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EFFECT OF DAYTIME AND NOCTURNAL BOUNDARY LAYERS HEIGHT ON SOME POLLUTANT GASES PROFILE OVER BAGHDAD CITY, IRAQ

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Abstract

Boundary layer height played an important role in the vertical diffusion of the pollutants .In this research total carbon monoxide column concentration data TCCO, boundary layer height (in meter) (BLH) is consider to study relationship between it. Data taken from (European-Centre for-Medium Range-Weather-Forecasts) (ECMWF) at lat. 33.34 and long. 44.44 (degree) this Situated near the middle of Baghdad city at 8 hours (00,03,06,09,12,15,18,21) from every day for years (2003-2012). The MATLAB program was used to convert data formula from NetCDF (network Common Data Form) nc. File format to excel file. Correlation between boundary layer height (BLH) in (meter) and TCCO concentration column in (Kg/m^2) is accomplished, and consequences display correlation between this column gas and BLH. Two cases were used to find this relationship, First, the daily behaviour, and results show the BLH is low while the CO is high, and gradually decreases to lowest value about (0.67 Kg/m^2) at the hour 12 , when the BLH is at its maximum value (4975 m), then it decreases at night, where TCCO concentration increases. In Second fallouts, monthly and seasonal outlines are consequential and results show that during winter the BLH decrease, the CO concentration reaches its maximum value in February is (1.42 Kg/m^2), and then decrease during March to October until it reaches the lowest value (0.6009 Kg/m^2) during 2012 and increase during October to December, while the BLH is the maximum in May (4991m) in 2008 and gradually decreasing to December. The vital of this revision fundamentally situated in valuation airborne quality of Baghdad city, results show not direct relation between TCCO and BLH, because photochemical reaction in upper atmosphere.

Keywords **:** Boundary layer height (BLH), CO concentration column TCCO, linear regressions, ECMWF

Introduction

The study of the boundary layer height BLH occupies a special importance in many countries of the world, especially the industrial ones, due to their significant impact on public health and human safety. Therefore, many weather and climate scientists wanted to research on the BLH and its relationship with the increasing the atmospheric pollutants concentrations near to the earth surface and study of its other climatic characteristics, and the relationship of all of that to the atmospheric general cycle (Habeebullah, 2013). The atmospheric boundary layer is the bottom part of the troposphere where the earth's surface relates with the large scale atmospheric flow. BLH is a important parameter that is needed as input for the guess of pollutant concentrations, weather prediction and climate models (Lee, 2018). The BLH and its properties are influenced by different climatic factors such as wind, temperature, and solar radiation, amount of clouds, air turbulence and surface nature (Du, Chuanli *et al*., 2013). Diffusion and transference of lower atmospheric pollutant governed largely on the local planetary boundary layer (PBL) structure. Planetary boundary layer height (PBLH) is one of the important factors disturbing pollution concentration and large scale transport (Du *et al*., 2013).The boundary layer BL in high pressure regions over land consists of three major parts: a very turbulent mixed layer; a less turbulent residual layer containing former mixed-layer air; and a nocturnal stable boundary layer of random turbulence (Lee, 2018). Air pollution summary to the air substances, particulates, or organic materials such as gases (CO_2, CO, SO_2, NO, CH_4, CFC, etc.), that produced primarily by the incomplete burning of fossil fuels, for example by cars and other gasoline powered engines (Friedlander, 1973). This study concentrated on CO_X gases pollutants and compared with BLH through the daily time 24 hours. CO concentration consider one of the greatest significant trace smokes emitted from anthropogenic contamination and biomass burning, moreover, CO was familiar as an essential secondary greenhouse gas that could have an effect on worldwide climate with a quite long life time, Carbon monoxide (CO) is a poisonous gas, formed when carbon in fuel is not burned completely (Talbot, Robert, Huiting Mao, and Barkley Sive. 2005).the other CO_X family is CO_2, its a nonpoisonous gas, but consider now, unambiguously, warmed the Earth. According to the Stefan-Boltzmann, CO_2 gas, has a very strong absorption band at ~12-15μm, very close to the peak of the Earth's blackbody radiation, where trapping outgoing IR radiation (Osama *et al*., 2016). In Iraq there are many studies deal with Boundary Layer Height BLH, but relation with some pollutants concentrations is very few or not found. for example, Ahmed F. Hassoon used data of carbon monoxide column concentration from ECMWF, and compared with other elements included Boundary Layer Height (BLH) in meter, sensible heat flux (SSLHF) in units ($J.s/m^2$), over Basra province (Iraq) at every 3 hour 00, 03, 06, 09, 12, 15, 18, 21 and at four months (Jan, April, July, Oct.) from 2012. The statically simple linear regression and multiple linear regression is reported between them, in simple linear regression the effect of CO is don't clear specifically at months Jan and Oct., while in the April and July the correlation is significant specifically at BLH SSLHF at July. Where the simple correlation coefficient have values 0.482 and 0.44 respectively. Fattah A.Hassoon et. al. also study the distribution of (Total- Column- Carbon-Monoxide) (TCCO) gas in unit Kg/m^2 from (ECMWF) over Iraq and the surrounding regions, The study area consists of 961 grid points, MATLAB program was used to analyze and scheme spatial analysis data. The analyzed data of the southern and the middle parts of Iraq (Baghdad and Basra) were in consistence with the general seasonal cycle of TCCO in the Northern Hemisphere. Study exhibit a important improvement in winter and spring and small values of TCCO

