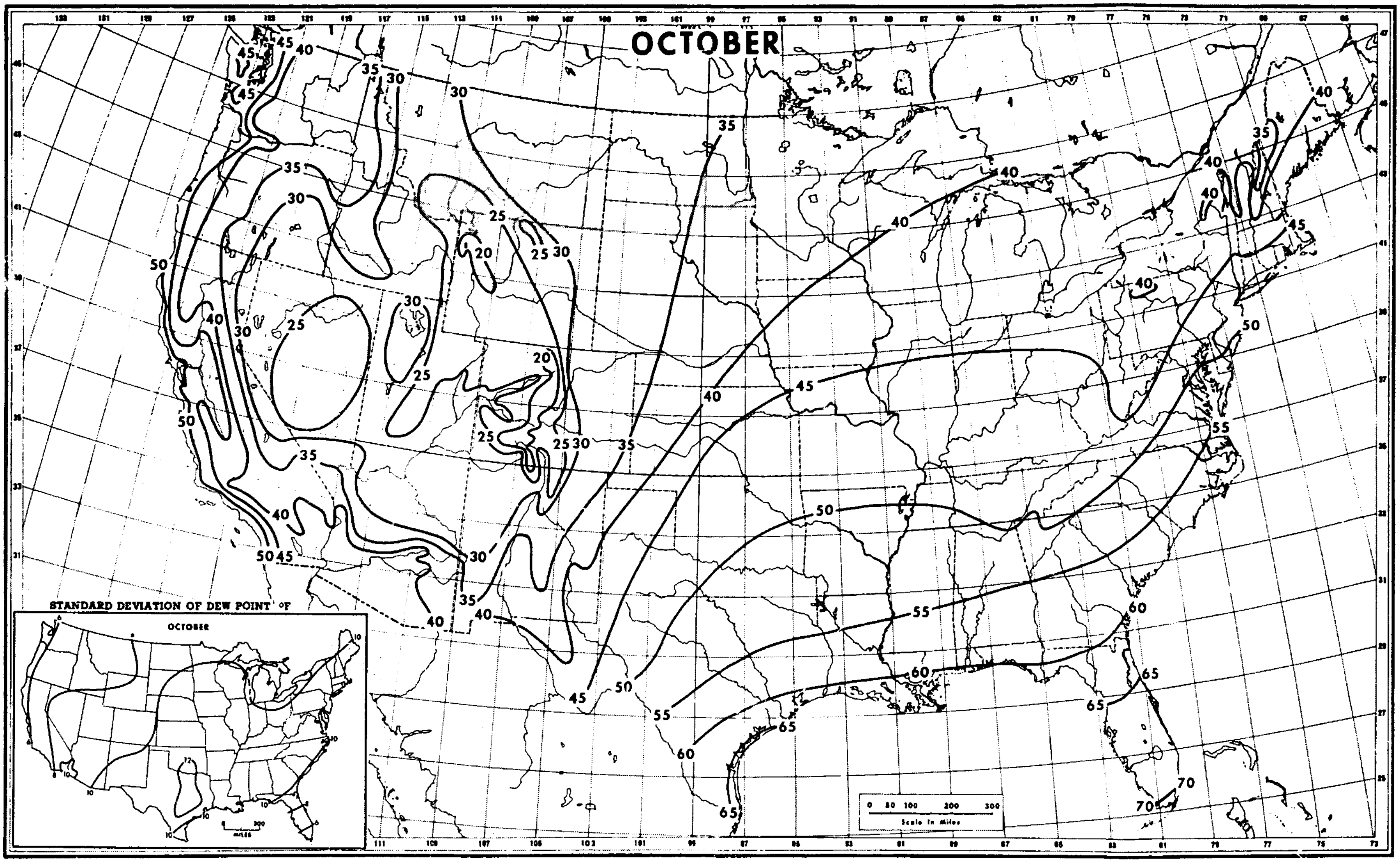


Figure 22

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

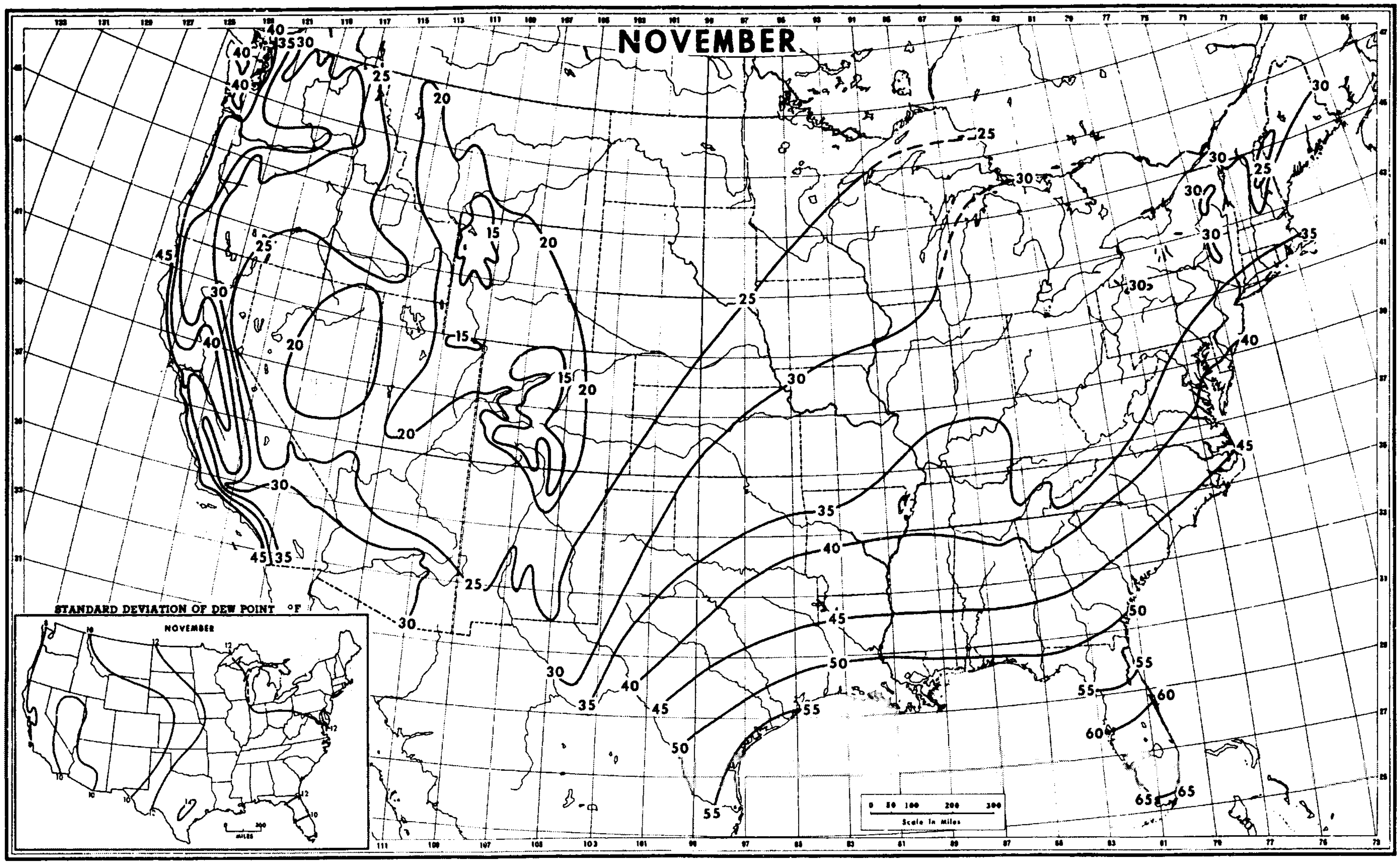


Figure 23

AVERAGE MONTHLY DEW POINT

Degrees Fahrenheit

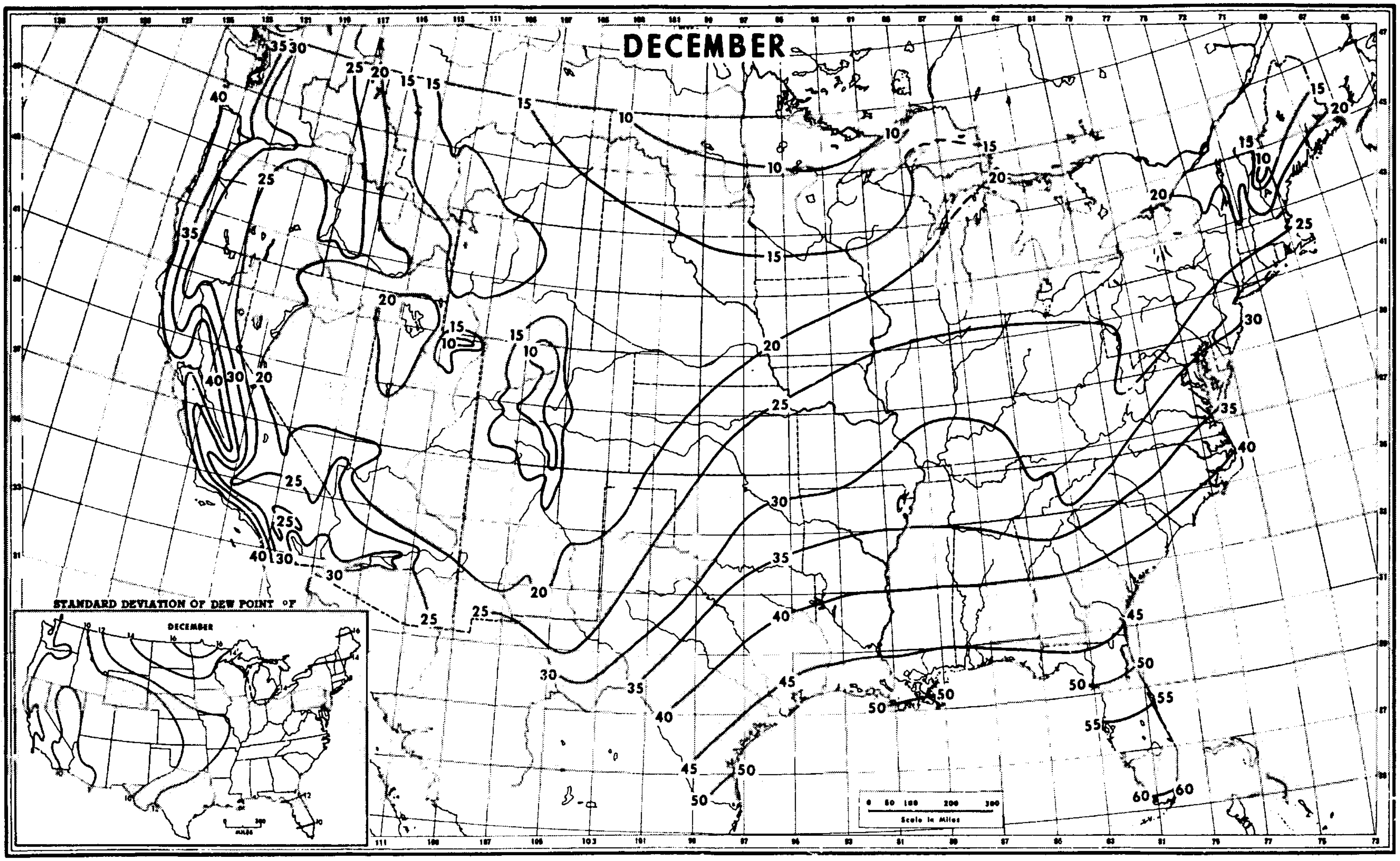


Figure 24

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

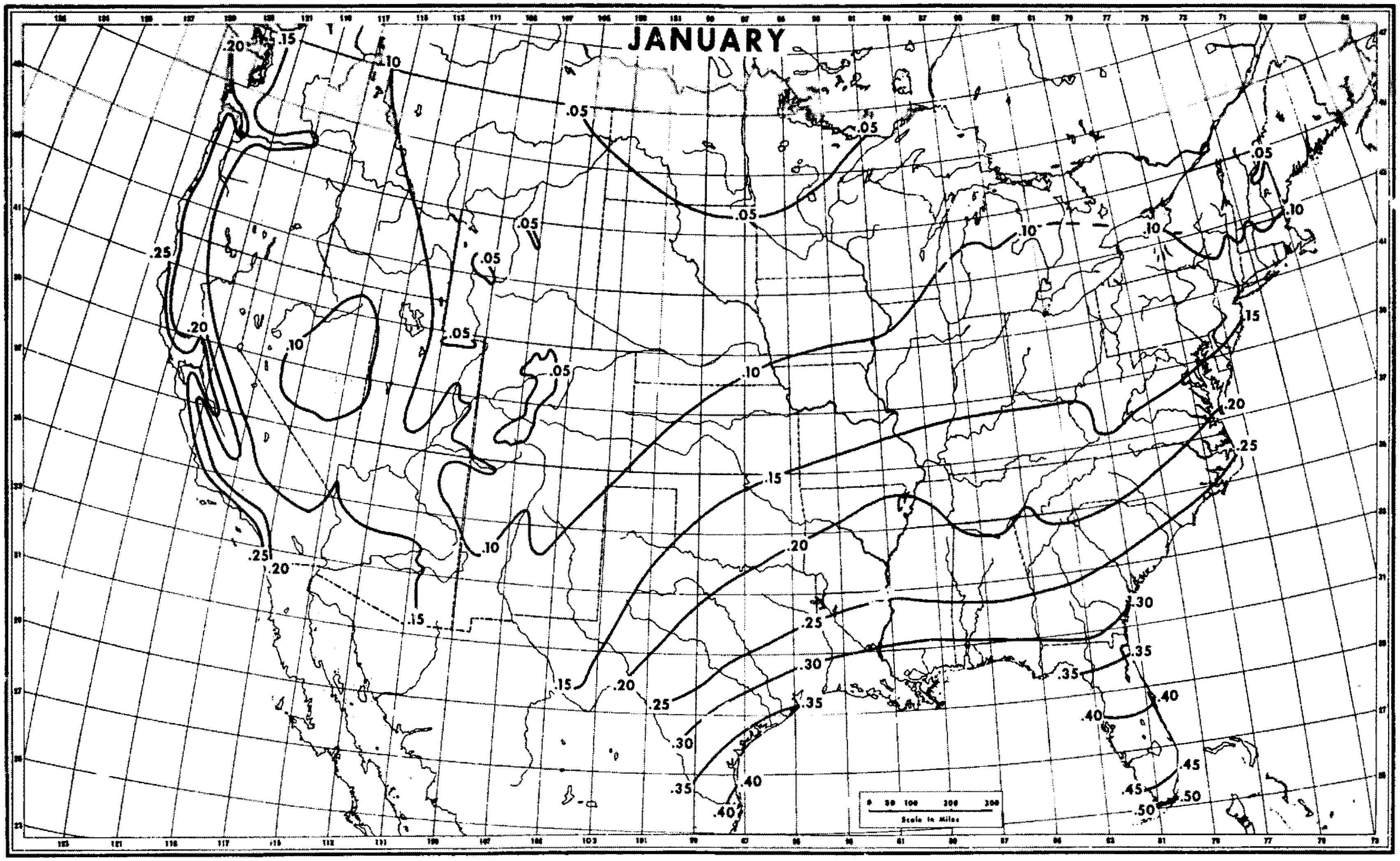


Figure 25

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

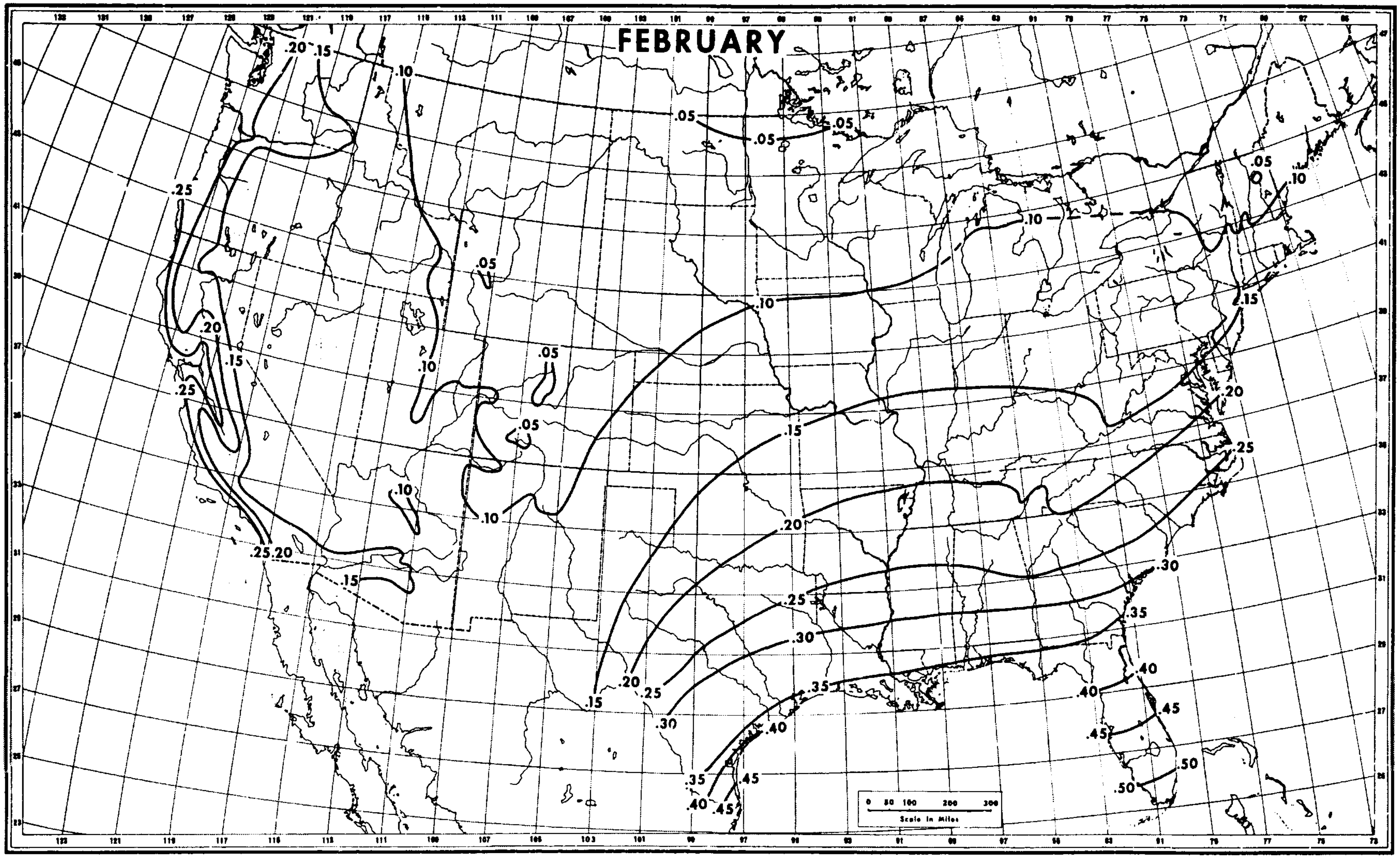


