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Assessment of surface ozone over residential environments

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ABSTRACT

Surface ozone (O_3) has become one of the most important topic of air quality and climate change researches. This is because of causing harmful effects on human health, climate, vegetation and materials. For these reasons, understanding the processes which control the origin, trends, distribution and effects surface O_3 are important. In this paper, the surface O_3 concentration was investigated experimentally and numerically over residential environment. Surface O_3 was measured using Visible blind Ultraviolet sensors (UV Ozone Analyzer) over the period of 2008-2010 in Kuwait international airport. A back trajectory method based on HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used for assessing the surface O_3 over residential environment. The diurnal, and seasonal variations of surface O_3 were analyzed and discussed. Furthermore, the effect of meteorological conditions on the surface O_3 was also analyzed. Diurnal variation shows that maximum O_3 concentration was at the noon and about minimum in the evening. Seasonal variation showed that February was a highest rate of O_3 concentration. Power stations are a major point source for O_3 precursors. The surface O_3 shows a medium correlation with temperature and a week correlation with wind speed.

Keywords: HYSPLIT model; Meteorological conditions, Residential environment; Surface ozone; UV sensors

INTRODUCTION

Ozone (O_3) is a natural element in an urban environment and plays a major source of atmospheric pollution, and climate change. High concentrations O_3 has detrimental effects on human health and vegetation. The high concentration of O_3 is due to an increasing concentration of the combination of formation, transport, destruction and deposition (sources: photochemical reactions, downward transport from stratosphere, and long-range transport of ozone from pollutant locations). According to United state Environmental Protection Agency (EPA), surface ozone can cause serious health impacts depending on the concentration rate and time of exposures. Furthermore, according to Intergovernmental Panel on Climate Change (IPCC), ozone is also a greenhouse gas that directly contributes to global warming.

In the last few decades the phenomenon of O_3 pollution has been analyzed extensively. There have several studies reporting of the surface O_3 at different locations in the world [1-5]. The O_3 concentration from continuous observation were calculated by Minoura [6] and compared with the concentrations of NO and NO_2 and meteorological conditions. Lal [7] measured O_3 concentration and its precursor gases (NO_x, CO and CH_4) in an urban site in tropical India. O_3 concentrations are observed to be maximum during autumn and winter months due to higher amounts of precursor gases in spite of lower solar radiation. Vukovich and Sherwell [8] used the O_3 data from the United States Environmental Protection Agency's (EPA), Aerometric Information Retrieval System (AIRS) and surface and upper air meteorological data from National Weather Service (NWS) stations to determine the meteorological conditions in the Baltimore–Washington corridor area. The results show that high temperatures and large concentrations of water vapor are necessary for high ozone in this area.

Recently, an extensive studying the O_3 trends and the underlying causes have been conducted in the worldwide. Most of the study showed increasing O_3 concentrations at rural and urban areas in the western United States [9-11] at an Atlantic coastal site in Europe, and at surface sites and a mountain-top site in Japan during springtime [12, 13]. Several studies according to strongly linked the trends in ground-level O_3 in the urban and rural areas to the changes in anthropogenic emissions of ozone precursors such as NO_x, CO, and VOC [14, 15]. **Reddy *et al*.** [16] discussed the diurnal and seasonal variation of surface O_3 concluding that not only sun radiation plays a major role in high concentration of surface O_3. **Im *et al*.** [17] measured O_3 mixing ratios at three different sites (urban/traffic, semi-rural and rural/island) in Istanbul to determine the diurnal, monthly and seasonal variations of O_3 and nitrogen oxides (NOx) and to study the local and regional impacts. Toh et al. [18] analyzed the surface O_3 concentrations at the Tanah Rata regional Global Atmosphere Watch (GAW) station, Malaysia during period 2006 to 2008. The hourly O_3 shows a positive correlation with temperature and a negative correlation with relative humidity and surface pressure.