in summer season (Hassoon, Ahmed Fattah, Firas Sabeeh Basheer, and Thaer Obaid Roomi. 2019).

The study, is an attempt to determination the basic effect of the boundary layer height on the COx concentration through long period by ECMWF and also from surface measurement stations; realize relation between boundary layer height (BLH) and concentrations of co and columns of TCCO and also CO_2 concentration measured instantaneously . The study comprised evaluated seasonally, monthly and daily, calculate BLH by paratrazation of hourly boundary layer height and pollutant concentration from CO_X recorded also concern.

Location and Data organizing

Location study is consist of two stations, every station used specified method in obtain BLH and CO_X pollutant.

The first station located in center of Baghdad city at a square area containing latitude and longitude 33.32^0, 44.04^0, respectively. Data of this station is from ECMWF, (https://www.ecmwf.int/), where data is re-analyzed using model Monitoring Atmospheric composition and Climate (MACC) from website (https://apps.ecmwf.int/ datasets/ data/macc-reanalysis/levtype=sfc/) there is many steps to select time period and parameters used, the most accurate spatial resolution is 0.125*0.125 degree latitude, while time interval is every 3 hours. Almost every parameter such as total column of CO concentration TCCO and boundary layer height BLH is download by NC file and transformed to axel file extension through built up matlab program , see figure 1

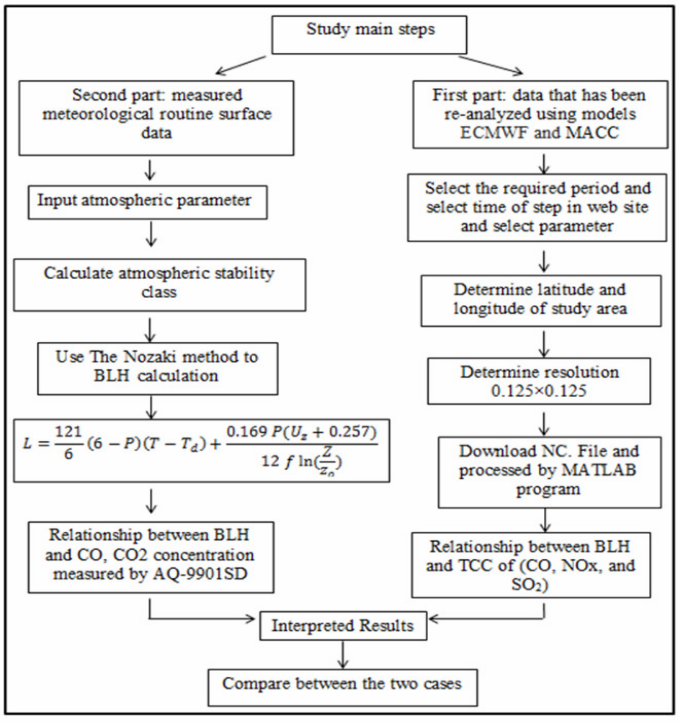


Fig. 1 : Flow chart and summery of data processing at this study

The second location study is consider as land surface station installed at height 6m above ground, at north area of Baghdad city (Al-Hurra town), that consider as residential region. The data measured by AQ-990SD device , this recorded CO, CO_2 and atmospheric parameter (temperature , relative humidity , dew point) by connected sensors every 15min, see figure 2. Paramatrization atmospheric element by Nozaki method is used to calculate boundary layer height BLH.