Figure 26

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

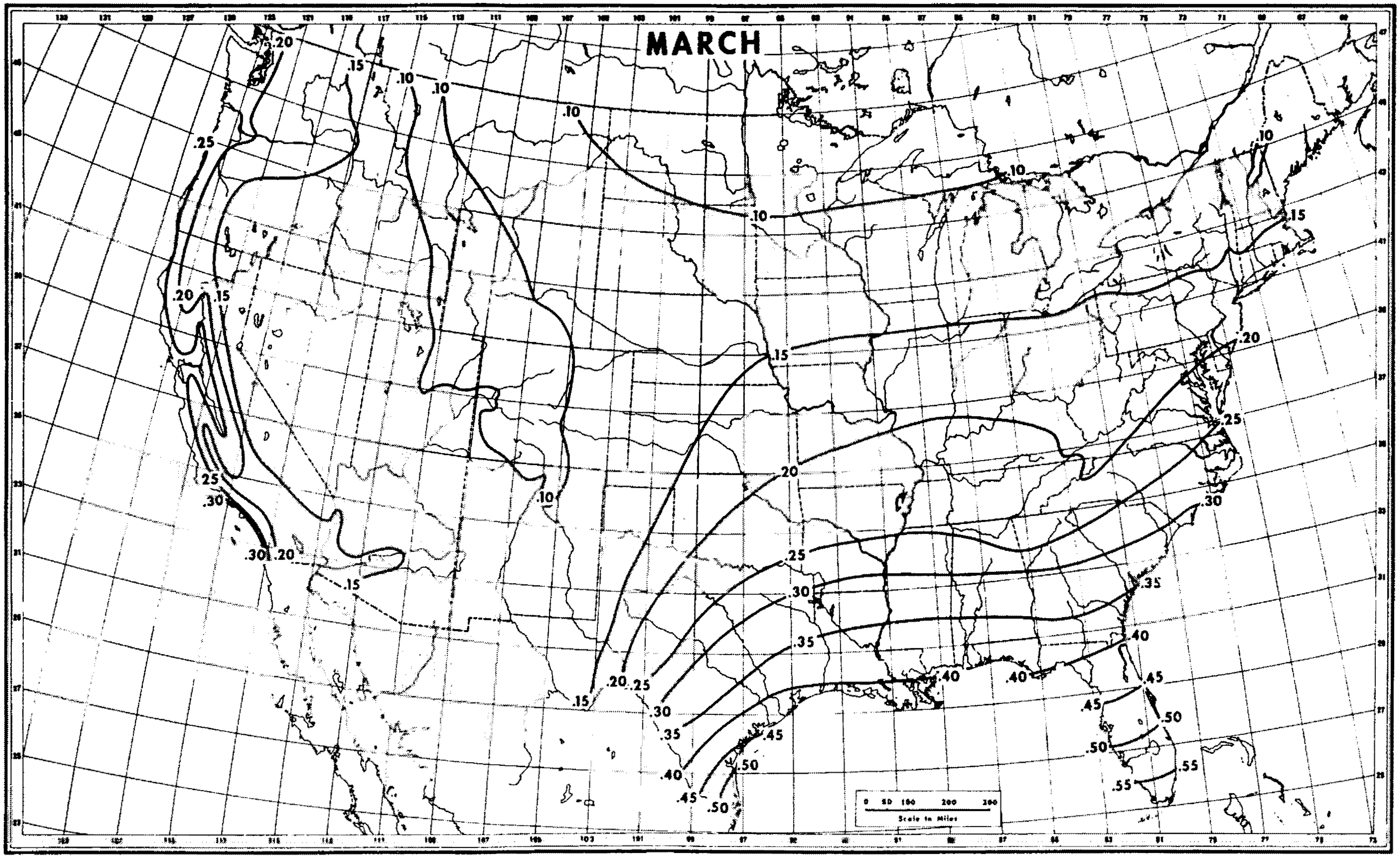


Figure 27

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

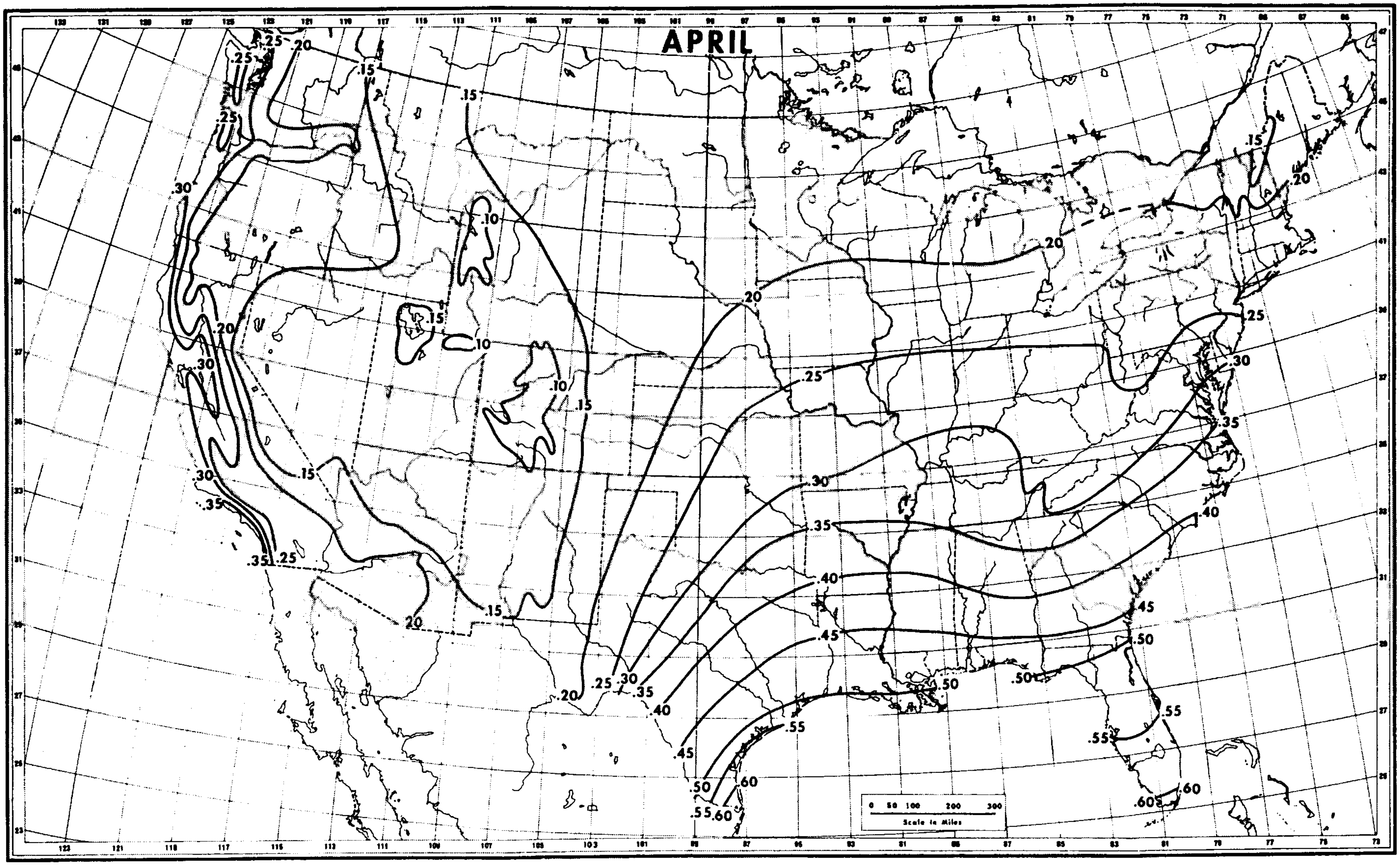
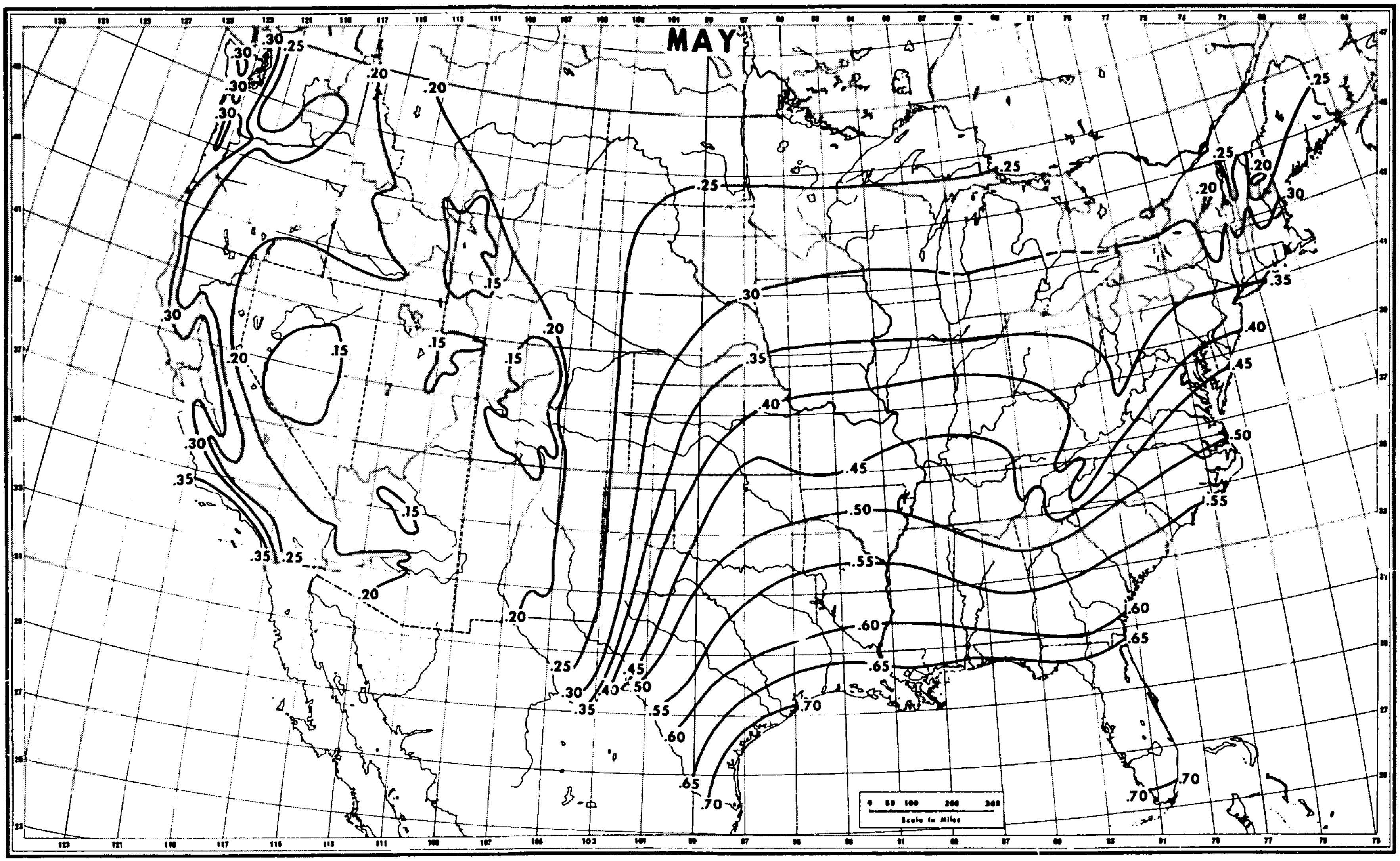


Figure 28

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury



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AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

