Journal of Water Resource and Protection, 2014, 6, 1475-1500
Published Online November 2014 in SciRes. http://www.scirp.org/journal/jwarp
http://dx.doi.org/10.4236/jwarp.2014.615136

Kp Pan Evaporation and ETo Monthly Maps Using Information of 60 Weather Observatories Included in the Climate Normals (1941-1970) from Mexico

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Received 21 September 2014; revised 18 October 2014; accepted 6 November 2014

Abstract

The most precise equation in order to estimate the evapotranspiration (ET) of crops is the Penman-Monteith (PM). However, the PM equation needs specific data that, in the majority of Mexico's irrigation districts, it is not available because there are few automated weather stations. For this reason, it is convenient to develop simple methods that allow to precise estimation of ET. A reliable way to estimate ET is by using the pan evaporation that, according to the revised literature, continues to be used nowadays. Investigators like to include its use in irrigation water management projects in various parts of the world. However, this method uses Kp from the FAO that is not calibrated in Mexico. The use of FAO Kp affects the precision of the results, since some variables like radiation, wind, temperature and relative humidity vary from place to place; therefore ET is under estimated or overestimated. This paper presents an original contribution across method to estimate "Kp pan evaporation and ETo monthly maps", using information from 60 weather observatories included in The Climate Normals (1941-1970) from Mexico, based on the PM method and the class A pan evaporation. Once the Kp values were obtained from each weather observatory, the Kringing method was used. This way, by interpolating data of the triad "latitude, longitude and Kp" and "latitude, longitude and ET", monthly normalized maps of Kp and ET were established for Mexico, except the upland areas (Sierra Madre Occidental and Sierra Madre Oriental), as well as other highland zones above 2700 meters over sea level, for the highest observatory is located in Toluca, State of Mexico (key 14-0039), at 2680 m over sea level.

Keywords

Reference Evapotranspiration, Pan Evaporation, Kp Pan Evaporation

How to cite this paper: Mundo-Molina, M. (2014) Kp Pan Evaporation and ETo Monthly Maps Using Information of 60 Weather Observatories Included in the Climate Normals (1941-1970) from Mexico. *Journal of Water Resource and Protection*, **6**, 1475-1500. http://dx.doi.org/10.4236/jwarp.2014.615136

1. Introduction

Earth's climate instability, local climate changes and the potential threat of anthropogenic climate change (one of the most discussed hypothesis nowadays), is generating abundant rainfalls and great runoffs in certain zones of the country (especially when extreme hydrometeorology events occur), and droughts in others locations. The anthropogenic climate change hypothesis presents unfavorable scenarios for the immediate future, especially for the northern part of Mexico where water is scarce. Mexico's most important irrigation districts are located in the north, and it's in the agricultural sector where most water is consumed, as irrigation districts use 80 of every 100 liters of water in the country with a very low efficiency (50% of water is wasted). It is precisely in this sector where water must be used effectively, by programming and properly estimating the water demand of crops.

One of the most important components of the hydrologic cycle is the evapotranspiration (ET), the estimation of which is essential in the fields of hydrology and irrigation engineering. In hydrology, the ET is needed for planning management of water resources in watersheds, and for the design of major engineering works. In irrigation engineering, the crop reference evapotranspiration is fundamental for the devising and water administration in irrigation systems. This depends on an adequate estimation of crop water requirements [1]-[3], where ET plays an essential part. Date and frequency of irrigation also depend on the accuracy of the ET estimations, as well as equitable distribution of water in irrigation zones [4]. This planning is important in Mexico where irrigation strategies need to maximize production per unit of water used. It is crucial that farmers improve not only irrigation methods, but also the knowledge of when and how much to water crops.

2. Background

To calculate irrigation schedules it is necessary to estimate ET through some method. There are methods like the Penman-Monteith, the Hargreaves, the Radiation and the FAO 24 to estimate with certain precision such variable, yet if more accuracy is required direct measurement devices can be used, such as the energy balance method (Bowen relation), the eddy covariance method, the lysimeter method and the automated weather stations. In contrast, another and much simpler method to estimate ET is the class A pan evaporation (PE); this method is frequently used in Israel and Spain's irrigation districts [5].

Mexico is introducing automated weather stations, especially in the northern part of the country; however, few users have access to the technology or the economic resources to acquire this type of stations. For this reason, developing simple and economic alternatives that allow the calculus of the ET value with an adequate precision is mandatory, either for administrating water resources and designing hydraulic projects or, in the case of irrigation engineering, for the correct determination of the irrigation frequency schedule. The Penman-Monteith is one of the most reliable methods but it needs data that either is not available for the user or inexistent. A version of the PM equation [6] is the following:

$$\mathrm{ETo} = \frac{0.408\Delta\left(\mathrm{Rn}-\mathrm{G}\right)+\gamma\dfrac{\mathrm{Cn}}{\mathrm{T}_2+273}\mathrm{U}_2\left(\mathrm{e}_\mathrm{s}-\mathrm{e}_\mathrm{a}\right)}{\Delta+\gamma\left(1+\mathrm{CdU}_2\right)} \tag{1}$$

where:

ETo = Referenced crop evapotranspiration ($mm \cdot h^{-1}$)
Rn = Net radiation on crop's surface ($MJ \cdot m^{-2} \cdot h^{-1}$)
G = Sensible heat flux from soil ($MJ \cdot m^{-2} \cdot h^{-1}$)
Cn = Numerator constant with changes reference type and calculation time step (Cn = 900, daily)
Cd = Denominator constant with changes reference type and calculation time step (Cd = 0.34, daily)
T_2 = Hourly average air temperature at 2 m over the ground (˚C)
U_2 = Hourly wind velocity at 2 m over ground (ms^{-1})

The values e_s and e_a are calculated using the maximum and minimum temperature per hour. G value is estimated during the day with the following expression [6]:

$$\mathrm{G} = 0.1\mathrm{Rn} \tag{2}$$

And during the night with:

$$\mathrm{G} = 0.5\mathrm{Rn} \tag{3}$$

These equations were validated using grass as the referenced crop, with a height of 0.12 m and a surface resistance of $r_c = 70\ sm^{-1}$ y $\alpha = 0.23$ (albedo).

On the other hand a simple way to calculate ET is by the use of the evapotranspiration equation that relates ET with E_v through a pan evaporation coefficient (Kp). According to [7]-[11], the PE is widely used in water management projects on many latitudes of the world, sometimes even with more assiduity than other, more precise methods; for example, in Israel, its use in agricultural holdings with drip irrigation is very common [5]. The PE is considered an adequate method to use at an ample range of locations, included humid zones [12]. This method estimates crop evapotranspiration using grass as reference. Grass evapotranspiration differs from the evaporation of the pan evaporation, depending on the characteristics of the site and climate conditions. Both relate through the Kp pan evaporation as it follows [7]:

$$Kp = \frac{ETo}{E_v} \tag{4}$$

where:

ETo = evapotranspiration of the reference crop (mm)

E_v = evaporation of the class-A pan evaporimeter (mm)

According to [13] many field studies have been made to compare the PE against empiric methods. Several of these studies were revised by [14] and almost all of the reported estimations based on the PE method were consistent and close to the precision level obtained from methods catalogued as the best [13]. [15] compared the Penman-Monteith method with the FAO 24 method, including the PE, in 16 districts of Australia for a wide range of climatic conditions. His principal conclusions on the PE method were the next: a) a satisfactory correlation exists between the PE and the Penman-Monteith methods for the total evaporation of three days or more. However, the pan evaporation data is obsolete unless precise values of Kp are used, b) the Kp of PE depends on local conditions so it must be determined using the pan evaporation data and the ET data obtained by the Penman-Monteith equation or the radiation method. With this basic idea a methodology was developed to calculate normalized monthly Kp pan evaporation and monthly isocurves from PE and the Penman-Monteith equation [6]. With the final aim to minimize errors and estimate the Kp pan evaporation from PE in its range of values (between 0 and 1), the coefficients proposed by [16] were used as reference values and also the characteristics of its evaporimeter. On the other hand, pan evaporation depends on the exact placement of the pan relative to wind exposure. Pans surrounded by tall grass may evaporate 20 to 30 percent less than pans placed in a fallow area. Rainfall may occur during the irrigation season and may add water to the pan, or thirsty animals wandering in the area may drink from the pan, thus detracting from its usefulness. To avoid water loss to drinking animals (especially birds), pans are often covered by screens. This may reduce the evaporation rate by some 10 to 20 percent, thus requiring the use of a correction factor. The differences between Kp from arid zones and Kp from humid zones were also considered. The authors recommended reducing the values from **Table 1**, 20% less in desert or semi desert zones, especially in places with intense wind and 5% to 10% for places with moderate wind (for humid and cold zones the Kp value was not reduced). For dry places the Kp value was elevated between a 20% and 30%. For humid zones with moderate wind, Kp was elevated between a 5% and a 10%.

Kp Pan Evaporation and ET Monthly Estimation in Mexico

Sixty weather observatories were located and analyzed through the country. This information was obtained from The Climate Normals (1941-1970), elaborated by the now extinct Department of Agriculture and Hydraulic Resources [17] that contains normalized climate normals data from 1941 to 1970. These observatories have climate information that works for the Penman-Monteith method [13], which was used to calculate ETo in each climate observatory (Equation (1)). The observatories used for the ETo calculus were the following:

On the other hand, the monthly evaporation (E_v) values in each observatory were obtained (see **Table 2**), which were measured in the field over a 30 year period. Thus, when clearing ET from the Equation (4), we have:

$$ETo = KpE_v \tag{5}$$

Matched 1 and 5:

$$Kp = \frac{Fs}{E_v} \tag{6}$$

Table 1. Kp coefficients proposed by FAO [16].

Class A, Pan Evaporimeter	Case A				Case B			
	Pan Surrounded by a Low Vegetal Cover				Pan A, Rainfed Fallow			
Average Relative Humidity %		Low < 40%	Medium 40% - 70%	High >70%		Low < 40%	Medium 40% - 70%	High >70%
Winds $km \cdot d^{-1}$	Distance Upwind from the Green Cover (m)				Distance Upwind from Fallow Rainfed (m)			
Weak	0	0.55	0.65	0.75	0	0.7	0.8	0.85
<175	10	0.65	0.75	0.85	10	0.6	0.7	0.8
	100	0.7	0.8	0.85	100	0.55	0.65	0.75
	1000	0.75	0.85	0.85	1000	0.5	0.6	0.7
Moderate	0	0.5	0.6	0.65	0	0.65	0.75	0.8
175 - 425	10	0.6	0.7	0.75	10	0.55	0.65	0.7
	100	0.65	0.75	0.8	100	0.5	0.6	0.65
	1000	0.7	0.8	0.8	1000	0.45	0.55	0.6
Strong	0	0.45	0.5	0.6	0	0.6	0.65	0.7
425 - 700	10	0.55	0.6	0.65	10	0.5	0.55	0.65
	100	0.6	0.65	0.7	100	0.45	0.5	0.6
	1000	0.65	0.7	0.75	1000	0.4	0.45	0.55
Muy fuertes	0	0.4	0.45	0.5	0	0.5	0.6	0.65
>700	10	0.45	0.55	0.6	10	0.45	0.5	0.55
	100	0.5	0.6	0.65	100	0.4	0.45	0.5
	1000	0.55	0.6	0.65	1000	0.35	0.4	0.45

where Fs is equal to Equation (1). Thus, the standard monthly Kp values were estimated for each observatory with equation 6, as shown in **Table 2**. Results are presented in **Table 3**.

With the values from **Table 3**, isocurves and maps of Kp pan evaporation and ETo were elaborated and standardized for all the country, by interpolating the *latitude*, *longitude*, *Kp* and *ET* data respectively (as a triad of values) with a Kringing grid method. With this data, a rectangular calculation mesh (rows and columns) was established. The grid method produces a regulated arrangement of the Z (Kp or ET) values from the XYZ (latitude, longitude and Kp or ET) irregularly spaced. The terms "irregularly spaced" mean that the points do not follow a particular pattern over a map, e.g. in practice many "spaces" were left without any data, which the method (Kringing) estimates by taking as a reference the closest values, filling these spaces by interpolation. The Kringing method has a mean weighed interpolation algorithm and incorporates a linear variogram model. The variogram is used to determine the local vicinity of the observations when an interpolation is performed in each node of the grid. The illustrations **Figures 1-12** show the Kp estimations for each month, normalized for Mexico.

With clearing Fs from equation 6 and the Kp and ETo data from **Table 2** and **Table 3** respectively, the ETo monthly normalized data was obtained in all observatories of the country (see **Table 4**). Thus, when *latitude*, *longitude* and *ET* data was interpolated, the maps shown in illustrations **Figures 13-24** were completed.