The period of measuring by this method continuous to about 32 different days, through the months April, May, July and August from 2015.

The difference between two data methods is also compared at this study, to exposure important of BLH in dispersion concentration gases, this case may be review in paragraph results and discussion.

Fig. 2: Air Quality Meter Device AQ-9901SD from LATRON CO

Materials and Methods

MACC Project Model

A research project (Monitoring-Atmospheric-Composition-and-Climate) (MACC) aim to creating the global and regional atmospheric environmental facilities for the European. MACC constructed on the prototype projects Global and regional Earthsystem Observing using Satellite and in-situ data, The project joint state of the skill atmospheric modelling with earth observation data to provide information facilities cover European air quality, global atmospheric conformation, climate, and UV and solar energy. The global model and data adjustment system used in MACC was grounded on (ECMWF) and Integrated Forecast System (IFS). MACC was to association of atmospheric composition data with a arithmetic model and data adaptation system to produce a reanalysis of atmospheric structure. The sensitive gases that were comprised as IFS model variables in the MACC reanalysis were (ozone) O_3, (carbon monoxide) CO, (nitrogen oxides) NOx, and (formaldehyde) HCHO. These four gases were designated in model, because they performance a key part in the contact of the atmosphere and have been measured by spaceborne implements with adequate density (Inness *et al*., 2013). This model used in this study to obtain (carbon monoxide) CO gas, as one of two method adopted.

Nozaki Model

Nozaki proposed an experimental model for estimating mixing heights. The model assumes that mixing heights result from the joint action of thermal and mechanical turbulence on the atmosphere, and there exists a potential connection and feedback effect between atmospheric movement and ground-level meteorological parameters.

The Nozaki empirical BLH determination method is based on routine surface meteorological observations for various Pasquill (1961) stability classifications. Pasquill (1961) classified the atmospheric stability into six classes from A to F in terms of increasing order from very unstable (A), moderately unstable (B), slightly unstable (C), neutral

(D), slightly stable (E), to moderately stable (F). The presence of class A indicates strong mixing whereas E or F gives rise to poor dispersion. Unstable conditions promote rapid dispersion of atmospheric contaminants and result in lower air concentrations compared with stable conditions. The atmospheric stability class is determined according to solar radiation calculated by solar altitude, cloud cover, and wind speed. The Nozaki BLH calculation method is as follows (Du, Chuanli *et al.,* 2013) :

$$BLH = \frac{121}{6}(6-P)(T-T_d) + \frac{0.169\,P(U_z+0.257)}{12\,f\ln\left(\frac{Z}{z_o}\right)} \quad \ldots\ldots\ldots(1)$$

$$f = 2\Omega\sin\varphi \quad \ldots(2)$$

where the BLH in (meter), P is the Pasquill stability level (Schnelle, Karl B., and Partha R. Dey 2000), value is 1-6 for A-F stability class, T is the surface air temperature, T_d is the surface air dew-point temperature, U_z is the measured mean wind velocity (m/s) at the height Z (Z=10 m), *f* is the Coriolis parameter (s^{-1}). Z_o is surface roughness length (1.4 m in this study) (Al-Draj, Aqeel G., and Monim H. Al-Jiboori. 2010), Ω is the (7.3×10^{-5} rad/s), and φ is the latitude (Du, Chuanli *et al.,* 2013).

Daytime Convective Mixed layer

Mixing layer height is the height up to which atmospheric properties or resources initiating from the surface are disconnected by turbulent vertical mixing events. The mixing layer if it is existing it will a part of the atmospheric boundary layer. Consequently, the mixing layer height is usually lighter than the boundary layer The detection of it must distinguish between the mixing layer height z_i, and the boundary layer height MLH, (Emeis, Stefan. 2010). The progression of the mixing layer is correlated to the solar heating of the earth's surface, In the afternoon the consequential turbulence tends to be combination heat, humidity and momentum vertically and recurrently (Oke, Timothy, 2002). The mixing layer (ML) develops shortly after sunrise. At the upper the ML is controlled by the stable layer called entrainment zone . entrainment layer formulas a conversion zone after that transform to free atmosphere (FA) above. Through the entrainment layer, warm air is expanded from above into the ML (entrainment). counteracting process air, transformed from the mixed layer and enters into the stable FA in the form of thermals (Hennemuth and Lammert, 2006) (Oke, Timothy 2002). In this study boundary layer recorded at daytime consider as height of convective mixed layer.