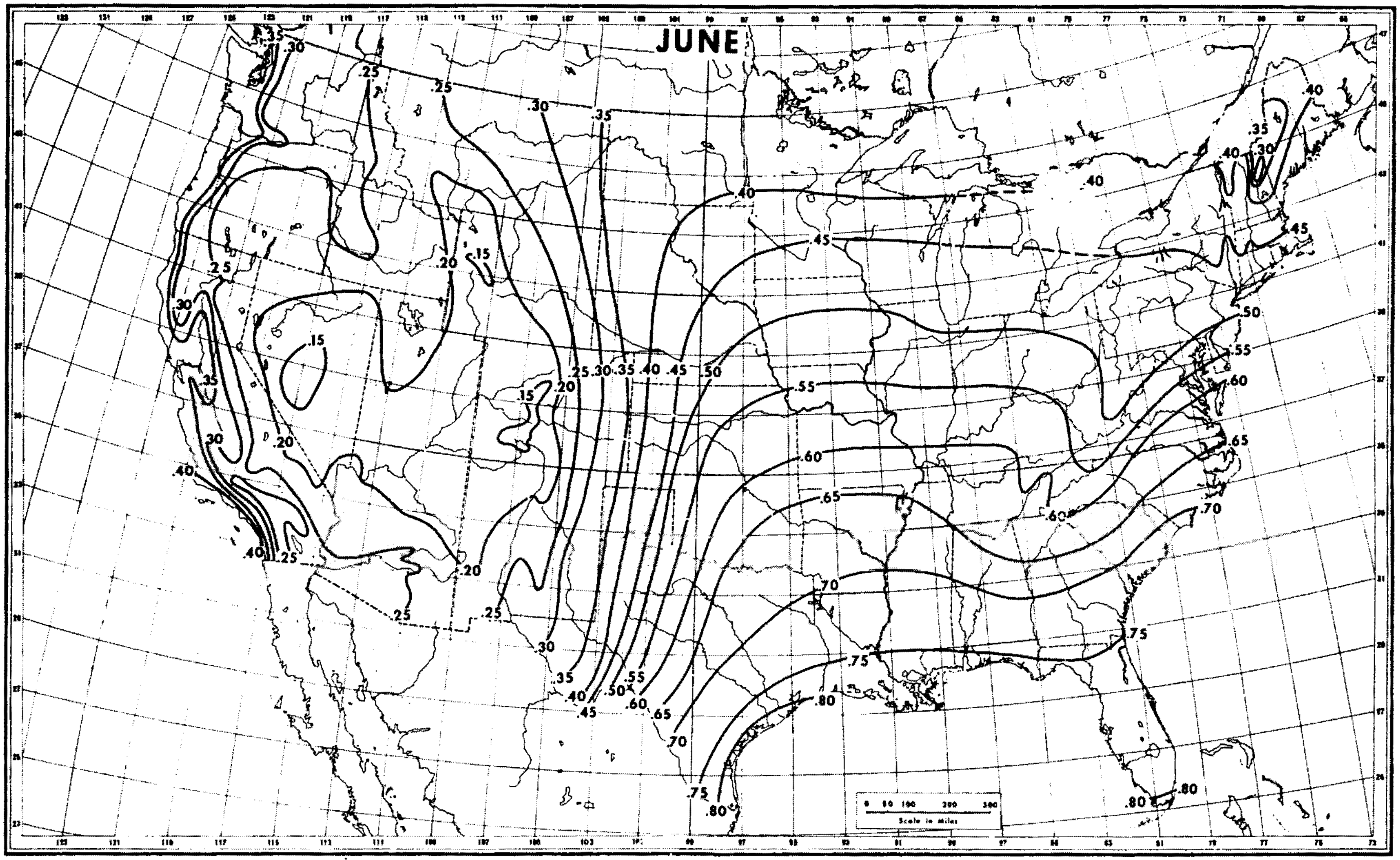


Figure 30

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

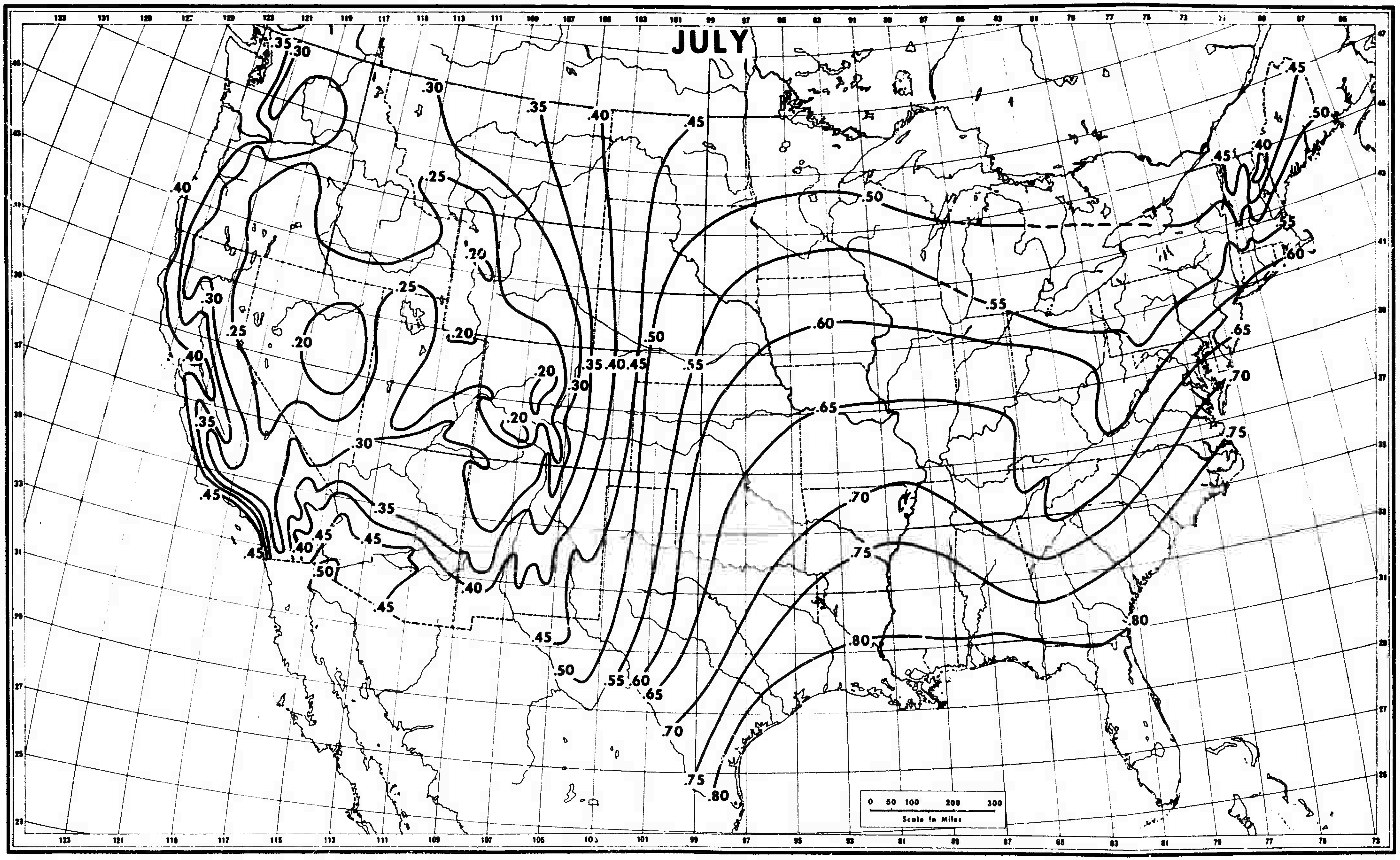


Figure 31

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

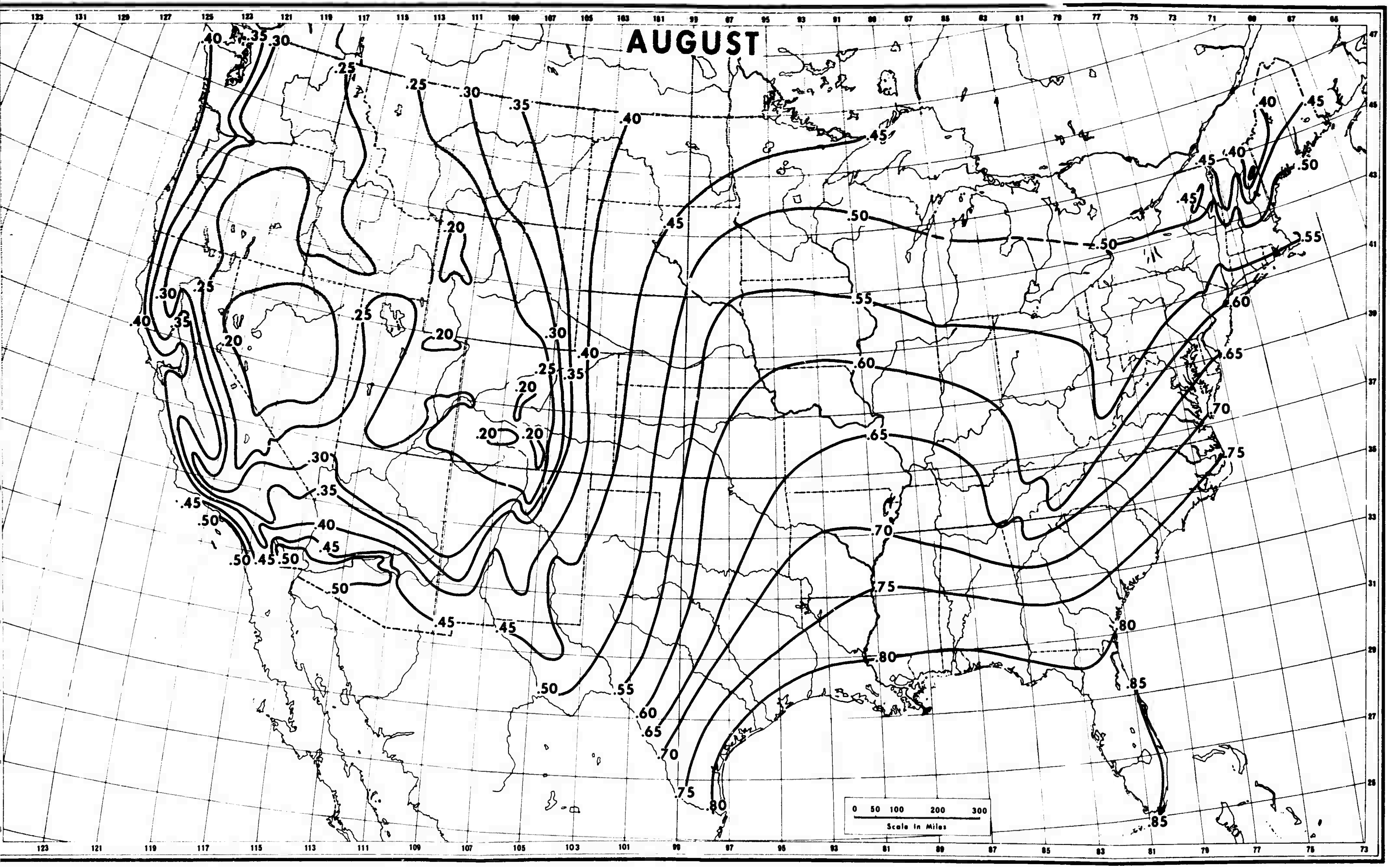


Figure 32

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

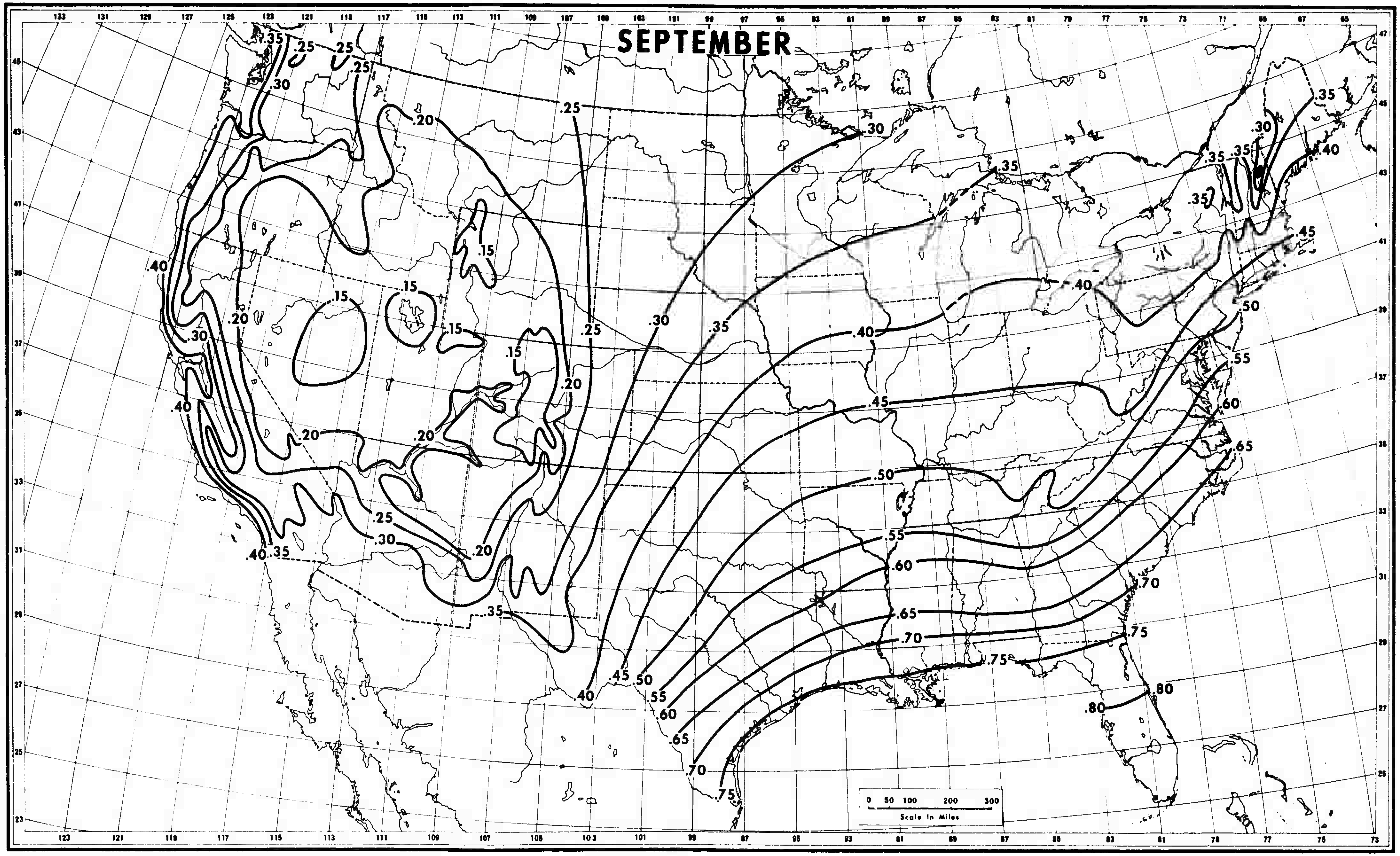


Figure 33

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