On the other hand, several studies of the surface O_3 has been conducted using mathematical modeling. Tang et al. [19] and **Edith *et al*.** [20] used HYSPLIT model and provide data assimilation on O_3 concentration and dispersion. The impact of different meteorological forcing on surface ozone by the modelling system RegCM3/CAMx studied by **Kurokawa *et al*.** [12]. While, the WRF/CMAQ model system used by **Im *et al*.** [16] to study episodic O_3 in Istanbul, Turkey. The results show that precursor emissions from Istanbul can contribute to O_3 formation downwind in the East Mediterranean while locally. Using the air quality model CAMx driven off-line by the regional climate model RegCM3, **Pires *et al*.** [21] analyzed the O_3 concentration behaviors at the different rural sites in Portugal using statistical methods. The daily maximum values occurred frequently in the afternoon at all monitoring sites. Using the NOAA HYSPLIT 4 trajectory model and the Model ML/EC9810 O_3 analyzer, O_3 concentrations in China from 2008 to 2009 studied by **Wang *et al*.** [22]. A significant positive correlation found between O_3 concentration and ambient temperature, indicating that the intensity of solar radiation was one of the several major factors controlling surface ozone production. **Akritidis *et al*.** [23] assessed the impact of chemical lateral boundary conditions (LBCs) on near surface O_3 over Europe for the period 1996–2000. The evaluation indicates that implementation of time and space variant chemical LBCs of a global chemistry transport model (CTM) improve the RegCM/CAMx performance.

Despite, previous studies have been conducted of the surface O_3 at different cities in the worldwide. There are still strong needs for improved understanding the origin, trends, distribution of surface O_3. Thus, the aim of this study was concerned to assess and analyze of the surface O_3 concentration and dispersion over Kuwait international airport and its effect on surrounding area. For this purpose, a measurement of surface O_3 samples was taken from the period 2008-2010, and the data analyzed in the hourly, daily, monthly averages to obtain diurnal and seasonal variation of surface ozone concentration. Then compared with actual meteorological, and sun radiation data at the same location. Using HYSPLIT model to calculate the atmospheric conditions controlling the concentration and dispersion of surface ozone generated from Kuwait international airport and transported to nearby areas.

Fig. 1: Areas surrounding Kuwait Airport

Fig. 2: The distance from Kuwait city to Kuwait Airport

MATERIALS AND METHODS

Site Description

Kuwait located in the northeastern corner of the Arabian Peninsula and cover an area approximately 17,800 km², extended between latitudes 28° 30' N and 30° 05' N and longitude 46° 3' E and 48° 35' E. The observation site is located in Kuwait international airport Meteorology department (29.2N 47.9E 63m). Kuwait International Airport is located 16 km south of Kuwait City (Fig. 1), the capital of Kuwait. It is sounded by major commercial and residential areas. From the north side it is close to Farwaniah and Khetan speared by the 6th ring road. West word there is Ashbilya and Jeeleb Alshyokh residential area. In the north east there is Janob Alsurra and in the east and south east it is sounded by Sabhan industrial area (Fig. 2). Kuwait Air Force headquarters and Al Mubarak Air Base located at a portion of the airport. A Kuwait Air Force museum is also present at the airport complex.

The country is characterized by a desert type environment with scanty rainfall, and dry hot weather. Summer is very hot especially in July and August, with mean temperature of 37.4 ºC and maximum temperature 45 ºC. The average yearly total precipitation is approximately 100 mm, with an evaporation rate of 16.6 mm/d. The winds in the area are from the North West, and at lesser extent are from the south east (Kuwait Meteorology Department).