Nocturnal Boundary layers

A stable boundary layer (SBL) starts to advance shortly before sunset, since the longwave radiative cooling near surface temperature inversion is formed (Hennemuth and Lammert, 2006). The depth of the SBL is defined as the height where turbulence intensity is a small fraction of its surface value (Stull, 2012). This layer is created as a response to radiative cooling during the night and the residual layer becomes the stable layer as a result of direct contact with the Earth's surface. The vertical movement is negligible in this layer but horizontal direction is active. In this study boundary layer height BLH at night time consider as nocturnal boundary layer height.

Carbon gases family (COx)

One of the important carbon gases family is Carbon monoxide, its a colorful, odorless gas, at high levels it consider, a toxic gas, it formed when oil is not burned completely. Carbon monoxide active quandaries to hemoglobin in red blood cells in quickness, dropping their ability to transportation and liberation oxygen throughout the body, causing central apprehensive system damage or death. while Low contacts can amplify cardiac complaints (Meetham, Alfred Roger 1981). It is a component of petrol-powered vehicle consume, which contributes about 60 percentage of all CO emissions general. In metropolises, most of 95 percent of all CO emissions may come from vehicle exhaust, Other sources of CO releases include manufacturing processes, non-transportation fuel ignition, and natural foundations such as wildfires. Ultimate CO concentrations naturally occur during the colder months of the year when CO automobile discharges are greater and at nighttime inversion conditions (where air pollutants are confined near the ground underneath a layer of warm air) this more frequent (Talbot *et al*., 2005; Inness, *et al*. 2013). on other hand CO_2 consider as retaining gas for radiation energy, thus Without CO_2 the Earth will be unbearably cold, but its elevated levels, cause temperatures to rise, leading to what is known as global warming. Carbon dioxide is released into the atmosphere from natural processes such as breathing, volcanic eruptions, in addition to various human activities such as deforestation and burning of fuel immediately. Roughly half the emitted CO_2 remains in the atmosphere and the other half goes into two sinks: oceans and biosphere (include plants and soil carbon) (Kalogirou, 2009). These gases implemented in this study by many different tools, such as direct measure or from satellite and numerical analysis, with larger period extend to half a decade.

Linear Correlation and Regression

Many statistics element can used to Describe the relationship between several variable such as mean values of the hourly data for months that represent the seasons in Iraq and in Baghdad province for air quality concentration and also boundary layer height BLH at daytime and nighttime. Personal correlation is one of the statistics element used to examine the influence of change in Boundary layer height on the COx concentration according to formula (Falkoni, Anamarija, and Goran Krajačić. 2016):

$$r = \frac{\sum_{i=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\left(\sum_{i=1}^{n}[(x-\bar{x}])\right)2}\sqrt{\left(\sum_{i=1}^{n}[(x-\bar{x}])\right)2}} \quad \ldots(3)$$

Where : r correlation coefficient

x = independent variable

y= dependent variable

$\bar{x}$ = average of x

$\bar{y}$ = *averages* of y

If two variables, one is independent x and the other is dependent y, so, the relation ratio of x and y can be represented by the straight line equation. (Perugu, Mallikarjuna, Aruna Jyothy Singam, and Chandra Sekhar Reddy Kamasani 2013), taken as:

$$Y = a + bx \quad \ldots(4)$$

This relationship were examined, COx concentration consider as dependent variable and the BLH boundary layer height represent the independent variable. This enables us to identify the degree and nature of relationship which exists between them, Where a and b are constants. The constant a is the rate of y when x = 0 is called the point of intersection of the regression line of the main axis y, the constant b is the slope of the gradient line and is sometimes named the regression coefficient y on x and is defined as the rate of change in y when the value of x changes one unit.

Result and Discussion

Results of this study divided to two parts according to method used to obtain data elements, thus data in this study divided to reanalysis data by ECMWF from MACC model, where BLH and COX pollutant is readily to plotting and obtain expected results.

The second one from empirical model depend on the Nozaki paramatrization method that depend on the routine atmospheric data to calculate BLH, while Cox is directly measured, all this can be explain in next paragraph.

