VARIATION OF SURFACE WATER VAPOR PRESSURE AND REFRACTIVITY OVER THE ARABIAN PENINSULA

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الخلاصة :

كان للوضع السائد في شبه الجزيرة العربية بعد انتهاء حرب الخليج بعض التأثير على الأحوال الجوية ، والتي أثَّرت بدورها على الانكسارية الرادارية في المنطقة . ومن خلال هذا البحث تُجرىٰ دراسة التغير اليومي والأُسبوعي والشهري لقيم ضغط بخار الماء والانكسارية الرادارية في عشرين موقع في شبه الجزيرة العربية . ولذلك فقد تَمَّ استخدام معدلات المتغيرات المناخية اليومية لفترة تقارب من (١٧) سنة . وقد أظهرت نتائج هذا البحث أنَّ للمواقع الساحلية قيم أعلى لضغط بخار الماء والانكسارية الرادارية من المواقع الداخلية . كما أُظهرت المواقع الشمالية قيم أعلى للمتغيرين من المواقع الجنوبية . ويقِّدم هذا البحث خريطة كنتورية للانكسارية السطحية وهي مفيدة لاستكمال المعلومات من المناطق التي لا توجد عنها معلومات مناخية . وبالإضافة فإنَّ هذا البحث يضع المبادىء لدراسة تقدير تأثير حرائق آبار النفط الكويتية على الانكسارية السطحية في المنطقة .

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ABSTRACT

The prevailing situation in the Arabian Peninsula after the Gulf war has had some impact on the meteorological conditions, that in turn has affected the radio refractivity in the region. In this paper an attempt is made to study the annual, monthly, and diurnal behavior of surface water vapor pressure and radio refractivity at twenty locations in the Arabian Peninsula. Daily average meteorological data for a period of approximately 17 years is used. In this study it is found that coastal locations show higher values of both the parameters compared to inland locations. However, the northern sites have higher values of surface water vapor pressure and refractivity than the southern region sites. A contour map is also presented which is useful for interpolating or extrapolating the surface refractivity values at locations where the data is not available. In addition, a study on the assessment of the impact of the burning of Kuwaiti oil fields on the surface refractivity in the region has been initiated.

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INTRODUCTION

Seasonal and diurnal changes in meteorological conditions at the earth surface and above play an important role in the study of radio horizon, signal strength, trapping of radio waves, and anomalous propagation of radio waves. An accurate knowledge of the radio refractivity is essential in arriving at optimum propagation criteria for radio communications, particularly in VHF, microwave, and troposcatter links, and for a realistic analysis of radar performance [1]. Also, the seasonal and diurnal variation is important from the point of view of correlating the surface refractivity with the vertical profile of refractivity. Attempts have been made elsewhere to deduce the vertical structure of refractivity from surface refractivity patterns at places where air meteorological data is not available [2].

Extensive work has been cited in the literature on various aspects of the radio refractivity in various countries. Bean and Dutton [3] have reported the synoptic radio climatology for the U.S.A. In another paper, Bean and Dutton [4] studied the climatology and developed radio meteorological parameters for telecommunications and planning, such as design of optimal separation of the terminals of ground based microwave relay systems and the determination of the bending of radio waves encountered in earth satellite links. Kulshrestha and Chatterji [5, 6] have reported the values of radio refractivity near the ground surface and at the 850 mb levels, as measured in India. Recently, Husain *et al.* [7] studied the diurnal variation of the vertical structure of refractivity and its effect on radar coverage.

In this paper, an attempt is made to study the annual, monthly, and diurnal changes in the values of water vapor pressure and surface refractivity for twenty locations in the Arabian Peninsula. The annual and monthly variations are calculated from daily average meteorological data while diurnal variations are obtained from hourly average meteorological data. A contour map which shows the variation of mean refractivity at the surface is presented which will be useful to find refractivity values at locations where meteorological data is not available. The initial results of the impact of burning of the Kuwaiti oil fields on the surface refractivity and water vapor pressure values at a coastal site, are also presented.

The refractivity is a function of meteorological parameters, namely temperature, pressure, and water vapor pressure. The surface refractivity values reported in this paper are calculated from Smith and Weintraub's formula [8]:

$$N = 77.6\,\frac{P}{T} + 3.73\times 10^{5}\,\frac{e}{T^{2}}\,, \tag{1}$$

where N is the surface refractivity in N-units, P is the pressure in mb, T is the temperature in K, and e is the water vapor pressure in mb.

DESCRIPTION OF OBSERVED DATA

In this study a total of twenty locations, as shown in Figure 1, are used to describe the nature of surface refractivity over the Arabian Peninsula. These sites are Dhahran (DH) on the eastern coast, Jeddah (JE), Al-Wajh (WA), Yanbu (YE), Medina (ME), and Taif (TI) in the west, Tabouk (TA), in the north-west, Turaif (TU), Arar (AR), Al-Jouf (JO), and Rafha (RA) in the north, Hail (HA), Gassim (GA), and Riyadh (RI) at the center, and Bisha (BI), Sulayel (SU), Khamis Mushait (KH), Gizan (GI), and Nejran (NE) in the south, and Quaisumah (QU) in the north-east.

Table 1 summarizes the number of years of data collected, the station height (in meters) above mean sea level, number of daily average data records, mean temperature (K), mean water vapor pressure (mb), mean station pressure (mb), and mean refractivity (N-units) for each location. The mean values of refractivity are calculated from daily average records of temperature, total pressure, and water vapor pressure. The diurnal variation of vapor pressure and refractivity are calculated for nine locations only (*i.e.* DH, RI, JE, TA, GI, JO, WA, GA, and NE). The number of hourly records for most of the stations were above 100 000 but in no case less than 40 000.

DISCUSSION

The discussion will be focussed on the monthly and hourly variation of water vapor pressure and refractivity with location. The yearly variation of refractivity will also be discussed.

Table 1 shows the variation of vapor pressure and refractivity for different locations. It is seen that the mean vapor pressure varies from a minimum value of 7.19 mb at JO in the north to a maximum of 28.77 at GI in the south west coast of the Red Sea while the mean refractivity varies from a minimum of 256.6 at KH which also lies in the south near the Red Sea to a maximum of 374.2 at GI. The extremum values of refractivity at GI and KH, though both lie in the same area, may be because: (*i*) GI is located at the coast while KH is an inland location, and (*ii*) GI is at 5 m above sea level while KH is at 2060 m. Figures 2 and 3 show the variation of mean, minimum, and maximum values (averaged over all the years) of water vapor pressure and surface refractivity for all the locations. It is evident from Figures 2 and 3 that maximum mean values of water vapor pressure and refractivity are found at coastal locations, *i.e.* DH, JE, GI, WA, and YE.