3. Discussion

With the proposed methodology in this paper, new monthly values for Kp pan evaporation were estimated for the 1941-1970 period of the climatological normals of the Mexican republic. The monthly Kp pan evaporation values have a national coverage. The use of Kp maps or the isolines make the PE not only a simple method but also an applicable one to any latitude of the country. However, it is important to take in consideration that: a) in places above 2700 m over sea level there are no climatological stations (Sierra Madre occidental, sierra Madre del Sur and mountains 2700 meters over sea level, which are represented on the maps with a brown color), and the Kp evaporation pan and ETo results may or may not be precise; therefore they must be used with caution,

Table 2. Climatic data.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ACAPULCO, GUERRERO	Longitude: 99˚56'				Latitude: 16˚50'		Altitude: 28 msnm					
TEMPERATURE (˚C)	26.5	26.6	26.8	27.4	28.7	28.7	28.8	29	28.3	28.3	27.8	26.9
RELATIVE HUMIDITY (%)	75	74	74	75	76	76	76	76	78	78	76	76
INSOLATION (Hs)	7.81	8.23	7.92	6.39	6.19	6.47	6.79	6.8	5.85	6.8	8.01	7.7
WIND VELOCITY (Km/h)	265.2	280.8	319.7	339.6	308.4	292.9	282.5	267.8	273	239.3	249.7	247.1
PRECIPITATION (mm)	8.6	0.9	0.9	2.5	29.4	226.9	227.9	267.3	386.7	162.6	49.6	7.8
EVAPORATION (mm)	150.07	149.33	184.71	191.27	182.5	179.87	188.47	177.29	159	164.6	152.21	149.21
AGUASCALIENTES, AGUASCALIENTES	Longitude: 102˚18'				Latitude: 21˚53'		Altitude: 1908 msnm					
TEMPERATURE (˚C)	13.8	15.4	17.9	20.7	22.5	21.9	20.6	20.5	19.7	18.1	15.9	14
RELATIVE HUMIDITY (%)	57	52	46	43	46	59	65	67	69	64	59	61
INSOLATION (Hs)	7.36	8.09	8.12	8.05	8.26	7.28	7.13	7.4	6.44	7.59	7.88	6.83
WIND VELOCITY (Km/h)	194.4	228.1	302.4	232.4	206.5	147.7	114.9	119.2	123.6	121.8	132.2	132.2
PRECIPITATION (mm)	16	8.3	5.7	16	13.2	97.6	107	108.3	93.6	40.3	11.1	20.1
EVAPORATION (mm)	130.73	166.91	237.59	264.17	279.43	224.22	190.61	185.73	161.41	156.8	137.86	118.26
CAMPECHE, CAMPECHE	Longitude: 90˚33'				Latitude: 19˚51'		Altitude: 5 msnm					
TEMPERATURE (˚C)	23.5	24.3	26.1	27.8	28.5	28.7	28	28	27.7	26.7	24.8	23.6
RELATIVE HUMIDITY (%)	79	76	73	72	73	75	77	79	80	79	80	80
INSOLATION (Hs)	5.99	7.08	6.9	6.9	6.87	6.26	6.33	7.15	5.55	5.8	6.02	4.91
WIND VELOCITY (Km/h)	87.3	102.8	113.2	124.4	93.3	89.8	99.4	74.3	54.4	47.5	71.7	88.1
PRECIPITATION (mm)	17.2	12.5	13.2	10.1	60.5	152.4	2.06	201.4	221.2	119	53.9	26.6
EVAPORATION (mm)	111.21	130.93	173.85	200.38	202.36	177.14	156.47	157	139.21	137.71	112.8	105.47
CHAPINGO, ESTADO DE MÉXICO	Longitude: 95˚54'				Latitude: 19˚29'		Altitude: 2250 msnm					
TEMPERATURE (˚C)	11.4	13	15.5	16.9	17.3	17.3	16.2	16	15.8	14.6	12.8	11.5
RELATIVE HUMIDITY (%)	60	55	51	54	62	70	75	76	76	73	69	66
INSOLATION (Hs)	7.31	8.26	8.11	7.92	7.88	6.24	5.75	6.29	5.41	6.83	7.78	7.42
WIND VELOCITY (Km/h)	105.8	190.4	194.6	126.9	118.4	93.1	78.7	77.8	80.4	79.5	93.1	86.4
PRECIPITATION (mm)	9	4.7	10.7	32.2	66.4	109.7	123.8	115.3	104.5	46.9	15.5	5
EVAPORATION (mm)	122.3	147.1	192.3	186.5	190.3	152.5	132.2	131.1	128.3	129.5	117.4	110
CHILPANCINGO, GUERRERO	Longitude: 99˚30'				Latitude: 17˚33'		Altitude: 1360 msnm					
TEMPERATURE (˚C)	19.9	20.5	21.8	22.8	23.3	22.2	21.5	21.5	21.2	21.4	20.8	19.9
RELATIVE HUMIDITY (%)	75	73	70	69	73	82	84	84	87	82	78	76
INSOLATION (Hs)	6.86	7.55	7.53	6.48	5.74	4.92	5.32	5.51	4.49	5.78	6.57	6.48
WIND VELOCITY (Km/h)	277.3	394	379.3	355.1	306.7	301.5	291.2	272.2	302.4	301.1	314.5	325.5
PRECIPITATION (mm)	5.6	2	2.2	6.4	45.3	104.1	149	116.9	146.2	51.3	18.7	1.6
EVAPORATION (mm)	125.9	135.9	179.3	184.6	161.1	119.9	104	104.6	94.1	125.1	114	108.4
CHIHUAHUA, CHIHUAHUA	Longitude: 106˚05'				Latitude: 28˚38'		Altitude: 1423 msnm					
TEMPERATURE (˚C)	9.9	12.2	15.5	20	24.1	27.1	25.6	24.9	22.6	18.9	13.8	10.1
RELATIVE HUMIDITY (%)	50	42	35	31	31	36	51	54	57	51	49	51
INSOLATION (Hs)	4.93	6.33	7.49	8.44	8.6	8.25	7.74	6.37	5.19	6.46	6.15	4.93
WIND VELOCITY (Km/h)	24.1	344.7	457.9	428.5	339.6	272.2	222.9	227.2	207.1	198.7	248	278.2
PRECIPITATION (mm)	7.5	2.8	3	3.6	10.5	34.7	76.6	79.2	52.4	17.8	5.1	7.3
EVAPORATION (mm)	145.55	163.64	277.85	311.85	306.31	285.8	205.73	160	135.5	146	132.33	139.6

Continued

COLIMA, COLIMA	Longitude: 103˚43'			Latitude: 19˚14'		Altitude: 494 msnm					
TEMPERATURE (˚C)	22.7	23.1	23.7	24.9	26.2	26.3	25.6	25.5	25	25.1	24.3	23.1
RELATIVE HUMIDITY (%)	62	60	57	54	57	71	77	78	80	76	70	66
INSOLATION (Hs)	6.79	7.92	7.26	6.19	5.01	4.19	4.01	4.52	3.68	5.08	6.55	5.8
WIND VELOCITY (Km/h)	337	397.4	449.3	423.4	422.5	380.2	319.7	328.3	341.3	328.3	384.5	263.5
PRECIPITATION (mm)	21.4	15.5	8.7	3.9	7.5	145.9	215.4	191.6	212.6	118.1	13.9	18.4
EVAPORATION (mm)	165.2	175	191.5	187.1	224.2	180.9	153	145.9	131.9	142.8	157.6	150.3
COMITAN, CHIAPAS	Longitude: 92˚08'			Latitude: 16˚15'		Altitude: 1530 msnm					
TEMPERATURE (˚C)	15.9	16.9	18.6	19.7	19.7	19.2	18.8	19.1	18.8	17.9	16.7	16.1
RELATIVE HUMIDITY (%)	80	78	76	77	79	82	81	81	83	84	82	82
INSOLATION (Hs)	6.61	6.85	7.34	6.09	5.66	5.08	5.99	6.21	5.03	4.47	5.97	6.33
WIND VELOCITY (Km/h)	224.6	287.8	272.2	237.6	207.4	194.4	190.1	155.5	207.4	211.7	194.4	211.7
PRECIPITATION (mm)	6.4	6.9	12.7	38.6	112.7	206	138.6	121.6	237.4	127.2	22.2	6.1
EVAPORATION (mm)	102.55	109.24	154.14	151.9	142	100.65	123.65	120.9	91.37	81.05	80.05	84.76
CORDOBA, VERACRUZ	Longitude: 96˚56'			Latitude: 18˚54'		Altitude: 924 msnm					
TEMPERATURE (˚C)	17.1	18.2	20.1	22.4	23.1	22.8	21.8	22.3	21.6	20.6	18.8	17.7
RELATIVE HUMIDITY (%)	81	78	75	72	74	80	80	81	84	83	83	82
INSOLATION (Hs)	2.96	3.26	3.26	2.3	2.37	3.56	3.86	4.42	3	3.21	3.08	2.9
WIND VELOCITY (Km/h)	442.2	439.5	448.4	423	376.5	346.9	287.6	270.7	339.2	423	431.5	423
PRECIPITATION (mm)	38.9	36.5	38.4	48.3	106.5	325.8	380.3	335.2	438.1	225.8	73.3	46.4
EVAPORATION (mm)	46.65	49.81	80.8	98.71	103.05	88.2	86.4	86.43	76.77	65.64	57.68	49.14
COZUMEL, QUINTANA ROO	Longitude: 86˚57'			Latitude: 20˚31'		Altitude: 3 msnm					
TEMPERATURE (˚C)	22.8	23.2	24.5	26	26.8	27.2	27.2	27.2	26.8	26	24.6	23.4
RELATIVE HUMIDITY (%)	84	83	81	81	82	85	86	86	88	87	84	85
INSOLATION (Hs)	6.3	7.1	6.1	6.9	6.4	6.4	6.5	6.2	6.2	6.4	6.8	7
WIND VELOCITY (Km/h)	350.8	389.7	437.2	362	278.2	238.5	245.4	245.4	222	259.2	349.9	345.6
PRECIPITATION (mm)	90.5	56.7	40.2	42.3	118.1	180.1	109.6	151.6	230.6	219.5	96.9	111.5
EVAPORATION (mm)	106	116	172	185	205	180	200	185	150	138	100	90
CULIACAN, SINALOA	Longitude: 107˚24'			Latitude: 24˚49'		Altitude: 84 msnm					
TEMPERATURE (˚C)	19.6	20.5	21.7	24.5	27.3	29.5	29.4	28.9	28.7	27.4	23.7	20.6
RELATIVE HUMIDITY (%)	71	65	61	57	57	64	74	79	79	74	68	71
INSOLATION (Hs)	6.11	6.67	7.42	7.06	7.95	7.37	6.18	6.39	6.51	7.37	7.11	5.92
WIND VELOCITY (Km/h)	150.3	158.1	188.4	213.4	221.2	226.4	170.2	142.6	138.2	138.2	149.5	137.4
PRECIPITATION (mm)	24.9	8.6	7	2.8	0.4	25	163.7	228.8	146.5	41.2	11.2	38.9
EVAPORATION (mm)	112.5	135.1	193.9	229.9	269.8	247.1	195.9	169.6	156.3	165.4	140.8	113.8
DISTRITO FEDERAL	Longitude: 99˚12'			Latitude: 19˚24'		Altitude: 2308 msnm					
TEMPERATURE (˚C)	12.6	14.4	16.6	17.6	17.8	17.3	16.1	16.2	15.7	15	13.9	12.7
RELATIVE HUMIDITY (%)	54	48	44	45	53	64	70	72	72	66	61	58
INSOLATION (Hs)	5.5	6.88	6.91	5.6	5.74	4.57	4.52	4.91	4.05	4.9	5.04	4.43
WIND VELOCITY (Km/h)	122.7	94.2	104.5	82.1	80.4	70.8	61.3	62.2	51.8	60.5	58.8	93.3
PRECIPITATION (mm)	9.6	3.5	9.2	27.1	52.3	126.1	155.9	152.8	135.5	53.5	15.2	6.1
EVAPORATION (mm)	80.74	106	161.21	155.94	145.14	115.53	93.24	9.56	83.32	80.29	73.26	64.76