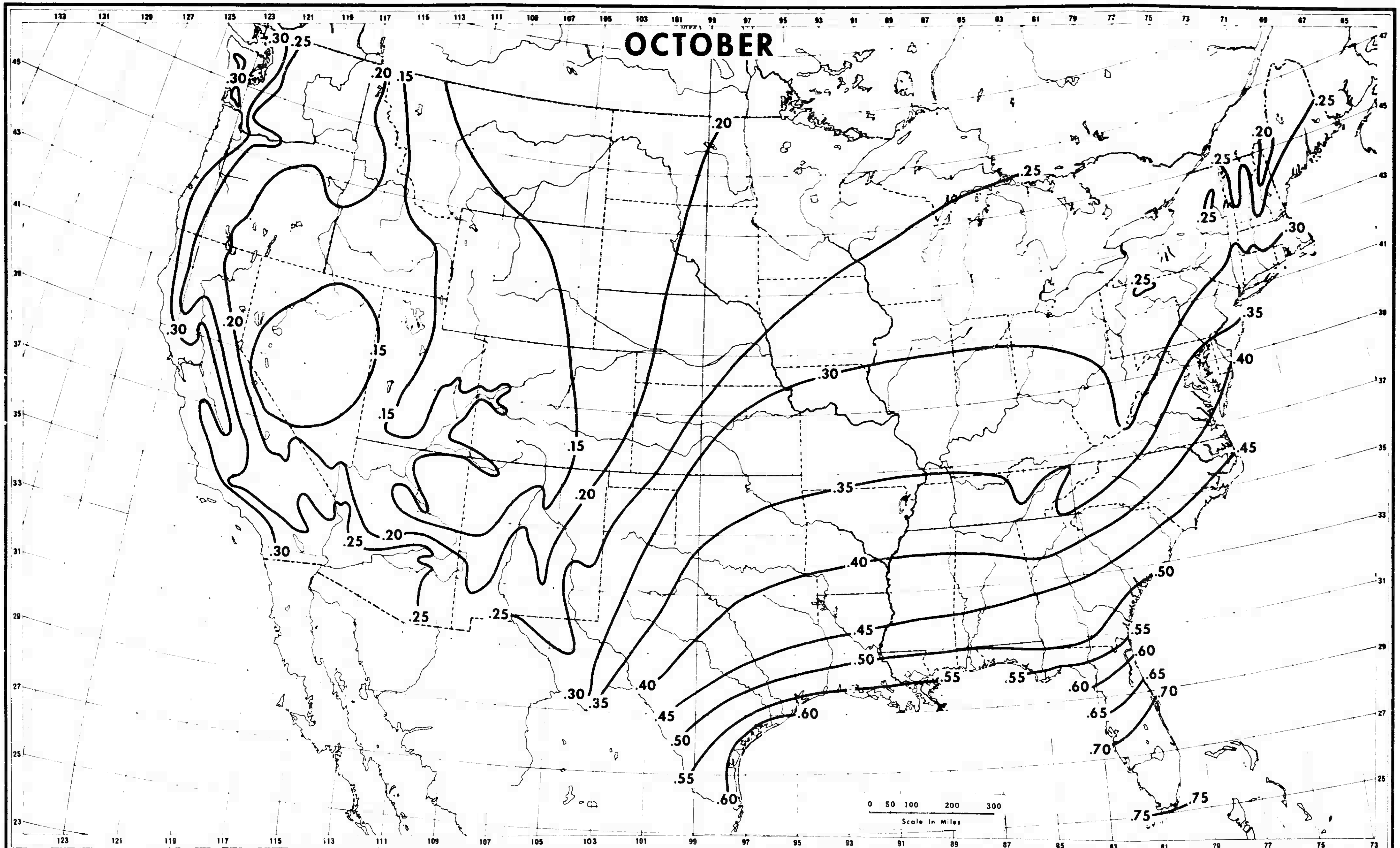


Figure 34

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

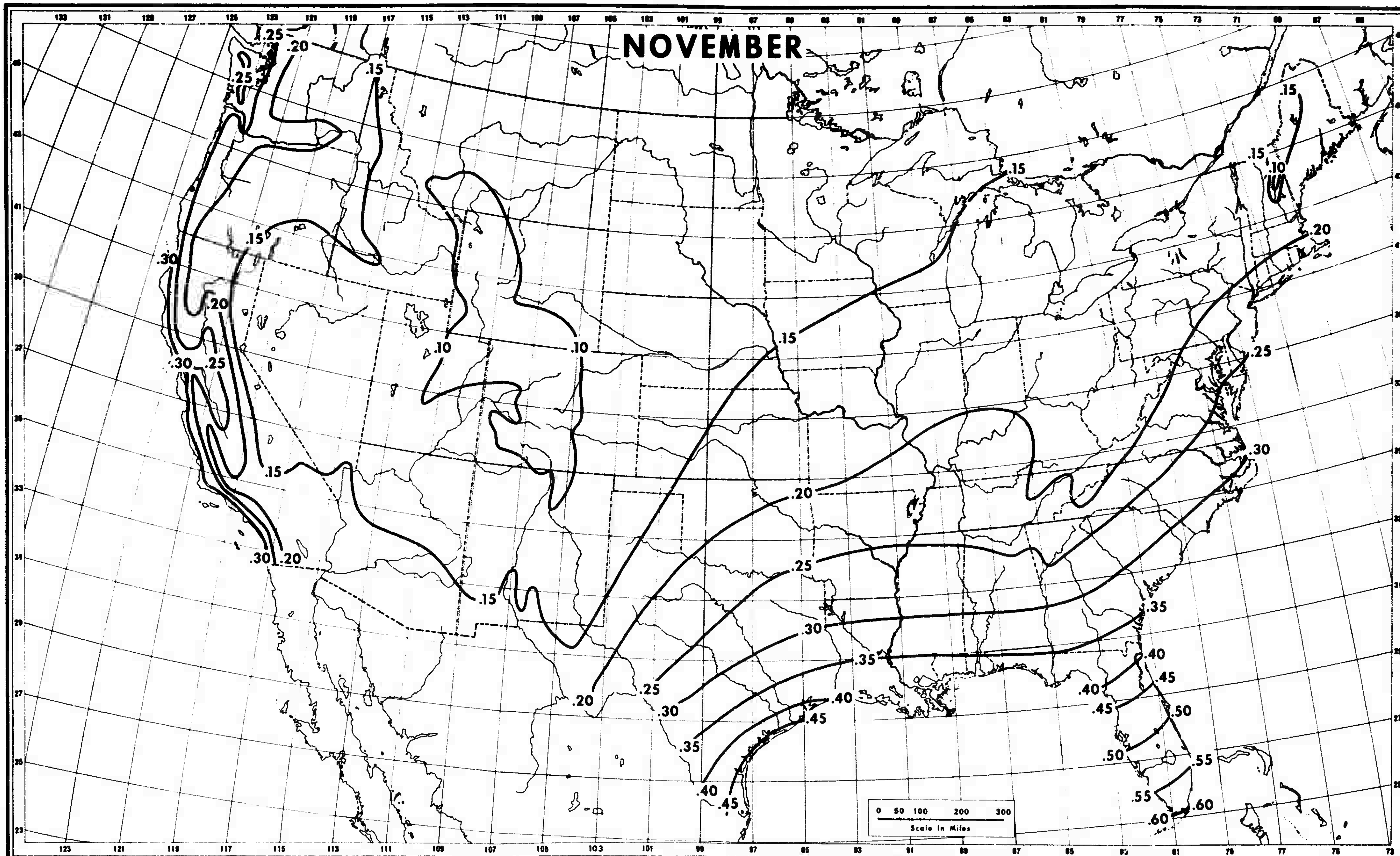


Figure 35

AVERAGE MONTHLY VAPOR PRESSURE

Inches of Mercury

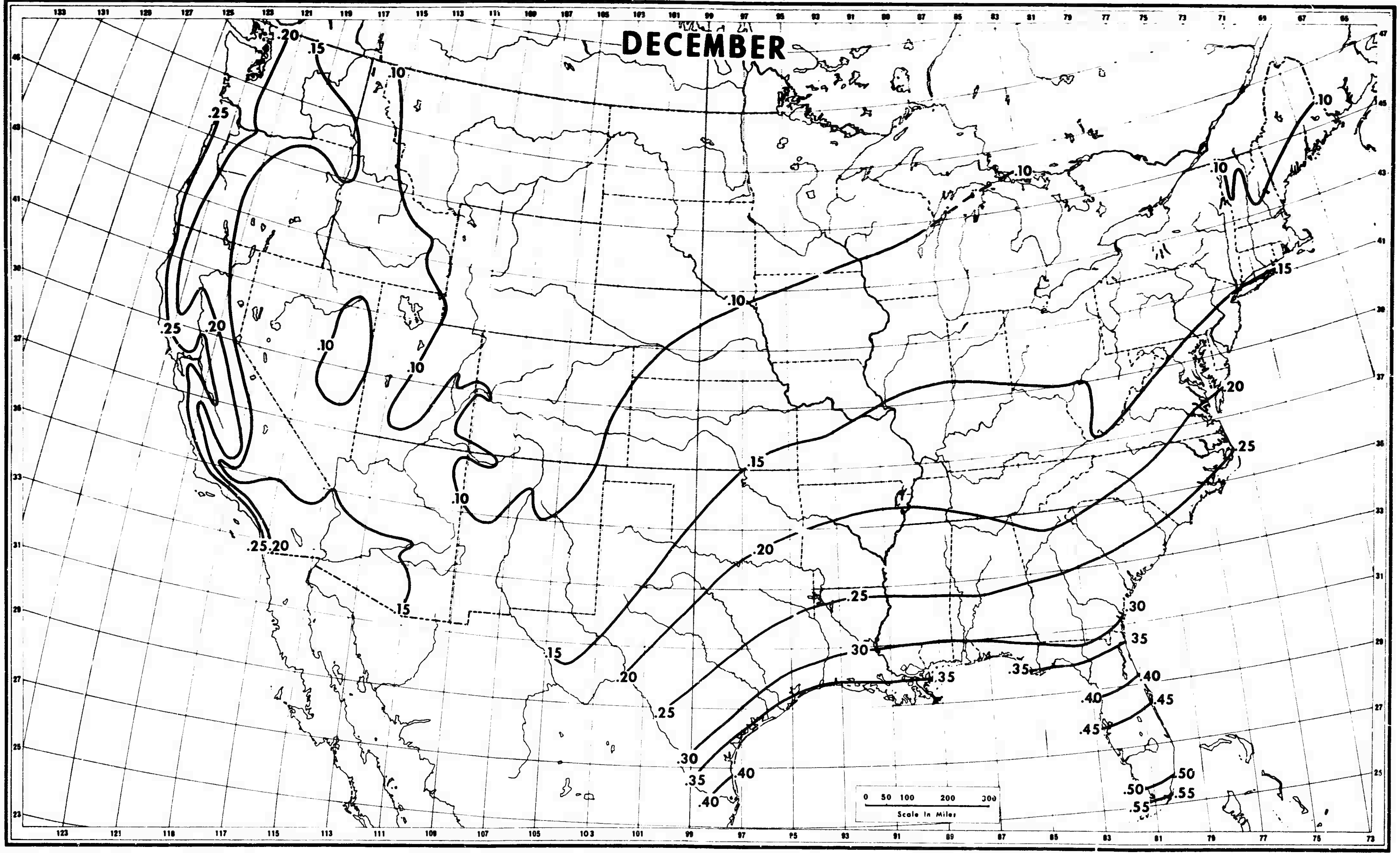
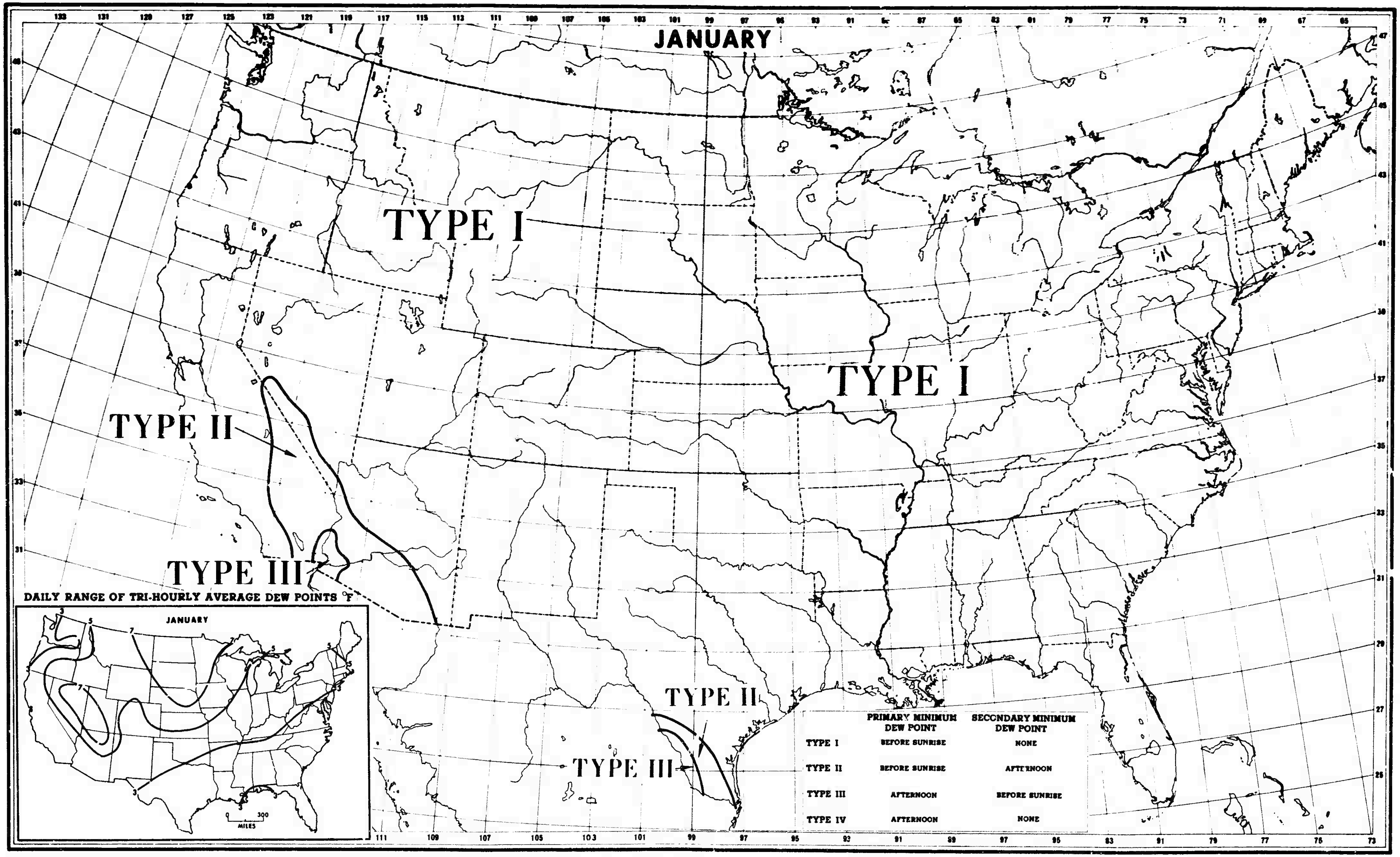


Figure 36

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT



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DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