The inland locations have smaller values of these parameters. A contour map which shows the variation of mean refractivity at the surface is shown in Figure 4. A decreasing pattern in the values of refractivity is seen from north to south, *i.e.* 282 at TU, 275 at ME, 270 at TI, 265 at BI, and 257 at KH. This decreasing trend is further verified in moving from AR with refractivity value of 286 to JO, HA, and GA with refractivity values 278, 273, and 263, respectively. A decreasing trend is also seen from RA to HA and NE with refractivity values of 287, 273, and 263, respectively. Similar type of trend is observed while moving from QU to RI and SU. At all these locations we observe one thing in common that the water vapor pressure remains the same, *i.e.* around 8 mb. The mean surface temperature is found to vary between 292 K to 301 K at all these locations discussed while the mean surface pressure vary from 797.8 mb at KH to 969.8 mb at QU. An increasing trend in the surface refractivity values for inland locations is observed from west to east, *i.e.* 270 at TI in the west, 280 at GA, and 285 at QU in the north eastern region. This type of presentation may be useful to find values of refractivity at places where no meteorological data is collected.

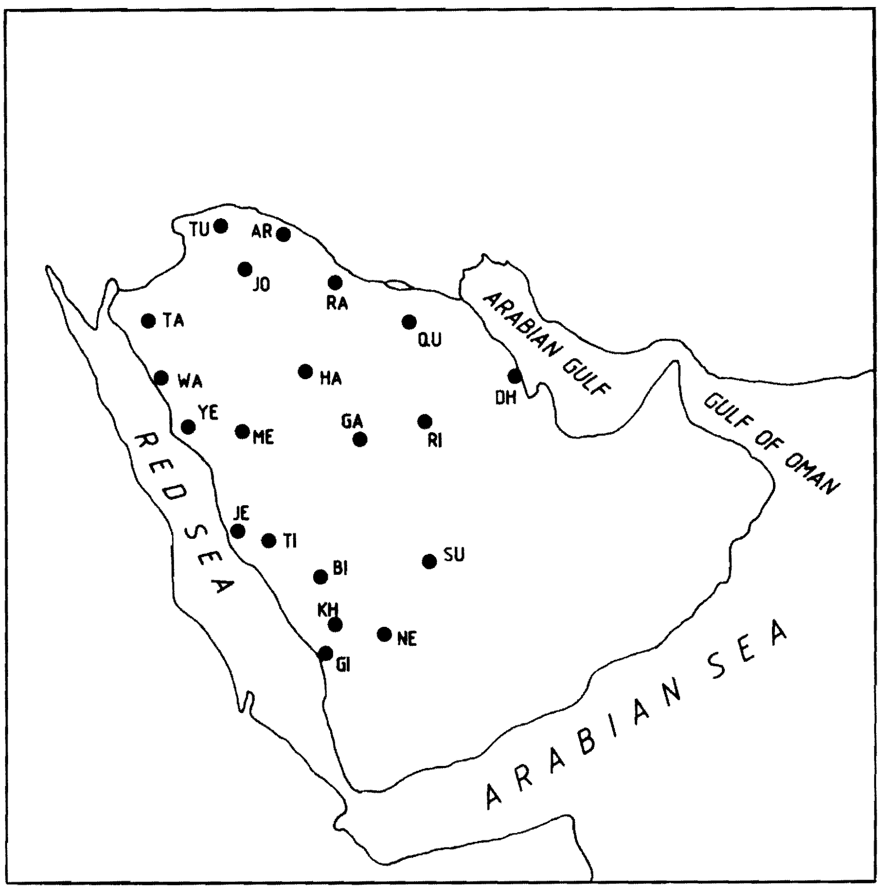

Figure 1. Location Map Showing the Study Area.

The yearly variation of mean refractivity from 1970 to 1989 is shown in Figures 5 and 6. In general it is noticed that there is no significant change in the values of mean refractivity. Almost constant values of refractivity are seen at coastal sites, *i.e.* DH, JE, GI, WA, and YE. A noticeable variation in refractivity values is seen at AR.

Monthly variations of mean vapor pressure and refractivity are shown in Figures 7 and 8, and 9 and 10, respectively. It is noticed from Figures 7*A*–7*C* and Figure 8*D* that the vapor pressure changes considerably for coastal sites. Its maximum values are observed in the summer months, *i.e.* May, June, July, August, and September, while its minimum in the winter months, *i.e.* November, December, January, February, and March. Almost the same pattern of refractivity persists for all coastal locations as shown in Figures 9*A*–9*C* and Figure 10*D*. However, for inland locations, the monthly variations of mean water vapor pressure are not affected that much. The surface refractivity is found to be lower for the summer months and a little higher for winter months, as seen in Figure 9*A* for RI, Figure 9*B* for TA and JO, Figure 9*C* for GA and ME, and Figures 10*A*–10*D* for HA, KH, QU, RA, SU, RI, and TU.

The diurnal variation of water vapor pressure and surface refractivity for nine locations is shown in Figures 11–14. In general, no significant diurnal changes are noticed in the variation of water vapor pressure and surface refractivity. A noticeable diurnal variation is seen at DH and WA in the values of vapor pressure as depicted in Figures 11*A* and 12 respectively. For inland locations, namely TA and JO as shown in Figure 11*B*, a slight variation is observed in the values of vapor pressure. The water vapor pressure as depicted in Figure 11*B* shows an increase with time after reaching a maximum at 11:00 local time, and starts decreasing towards the end of the day.

Table 1. Summary of Sites Used in This Study.

Station	No. of Years of Data	Station Height (m)	No. of Records	Mean Temperature (K)	Mean Station Pressure (mb)	Mean Water Vapor Pressure (mb)	Mean Refractivity (*N*-Units)
Dhahran	19	22	6894	298.8	1007.8	17.21	333.2
Riyadh	18	624	6483	299.0	942.1	7.74	277.2
Jeddah	19	17	6867	301.1	1007.2	22.43	351.4
Tabouk	17	771	6274	294.9	926.1	7.92	277.6
Gizan	17	5	6330	303.4	1007.8	28.77	374.2
Al-Jouf	15	562	5231	295.2	927.1	7.19	277.6
Al-Wajh	17	22	7316	297.7	1007.9	20.58	348.7
Gassim	14	648	5229	297.5	937.7	8.29	279.7
Medina	17	646	6297	301.1	938.9	7.98	275.1
Nejran	11	1275	4291	299.0	879.5	8.18	262.6
Arar	15	542	5903	295.3	949.7	8.39	285.6
Bisha	17	1167	6326	298.8	883.7	8.50	265.2
Hail	17	992	6333	295.1	901.2	8.29	272.6
Khamis-Mushait	17	2060	6336	292.0	797.8	10.17	256.6
Quaisuma	18	359	605	299.3	969.8	8.01	285.2
Rafha	16	443	6104	296.9	960.9	8.38	286.8
Sulayel	16	615	6117	301.2	941.4	8.17	276.5
Taif	17	1471	6310	295.7	854.9	10.52	269.5
Turaif	15	827	5705	292.2	920.5	8.49	281.7
Yanbu	18	6	6571	300.4	1008.2	20.66	345.4