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DURANGO, DURANGO	Longitude: 101˚40'				Latitude: 24˚02'		Altitude: 1889 msnm					
TEMPERATURE (˚C)	11.8	13.7	16.2	19.3	21.9	22.8	21	20.5	19.7	18.8	15.4	12.6
RELATIVE HUMIDITY (%)	49	44	36	36	39	49	59	61	62	57	49	52
INSOLATION (Hs)	6.71	7.57	8.49	8.26	8.28	7.86	6.78	6.51	6.55	7.28	7.3	5.82
WIND VELOCITY (Km/h)	146.9	198.7	194.4	190.1	194.4	198.7	155.5	164.2	190.1	146.9	146	151.2
PRECIPITATION (mm)	11.5	6.2	3.5	3.7	6.7	50.1	97.8	97.3	84	32.7	6.5	11.5
EVAPORATION (mm)	162.3	185.9	246.8	246.1	262.1	183.2	142.8	139.6	122.9	173.1	172.3	137.6
GUADALAJARA, JALISCO	Longitude: 103˚23'				Latitude: 20˚40'		Altitude: 1589 msnm					
TEMPERATURE (˚C)	15.2	16.9	19.1	21.5	23.2	22.3	20.5	20.5	20.1	19	17.2	15.5
RELATIVE HUMIDITY (%)	52	46	41	37	42	61	71	73	73	66	58	56
INSOLATION (Hs)	6.57	8.05	8.53	8.64	9.04	7.12	6.52	6.89	6.23	6.99	7.46	6.12
WIND VELOCITY (Km/h)	286	349.9	381	374.1	299.8	241.1	206.5	178.8	210	185.8	216.9	212.5
PRECIPITATION (mm)	12.7	5.9	6.2	8.7	24.6	164.6	250.3	195.6	148.8	59.7	11.3	13.2
EVAPORATION (mm)	130.3	165.1	231	257.3	272.5	202	158.8	146.5	128	130.9	122.8	109.8
GUANAJUATO, GUANAJUATO	Longitude: 101˚15'				Latitude: 21˚01'		Altitude: 2050 msnm					
TEMPERATURE (˚C)	14.1	15.8	18.2	20.3	21	20.1	19	19.1	18.3	17.6	16	14.6
RELATIVE HUMIDITY (%)	47	40	34	34	41	56	60	60	62	56	52	50
INSOLATION (Hs)	7.82	8.97	9.23	8.83	8.19	7.12	7.02	7.74	6.67	7.97	8.22	7.04
WIND VELOCITY (Km/h)	273.9	38.7	383.6	262.7	220.3	270.4	259.2	252.3	324.9	253.2	255.7	242.8
PRECIPITATION (mm)	11.6	3.7	4.6	20.8	33.1	129.2	121.2	118.1	119.8	42.9	16.2	10.5
EVAPORATION (mm)	138.9	168.4	232.9	258.3	250.7	204.9	181.6	180.8	170.2	174.1	149.2	132.7
GUAYMAS, SONORA	Longitude: 110˚54'				Latitude: 27˚55'		Altitude: 44 msnm					
TEMPERATURE (˚C)	18.3	19.2	20.7	23.5	26.4	29.5	31.2	31.2	30.8	27.7	22.4	19.3
RELATIVE HUMIDITY (%)	51	47	45	44	45	55	64	66	62	54	51	50
INSOLATION (Hs)	6.49	7.65	7.52	8.75	9.65	10.23	8.22	8.02	7.92	8.23	7.29	6.31
WIND VELOCITY (Km/h)	42.3	32.8	52.7	81.2	75.2	102	83.8	56.2	46.7	42.3	30.2	33.7
PRECIPITATION (mm)	14.9	6.1	3.1	1.2	0.2	1.9	45.5	58.7	37.4	24.1	8.4	16.9
EVAPORATION (mm)	97.59	117.44	175.93	225.29	263.65	275.12	240.24	206.69	190	156.08	111.53	83.56
HERMOSILLO, SONORA	Longitude: 110˚58'				Latitude: 29˚04'		Altitude: 237 msnm					
TEMPERATURE (˚C)	16.4	17.8	19.9	23.9	27.2	31.3	32.3	31.4	30.9	26.9	20.9	17.1
RELATIVE HUMIDITY (%)	50	43	40	34	30	34	48	53	48	42	45	49
INSOLATION (Hs)	5.57	6.56	6.92	7.46	8.79	8.63	7.37	7.81	7.03	8.15	6.47	6.18
WIND VELOCITY (Km/h)	25.1	32	44.1	29.4	36.3	32.8	15.6	14.7	23.3	14.7	13.8	21.6
PRECIPITATION (mm)	15.4	5.6	3.7	3.8	0.3	6.5	73.7	77.6	27.2	14.6	5.3	14.2
EVAPORATION (mm)	97.65	127.4	180.8	231.29	292.68	329.35	285.55	240.76	216.16	182.15	125.6	95.35
JALAPA, VERACRUZ	Longitude: 96˚55'				Latitude: 19˚32'		Altitude: 1427 msnm					
TEMPERATURE (˚C)	14.8	15.7	17.8	20.1	20.4	20	19.4	19.7	19.2	17.9	16.4	15.3
RELATIVE HUMIDITY (%)	79	77	74	73	76	81	80	79	83	82	79	78
INSOLATION (Hs)	4.36	4.88	4.61	4.51	4.46	4.17	4.77	5.26	3.74	3.98	4.5	4.23
WIND VELOCITY (Km/h)	465.3	507.6	516.1	465.3	401.9	372.2	291.9	275	346.9	431.5	461.1	444.2
PRECIPITATION (mm)	43.2	46.1	54.7	59.8	101.8	265.8	209.1	183.5	260	128.3	60.4	41.3
EVAPORATION (mm)	85.8	87.4	117.3	137.5	132.2	121.5	112.9	121.5	94.1	96.2	87.2	82.5

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LAGOS DE MORENO, JALISCO	Longitude: 101˚55'			Latitude: 21˚21'		Altitude: 1942 msnm					
TEMPERATURE (˚C)	13.8	15.5	18.1	20.7	22.2	21.4	19.6	19.6	19	17.8	15.9	14.2
RELATIVE HUMIDITY (%)	55	49	43	44	47	62	69	71	71	66	61	60
INSOLATION (Hs)	7.54	8	8.63	9.41	9.56	8.1	7.5	7.36	6.7	7.79	8.55	7.04
WIND VELOCITY (Km/h)	169.2	220	279.2	211.5	165	146.9	126.9	126.9	146.9	118.4	110	118.4
PRECIPITATION (mm)	13	6.3	4.6	9.1	24.6	94.4	109.3	108.2	98.9	44.3	11.3	11.3
EVAPORATION (mm)	94	126	193	217	243	175	138	132	111	105	89	80
LA PAZ, BAJA CALFORNIA	Longitude: 110˚25'			Latitude: 24˚10'		Altitude: 10 msnm					
TEMPERATURE (˚C)	17.9	18.8	19.9	22.2	24.6	26.5	29.2	29.7	29.1	26.6	22.9	19.5
RELATIVE HUMIDITY (%)	69	62	62	61	60	59	60	64	65	64	64	65
INSOLATION (Hs)	7	7.11	6.65	6.8	7.1	7.07	6.84	6.58	6.7	6.84	7.07	6.42
WIND VELOCITY (Km/h)	290.3	284.3	215.1	274.8	248	227.2	182.3	199.6	214.3	221.2	265.2	292
PRECIPITATION (mm)	14.7	3.5	2	1.1	0.2	2.4	13.2	36.4	65.3	12.7	5.4	20.1
EVAPORATION (mm)	169.2	155.9	184.8	172.8	173.2	170.2	182.9	192.3	182.8	182.8	172.9	173.5
LEON, GUANAJUATO	Longitude: 101˚41'			Latitude: 21˚07'		Altitude: 1885 msnm					
TEMPERATURE (˚C)	15.5	17.1	19.8	22.2	23.5	22.2	20.8	20.8	20.4	19.2	17.5	15.8
RELATIVE HUMIDITY (%)	60	55	49	47	51	61	66	67	67	63	59	61
INSOLATION (Hs)	5.52	5.95	5.7	4.86	5.33	4.72	4.82	5.21	4.72	5.66	6.05	5.15
WIND VELOCITY (Km/h)	127	19.8	222	182.3	125.3	130.5	114.9	108	121	101.1	109.7	104.5
PRECIPITATION (mm)	10.7	5.3	5.7	7.8	28	117.8	12.9	138	109.5	45.7	13.6	10
EVAPORATION (mm)	183.8	212	287.3	324.8	328	257.1	230	214	199.8	206.7	181.6	172.2
LERDO, DURANGO	Longitude: 103˚31'			Latitude: 25˚32'		Altitude: 1135 msnm					
TEMPERATURE (˚C)	12.9	15.7	19.1	23.4	26.3	27.8	27.2	26.5	24.4	21.1	16.4	13.7
RELATIVE HUMIDITY (%)	47	38	33	31	32	41	46	49	55	53	48	50
INSOLATION (Hs)	6.71	6.82	6.48	6.6	5.68	6.73	6.48	6.19	6.27	6.48	7	6.42
WIND VELOCITY (Km/h)	173.7	184.9	184.9	118.4	167.6	171.9	159.8	146.9	164.2	146	158.1	158
PRECIPITATION (mm)	10.5	6.2	3.9	5.9	15	29.4	34.5	40	54.3	28.5	7.7	8.2
EVAPORATION (mm)	100	134.4	199.9	236.4	271.4	259	244.2	221.5	170.4	139.1	108.5	88.6
MAZATLAN, SINALOA	Longitude: 106˚25'			Latitude: 23˚12'		Altitude: 3 msnm					
TEMPERATURE (˚C)	20.1	20	20.3	22.2	24.7	27.2	28.1	28.4	28.1	27.1	24.1	21.5
RELATIVE HUMIDITY (%)	76	75	77	76	76	75	77	78	79	78	73	73
INSOLATION (Hs)	6.14	6.97	7.91	8.34	8.86	8.17	6.8	6.93	6.23	7.58	6.99	5.89
WIND VELOCITY (Km/h)	190.9	239.3	229	235.9	215.1	234.1	204.8	176.3	274.8	219.5	203	163.3
PRECIPITATION (mm)	15.7	4.2	3.1	3.4	0.4	31.3	153.7	203.9	227.8	75.3	14.1	15.2
EVAPORATION (mm)	78.22	94.88	140.3	163	181.07	166.17	144.57	118.07	102.21	100.63	91.79	71.59
MERIDA, YUCATAN	Longitude: 89˚39'			Latitude: 20˚59'		Altitude: 9 msnm					
TEMPERATURE (˚C)	23	23.7	25.8	27.4	28	27.8	27.4	27.5	27.1	25.9	24.2	23.2
RELATIVE HUMIDITY (%)	73	69	66	65	67	73	76	76	79	78	75	74
INSOLATION (Hs)	5.58	5.76	6.38	6.55	7.4	7.01	6.95	6.93	6.06	5.75	5.84	5.64
WIND VELOCITY (Km/h)	161.6	199.6	221.2	224.6	210.8	192.7	159	108	95	136.5	187.5	160.7
PRECIPITATION (mm)	31.4	28.3	15.4	15.8	73.5	129.5	128.3	154.4	197.3	112.5	35.1	35.3
EVAPORATION (mm)	142	146.5	193.5	206.7	222.6	190.8	186.9	185.3	158.2	154.3	145.7	138.4