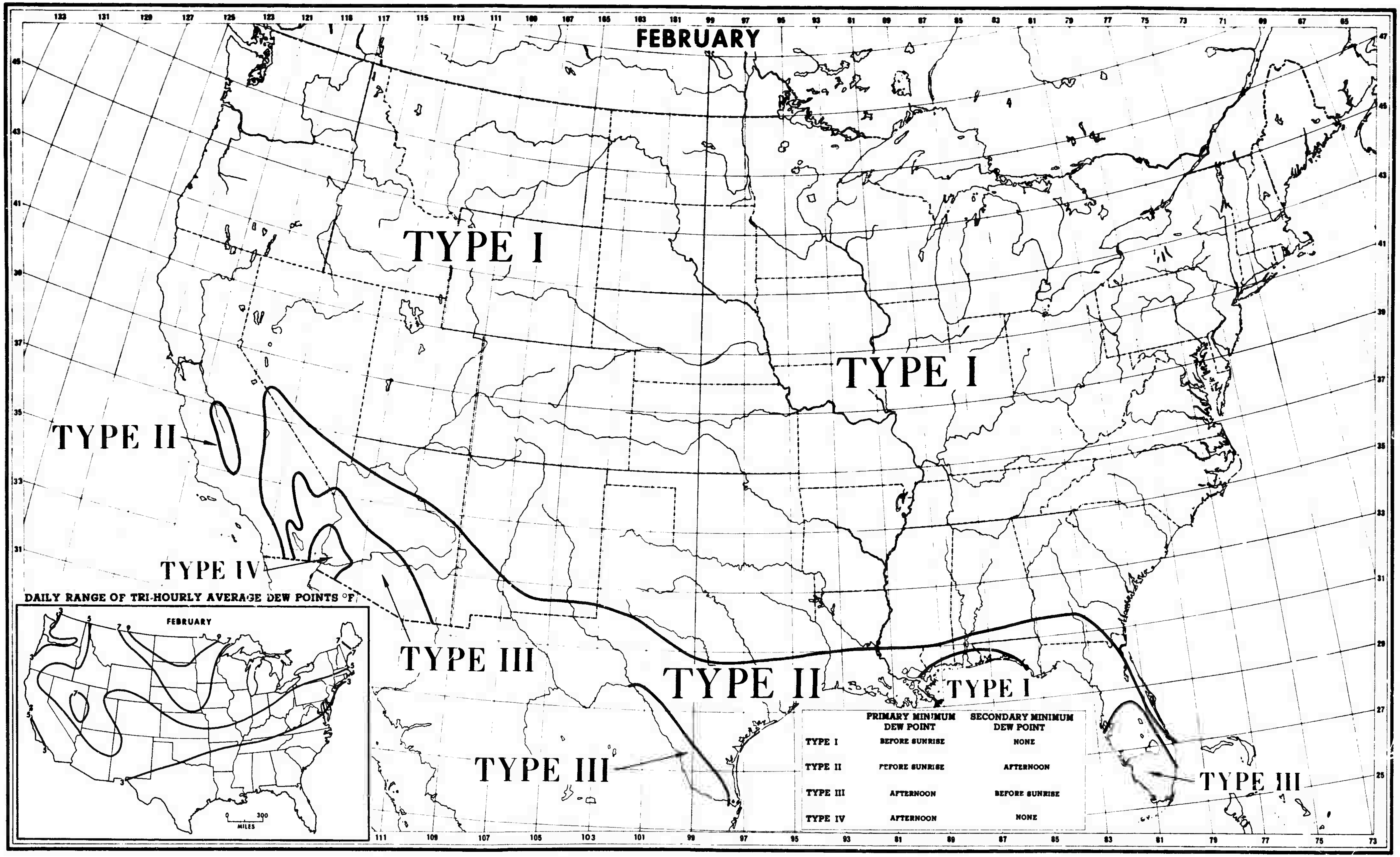


Figure 38

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

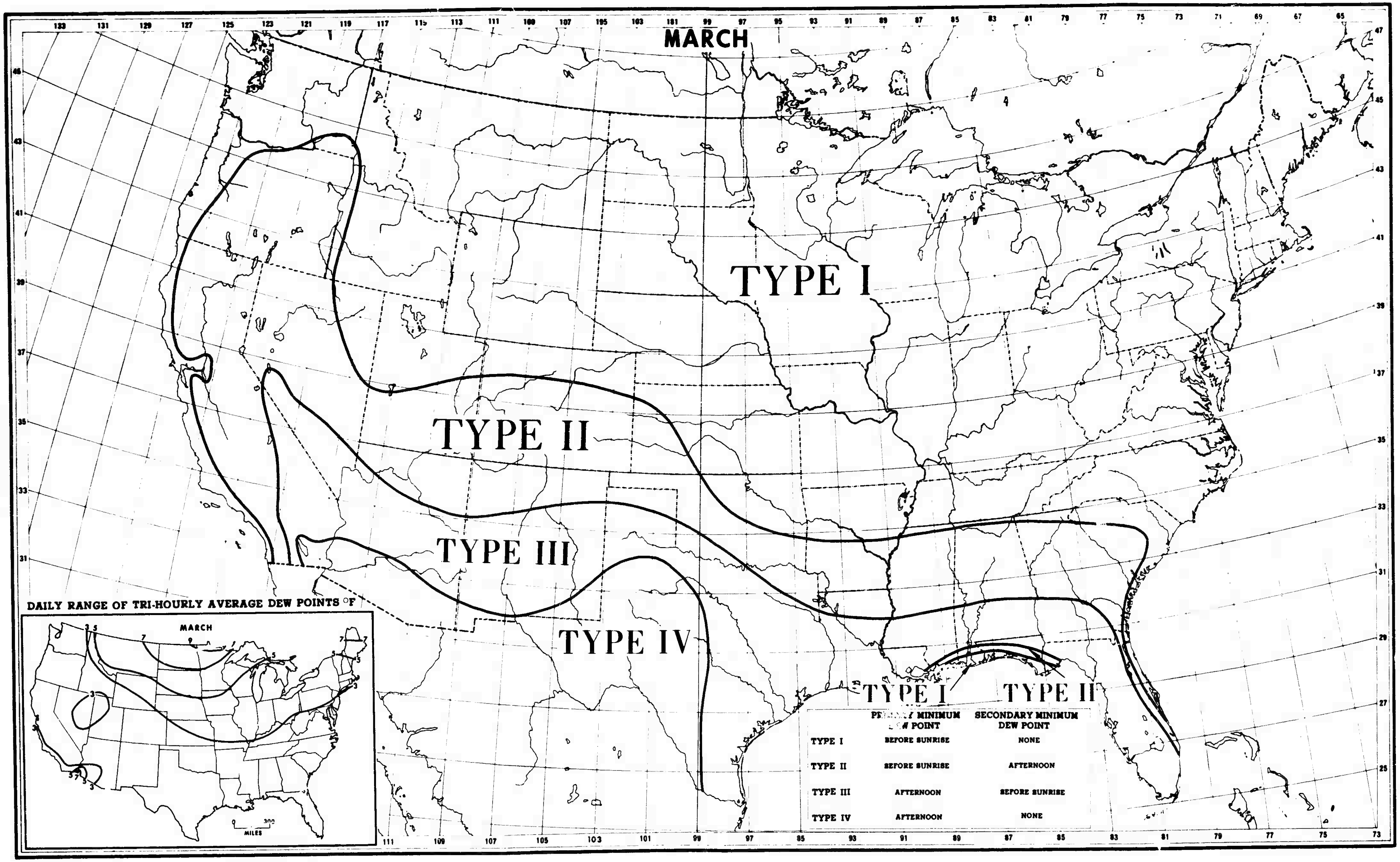


Figure 39

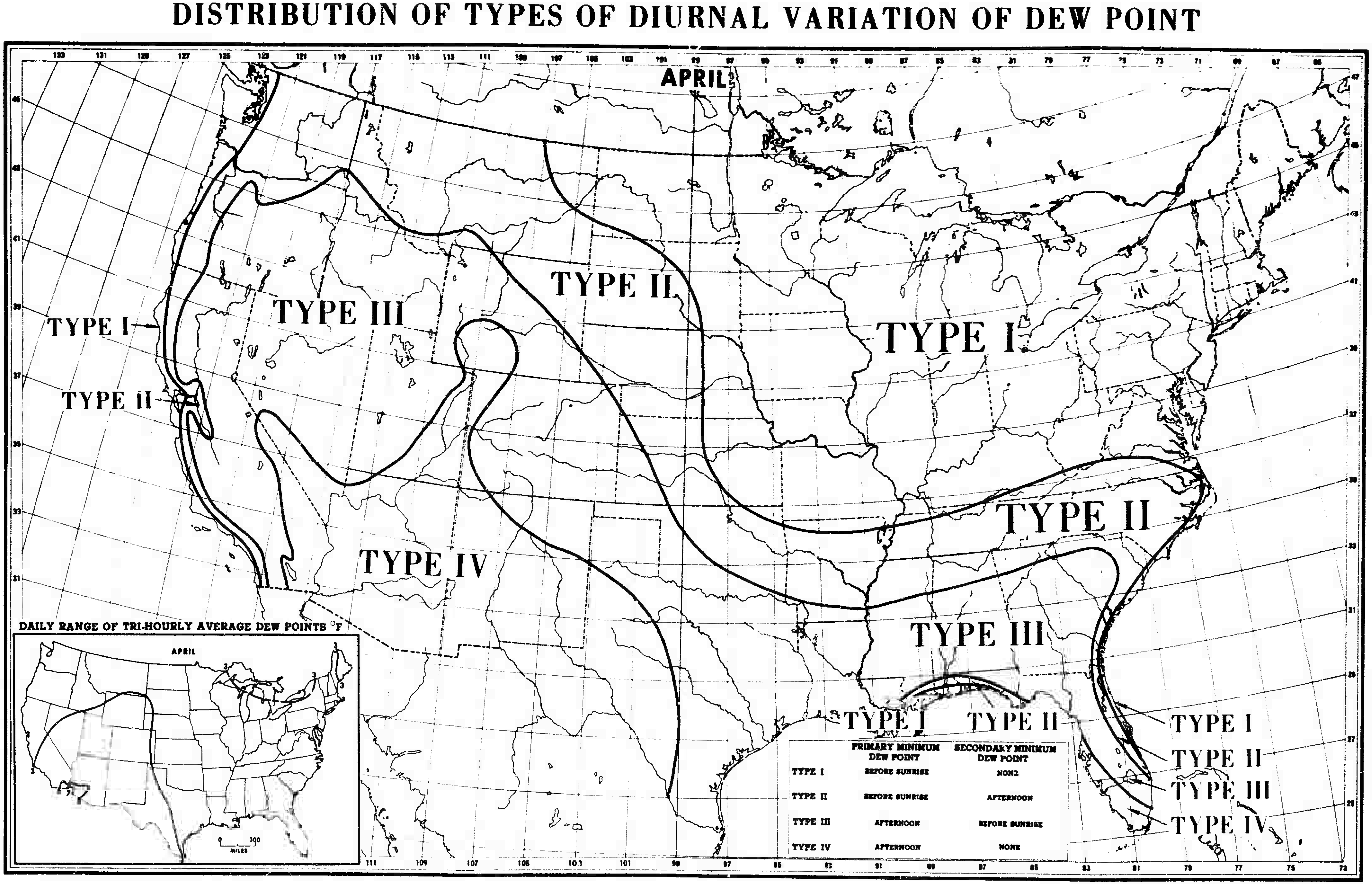

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT
APRIL
TYPE I
TYPE II
TYPE III
TYPE IV
DAILY RANGE OF TRI-HOURLY AVERAGE DEW POINTS °F
PRIMARY MINIMUM DEW POINT
SECONDARY MINIMUM DEW POINT
TYPE I BEFORE SUNRISE NONE
TYPE II BEFORE SUNRISE AFTERNOON
TYPE III AFTERNOON BEFORE SUNRISE
TYPE IV AFTERNOON NONE