First Part: MACC Model by ECMWF:

Time Series

Time series is very important case, because it show the behavior of all data, with the time. In this study hourly data for BLH and TCCO were plotted every 3 hours through the years from 2003 to 2012, figure 3. Figure 3 show trend of TCCO that have wavey figure shape, and dispersion TCCO data about wavey line is less than that founded in disperted grid points in BLH. The trend TCCO values very large in first month of every year, but depress to less value in the last month from every year,(autumn months), see figure 3, TCCO plotted values. Most large hourly values in BLH concentrated at the hottest month of summer season for every year, see figure 3, BLH plotted values.

Table 1, show also the maximum and minimum values for TCCO and BLH at every month for the ten study years (2003-2012). Most minimum hourly values for BLH concentrated in the midnight and at winter season month. While maximum hourly value is founded in noon at 12 UTM nearly for every year. The case is different in TCCO where most minimum values concentrated at noontime and at summer months, while maximum hourly value in midnight at hours (0-3) UTM, and at winter month, but there is some abnormal recorded in some years, see table 1, (Parts values TCCO).

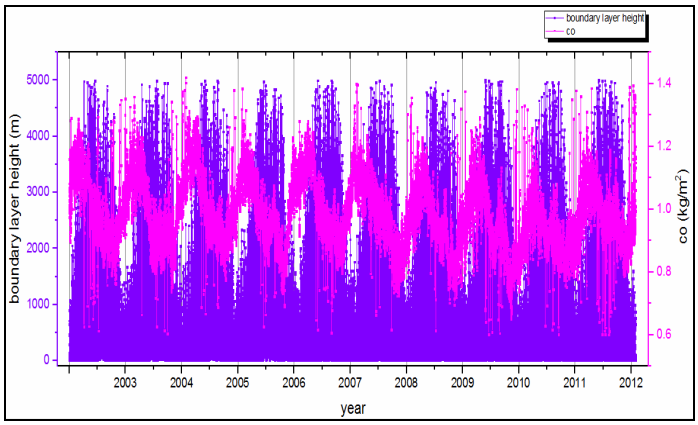


Fig. 3 : Time series of boundary layer height (BLH) and (TCCO) columns concentration for the period (2003-2012).

Table 1: Maximum and minimum hourly values for TCCO and BLH for Years (2003-2012).

Year	BLH (meter)						TCCO (kg/m^2)					
	Min.	date	hour	Max.	date	hour	Min	date	hour	Max.	Date	hour
2003	10.36	26-Dec	0	4985.7	16-Jun	15	0.61298	7-Jul	12	1.35157	28-Dec	3
2004	10.21	30-Dec	0	4990.7	17-Jul	12	0.60525	24-Sep	12	1.37464	31-Dec	0
2005	10.49	14-Jan	18	4985.4	13-Aug	12	0.66753	27-May	12	1.4202	22-Jan	3
2006	10.16	12-Feb	3	4977.5	6-Jul	12	0.62581	7-Jun	12	1.38421	20-Jan	0
2007	10.32	25-Jan	3	4996.4	18-Aug	12	0.60618	18-Aug	12	1.28095	25-Jan	0
2008	10.15	2-Feb	3	4991.7	23-Jun	12	0.61623	8-Sep	12	1.39897	27-Jan	3
2009	10.38	16-Jan	18	4969.2	21-Jun	12	0.61521	21-Jun	12	1.37535	29-Dec	0
2010	10.3	23-Nov	3	4999.4	7-May	12	0.60254	30-May	15	1.3824	27-Nov	3
2011	10.18	13-Feb	3	4966.6	8-Jun	12	0.6019	23-Aug	12	1.37818	15-Dec	3
2012	10.3	15-Dec	3	4999.5	6-May	12	0.60092	12-Jul	12	1.39428	16-Dec	18

Relationship Between BLH and TCCO concentration

Daytime and Nighttime

Time is very important factor because daytime boundary layer and nocturnal layer is controlled by this factor, see paragraph 3.3 and 3.4. the aim of this study is test the BLH constructed at daytime and nighttime and test its effect on concentration of same trace gases TCCO in this study. But time duration for day and night hours change according to the season from the year and because the interval period is 3hours, thus hourly values don't available, thus daytime hours included the hours 6, 9, 15,18 at summer months and hours 9,15 some times in winter month, overall the case is reverse at winter months, this depend on the the solar height angle . figure 2.a show the TCCO and BLH at daytime, in this period most BLH values is relatively high, and there is indirect relation with TCCO. Figure 2b the case change where the values of BLH have small values in most hours of night, this most be return to disappear the activity of the convection.