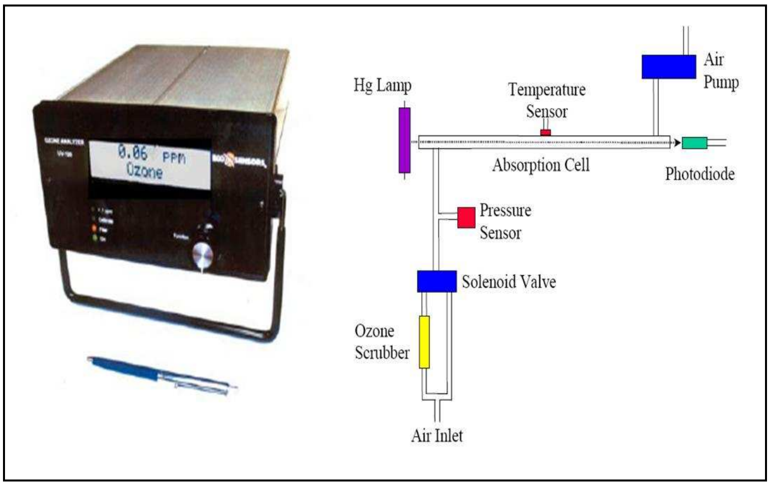

Fig. 3: Surface ozone device measurement UV-100

Measuring Instruments

The surface O_3 measurement was taken from the period 2008 – 2010, using the Visible blind Ultraviolet sensors (UV), which is a UV absorption analyzer designed specifically for ozone. The UV ozone sensors were located at Kuwait international airport; meteorology department, as shown in Fig. 3. The measurements are in 10 sec intervals then it will be logged into meteorology department server. The continuous air temperature and relative humidity (RH) wind speed, and direction data are used from Kuwait meteorology department taken from Kuwait international Airport Automatic weather station. According to the sensor operating manual it was designed to enable accurate measurements of O_3 over wide dynamic ranges extending the from a limit of detection of 0.01 ppm to un upper limit of about 1000 ppm.

The theory of operation depends on absorption of UV light. It has long been used to measure atmospheric O_3 with high precision and accuracy. The O_3 molecule has an absorption maximum at 254 nm, coincident with principle emission wavelength of low-pressure mercury lamp. The measurement based on the attenuation of light passing through 6.2 cm long absorption cell fitted with quartz window. A low-pressure mercury lamp is located on one side of the absorption cell, and a photodiode is located on the opposite side of the absorption cell. The photodiode has a built in interference filter centered on 254 nm, the principle wavelength of light emitted by mercury lamp. An air pumps draws sample air into the instrument at flow rate approximately 1 L/min. A solenoid valve switches so as alternately send this air directly into absorption cell or through an ozone scrubber and then into the absorption cell. The intensity of light at the photodiodes is measured in air that has passed through the ozone scrubber and air that has not passed through the scrubber. The O_3 concentration is calculated from the Beer- Lambert Law. Meteorological conditions were included wind direction, wind speed, temperature, visibility, and relative humidity, which is continuously, measured automatically using an automatic weather station at the same sampling site.

Surface Ozone (O_3) Dataset

A complete data set of the surface O_3 data was obtained from DGCA Meteorological Department. The complete dataset comprised of 5,686,832 records where each record was an instantaneous reading of O_3 measuring in (ppm), time in hours, minutes and seconds according to Kuwait Standard Time (KST) and date of the recording. The dataset comprised of recorded temporally separated by a period of 10seconds. Also shows that for the period prior to 1 Feb 2008 45% of the total possible records are missing whereas after 1Feb2008 6% are missing. The discrepancies are due primarily to a period of "settling in" where technicians gained experience in maintaining the instrument and the methods of calibration were fully established. Analysis of data prior to 1 February 2008, shows random trends in the data series as well as many periods of unusual spikes in the times series data. In consideration of these factors, all data prior to 1 February 2008 was considered not reliable and not usual for the purposes of this paper and have been excluded.

Data Analysis

PV-WAVE 9.0 program by Visual Numerics Inc. was used to perform all statistical analysis. It was used due to its capability to deal with huge record of data. It is used in Kuwait Meteorology department to generate climatological products from 25 automatic weather stations. PV-WAVE is an array oriented fourth-generation programming language used by engineers, scientists, researchers, business analysts and software developers to build and deploy Visual Data Analysis applications. These applications let users manipulate and visualize complex or extremely large technical datasets to detect and display patterns, trends, anomalies and other vital information. The O_3 time series dataset consists of discrete data samples taken every ten seconds. To match the one time resolution of data held in the DGCA Climate Database to allow comparison of O_3 and meteorological data, the following steps were taken:

1. Create a 10-minute time series from the 10-second O_3 data by calculating the arithmetic mean of the 10-second data comprising the 10-minute period. The mean was taken as $10\min = \left(\sum 10\sec\right) \div n$. As a result of averaging 120,334 records 10-minute records were generated.
2. Using PV-Wave IMSL function CONVOL1D, a 10-point moving average was calculated for the 10-minute data. On generation of the moving average, every 10^{th} point was extracted to form a 1-hourly time series. The moving average technique maintains overall trends in the time series.

Where missing records were detected in calculation both the 10-minute and 1-hour records the subsequent record generated was marked as not valid. As noted in table3, this accounts for approximately 6% of all data.