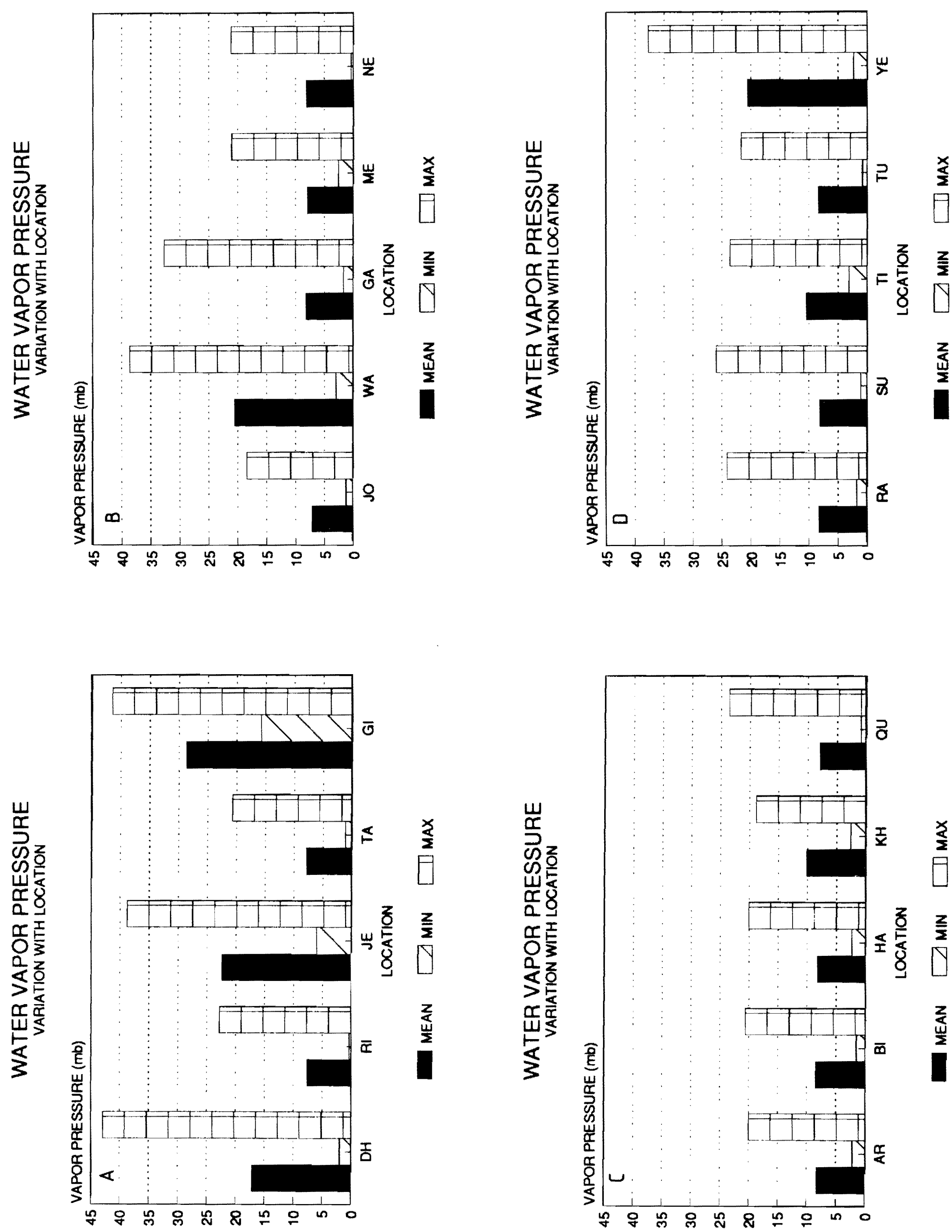

Figure 2. Variation of Water Vapor Pressure with Location.

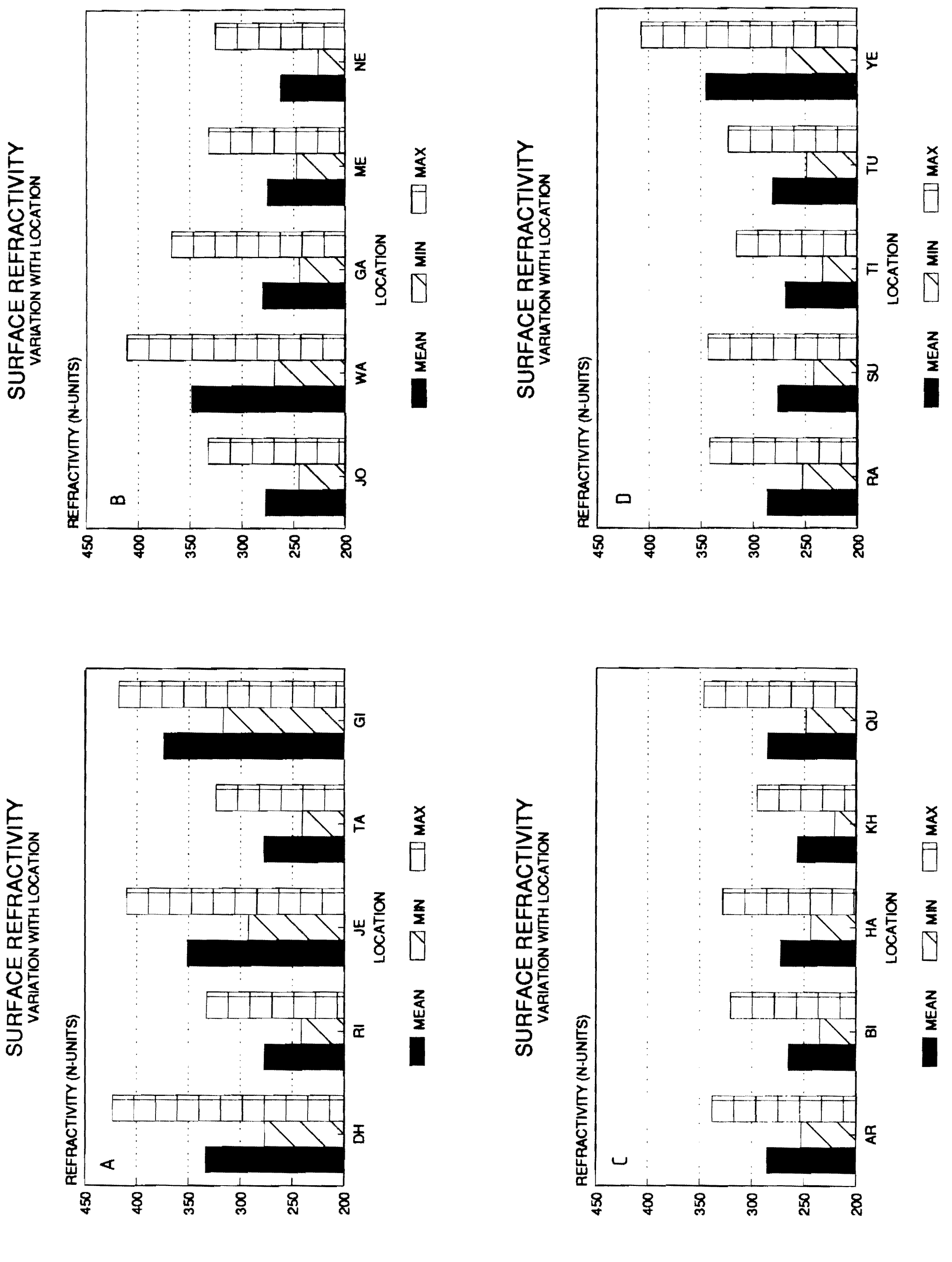

Figure 3. Variation of Surface Refractivity with Location.