Figure 40

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

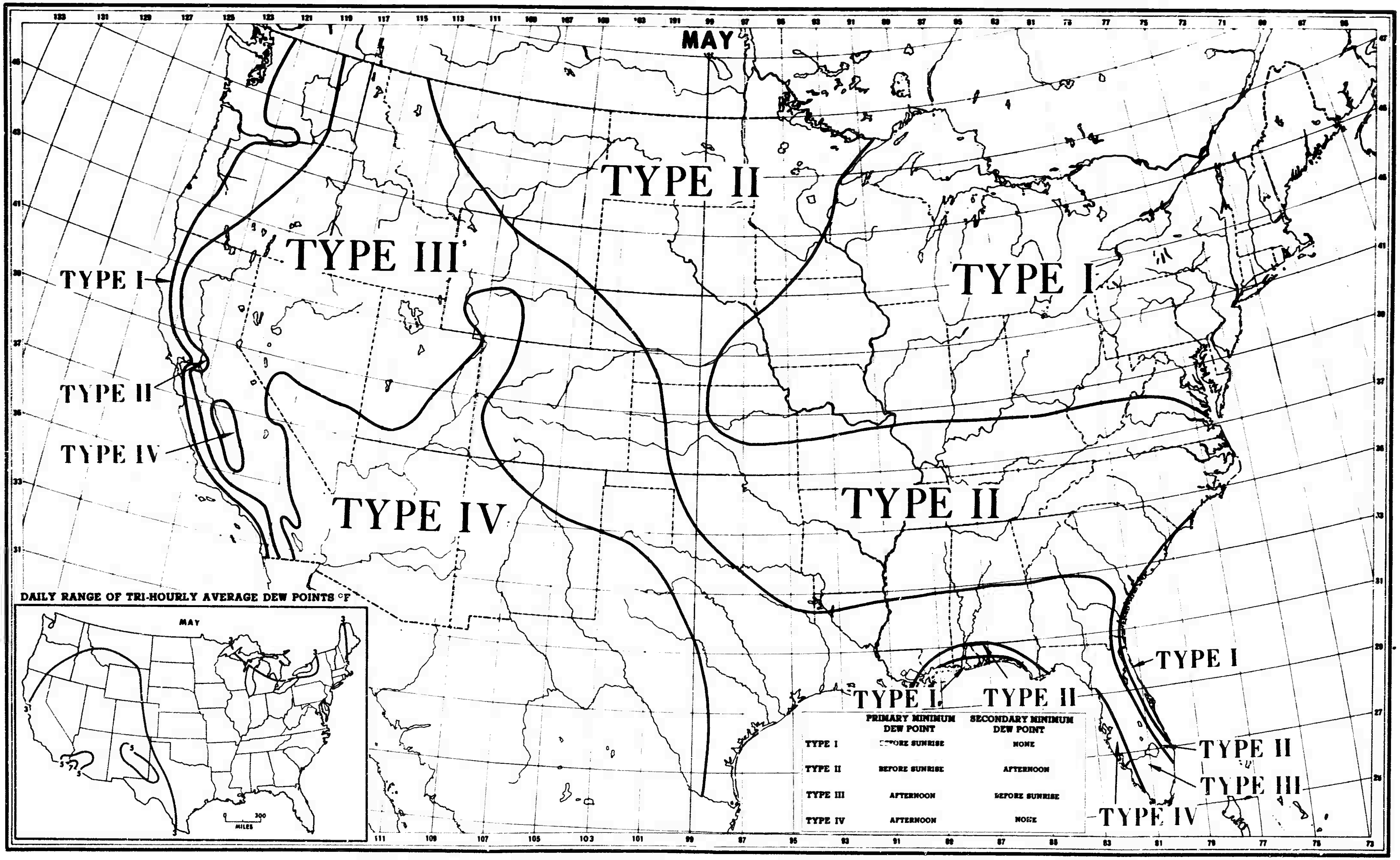


Figure 41

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

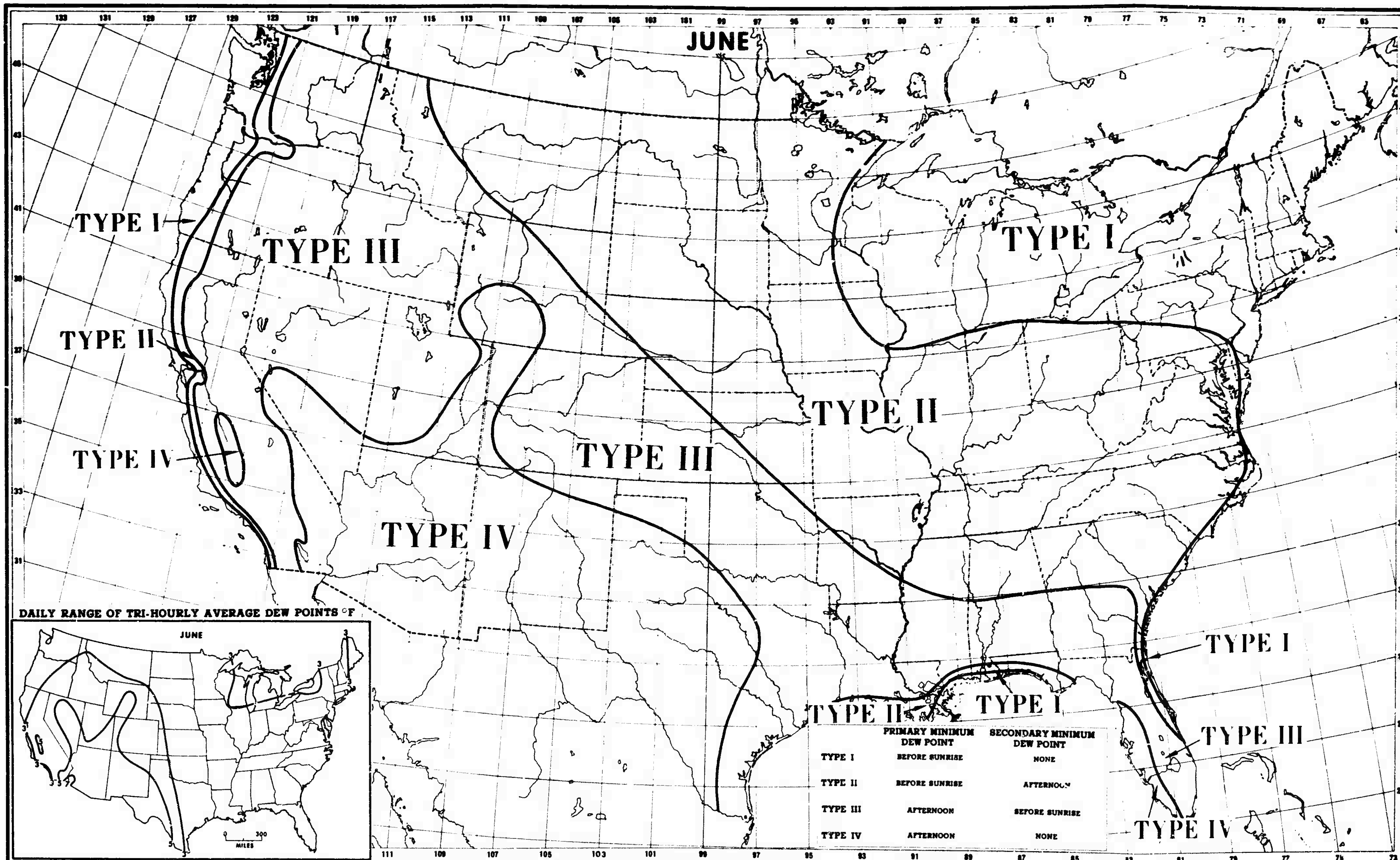


Figure 42

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

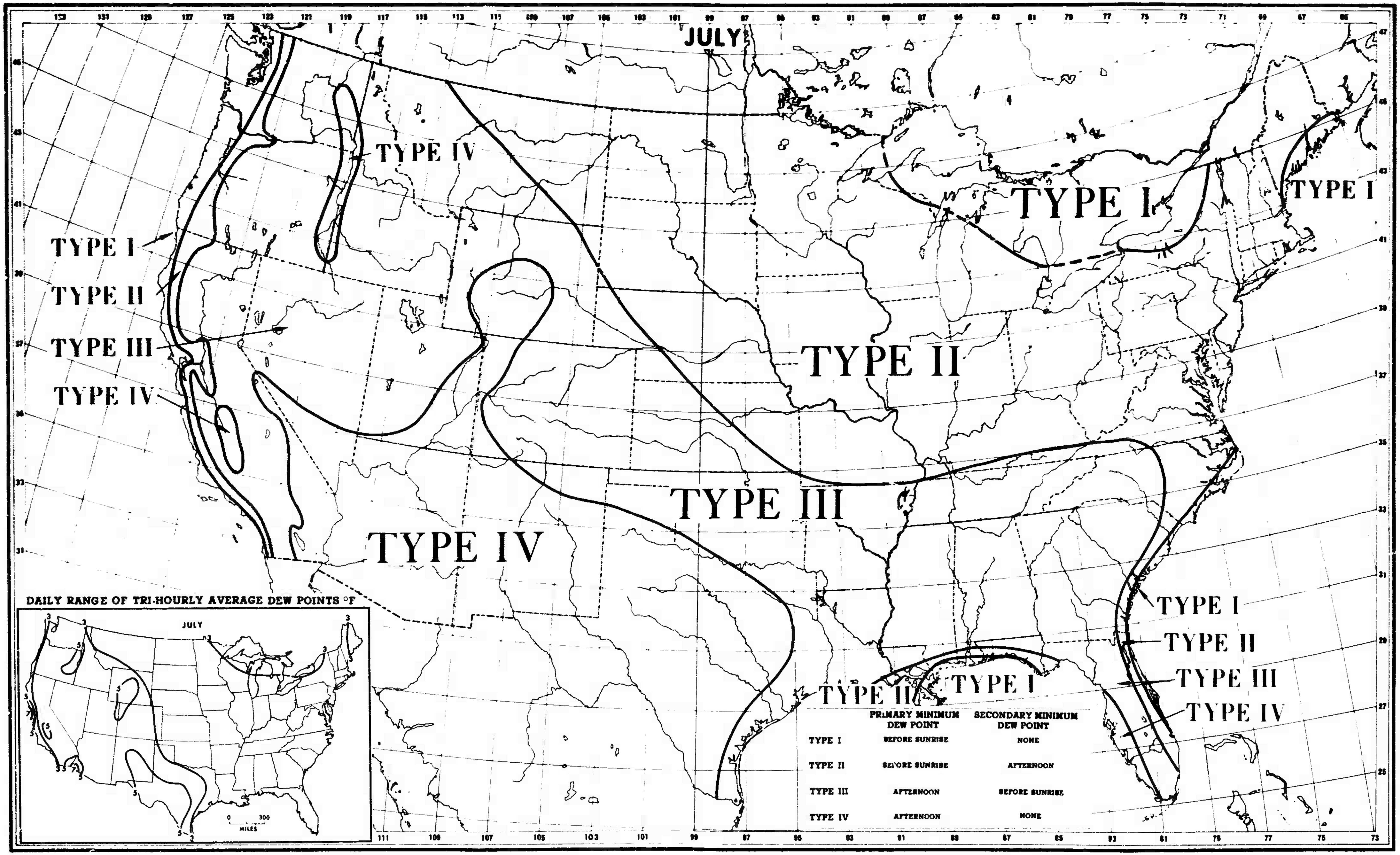


Figure 43