Data assimilation Model and Approach

The HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model by NOAA model is a complete system for computing trajectories complex dispersion and deposition simulations using either puff or particle approaches. Moreover, in the Eulerian modeling approach, air concentrations are computed for every grid cell by integrating the pollutant fluxes at each grid cell interface due to diffusion and advection. In the Lagrangian modeling approach, air concentrations are computed by summing the contribution of each pollutant puff that is advocated through the grid cell as represented by its trajectory [24].

The meteorological data fields required for the calculations was obtained from Kuwait Meteorological department reanalyzed meteorological data archive. The data was converted and re configured to a format compatible using special scripting for direct input to the model. The model's meteorological data structure is compressed and in direct-access format. Each time period within the data file contains an index record that includes grid definitions to locate the spatial domain.

RESULT AND DISCUSSIO

Frequency Distribution

Figure 4 is a bar diagram shows the frequency distribution of 1-h average of surface O_3 concentrations in different ranges for the study period (February 2008 – April 2010) at Kuwait International Airport. It shows that 90% of all O_3 measurements lie in the range of 0.000-0.039 ppm and the remaining 10 % in the range 0.04-0.5 ppm a total data points are 86932. Therefore, according to air quality standard most of the data lies in the good and moderate range of surface ozone. But it is important to notice that 1-h averages of O_3 exceeds air quality standard on few occasions in the spring and fall season. The results of the seasonal variation of O_3 were presented and discussed below.

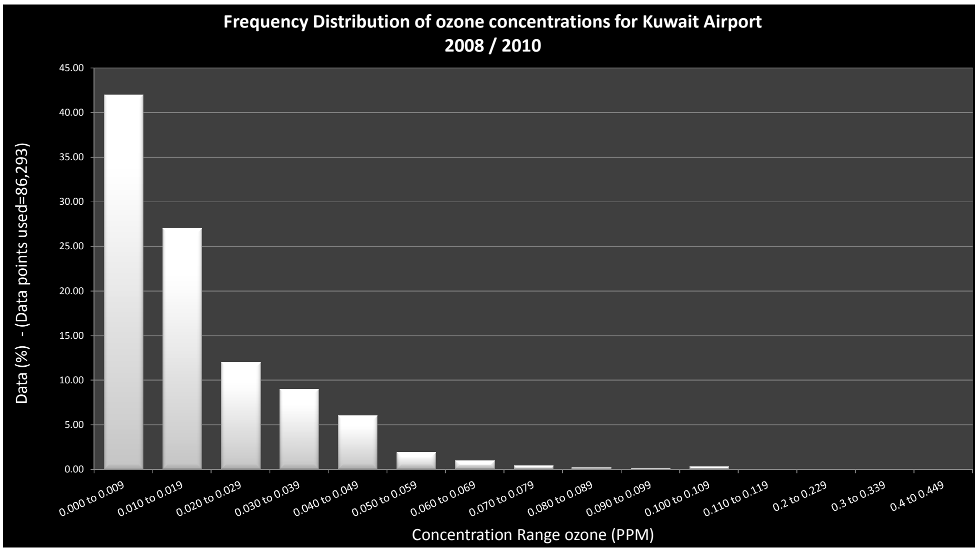

Fig. 4: Distribution of surface ozone data

Diurnal Variations

Figure 5 shows the annual average diurnal variation of O_3 concentration over period February 2008 April 2010 at Kuwait International Airport. The vertical lines on the curve denote the 1 σ standard deviation. Diurnal variation shows maximum O_3 concentration about 0.029 ± 0.03 ppm at noon (1200 h) and minimum about 0.01 ± 0.019 ppm in the evening (2100 h). The O_3 concentration begins to increase at (0600h) in the morning, and attains its maximum level at noon, which suggested the starting of rush hours in Kuwait street start early in the morning where people start go to their work, thus primary source of (NOx) and (VOCs) are been discharge in the atmosphere. Variation in O_3 is important since photochemical production of is strongly influenced by daily changing major precursor concentrations due to diversified natural and anthropogenic sources and variable influence of meteorological parameters. Low O_3 concentrations at night because of absence of photolysis of (NOx) [7]. In few occasions though, a significant increase of O_3 was present during the night time with the absence of sun light, as a result it is suggested that O_3 was transported from other sources.