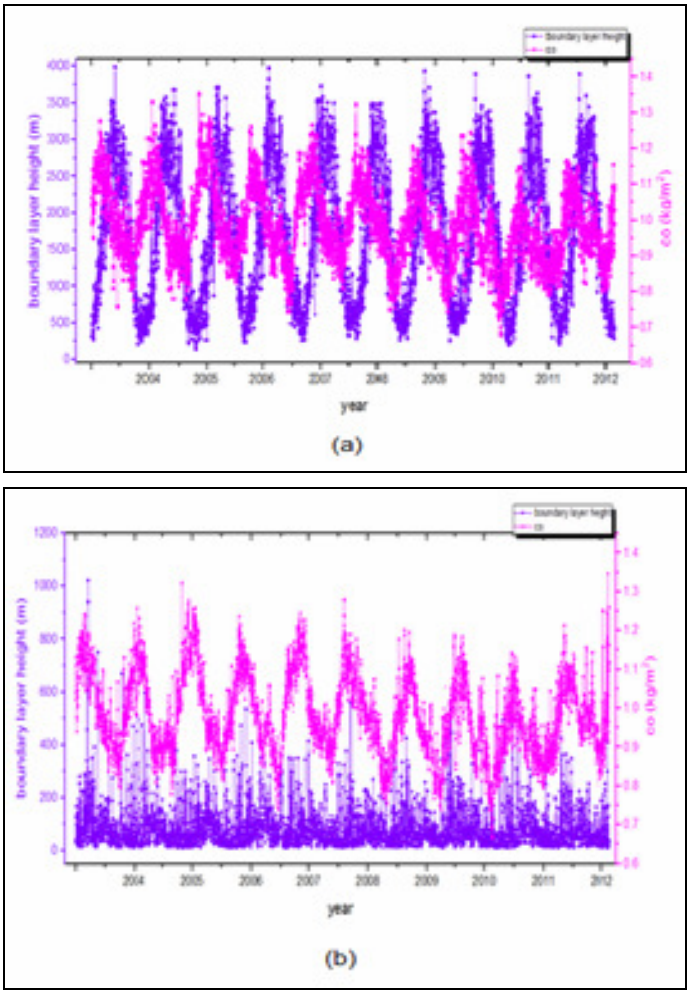


Fig. 4 : Hourly data for BLH and TCCO through (2003-2012) (a) daytime, (b) night time.

An example of the daily change through one day selected a day 26 of July of 2012 for the time (00, 03, 06, 09, 12, 15, 18, and 21) UTC. Not that the inverse relationship between the CO concentration and BLH where at time 0, 3, 6 and 9 the CO concentration is high and BLH is low, and is taken gradually increasing from 6 hour until the maximum (4975m) at 12 hour, while the CO concentration is at the minimum (0.673kg/m^2) and increases gradually while remain values high during the night when the BLH decreases gradually at 15 hour until it reaches the lowest value at 21 hour, figure 5.

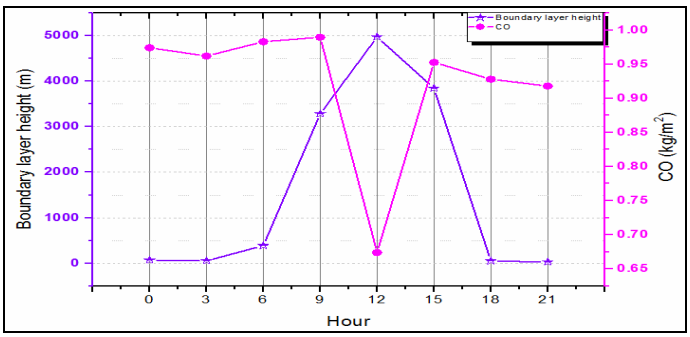


Fig. 5 : Hourly variation of BLH and (TCCO) columns concentration during day 26 July 2012

Monthly and Seasonally

To expose and examine the affiliation between BLH and TCCO concentration, monthly averages archived from ECMWF, that resulted from hourly data and plotted in the same period, see figure 6. This crucial to evaluated the consequence of BHL on TCCO concentration that dispersed in air. For example (2003), from January to February, where BHL is decreased, TCCO is at higher levels, while from March to May, there is decreases in TCCO concentration With increases boundary layer height, the case is continues from June to August where TCCO concentration reductions with increases of boundary layer height, from August to December, the boundary layer height gradually declines until it touches the lowest value in December, while the concentration of TCCO remains to reductions until it spreads the lowest value in October and then growths, as shown in figure 7 .