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MORELIA, MICHOACAN	Longitude: 101˚11'				Latitude: 15˚42'		Altitude: 1941 msnm					
TEMPERATURE (˚C)	14.4	16.1	18.3	20.1	20.9	20	18.7	18.6	18.4	17.5	16	14.7
RELATIVE HUMIDITY (%)	60	5400	4900	4800	5400	6700	7200	7200	7300	6900	6600	6500
INSOLATION (Hs)	5.89	6.7	7.08	6.34	5.96	5.01	4.92	5.66	6.22	6.02	6.31	5.4
WIND VELOCITY (Km/h)	189.2	250.6	249.7	178.8	145.2	135.6	103.7	143.4	164.2	165.9	204.8	163.3
PRECIPITATION (mm)	14.9	5.2	4.2	17.3	43.4	144.9	170.4	155.9	132.9	58.7	16	12.2
EVAPORATION (mm)	108	130	187	203	206	158	136	133	117	117	111	95
MONTERREY, NUEVO LEON	Longitude: 100˚18'				Latitude: 25˚40'		Altitude: 536 msnm					
TEMPERATURE (˚C)	14.9	16.9	20	24	26	27.7	28.4	28.2	25.8	22.3	18.1	15.7
RELATIVE HUMIDITY (%)	66	65	61	63	66	66	63	65	70	71	70	68
INSOLATION (Hs)	3.8	4.15	4.68	4.39	5.23	613	6.76	6.2	4.74	4.05	4.11	3.69
WIND VELOCITY (Km/h)	165	238.5	3.43	309.3	315.4	391.4	395.7	366.3	234.1	184	129.3	129.3
PRECIPITATION (mm)	13	19.9	15.4	27.7	34.8	63.3	46	96.2	152.2	85.1	23.2	11.1
EVAPORATION (mm)	107	119	183	190	196	222	235	221	164	133	109	94
OAXACA, OAXACA	Longitude: 96˚43'				Latitude: 17˚04'		Altitude: 1550 msnm					
TEMPERATURE (˚C)	18.3	19.7	21.9	23.2	23.3	21.9	21.1	21.3	20.7	20	19.1	18.3
RELATIVE HUMIDITY (%)	52	48	47	48	53	61	61	61	65	61	57	53
INSOLATION (Hs)	6.42	7.77	6.64	4.24	5.22	4.72	4.7	4.36	3.52	5.31	6.34	5.88
WIND VELOCITY (Km/h)	210	209.1	220.1	232.4	203	200.4	179.7	189.2	210	239.3	216	189.2
PRECIPITATION (mm)	3.4	2.7	6.8	26.1	69.8	133.9	79.7	99.9	122.9	49.7	7.1	4
EVAPORATION (mm)	118	146	200	204	189	140	127	128	111	126	118	112
ORIZABA, VERACRUZ	Longitude: 97˚06'				Latitude: 18˚51'		Altitude: 1284 msnm					
TEMPERATURE (˚C)	16.1	17.1	19.2	21.2	21.6	21.1	20.2	20.6	20.3	19	17.5	16.5
RELATIVE HUMIDITY (%)	77	74	71	68	72	78	80	78	81	82	80	78
INSOLATION (Hs)	4.47	4.59	4.39	3.82	3.39	4.06	4.45	4.76	3.9	4.45	4.18	4.29
WIND VELOCITY (Km/h)	380.7	414.5	414.5	380.7	329.9	308.8	353.8	249.6	304.6	380.7	384.9	372.2
PRECIPITATION (mm)	42.4	33.6	34.3	40.7	119.3	395.7	421.5	353.5	357.4	200.1	75.5	42.7
EVAPORATION (mm)	66.85	77.5	125.69	137.5	128	106.75	109.17	104.82	101.55	87.75	77.17	66
PACHUCA, HIDALGO	Longitude: 98˚44'				Latitude: 20˚08'		Altitude: 2426 msnm					
TEMPERATURE (˚C)	12	13.3	15.4	16.4	16.1	15.4	14.5	14.7	14.1	13.5	12.6	12.1
RELATIVE HUMIDITY (%)	61	56	52	54	61	70	74	74	77	72	67	68
INSOLATION (Hs)	7.88	8.38	7.94	7.5	8.02	6.91	6.99	7.38	6.03	7.24	7.81	7.48
WIND VELOCITY (Km/h)	194.4	267.8	280.8	194.4	155.5	129.6	112.3	99.4	121	125.3	138.2	164.2
PRECIPITATION (mm)	10.9	6.1	11	30.6	38.9	64.9	43.5	48.2	68.2	31.8	11.6	5.9
EVAPORATION (mm)	106.93	128.77	169.85	173	180.83	143.38	134.95	143.2	123.33	124	104.88	101.64
PIEDRAS NEGRAS, COAHUILA	Longitud: 100˚31'				Latitud: 28˚42'		Altitude: 220 msnm					
TEMPERATURA (˚C)	11.1	14.2	18.2	22.8	26.4	29.6	30.7	30.3	27.2	22.2	15.6	11.6
HUMEDAD RELATIVA (%)	69	66	60	62	66	63	62	64	69	71	71	72
PROGRESO, YUCATAN	Longitud: 89˚39'				Latitud: 21˚18'		Altitude: 8 msnm					
TEMPERATURA (˚C)	22.7	23.2	24.7	26.1	26.7	27.2	27	27.1	27.1	26.5	24.6	23.3
HUMEDAD RELATIVA (%)	77	74	73	74	77	80	82	83	81	77	75	77
INSOLACION (Hs)	6.4	6.84	6.42	6.18	6.96	7.51	7.65	7.47	6.72	6.64	6.44	6.34

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VELOCIDAD DEL VIENTO (Km/h)	190.4	220	245.3	241.1	220	194.6	169.2	126.9	114.2	146.9	207.3	186.1
PRECIPITACION (mm)	17.5	14.9	5.6	4.6	29.9	53.4	38.1	50.6	90.2	64.5	29.8	24.9
EVAPORACION (mm)	83.57	97.71	144.25	171.55	182.61	160.65	152.65	145.61	130.13	123.45	93.19	84.09
PUEBLA, PUEBLA	Longitud: 98˚12'				Latitud: 19˚02'		Altitude: 2162 msnm					
TEMPERATURA (˚C)	14	15.5	17.7	18.8	19.2	18.3	17.4	17.8	17.2	16.6	15.5	14.1
HUMEDAD RELATIVA (%)	54	49	43	45	54	64	66	67	70	65	59	57
INSOLACION (Hs)	7.72	8.48	8.28	8.03	7.59	6.82	6.71	7.19	5.69	7.16	7.67	7.55
VELOCIDAD DEL VIENTO (Km/h)	149.5	169.3	152.9	134.8	125.3	126.1	108	107.1	137.4	109.7	146.9	121
PRECIPITACION (mm)	7.6	5	6.1	27.5	70.3	147.2	128.3	162.1	159.2	72.5	22.6	6
EVAPORACION (mm)	133.8	153.6	217.2	206.8	179.6	124.6	124.1	119.9	101	123.5	120.1	119.9
RIO VERDE, SAN LUIS POTOSI	Longitude: 100˚00'				Latitude: 21˚58'		Altitude: 987 msnm					
TEMPERATURE (˚C)	15.3	17.7	20.3	23.3	21.9	25	24	24	22.8	20.3	17.7	15.8
RELATIVE HUMIDITY (%)	73	70	64	64	66	69	73	72	77	76	76	75
INSOLATION (Hs)	5.29	5.91	6.15	5.84	6.35	6.24	6.62	6.69	5.33	5.39	5.37	5.1
WIND VELOCITY (Km/h)	167.5	236.9	287.6	203	60.7	165	144.7	146.4	145.5	118.4	122.7	118.4
PRECIPITATION (mm)	10.3	6.3	6.8	20.1	31.5	79.1	63.4	77.9	104.4	57.2	17.6	10.3
EVAPORATION (mm)	72	95.63	148.79	168.11	173.55	164.5	148.06	144.95	113.45	96.05	73.89	63.65
SALINAS CRUZ, OAXACA	Longitude: 95˚12'				Latitude: 16˚10'		Altitude: 6 msnm					
TEMPERATURE (˚C)	25.5	25.9	27.1	28.7	29.8	28.6	28.7	28.8	27.8	27.5	26.8	26
RELATIVE HUMIDITY (%)	62	64	68	68	66	74	69	70	74	67	62	62
INSOLATION (Hs)	8.02	9.09	9.07	7.55	6.95	5.38	6.27	6.94	5.24	7.35	8.3	7.71
WIND VELOCITY (Km/h)	550.4	500.3	487.3	418.2	409.5	300.7	368.1	387.9	362	489	490.8	541.7
PRECIPITATION (mm)	4.3	3.6	2.4	0.5	37.3	266.2	176.2	190.9	259.6	95.8	22	4.2
EVAPORATION (mm)	175.5	194.75	186.6	187	197	150.4	183.25	158.8	146.6	170.5	168	153.33
SALTILLO, COAHUILA	Longitude: 100˚59'				Latitude: 25˚27'		Altitude: 1609 msnm					
TEMPERATURE (˚C)	11.7	13.6	15.7	19.6	21.5	22.7	22.6	22.2	19.9	17.4	14.4	12.6
RELATIVE HUMIDITY (%)	62	59	54	54	58	62	65	68	72	70	64	62
INSOLATION (Hs)	5	5.85	6.11	5.58	6.09	6.69	6.35	6.37	5.64	6.07	5.71	4.54
WIND VELOCITY (Km/h)	171.1	241.9	335.2	298.1	299.8	354.2	353.4	341.3	224.6	181.4	156.4	157.2
PRECIPITATION (mm)	9.2	10.6	5.8	11.4	22.9	35.3	39.2	43.7	46.8	23.2	10.7	10.6
EVAPORATION (mm)	117	141.2	204.3	230.1	252.5	240.9	223.3	214.9	162.3	138.5	114.3	109.9
SAN CRISTOBAL DE LAS CASAS, CHIAPAS	Longitude: 92˚38'				Latitude: 16˚44'		Altitude: 2276 msnm					
TEMPERATURE (˚C)	12.3	13	14.1	15.2	15.4	15.6	15.7	15.6	15.2	14.4	13.7	12.3
RELATIVE HUMIDITY (%)	81	79	78	78	79	79	79	78	80	81	81	81
INSOLATION (Hs)	6.88	7.16	6.24	5.67	5.21	4.49	5.5	5.87	3.85	5.12	6.09	6.32
WIND VELOCITY (Km/h)	300.7	311	308.4	280.8	246.2	220.3	220.3	224.6	233.3	267.8	254.9	276.5
PRECIPITATION (mm)	8	8.4	17.6	56.5	116.3	240.8	165.7	174.8	242.4	121.8	35	13.3
EVAPORATION (mm)	81	79	112	116	106	89	103	106	82	69	65	68
TAMPICO, TAMAULIPAS	Longitude: 97˚51'				Latitude: 22˚13'		Altitude: 12 msnm					
TEMPERATURE (˚C)	18.5	20	21.8	24.8	26.8	27.5	27.9	28.2	27.3	26	22.2	19.9
RELATIVE HUMIDITY (%)	81	81	80	82	81	82	80	80	81	79	79	80

Continued

INSOLATION (Hs)	5.9	6.6	5.6	6	5.9	6	6.3	5.9	5.8	5.8	5.9	5.8
WIND VELOCITY (Km/h)	305	437.2	511.2	443.2	409.5	328.3	285.1	249	279.9	275.6	288.6	279.9
PRECIPITATION (mm)	28.5	15.6	13.6	20.7	41.8	128.6	122	123.9	286.5	132.3	47.6	24.8
EVAPORATION (mm)	95	105	130	124	125	90	93	90	80	83	80	83
TAPACHULA, CHIAPAS		Longitude: 92˚16'			Latitude: 14˚51'		Altitude: 182 msnm					
TEMPERATURE (˚C)	25.6	26.2	27.1	27.6	27	26	26.1	26.2	25.6	25.6	25.8	25.5
RELATIVE HUMIDITY (%)	67	65	66	70	75	79	77	77	80	79	75	70
INSOLATION (Hs)	6.75	6.57	5.28	3.76	4.66	4.46	5.02	5.17	4.15	5	6.23	6.13
WIND VELOCITY (Km/h)	165	228.1	235.9	195.3	158.1	159.8	148.6	169.3	176.3	148.6	120.1	130.5
PRECIPITATION (mm)	4.9	5	34.6	103.2	293	428.3	366.7	337.2	488.5	402.3	72	16.7
EVAPORATION (mm)	95	101	119	107	99	78	85	83	73	76	74	80
TLAXCALA, TLAXCALA		Longitude: 98˚14'			Latitude: 19˚19'		Altitude: 2252 msnm					
TEMPERATURE (˚C)	13.9	15.2	17.4	18.6	18.5	18	17.1	17.3	17.1	16.6	15.3	14.3
RELATIVE HUMIDITY (%)	50	46	43	46	53	64	66	66	67	60	55	53
INSOLATION (Hs)	6.24	6.49	5.82	4.72	5.54	4.96	4.96	4.94	4.53	5.93	6.66	6.28
WIND VELOCITY (Km/h)	232.4	389.7	357.7	216	164.2	120.1	96.8	95	129.6	114	162.4	198.7
PRECIPITATION (mm)	7	5.8	6.7	27	82.7	149	158.4	153.5	134.6	62.1	23.4	9.4
EVAPORATION (mm)	123.28	144.72	204.09	196.52	187.67	152.33	141.43	137.68	117.83	137.33	122.26	108.46
TOLUCA, ESTADO DE MEXICO		Longitude: 99˚40'			Latitude: 19˚18'		Altitude: 2680 msnm					
TEMPERATURE (˚C)	10	11.5	13.2	14.5	14.8	14.3	13.3	13.3	13.2	12.6	11.4	10.4
RELATIVE HUMIDITY (%)	57	53	49	5.1	61	72	75	74	76	70	64	62
INSOLATION (Hs)	6.34	6.88	6.43	5.4	5.55	4.87	4.96	4.96	4.19	5.36	6.08	5.67
WIND VELOCITY (Km/h)	241.9	280.8	286	254.9	210	294.6	235.9	209.1	225.5	200.4	210.8	201.3
PRECIPITATION (mm)	9.4	4.3	11	27	66.1	139.8	149.6	153.6	118.8	60.5	23.1	9.2
EVAPORATION (mm)	105	123	177	178	160	125	112	108	100	105	97	92
TULANCINGO, GUERRERO		Longitude: 98˚22'			Latitude: 20˚05'		Altitude: 2222 msnm					
TEMPERATURE (˚C)	12	13.3	15.8	17.1	17.3	17.1	16.1	16.1	15.5	14.2	13	12
RELATIVE HUMIDITY (%)	72	69	66	66	70	79	81	81	84	81	78	75
INSOLATION (Hs)	6.8	7.62	7.11	7.1	7.3	6.49	6.18	6.62	4.88	6.03	6.67	6.44
WIND VELOCITY (Km/h)	237.6	324	328.3	237.6	194.4	159.8	127.9	121	146.9	152.3	169.2	203
PRECIPITATION (mm)	9.5	7.2	11	29.2	49.8	91	62.7	68.7	127.3	53.1	23.4	10.1
EVAPORATION (mm)	89	106	168	172	169	131	117	118	98	91	80	80
TUXTLA GUTIERREZ, CHIAPAS		Longitude: 93˚07'			Latitude: 16˚45'		Altitude: 528 msnm					
TEMPERATURE (˚C)	22.2	23	25	26.2	26.8	25.5	25.2	25.1	24.8	24	23	22.1
RELATIVE HUMIDITY (%)	76	73	70	68	71	77	79	79	78	77	76	76
INSOLATION (Hs)	5.54	6.66	6.12	4.6	5.2	4.78	5.5	5.07	4.29	4.95	5.81	5.56
WIND VELOCITY (Km/h)	345.6	354.2	349.9	315.4	280.8	241.9	246.2	254.9	263.5	311	302.4	328.3
PRECIPITATION (mm)	0.5	1.4	18.9	9.1	68.1	184.9	148	159	188.3	58.6	12.2	0
EVAPORATION (mm)	112.97	130.52	138.32	189.87	183.19	118.87	113.16	115.47	91.9	100.73	96.63	96.94
VERACRUZ, VERACRUZ		Longitude: 96˚08'			Latitude: 19˚12'		Altitude: 16 msnm					
TEMPERATURE (˚C)	21.45	22.1	23.4	25.8	27.4	28	27.8	28.2	27.7	26.5	24.3	22.6
RELATIVE HUMIDITY (%)	80	81	81	81	79	80	79	78	79	75	77	79