The surface refractivity shows an increasing trend at RI, JE, TA, JO, GA, and NE, as seen in Figures 13 and 14, in the early hours of the day and a decreasing trend towards the end of the day, then it again increases after sunset because of the fact that the water vapor pressure has almost the same trend. However, the behavior of surface refractivity at DH in Figure 13*A* and at WA in Figure 14 is somewhat different from other locations. It is seen in Figure 13*A* that surface refractivity for DH first decreases, and, after reaching a minimum at noon time, it again increases till almost midnight. It has been noticed that at WA the refractivity first decreases and after reaching a minimum at 07:00 local time it increases till 18:00 local time, and then again decreases.

In order to study the effect of air pollution due to the burning of oil wells in Kuwait, the surface water vapor pressure and refractivity values at Dhahran are calculated from 13 to 17 March and April for the years 1990 and 1991. The average values are compared in Table 2.

Table 2. Average Values of Water Vapor Pressure and Refractivity at Dhahran.

Months	1990		1991	
	Water Vapor Pressure	Refractivity	Water Vapor Pressure	Refractivity
March	13.66	328.40	13.94	328.33
April	14.34	318.70	10.82	310.85

It is noticed that the values of both parameters remain almost unchanged during March for both years 1990 and 1991. However, the water vapor pressure decreases from 14.34 mb in April 1990 to 10.82 mb in April 1991, *i.e.* a decrease of 24.5%. The refractivity value is observed to have decreased from 318.7 in 1990 to 310.85 in April 1991, *i.e.* a decrease of 2.4%, which indicates the impact of the presence of the smoke in the region. It is expected that such changes will be more significant during summer months. A comprehensive work on the assessment of the effect of air pollution on refractivity is under investigation.

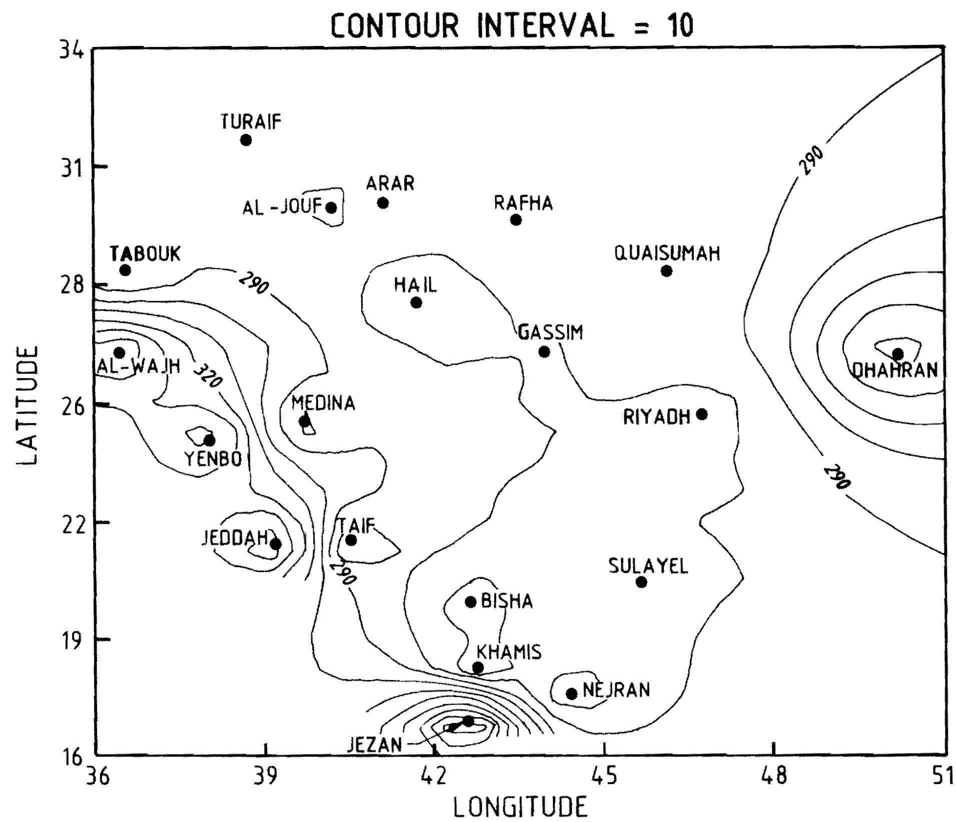

Figure 4. Contour Map Showing the Surface Refractivity.