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

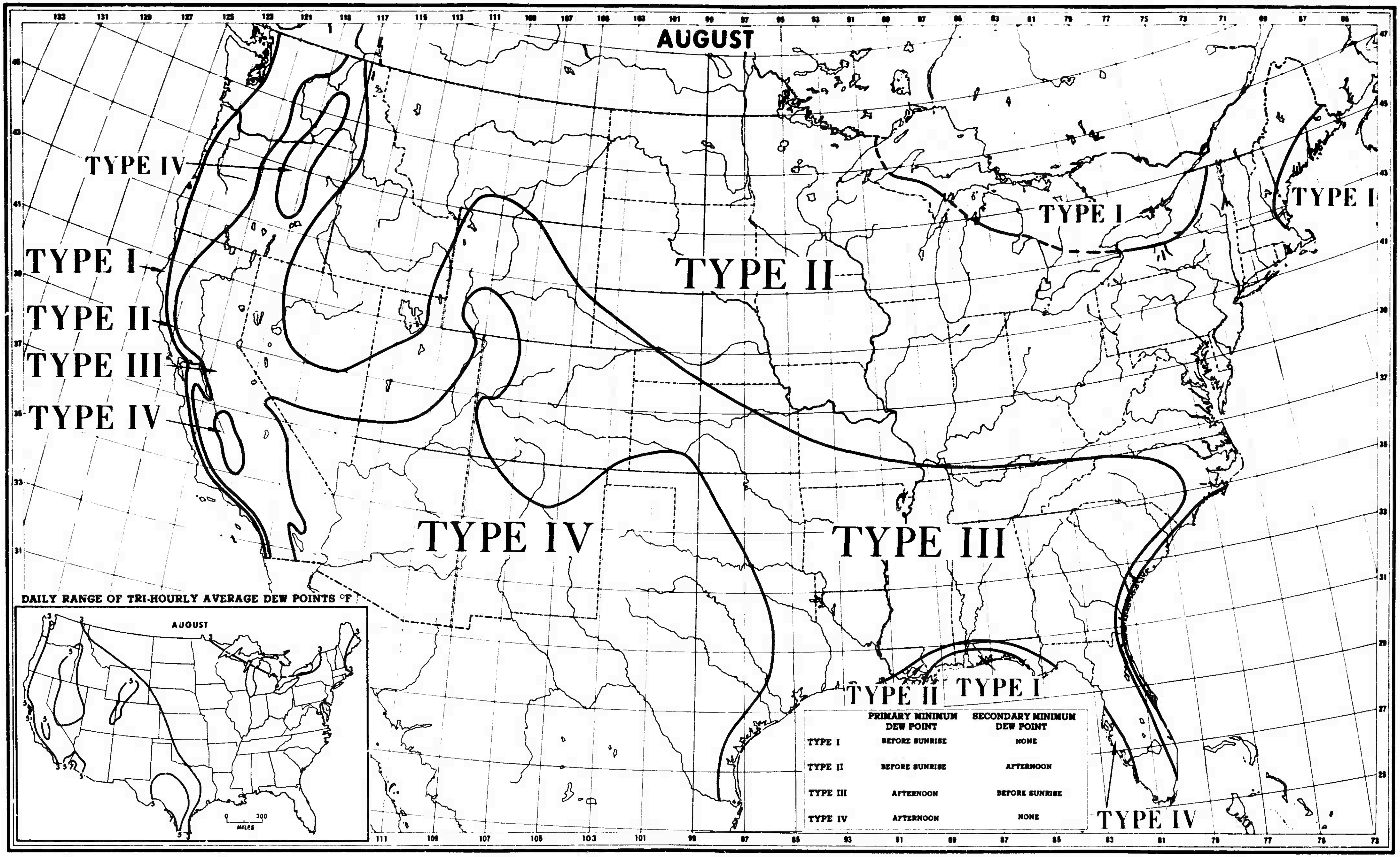
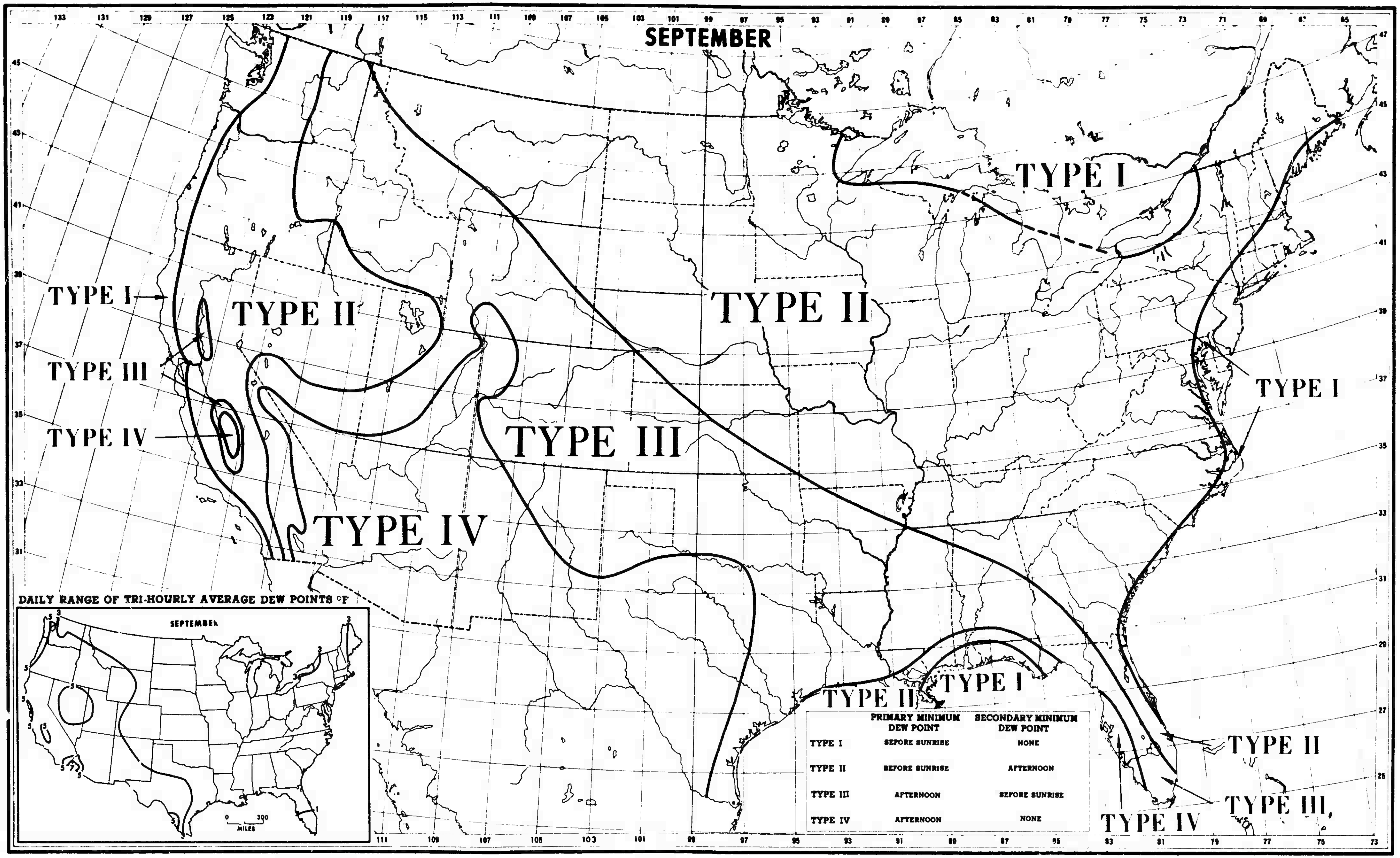


Figure 44

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT



	PRIMARY MINIMUM DEW POINT	SECONDARY MINIMUM DEW POINT
TYPE I	BEFORE SUNRISE	NONE
TYPE II	BEFORE SUNRISE	AFTERNOON
TYPE III	AFTERNOON	BEFORE SUNRISE
TYPE IV	AFTERNOON	NONE