Continued

INSOLATION (Hs)	4.85	6.01	5.32	5.68	6.34	6.92	6.69	7.64	5.4	6.01	5.27	4.8
WIND VELOCITY (Km/h)	698.1	679.1	681.7	665.3	577.2	534.5	434.6	417.3	521.9	699	686.9	671.3
PRECIPITATION (mm)	19.5	14.4	18.4	16	64.7	272.4	386.4	298.8	354.2	174.9	62.6	27.4
EVAPORATION (mm)	79.74	88.07	123.73	137.35	138.07	125.3	105.08	114.21	107.05	103.04	88.42	78.17
ZACATECAS, ZACATECAS		Longitude: 102˚34'			Latitude: 22˚47'		Altitude: 2612 msnm					
TEMPERATURE (˚C)	9.4	10.6	12.8	15.5	17	16.3	14.8	14.9	13.8	13.1	11.7	9.9
RELATIVE HUMIDITY (%)	45	40	33	31	39	60	67	67	73	61	50	51
INSOLATION (Hs)	6.93	7.77	7.7	7.86	8.78	7.34	7.28	7.2	5.99	6.52	7.57	6.37
WIND VELOCITY (Km/h)	177.1	259.2	311	263.5	187.5	182.3	164.2	226.4	178.8	165.9	204.8	208.2
PRECIPITATION (mm)	5	2.5	3.1	4.4	7.1	41.4	44	61.4	45.9	22	7.4	4.7
EVAPORATION (mm)	111	152.92	217.25	232.27	241.75	208.08	152.75	170.18	169.9	168.62	127.17	107.83

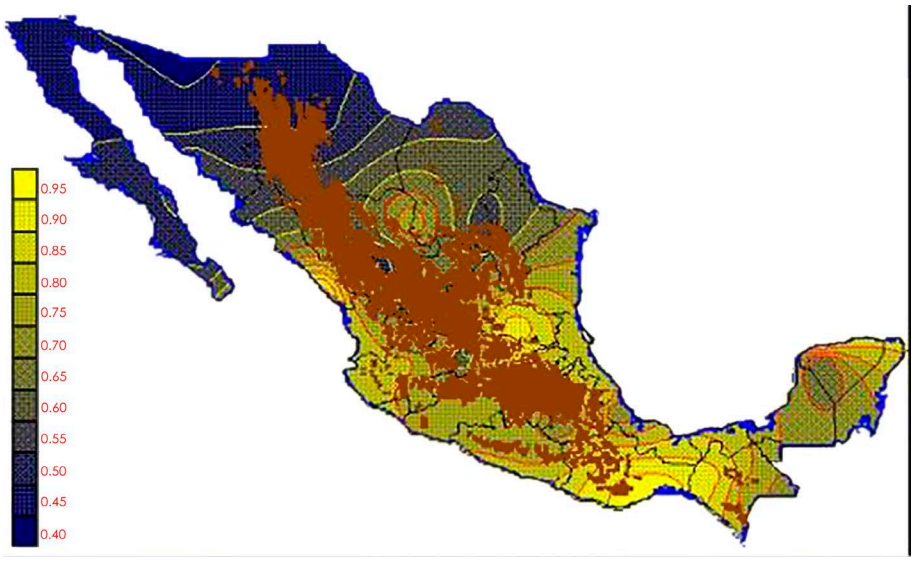

Figure 1. January Kp.

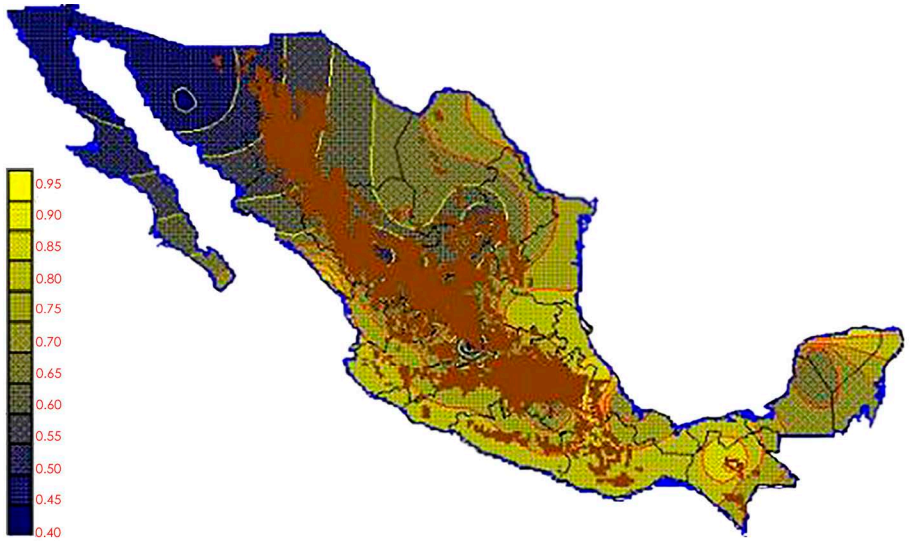

Figure 2. February Kp.

Table 3. Kp coefficients for each observatory in the country.

Weather Station	Longitude	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Acapulco	−99.93	16.83	0.83	0.84	0.83	0.77	0.83	0.82	0.82	0.87	0.84	0.80	0.83	0.80	0.82
Aguascalientes	−102.30	21.88	0.65	0.59	0.62	0.59	0.60	0.61	0.68	0.68	0.66	0.65	0.62	0.61	0.63
Campeche	−90.55	19.85	0.73	0.70	0.70	0.67	0.69	0.74	0.86	0.86	0.79	0.74	0.75	0.70	0.74
Chapingo	−98.90	19.48	0.58	0.60	0.63	0.64	0.65	0.70	0.77	0.78	0.69	0.67	0.63	0.60	0.66
Chihuahua	−106.08	28.63	0.50	0.61	0.60	0.65	0.73	0.74	0.88	1.00	0.93	0.78	0.69	0.55	0.74
Chilpancingo	−99.50	17.55	0.77	0.79	0.78	0.76	0.83	0.90	1.04	1.03	0.96	0.80	0.84	0.87	0.85
Colima	−103.72	19.68	0.79	0.81	0.95	1.00	0.84	0.79	0.83	0.86	0.82	0.83	0.80	0.74	0.84
Comitan	−92.13	16.25	0.76	0.77	0.73	0.72	0.77	0.97	0.85	0.88	1.00	1.01	0.95	0.87	0.84
Cordoba	−96.93	18.90	1.54	1.56	1.30	1.16	1.13	1.21	1.24	1.24	1.14	1.32	1.26	1.42	1.26
Cozumel	−86.95	20.52	0.83	0.81	0.70	0.71	0.65	0.70	0.64	0.67	0.74	0.76	0.96	0.98	0.74
Culiacan	−107.40	24.82	0.68	0.64	0.65	0.65	0.66	0.69	0.76	0.81	0.79	0.72	0.68	0.66	0.70
Distrito Federal	−99.20	19.40	0.91	0.75	0.68	0.68	0.77	0.84	1.02	1.00	0.97	0.98	0.89	0.99	0.84
Durango	−104.67	24.03	0.46	0.49	0.53	0.60	0.64	0.87	0.97	0.93	0.96	0.20	0.51	0.53	0.65
Guadalajara	−103.38	20.67	0.81	0.77	0.76	0.77	0.73	0.73	0.81	0.84	0.86	0.83	0.82	0.82	0.78
Guanajuato	−101.25	21.02	0.77	0.45	0.79	0.67	0.67	0.72	0.78	0.78	0.75	0.71	0.72	0.74	0.71
Guaymas	−110.90	27.92	0.58	0.54	0.56	0.58	0.59	0.63	0.68	0.73	0.68	0.69	0.62	0.64	0.63
Hermosillo	−110.97	29.07	0.46	0.44	0.49	0.45	0.46	0.43	0.49	0.57	0.52	0.50	0.45	0.47	0.48
Jalapa	−96.92	19.53	0.85	0.90	0.91	0.85	0.88	0.83	0.93	0.88	0.92	0.87	0.89	0.90	0.88
La Paz	−110.42	24.17	0.54	0.65	0.65	0.82	0.93	0.96	0.91	0.85	0.83	0.76	0.67	0.58	0.76
Lagos de Moreno	−101.92	21.35	0.90	0.80	0.79	0.73	0.68	0.79	0.93	0.92	0.97	0.97	0.94	0.91	0.83
León	−101.98	21.12	0.41	0.43	0.45	0.41	0.41	0.47	0.50	0.52	0.50	0.46	0.45	0.41	0.45
Lerdo	−103.52	25.53	0.81	0.71	0.67	0.57	0.62	0.67	0.69	0.69	0.78	0.81	0.84	0.86	0.70
Mazatlan	−106.42	23.20	1.02	0.92	0.79	0.77	0.81	0.90	1.01	1.20	1.27	1.24	1.10	1.14	0.98
Mérida	−89.65	20.93	0.62	0.67	0.71	0.73	0.74	0.77	0.76	0.73	0.73	0.69	0.65	0.62	0.71
Monterrey	−100.30	25.67	0.61	0.65	0.69	0.71	0.79	0.78	0.83	0.81	0.76	0.73	0.63	0.63	0.74
Morelia	−101.18	19.70	0.77	0.77	0.73	0.65	0.64	0.70	0.78	0.82	0.88	0.83	0.78	0.79	0.75
Oaxaca	−96.72	17.07	0.93	0.81	0.75	0.71	0.77	0.90	0.98	0.96	0.97	0.94	91.00	0.91	0.86
Orizaba	−97.10	18.85	1.17	1.09	0.90	0.89	0.92	1.00	0.98	1.03	0.92	1.01	1.00	1.15	0.99
Pachuca	−98.73	20.13	0.76	0.74	0.76	0.72	0.70	0.75	0.79	0.74	0.72	0.70	0.72	0.73	0.74
Piedras Negras	−100.52	28.70	0.60	0.79	0.71	0.74	0.72	0.81	0.69	0.71	0.70	0.63	0.80	0.77	0.72
Progreso	−89.65	21.30	1.07	1.00	0.88	0.77	0.78	0.86	0.92	0.92	0.91	0.92	1.07	1.04	0.91
Puebla	−98.20	19.03	0.65	0.64	0.59	0.64	0.74	0.94	0.93	0.97	0.80	0.79	0.74	0.66	0.75
Rio Verde	−100.00	21.93	0.95	0.86	0.84	0.76	0.76	0.79	0.90	0.90	0.92	0.95	0.96	0.98	0.86
Salina Cruz	−95.20	16.17	1.03	0.86	1.01	0.97	0.99	0.97	0.95	1.12	0.98	1.06	1.07	1.17	1.01
Saltillo	−100.98	25.45	0.55	0.56	0.60	0.59	0.60	0.65	0.69	0.67	0.66	0.67	0.62	0.56	0.62
San Cristobal	−92.63	16.73	0.87	0.95	0.82	0.81	0.91	1.00	0.95	0.94	0.99	1.17	1.10	0.99	0.94
Tampico	−97.85	22.22	0.80	0.80	0.85	0.96	1.09	1.46	1.52	1.51	1.53	1.38	1.14	0.94	1.14
Tapachula	−92.27	14.92	1.23	1.24	1.21	1.17	1.26	1.43	1.41	1.48	1.45	1.39	1.36	1.29	1.31
Tlaxcala	−98.23	19.32	0.79	0.30	0.74	0.65	0.67	0.69	0.74	0.74	0.79	0.69	0.73	0.82	0.73
Toluca	−99.67	19.30	0.77	0.74	0.67	0.66	0.70	0.79	0.85	0.86	0.81	0.80	0.79	0.78	0.76
Tulancingo	−98.37	20.08	0.81	0.79	0.68	0.68	0.72	0.80	0.88	0.87	0.84	0.88	0.86	0.82	0.79
Tuxtla Gutierrez	−93.12	16.75	0.91	0.86	0.78	0.75	0.79	1.03	1.11	1.06	1.21	1.13	1.07	1.03	0.94
Veracruz	−96.13	19.20	1.27	1.12	0.96	0.95	1.11	1.20	1.45	1.41	1.30	1.51	1.39	1.37	1.23
Zacatecas	−102.57	22.78	0.69	0.62	0.64	0.64	0.62	0.59	0.76	0.68	0.53	0.53	0.67	0.70	0.63

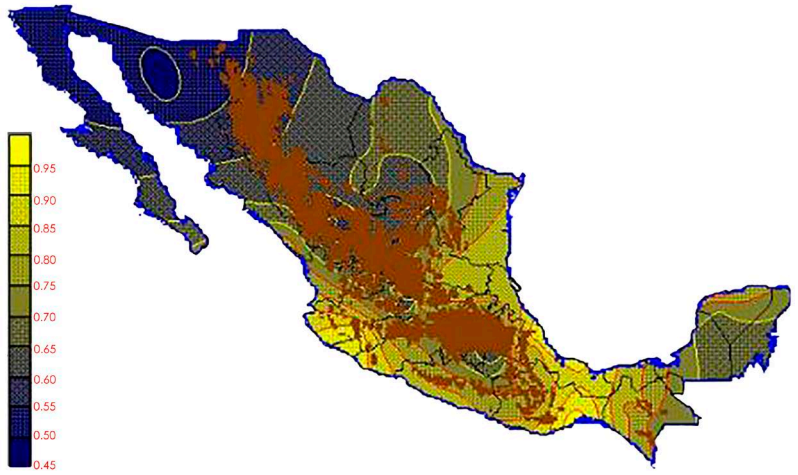

Figure 3. March Kp.