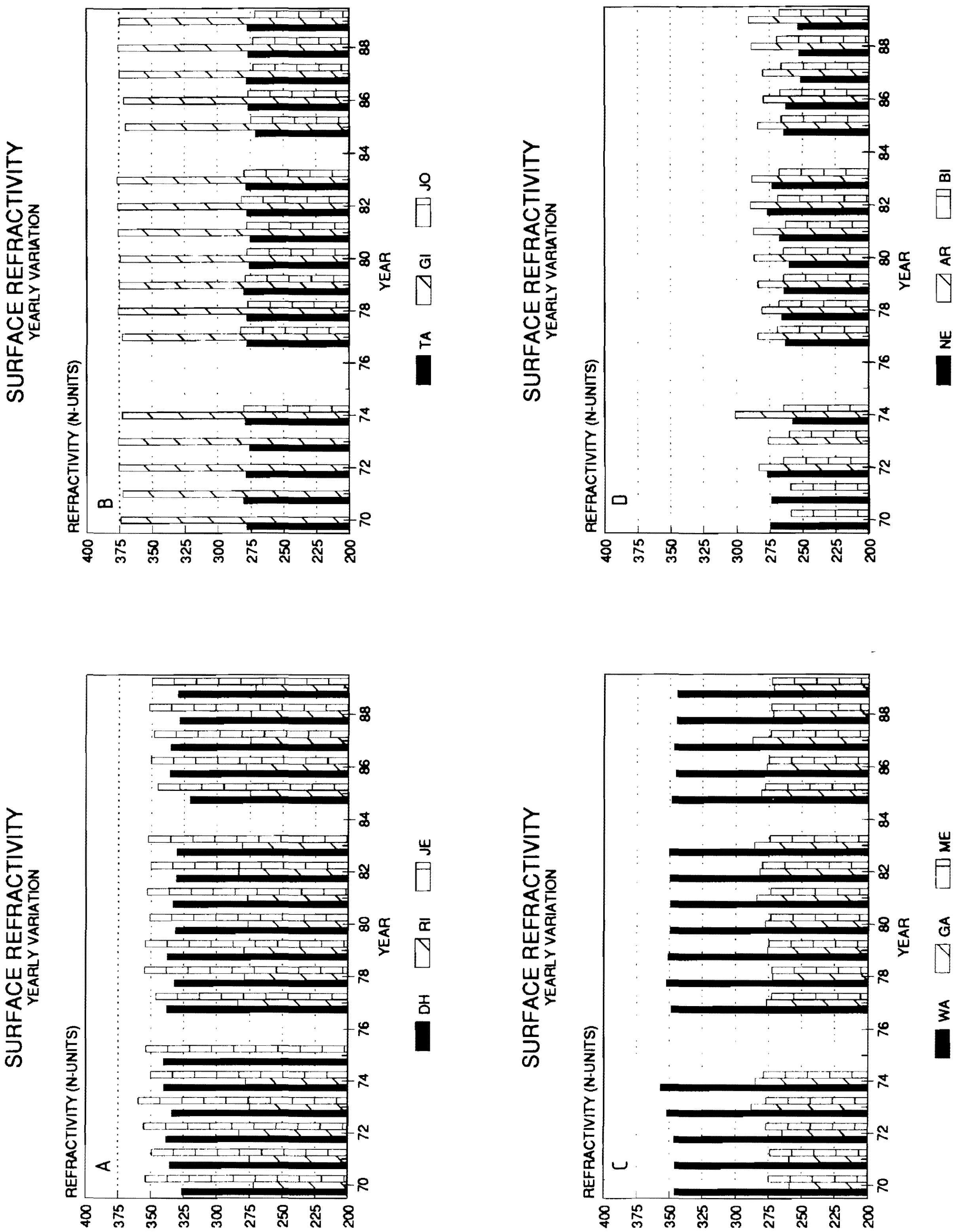

Figure 5. Yearly Variation of Surface Refractivity.

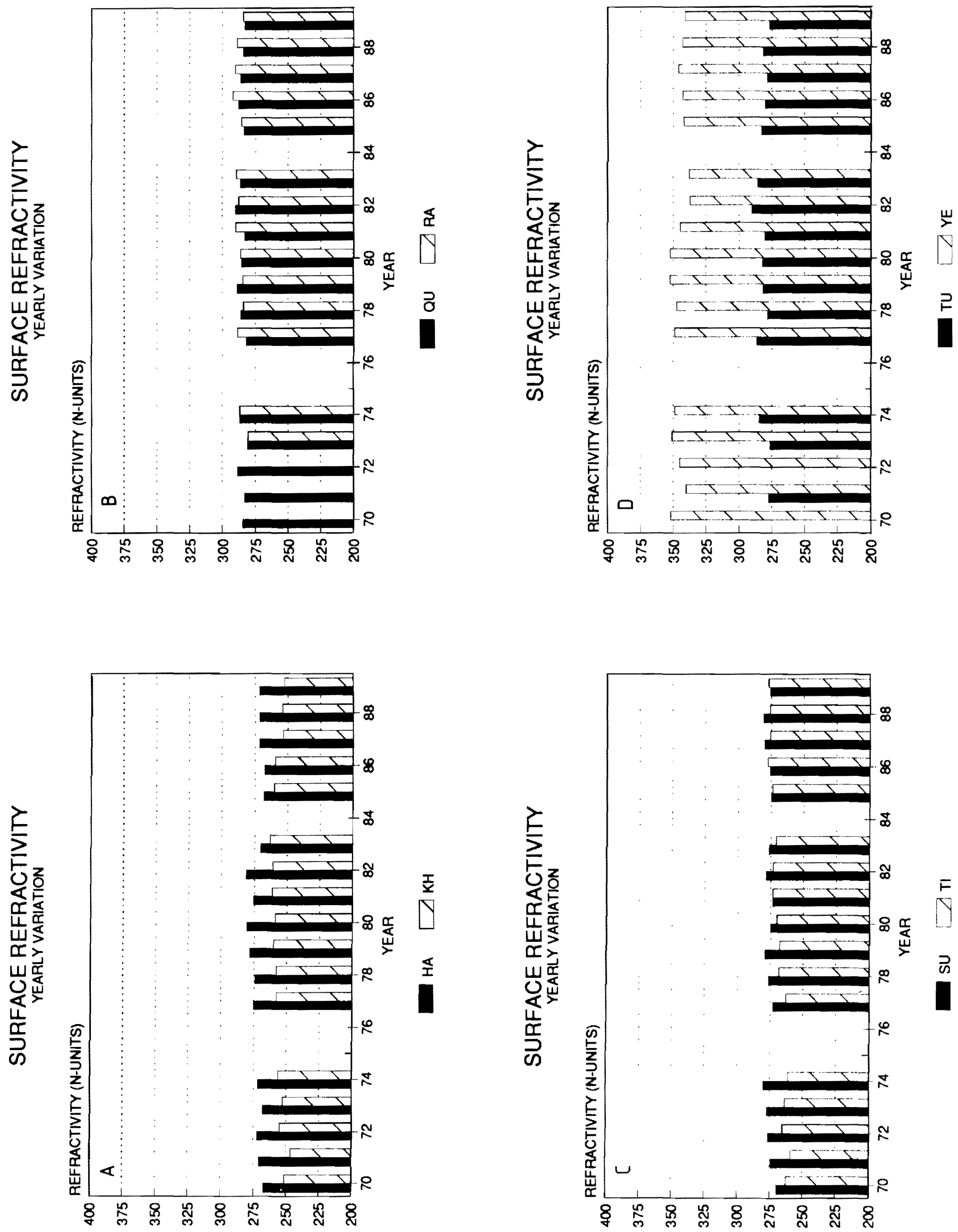

Figure 6. Yearly Variation of Surface Refractivity.