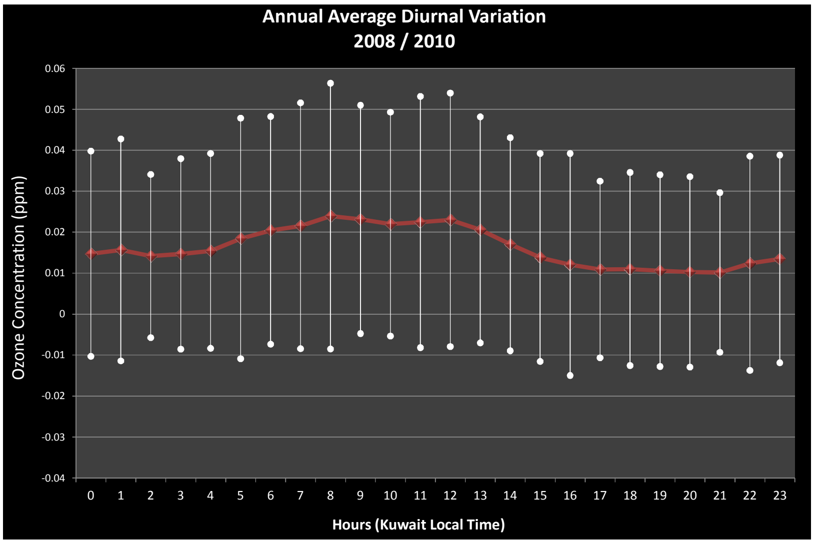

Fig. 5: Surface ozone diurnal variation

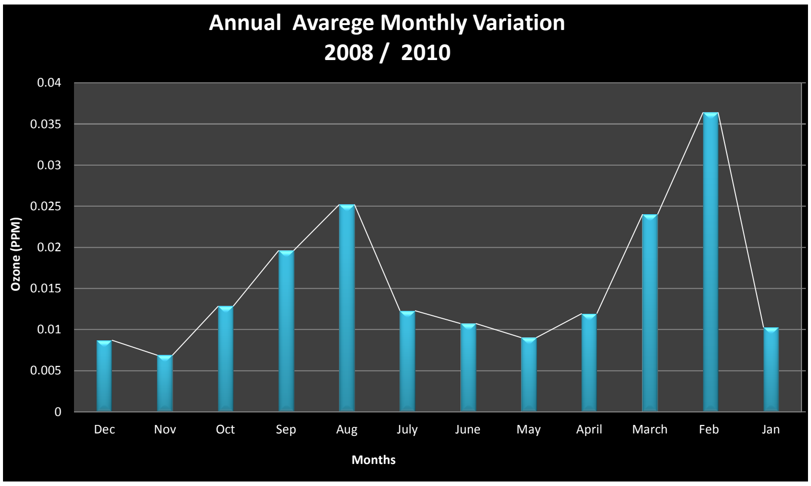

Fig. 6: Surface ozone seasonal variation

Seasonal Variation

Figure 6 shows the seasonal variation of O_3 indicating that the change in atmospheric conditions plays a major role in O_3 dispersion and concentration. There major finding were observed from the seasonal variation, first one is that February shows a highest mean of concentration about 0.03 ppm. Second, in April the hourly average start to drop down then it begins to increase slightly in July and August, due to intense sun radiation in the summer. As a result in summer season more surface ozone been generated but the generation of ozone does not only depend on sun radiation but also to other atmospheric condition that determine the concentration and dispersion. It is known that during the summer season the wind speed is fresh wind reaching more than 45 km/h. Hence, the situation favorable for concentration at the site location is very low, because most of the ozone been dispersing to other location. According third, the mean hourly average is the lowest in November and December, less than 0.01 ppm. In general, the hourly of O_3 start to increase significantly during spring season, then it drops down at the begging of the summer, but begins to increase again in August and September. Then it drops significantly through October to January. The high rate of O_3 is also due to stagnant atmospheric conditions (temperature inversion at the ground level). The lower rate in July is due to shorter (O3) lifetimes as compared to other months, [25].