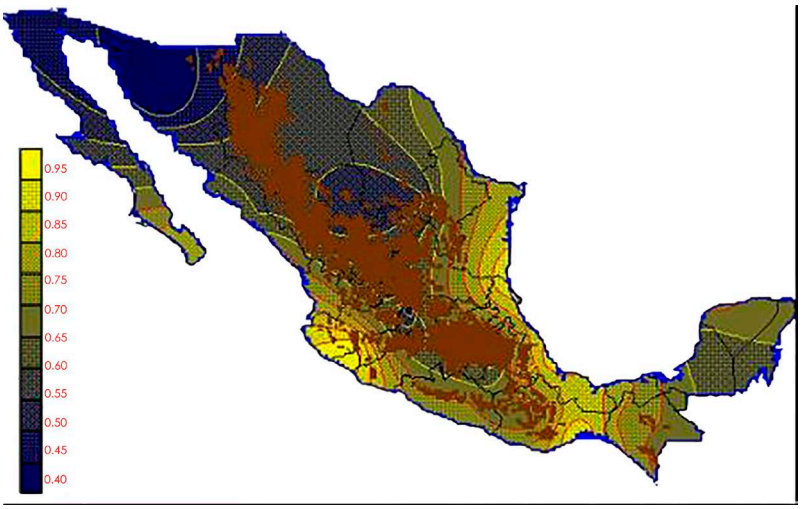

Figure 4. April Kp.

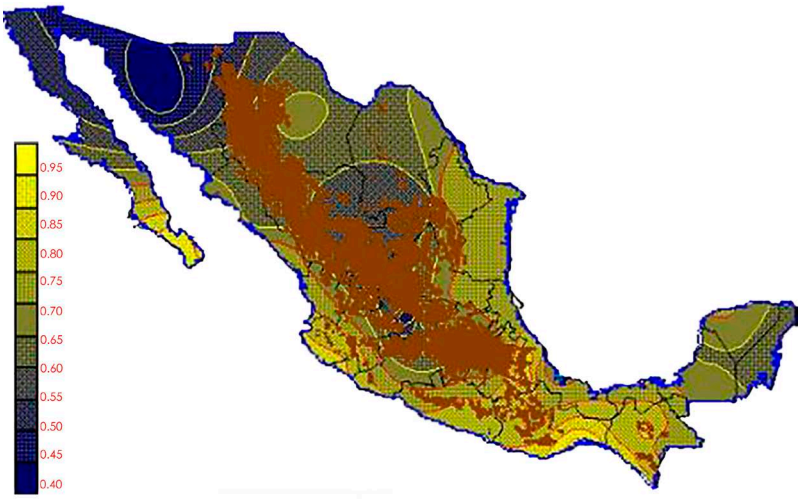

Figure 5. May Kp.

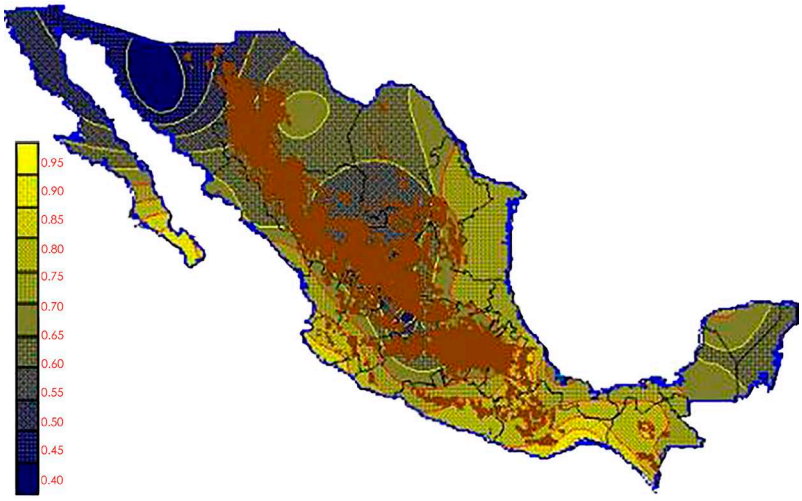

Figure 6. June Kp.

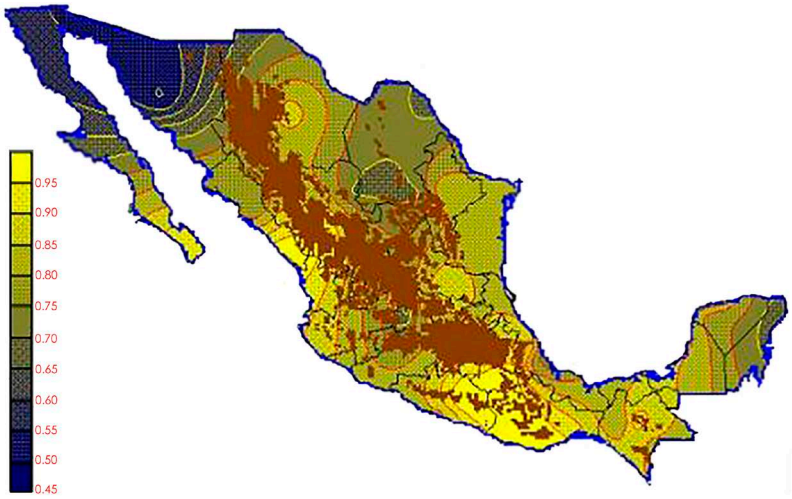

Figure 7. July Kp.

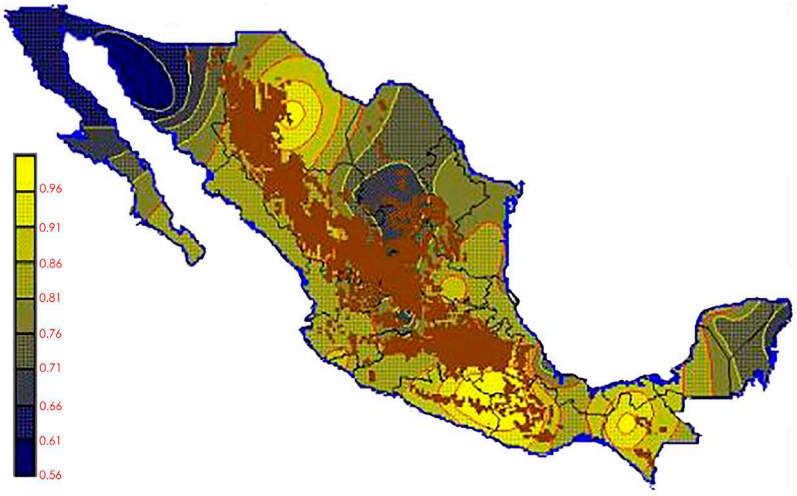

Figure 8. August Kp.

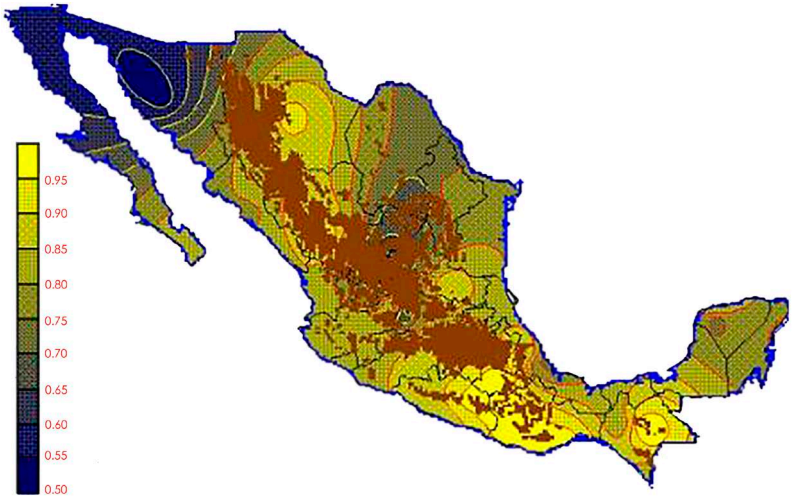

Figure 9. September Kp.

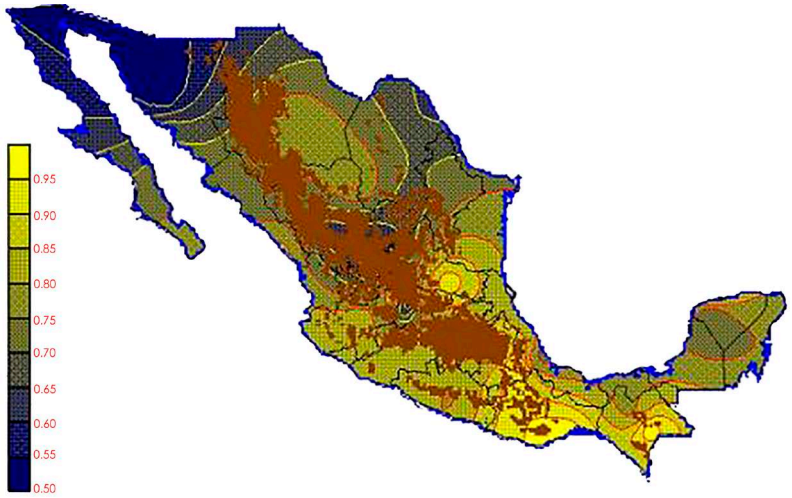

Figure 10. October Kp.

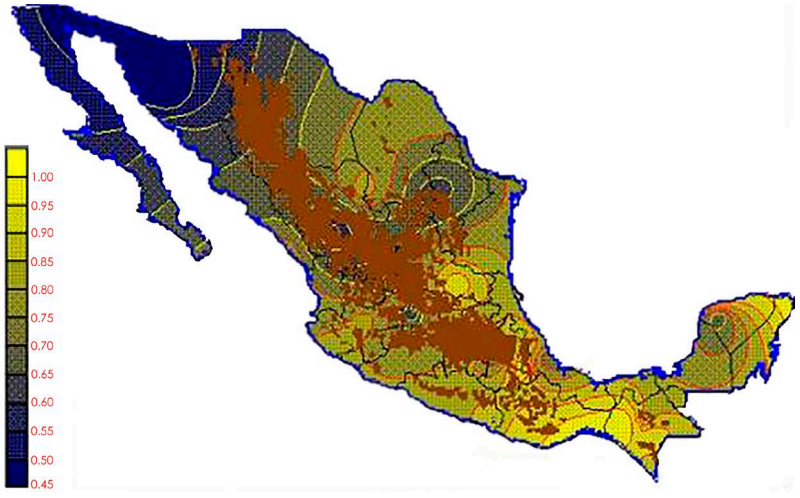

Figure 11. November Kp.

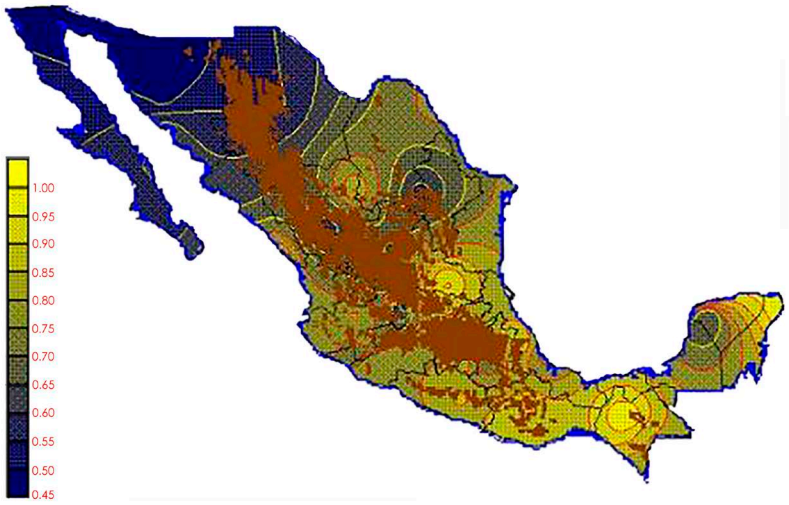

Figure 12. December Kp.