Figure 45

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

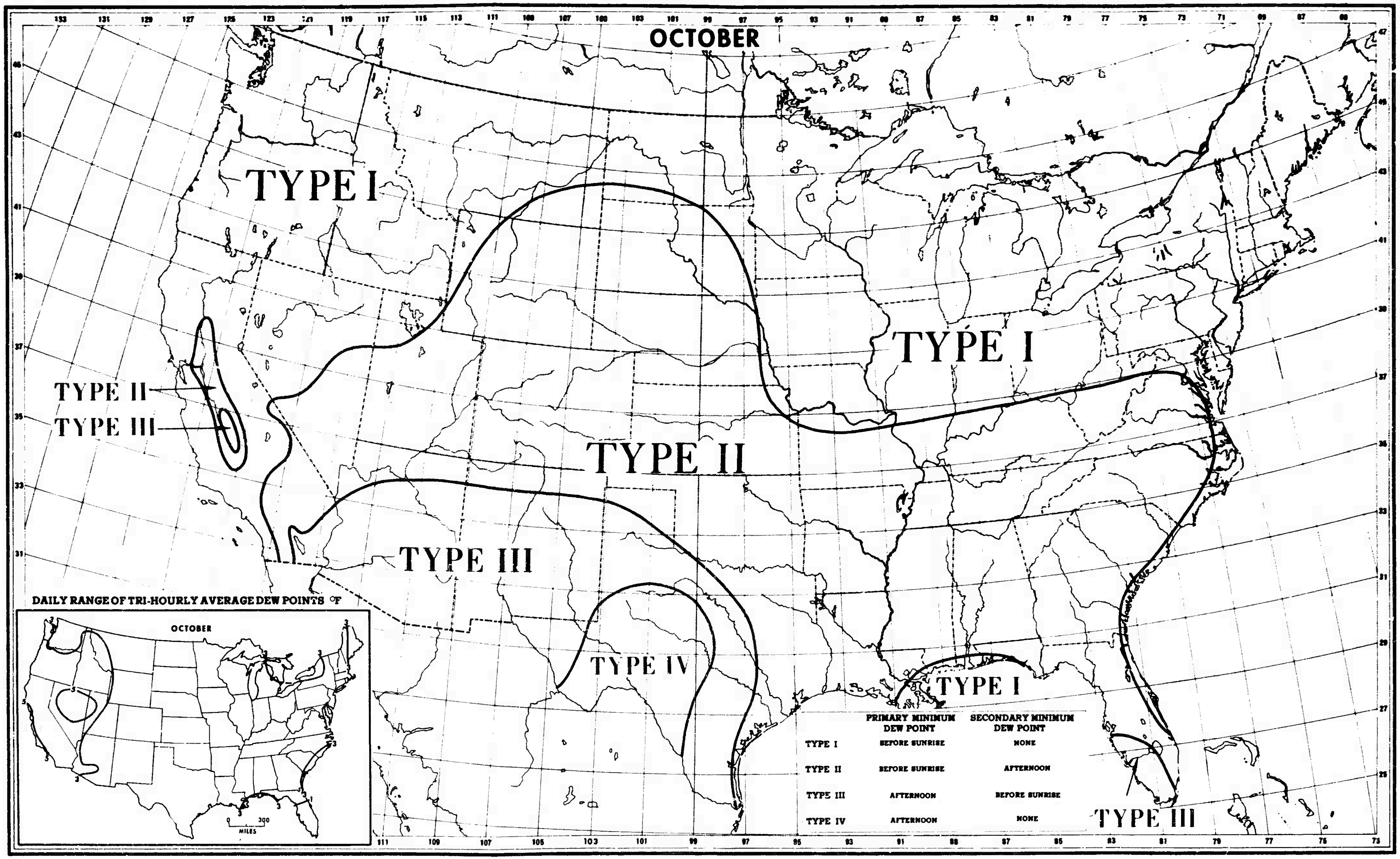


Figure 46

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

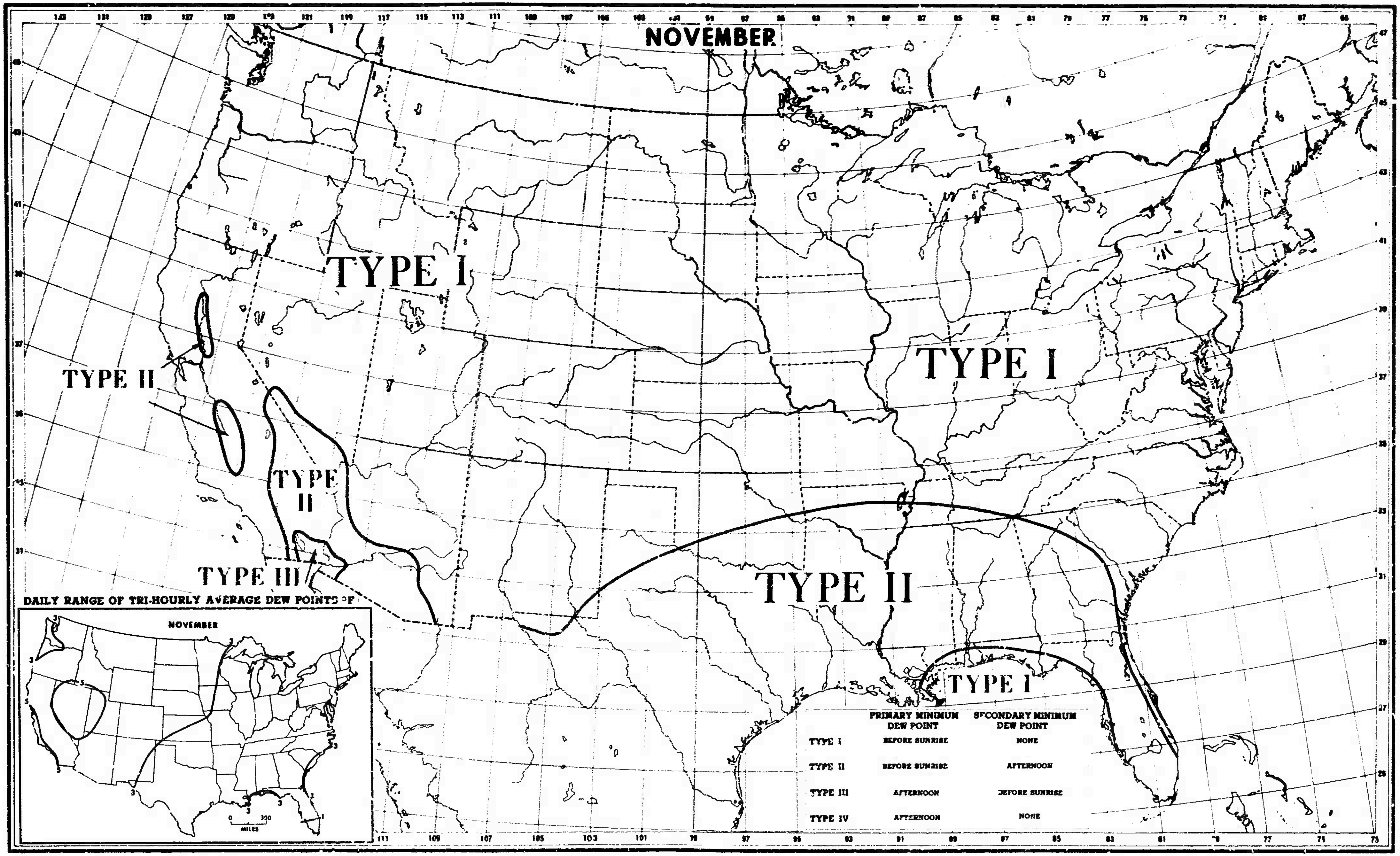


Figure 47

DISTRIBUTION OF TYPES OF DIURNAL VARIATION OF DEW POINT

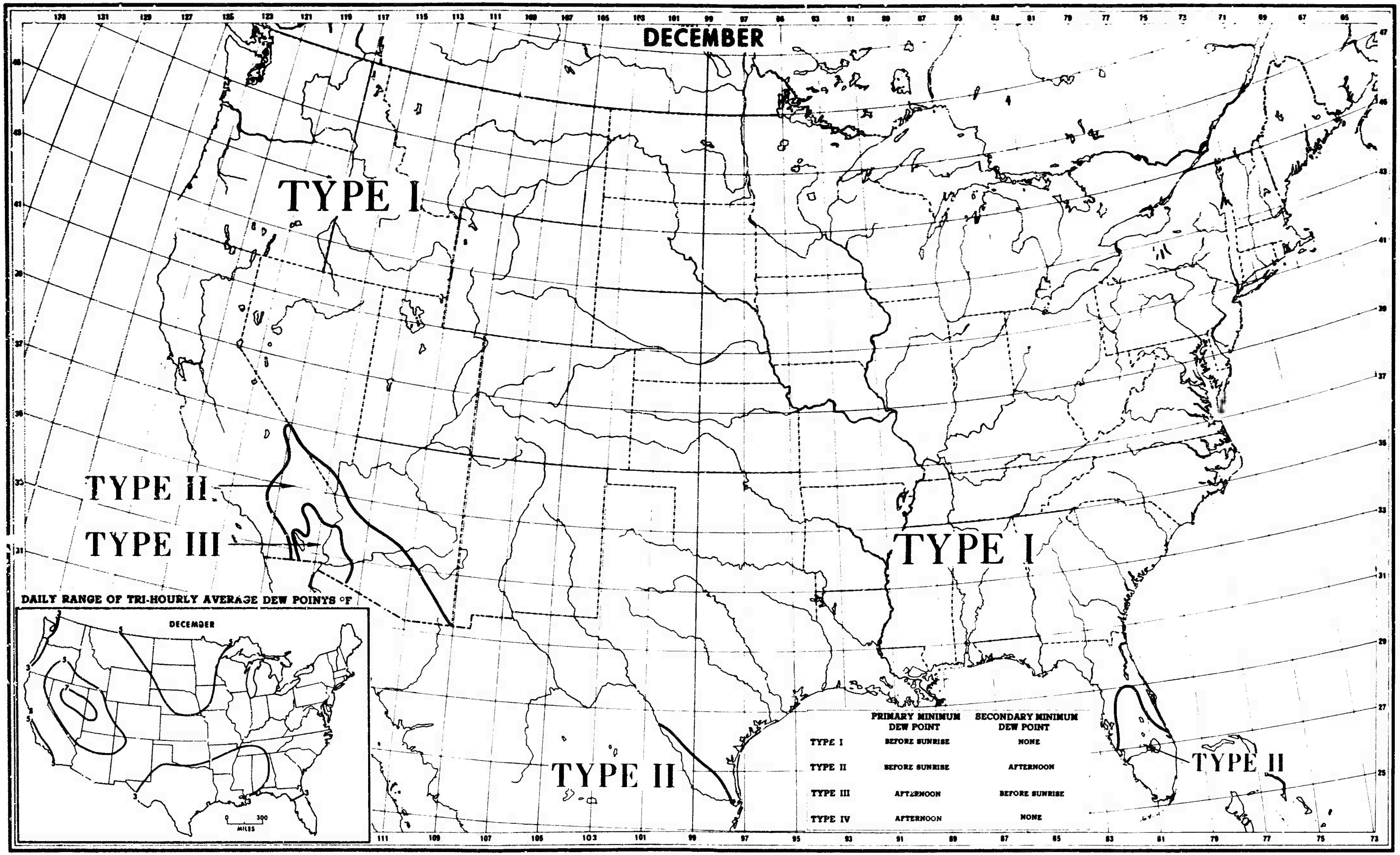


Figure 48

Unclassified

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3 REPORT TITLE

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

DODD, ARTHUR V.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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13. ABSTRACT

Maps showing the distribution in the United States (except Hawaii and Alaska) of average monthly dew point and its standard deviation, average monthly vapor pressure, and types of diurnal variation and range of dew point are presented and discussed. The maps are based on hourly psychrometric observations at nearly 200 stations for lengths of record of about ten years. The principal features of the maps are evidence of different humidity controls in different areas of the country. The tendency toward east-west alignment of the isopleths in the East, the varied pattern approximating contours in the mountainous areas, and the north-south alignment of the isopleths near the West Coast reflect the differing controls.

Four types of diurnal variation of dew point are defined based on the time of occurrence of the average minimum dew point. Type I is indicative of moisture availability at the earth's surface with highest dew points during the day. Type IV is found in dry areas and has lowest dew points during the day. Types II and III are transitional with both morning and afternoon minimum of dew point in the daily cycle.

Areas of the United States with differing humidity regimes are delineated in Part IV of the study. The areas, differentiated on the basis of average annual dew point and the range of average monthly dew points, reflect the dominant control of latitude in the East, altitude in the mountain states, and exposure on the West Coast. This final section serves to summarize the maps presented in the report.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Maps	8					
Distribution	8				8	
Dew point	1		1			
Average	0					
Monthly	0					
United States	9		9		9	
Vapor pressure	1					
Diurnal variations			8			
Range (Extremes)			8			
Humidity					1	
Armed Forces Operations					4	

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13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.