Table 2: Correlation coefficient between ozone and the meteorological conditions

Ozone (O_3)	Correlation coefficient, %				
	Temperatu re	Visibility	Relative humidity	Wind direction	Wind speed
	50	40	30	10	1

Meteorological Conditions Effects

Since meteorological condition plays a major role controlling the O_3 concentration and dispersion, it is important to correlation between certain meteorological condition and ozone. Hourly mean meteorological data (wind direction, wind speed temperature, visibility, and relative humidity) was measured during period 2008-2010 at the same O_3 sampling site Table 1 shows the correlation coefficient between the O_3 concentration and the meteorological conditions. The correlation between the O_3 and temperature shows a medium correlation. This is because intense solar radiation yields to higher air temperature resulting in more O_3 generation. This result appears consistent with the observations of **Toh *et al*.** [17]. The location site of high O_3 concentration more than 0.2 ppm is related to temperature ranging between 15 to 25 C. Furthermore, visibility and relative humidity show a fairly correlation with the O_3. Visibility was affected by different parameters such as haze, fog, mist and rain. The maximum relative humidity was observed 95 %. On the other hand, The wind speed was a week correlated with the O_3 concentration. The maximum wind speed was 17.5 m/s. The wind direction was also a significant correlated the O_3, where high concentration more than 0.2 ppm is associated with two primary direction 100 to 180 degrees (South Easterly to southerly) and 300 to 360 degrees (North westerly to Northerly). Hence, most of the high O_3 concentration was generated at the spring season, and at most case it is been transported from nearby source. Moreover, the stable atmospheric condition during the spring season is responsible for huge level O_3 concentration at the site location.

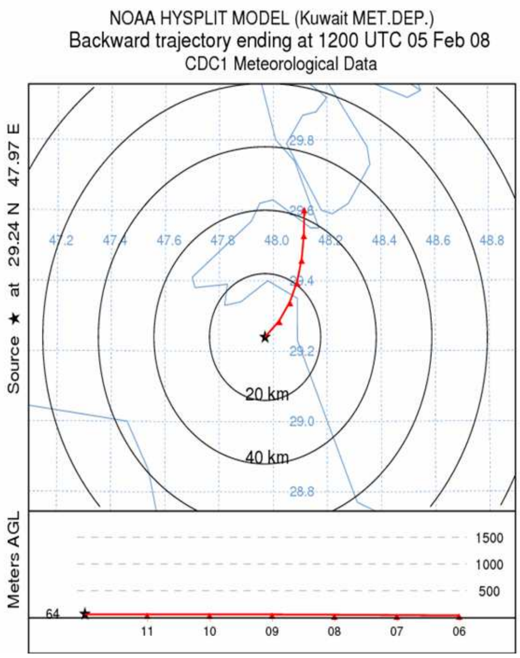

Fig. 7: Back trajectory result: first case.

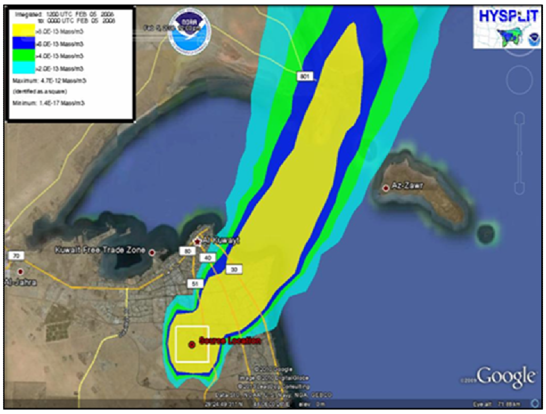

Fig. 8: Surface ozone over residential environment: first case.

Case Studies: Ozone (O_3) Simulation

Three cases were studied using the HYSPLIT model. These cases were selected because of the high O_3 concentration were observe at the site location mentioned earlier. Using the HYSPLIT model with back trajectory technique to determine the point source of the origin of O_3 high rate concentration at the site location. The hourly of O_3 was observed to be at high rate more than 0.1 ppm.

The first case was on the 5th of February 2008, which is shown in Fig. 7. The hourly average started to increase early in the morning where an hourly average of higher rate observed at 12:00 and 13:00 with 0.1 ppm then continue with an hourly average of 0.03 ppm through the rest of the day**.** Therefore the initial time of the run was set at 12:00 UTC which is 15:00 KST. The ending time of the model simulation is 00:00 UTC which is 03:00 KST. Fig. 8 shows the O_3 over residential environment, where the plumes is pointing to Alsubia power station at the north easterly tip of Kuwait bay. Furthermore, Fig. 8 shows the 6 hours back trajectory starting at 12:00

UTC and ending 6:00 UTC. It is also evident that the origin of source is same source mentioned above.