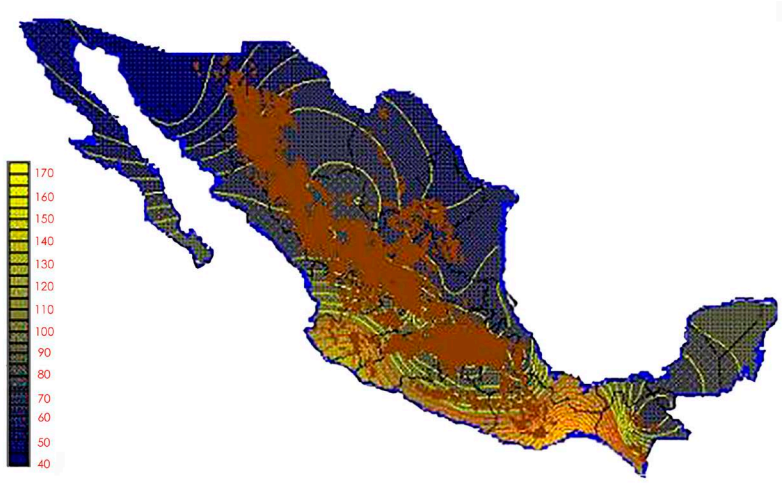

Figure 13. ETo January.

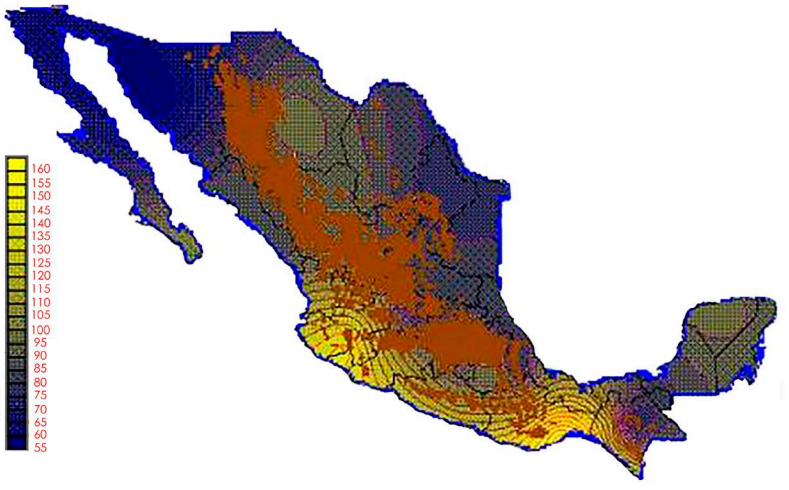

Figure 14. ETo February.

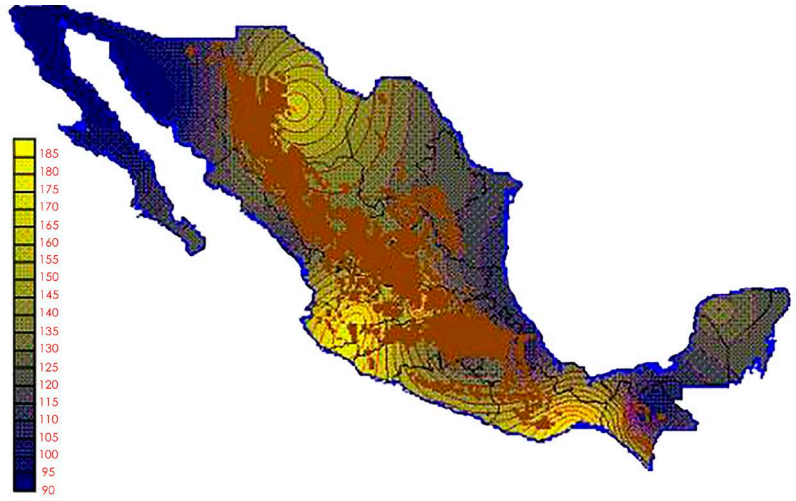

Figure 15. ETo March.

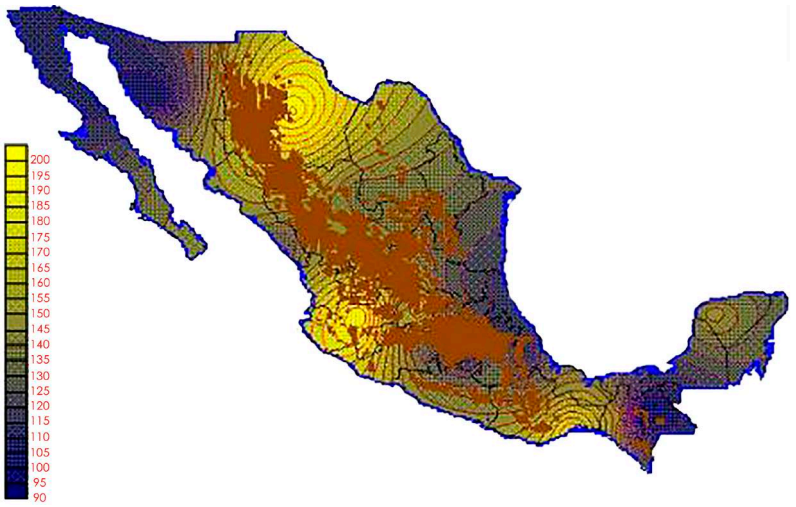

Figure 16. ETo April.

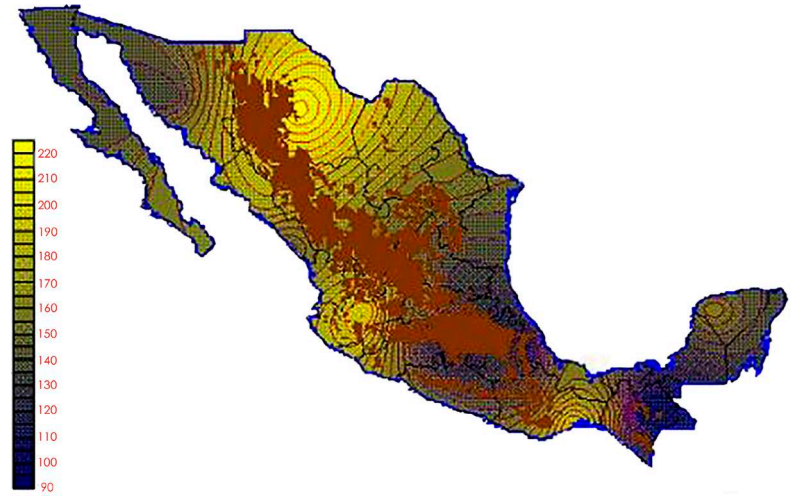

Figure 17. ETo May.

Figure 18. ETo June.

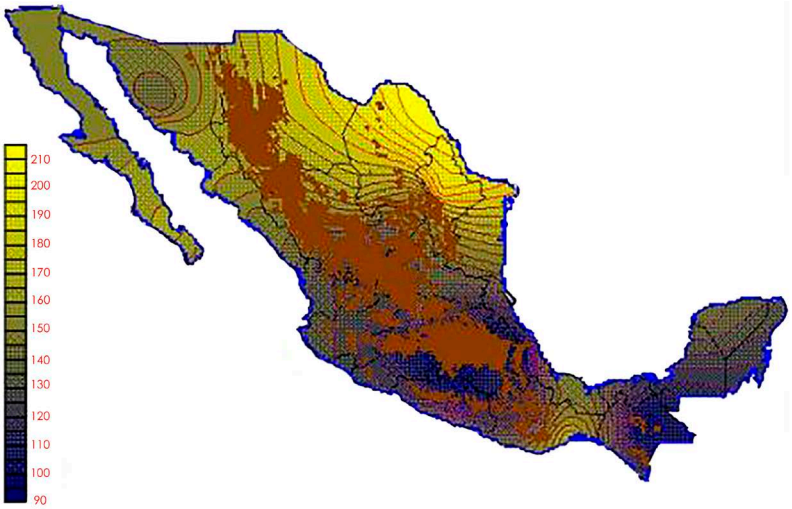

Figure 19. ETo July.

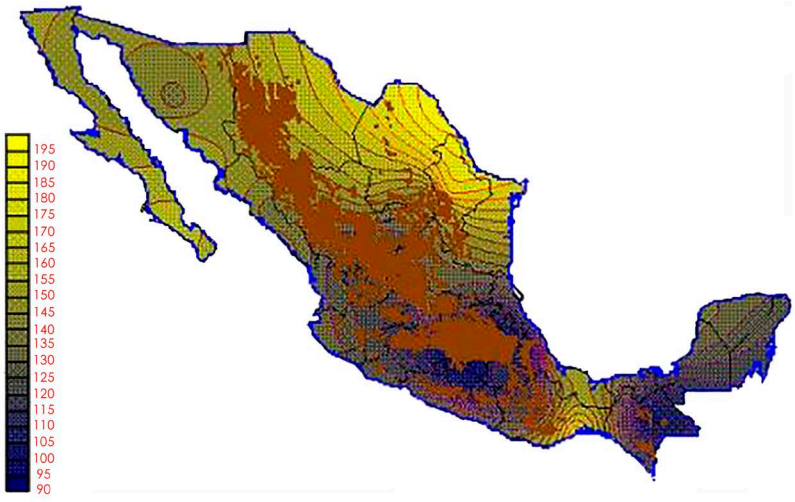

Figure 20. ETo August.

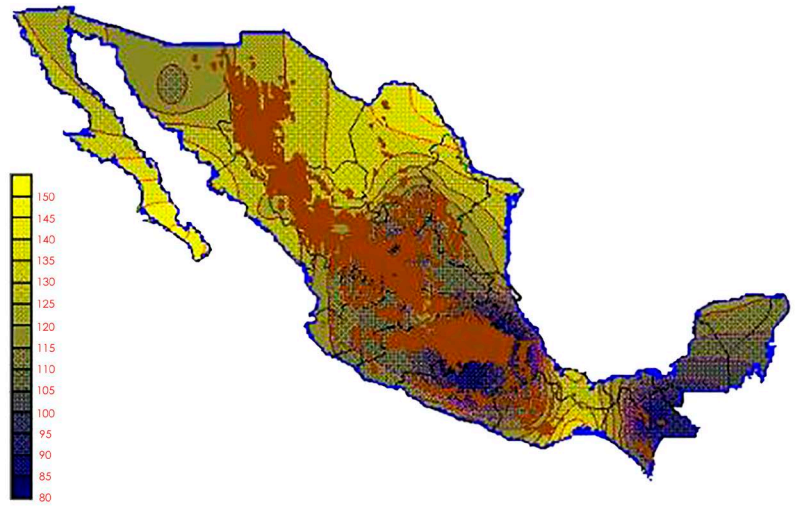

Figure 21. ETo September.

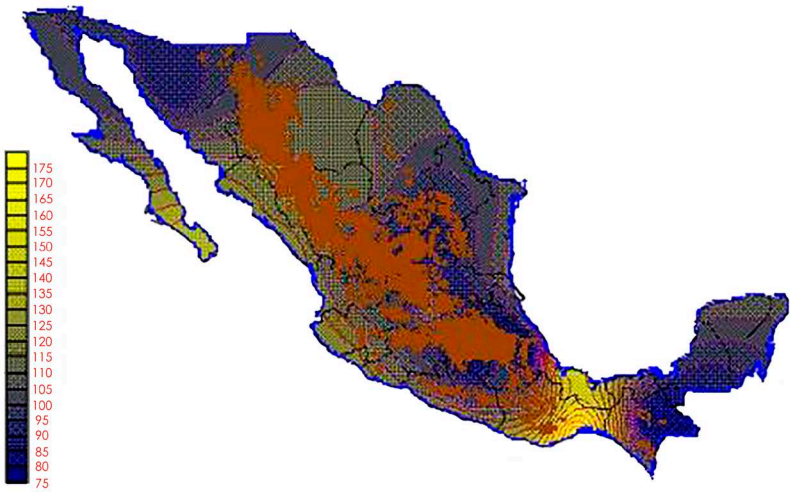

Figure 22. ETo October.