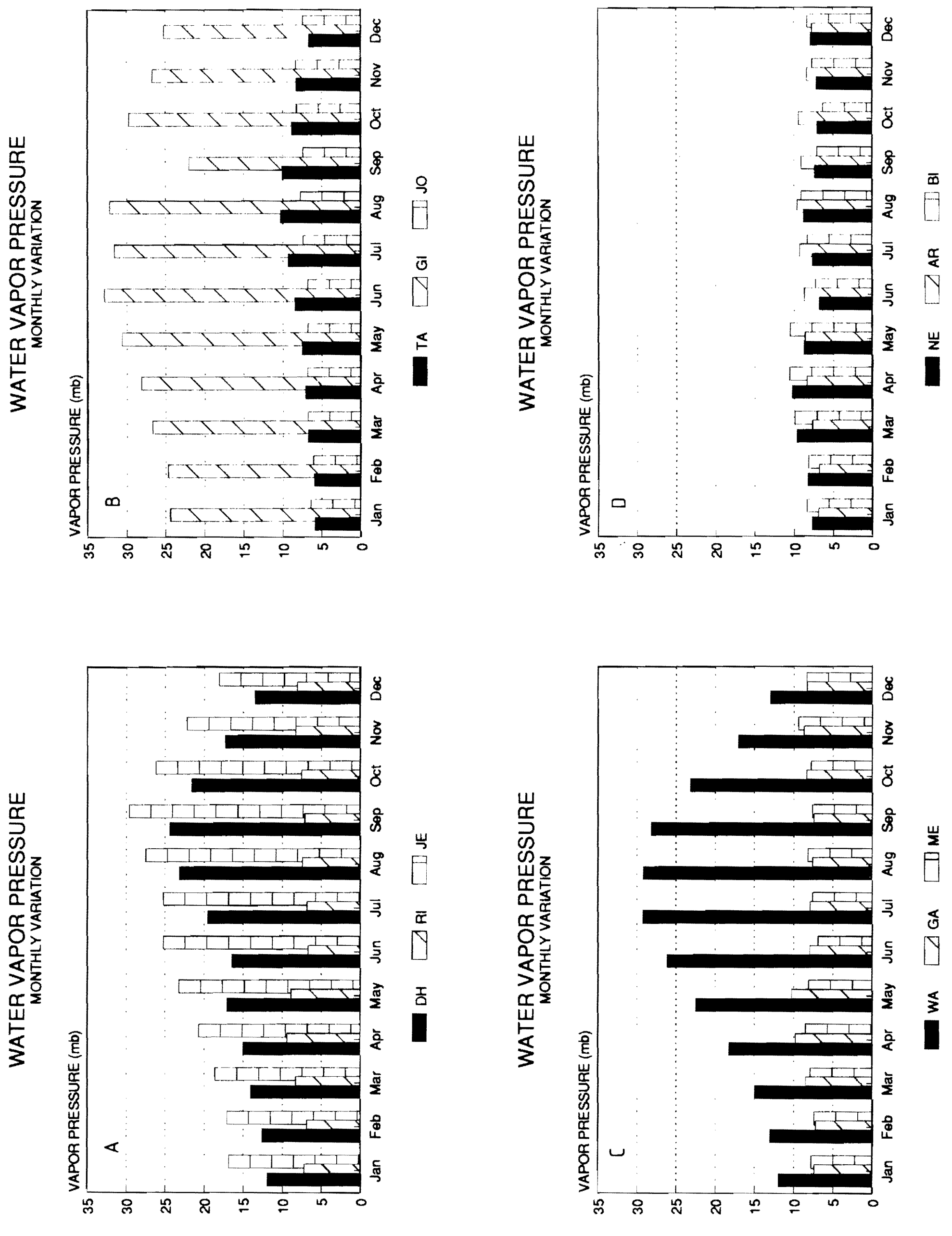

Figure 7. Monthly Variation of Water Vapor Pressure.

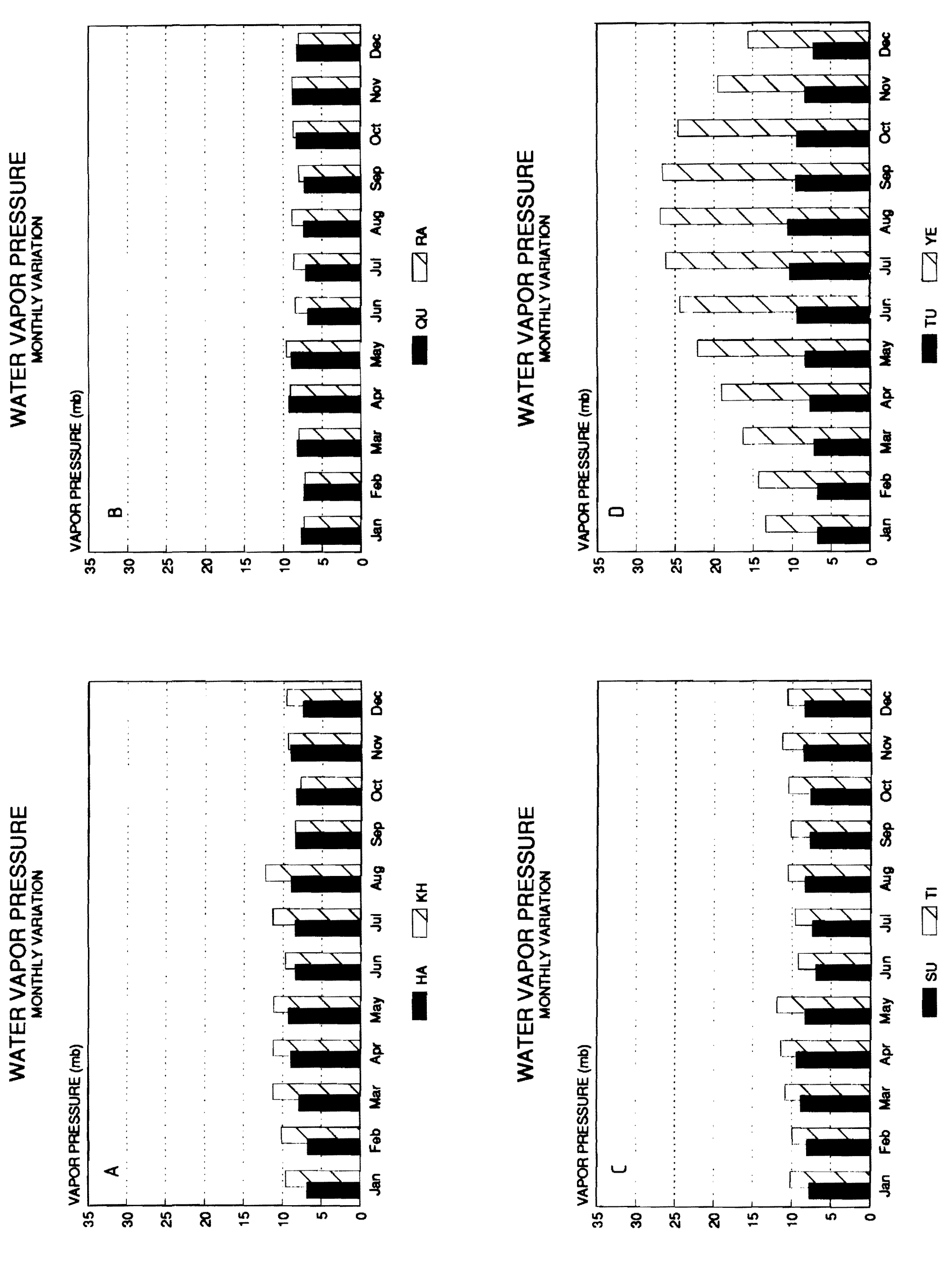

Figure 8. Monthly Variation of Water Vapor Pressure.