The second case was on the 6th of August 2008, which is shown in Fig. 9. The hourly average was at normal rate in during night time at 0.04 ppm then it started to increase to 0.08 ppm a moderate rate from 10:00 in the morning till 14:00 in the afternoon**.** Then the rate drops down to 0.05 and attains that rate till the rest of the day. Therefore the initial time of the run was set at 12:00 UTC which is 15:00 KST. The ending time of the run is 00:00 UTC which is 03:00 KST. The O_3 over residential environment is shown in Fig. 10, where the plume is pointing to ALDOHA power station. Moreover, Fig. 10 shows the 3 hours back trajectory starting at 12:00 UTC and ending 6:00 UTC. It is also evident that the origin of source is same source mentioned above. It is important to note that during the summer the days are longer than night, thus more heat and more sunlight generate more surface ozone, beside that the power station is at its maximum capacity from using air condition at summer time indoors which yield to more emission of NOx VOC in the atmosphere. As a result the emission is a continuous possesses through the night time, and with the sun rises the process producing the surface ozone starts early.

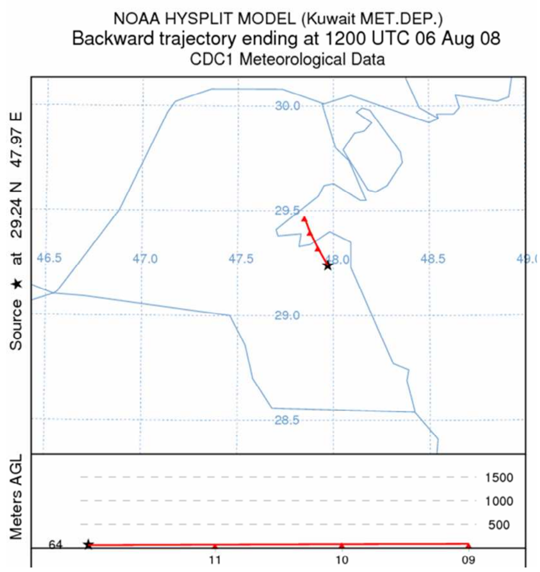

Fig. 9: Back trajectory result: second case

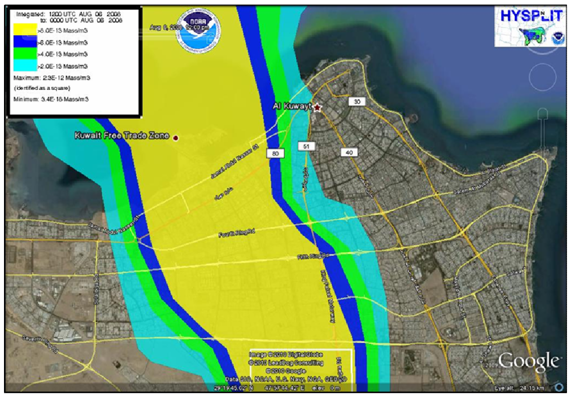

Fig. 10: Surface ozone over residential environment: Second case

The third case was on the 17th of February 2009 which is shown in Fig. 11. This case was really a phenomenal, it shows really very high rates of hourly averages of surface ozone. Most of the hourly averages are higher than 0.1 ppm which is a very high rate. During night time the rate was 0.15 ppm at midnight, then it start to increase significantly to 0.31 ppm at 10:00 in the morning. After that started to drop down in the afternoon, but attain an hourly average of 0.17 ppm**.** Therefore the initial time of the run was set at 12:00 UTC which is 15:00 KST. The ending time of the run is 00:00 UTC which is 03:00 KST. The O_3 over residential environment is shown in Fig. 12, where the plume is pointing to ALMAQWA site used by Kuwait Oil Company for oil flaring. The site is very close from Kuwait Airport at the southern direction.

Moreover, Fig. 12 shows the 3 hours back trajectory starting at 12:00 UTC and ending 6:00 UTC. It is also evident that the origin of source is same source mentioned above. It is not typical to have a high rate of O_3 during night time, because the source of the heat does not exist. In this case the source of heat is the flares that trigger the process to produce surface ozone at the site and disperse it to the observation site. Thus, the industrial process especially crude oil flaring can cause an intense rate of surface O_3.