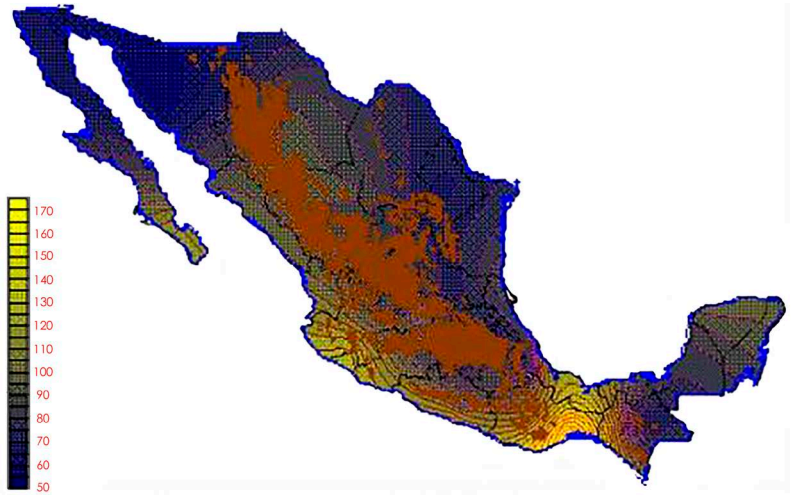

Figure 23. ETo November.

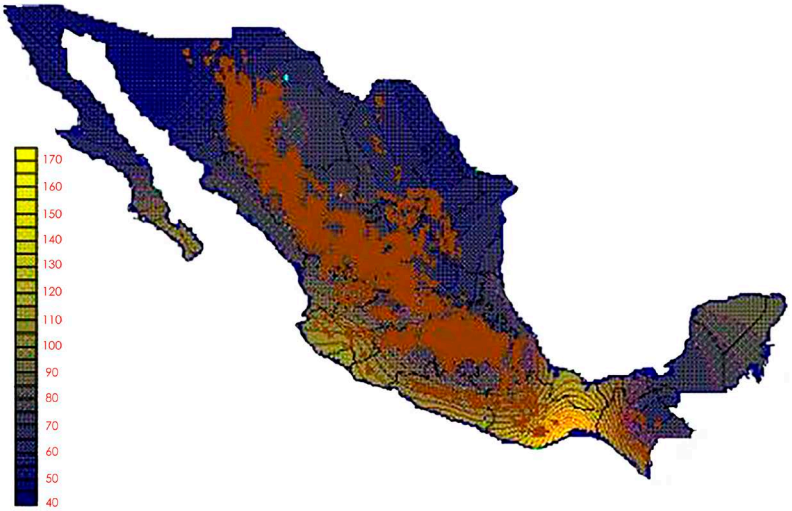

Figure 24. ETo December.

b)The method only uses an average monthly data from 30 years climate normal to estimate ETo values because the monthly data were not available for each year, c)The method uses only 60 weather observatories located mainly in urban areas because in Mexico there are only 60 weather observatories, d) The interpolation method used data of weather observatories located from 3 meters over sea levels (Mazatlán Sinaloa) up 2680 meters over sea level (Toluca, Mexico), e) is important to note that if paper were results used to estimate Kp data for a given E_v, bread surrounding characteristics should be considered as indicated in the last paragraph of index 2.

On the other hand numerous studies suggest that measures must be taken when interpreting the results found with the PE method, because the location, the maintenance of the pan evaporimeter and the Kp estimation influence in the precision of the ET. For example, the size of the evaporimeter has important effects on the Kp factor in dry zones, when these are surrounded by dry and barren surfaces. In humid climates the size of the evaporimeter is less significant, however when it is placed in large crop areas, e.g. in grass crops, its size or may not be of importance [8]. Other aspect to have in consideration is the low values of Kp in dry and windy climates, compared to the ones obtained from humid places. Some of this assertions have been reported by [18] and [16]. In 1996 [19] published a study which explained that in dry climate, the Kp estimations could be altered under the following conditions: severe drought, strong winds and low radiation situations in some spring and autumn months; under these circumstances the Kp pan evaporation values can be reduced down to half of the normal value when placed in large grass areas. More recently, [20] reported that the Kp values for wheat decreased between a 20% and a 25% in dry and windy days in April. The normal value ranges oscillate between 0.90 and 0.95 for wheat crops (high stature crops). Apparently high stature crops cause certain aerodynamic conditions in pan evaporimeters that, in arid zones, affect less said factors. For dry and windy climates it is necessary to calibrate this methodology, as well as possessing data from several years to emit judgment on the obtained Kp pan evaporation values.

4. Conclusion

Estimating ET to determine calendars or water demand remains a main problem in the irrigation districts, even when there are a variety of direct and indirect methods. For example, an indirect and precise method like the Penman-Monteith needs data that in most cases are either not available for the user, or inexistent. The ET calculus through automated weather stations is a direct and precise method, but its elevated cost makes it difficult to use. Automated weather stations have a good precision to measure climatological parameters and calculate ET, though the cost is extremely high as well. There is a simple method to estimate ET using the class A pan evaporimeter (PE), which can perform ET estimations in a simple and economic way (the cost of the PE is 500 American dollars approximately), but if the right Kp pan evaporation values are not used, the accuracy of these estimations will not be satisfactory. This paper presents a method to estimate “Kp pan evaporation and ETo

Table 4. ET monthly estimation from all observervatories in the country.

Weather Station	Longitude	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Acapulco	−99.93	16.83	124.18	126.16	153.33	146.61	151.68	148.10	154.71	154.05	133.63	126.25	126.25	119.34	1670.40
Aguascalientes	−102.30	21.88	84.91	98.64	148.30	155.96	166.89	137.36	129.59	126.27	107.31	102.58	85.10	72.69	1415.58
Campeche	−90.55	19.85	80.87	91.87	121.83	134.02	140.19	130.72	134.03	134.99	109.86	101.42	84.97	74.08	1338.86
Chapingo	−98.90	19.48	71.26	88.80	121.06	119.71	123.96	106.05	102.32	102.07	88.11	86.79	73.96	66.09	1150.29
Chihuahua	−106.08	28.63	72.98	100.27	166.73	203.74	224.89	210.40	180.40	160.31	125.87	114.22	91.51	77.17	1728.50
Chilpancingo	−99.50	17.55	96.74	107.90	139.24	140.01	134.21	108.21	108.04	107.60	90.00	99.94	96.01	94.81	1322.70
Colima	−103.72	19.68	131.15	141.98	181.57	186.87	188.91	142.61	126.61	126.03	108.41	118.55	125.41	111.23	1689.33
Comitan	−92.13	16.25	78.45	83.73	112.03	109.19	109.25	97.68	105.70	106.41	91.68	82.04	76.28	73.59	1126.02
Cordoba	−96.93	18.90	72.06	77.82	105.35	114.70	116.96	106.34	106.73	106.77	87.82	86.57	72.79	69.75	1123.65
Cozumel	−86.95	20.52	87.83	93.63	119.92	130.53	133.45	125.11	128.54	124.72	110.96	104.94	95.87	87.85	1343.34
Culiacan	−107.40	24.82	76.39	86.85	126.09	148.29	177.34	170.54	148.09	137.08	123.36	119.00	96.22	75.53	1484.86
Distrito Federal	−99.20	19.40	73.72	79.18	108.97	106.03	111.91	97.11	95.45	94.54	80.59	78.78	65.37	63.94	1055.59
Durango	−104.67	24.03	74.35	91.49	131.99	147.70	167.46	158.64	138.25	129.69	117.65	106.70	87.17	72.51	1423.59

Continued

Guadalajara	−103.38	20.67	105.68	126.55	176.57	197.79	197.73	147.08	128.00	122.74	110.12	108.54	100.29	90.44	1611.52
Guanajuato	−101.25	21.02	107.33	75.72	183.22	173.52	168.56	147.67	141.31	141.45	127.40	123.83	107.89	98.12	1596.01
Guaymas	−110.90	27.92	56.44	63.44	98.10	130.22	155.34	172.61	162.53	151.00	129.54	107.78	68.60	53.44	1349.03
Hermosillo	−110.97	29.07	44.88	56.12	89.41	103.92	134.76	140.65	138.79	137.16	112.86	90.87	56.53	45.01	1150.94
Jalapa	−96.92	19.53	73.07	78.58	106.58	116.42	116.13	100.39	104.89	107.32	86.95	84.10	77.89	74.04	1126.34
La Paz	−110.42	24.17	91.68	101.72	119.37	141.85	160.86	163.12	166.68	164.41	151.59	138.42	155.44	100.71	1615.85
Lagos de Moreno	−101.92	21.35	84.61	100.64	151.52	158.07	164.32	138.61	128.15	121.74	107.47	101.66	84.08	73.09	1413.96
León	−101.98	21.12	75.23	91.40	130.28	132.51	132.97	119.71	115.08	112.36	100.56	95.16	80.97	69.75	1255.99
Lerdo	−103.52	25.53	80.71	95.45	134.30	135.34	169.60	172.36	168.01	153.62	133.68	113.34	91.07	76.20	1523.69
Mazatlan	−106.42	23.20	79.94	86.99	110.94	125.84	145.96	150.32	145.58	142.08	129.99	124.41	100.71	81.38	1424.14
Mérida	−89.65	20.93	88.19	98.67	137.62	151.00	163.69	146.32	142.54	135.55	114.79	106.29	94.71	85.70	1465.07
Monterrey	−100.30	25.67	64.82	77.48	125.51	135.83	155.07	172.84	193.99	178.42	124.55	96.96	68.72	59.47	1453.65
Morelia	−101.18	19.70	83.36	100.12	136.66	132.77	131.19	111.28	105.61	109.26	103.40	97.01	86.35	74.68	1271.71
Oaxaca	−96.72	17.07	109.59	118.27	149.74	144.26	146.10	126.41	124.35	122.52	108.05	118.64	107.81	101.61	1477.36
Orizaba	−97.10	18.85	78.42	84.68	113.02	122.75	118.28	106.29	107.00	107.62	92.68	88.58	76.85	75.67	1172.14

Continued

Pachuca	−98.73	20.13	81.22	95.62	128.82	124.43	125.82	107.83	106.59	106.04	88.45	87.39	75.83	73.96	1202.01
Piedras Negras	−100.52	28.70	62.90	78.68	123.82	147.31	169.94	201.55	220.34	196.67	143.70	107.35	71.12	55.72	1579.09
Progreso	−89.65	21.30	89.05	97.65	126.70	132.63	142.47	138.48	140.35	134.59	118.83	114.09	99.99	87.76	1422.58
Puebla	−98.20	19.03	87.11	98.30	128.59	131.88	132.57	117.70	115.49	116.02	98.95	97.80	88.92	79.68	1293.01
Rio Verde	−100.00	21.93	68.39	82.40	124.72	128.04	131.78	130.36	132.72	130.37	104.84	91.03	71.04	62.51	1258.21
Salina Cruz	−95.20	16.17	180.48	166.23	188.67	182.02	195.97	146.01	173.62	177.82	143.44	180.15	179.18	179.23	2092.80
Saltillo	−100.98	25.45	64.30	79.11	122.81	135.46	151.48	156.03	154.04	143.08	107.55	92.25	71.25	62.08	1339.44
San Cristobal	−92.63	16.73	70.55	74.77	92.05	94.31	96.15	89.32	97.73	100.03	81.83	80.71	71.57	67.62	1016.12
Tampico	−97.85	22.22	76.03	84.11	110.06	118.85	135.95	131.55	141.63	135.92	122.36	144.65	91.29	78.36	1340.77
Tapachula	−92.27	14.92	116.54	125.35	143.76	124.72	124.67	111.90	119.79	122.99	105.63	106.02	101.00	102.86	1405.23
Tlaxcala	−98.23	19.32	96.99	120.56	150.82	128.44	126.05	105.83	103.97	101.42	93.49	94.68	89.43	89.10	1300.78
Toluca	−99.67	19.30	80.66	90.43	119.08	177.33	112.78	98.53	94.87	93.03	81.00	83.63	76.50	71.34	1119.16
Tulancingo	−98.37	20.08	72.47	84.11	113.79	117.69	121.02	104.86	102.77	102.50	82.02	80.23	68.76	65.88	1116.10
Tuxtla Gutierrez	−93.12	16.75	102.78	112.01	143.73	141.83	145.15	121.96	125.68	122.35	111.49	114.03	103.60	99.98	1444.60

Continued

Veracruz	−96.13	19.20	101.49	98.20	118.99	130.98	153.16	150.64	152.68	160.68	138.75	155.51	122.79	106.78	1590.65
Zacatecas	−102.57	22.78	77.04	94.77	138.37	149.16	149.96	123.54	116.53	114.99	90.72	89.72	85.69	75.72	1306.19

monthly maps", using information from 60 weather observatories included in The Climate Normals (1941-1970) from Mexico, based on the PM method and the class A pan evaporation. Once the Kp values were obtained from each weather observatory, the Kringing method was used. This way, by interpolating data of the triad "latitude, longitude and Kp" and "latitude, longitude and ET", monthly normalized maps of Kp and ET were established for Mexico, except the upland areas (Sierra Madre Occidental and Sierra Madre Oriental), as well as other high-land zones above 2700 meters over sea level, for the highest observatory is located in Toluca, State of Mexico (key 14-0039), at 2680 m over sea level. For their relevance in this paper is presented 12 ETo maps and 12 Kp maps.

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