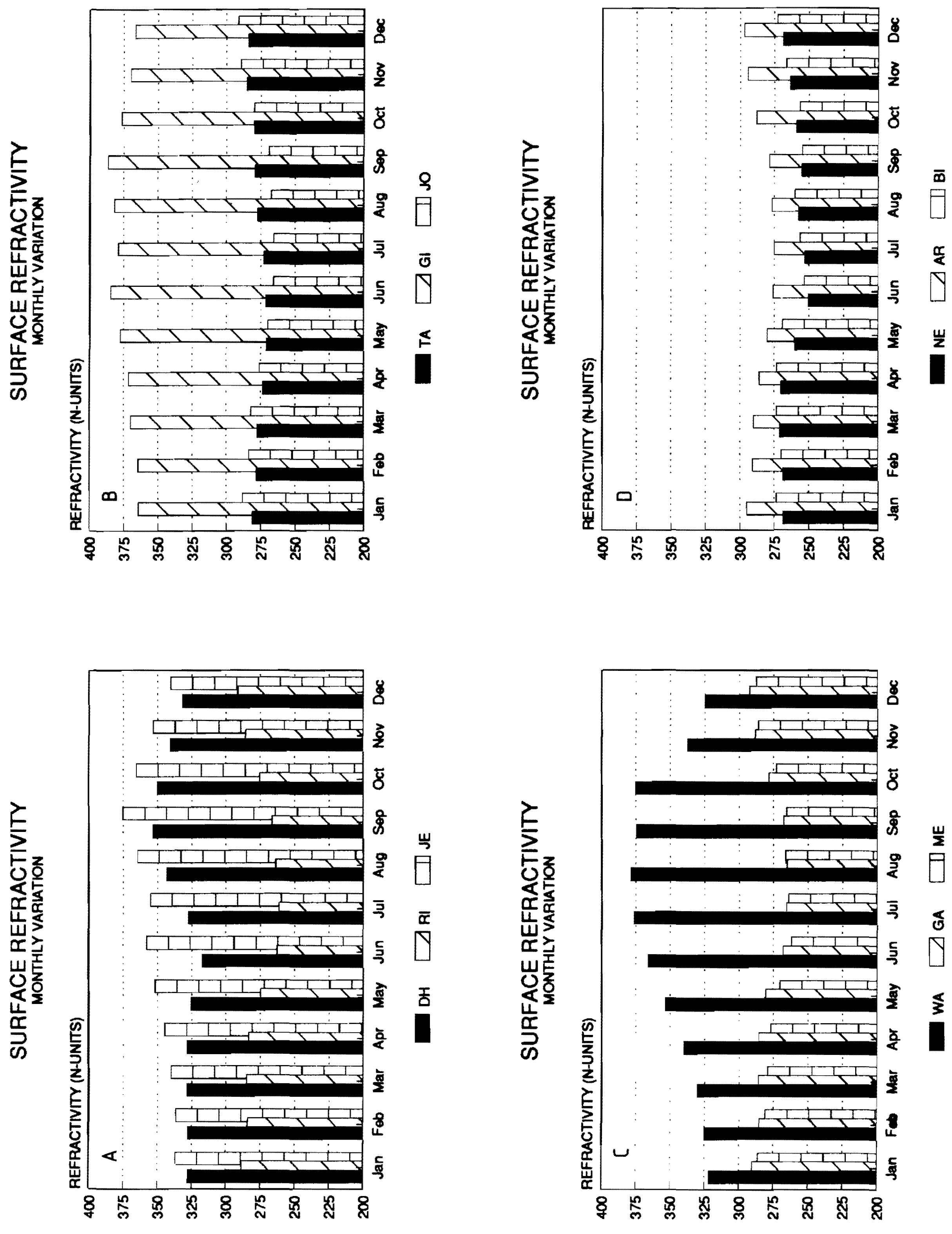

Figure 9. Monthly Variation of Surface Refractivity.

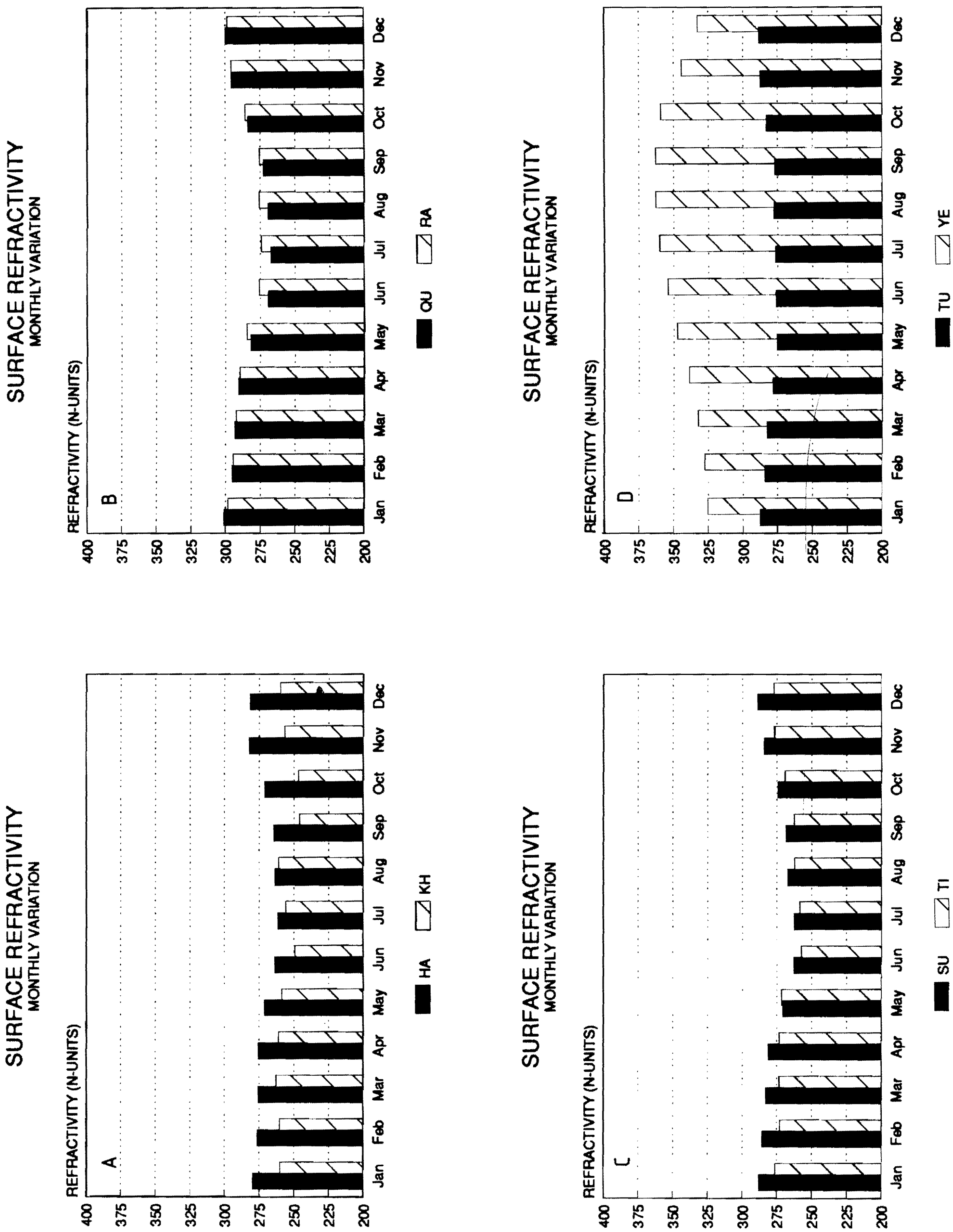

Figure 10. Monthly Variation of Surface Refractivity.