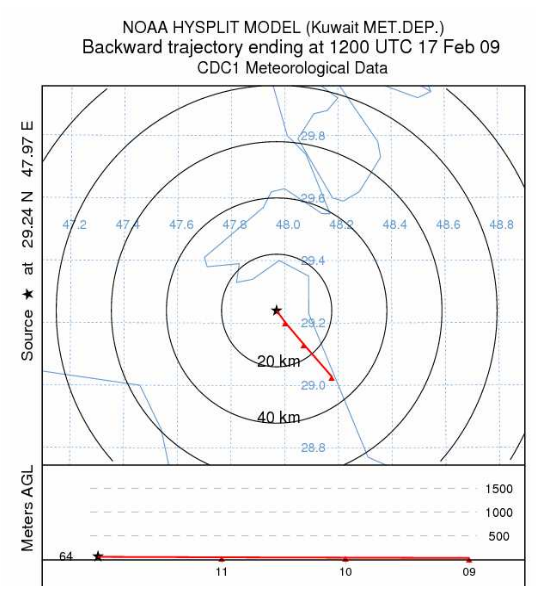

Fig. 11: Back trajectory result: third case

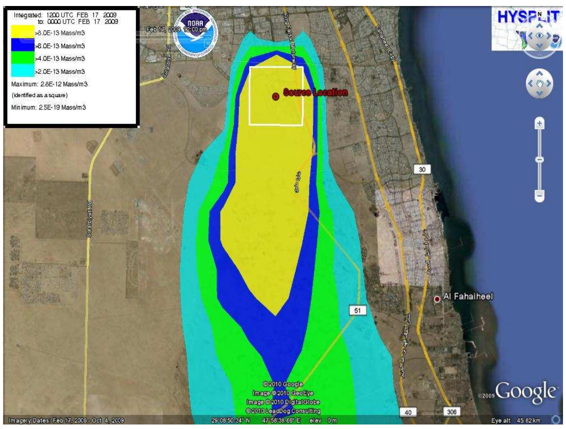

Fig. 12: Surface ozone over residential environment: Third case

CONCLUSION

The surface O_3 measurements at Kuwait international airport during over period February 2008 – April 2010 were presented in the present work. Assessment of surface O_3 was performed using back trajectory method based on HYSPLIT model via three case studies. The results show that the range of O_3 concentration was under air quality standard. The correlation of the O_3 concentration indicate a medium with temperature, a fairly with visibility and relative humidity, and a week with wind speed. Diurnal variation shows that maximum O_3 concentration was at the noon (12 pm -6 pm) and minimum about in the evening. The O_3 concentration begins to increase in the morning and attains its maximum level at noon. Low O_3 concentrations found at the night. Seasonal variation shows that February is a highest rate of concentration Surface O_3 generated during the summer season. A major point source for O_3 precursors was from ALDOHA power station in the night and from Alsubia power station in the morning.

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الملخص العربي

تقييم الأوزون السطحي على البيئات السكنية

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أصبح الأوزون السطحي (O_3) أحد أهم موضوعات أبحاث جودة الهواء وتغير المناخ في البيئة الحضرية. وذلك لأنه يتسبب في آثار ضارة على صحة الإنسان والمناخ والغطاء النباتي والمواد. لهذه الأسباب، فمن الضروري فهم العمليات التي تتحكم في أصل O_3 واتجاهات O_3 وتوزيع O_3 واثأر O_3. ولهذا في البحث الحالي، يتم دراسة تركيز O_3 عمليا وعدديا على البيئة السكنية. عمليا تم قياس O_3 باستخدام أجهزة استشعار الأشعة فوق البنفسجية المرئية (محلل الأشعة فوق البنفسجية الأوزون) خلال الفترة ٢٠٠٨–٢٠١٠ في مطار الكويت الدولي. و عدديا تم استخدام طريقة المسار الخلفي على أساس نموذج HYSPLIT لتقييم السطح O_3 على البيئة السكنية. وقد تم تحليل التغيرات النهارية، والموسمية للأوزون السطحي ومناقشتها. وعلاوة على ذلك، تم أيضا تحليل تأثير الأحوال الجوية على O_3. وأظهرت النتائج التباين في تركيز الأوزون حيث يظهر أقصى تركيز للأوزون في الظهر والحد الأدنى للتركيز في المساء. ويظهر التفاوت الموسمي الأعلى معدل لتركيز O_3 في فبراير. وأظهرت النتائج انه يوجد علاقة قوية للأوزون مع درجة الحرارة ومع سرعة الرياح. وأن محطات الكهرباء تكون المصدر الرئيسي للأوزون.