CONCLUSION

In general, a decreasing trend is noticed in the values of surface refractivity in going from north to south. The values of water vapor pressure remain around 8 mb almost at all inland locations, *i.e.* TU, ME, BI, AR, HA, GA, SU, NE, RA, QU, and RI. The decreasing trend from north to south is observed only at inland locations. It is also observed that the eastern coast has lower values of refractivity than the western coast. It is concluded that the water vapor pressure and refractivity values have their maximum at coastal sites and lower values at inland sites. The maximum value of water vapor pressure (*i.e.* 29 mb) is obtained at GI while its minimum, *i.e.* 7.0 mb is at

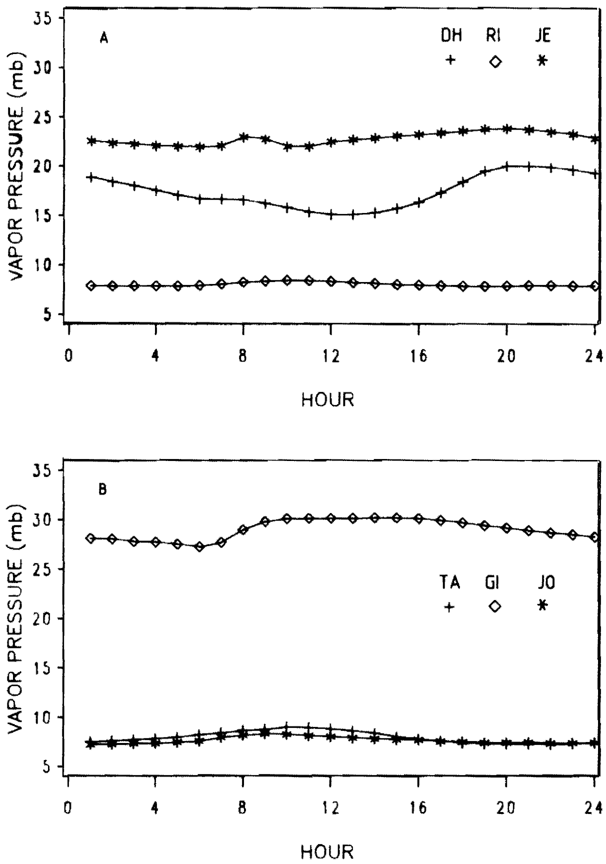

Figure 11. Diurnal Variation of Water Vapor Pressure.

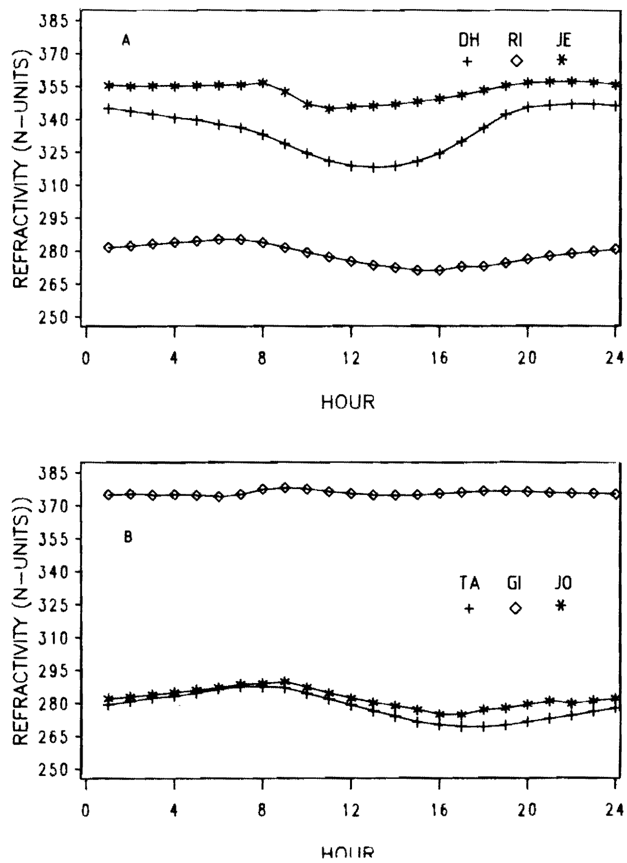

Figure 13. Diurnal Variation of Surface Refractivity.

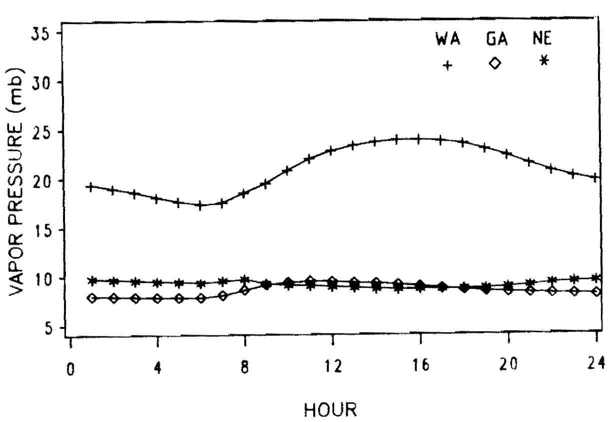

Figure 12. Diurnal Variation of Water Vapor Pressure.

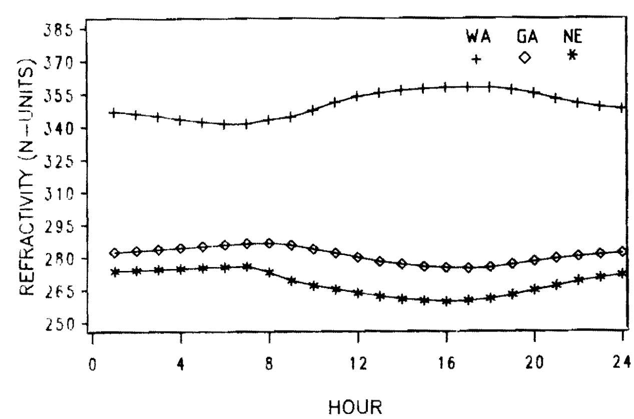

Figure 14. Diurnal Variation of Surface Refractivity.

JO. On the other hand, refractivity has its maximum at GI and minimum at KH. The coastal locations DH, JE, GI, WA, and YE, show consistent values of both parameters over the period of investigation.

To further investigate the variation of the refractivity, the whole study area is divided into four regions. The first region include TU, AR, TA, JO, and RA. In this region it is concluded that the mean surface values of temperature, water vapor pressure, and refractivity vary between 292–297 K, 7–8.5 mb, and 277 to 287 *N*-units, respectively. In the second region, which include ME, HA, QU, GA, and RI, these parameters have values between 295 and 301 K, 7.7 and 8.3 mb and 273 and 285 *N*-units, respectively. In the third region, which includes TI, BI, SU, KH, and NE, the values of temperature, water vapor pressure, and refractivity vary between 292 and 301 K, 8.2 and 10.5 mb, and 257 and 277 *N*-units, respectively. The fourth region includes coastal location only, *i.e.* WA, YE, JE, GI on the west coast and DH on the east coast. At these sites, the temperature varies from 298 to 303 K, water vapor pressure from 17 to 29 mb, and refractivity from 333 to 374 *N*-units. From this analysis, it is concluded that the region four sites have highest ranges of temperature, water vapor pressure, and refractivity values, while the region three sites have the minimum ranges of all the parameters. It is also concluded that the temperature, water vapor pressure, and refractivity values have a decreasing trend in their values from region one through region two to region three.

It is also concluded that the values of water vapor pressure and refractivity show a seasonal pattern for all coastal locations, *i.e.* these parameters at DH, JE, GI, WA, and YE show an increasing pattern from January to July, August, and September and then a decreasing pattern towards the end of the year. However, for inland locations, the water vapor pressure values show an insignificant change during the year, but the refractivity is found to decrease from January to July, August, and September and to increase towards the end of the year.

It has been noticed that the burning of the Kuwaiti oil fields has a significant effect on the meteorological conditions in general and the surface water vapor pressure and refractivity in particular. A comprehensive assessment of the impact of the Gulf War on the air pollution and hence on the refractivity in this region is currently under investigation.

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