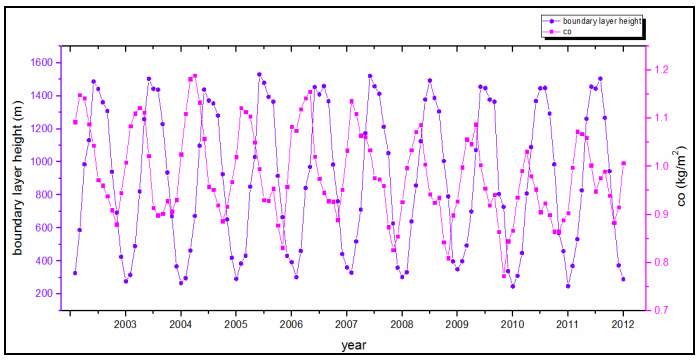


Fig. 6 : Monthly average of BLH and (TCCO) concentration for the period (2003-2012).

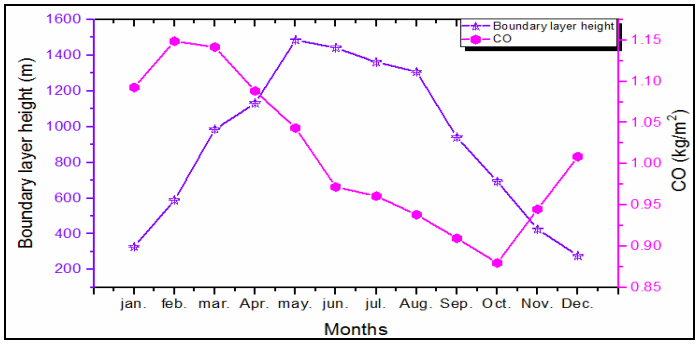


Fig. 7 : Monthly average of BLH and (TCCO) concentration for the year (2003).

Also; plotted seasonal averages of TCCO concentration (kg/m^2) that archived from ECMWF and at duration (2003-2012), with seasonal averages of boundary layer height (BHL) (in meter) in the same period, see figer-8

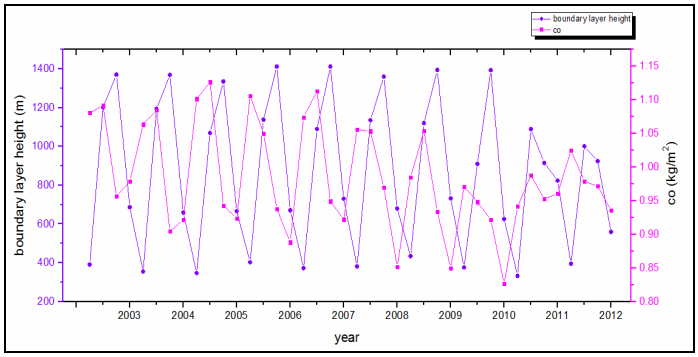


Fig. 8 : Seasonally average of BLH and (TCCO) concentration for the period (2003-2012).

Seasonal data resulted from hourly TCCO and BLH at about ten years, is the best to represent the relationship between convective daytime layer and nocturnal layer in one hand and TCCO in otherhand, this retain to nature of convective boundary layer domain in summer time. In winter season most the frequent domain is nocturnal layer. the events of hours through the day (daytime, nighttime) is almost frequent at the year, through the summer and winter.

Thus study relationship between BLH and TCCO for Baghdad city is very really good through the seasonal data. Correlation coefficient applied according to equation 3, 4 and equation resulted can implemented to represent the case.

Table 2, lists the constants a, b resulted from this relationship, this constants represent the slope and intercept, table 2, also contains the Adj-R square to represent the normal relation. Overall the relation is weak In particular in winter season, this case retain to that TCCO may be not effected totally by BLH, and there is other element. Consequently, TCCO represent the column of CO that extended to 12km and not the BLH height that extend to about 3-5 km above ground in the some convective cases. TCCO also may effected by upper layer to change its concentration and depend in fist one on the photochemical reaction, that may be change its concentration according to day from the year and the amount of solar radiation transmitted.

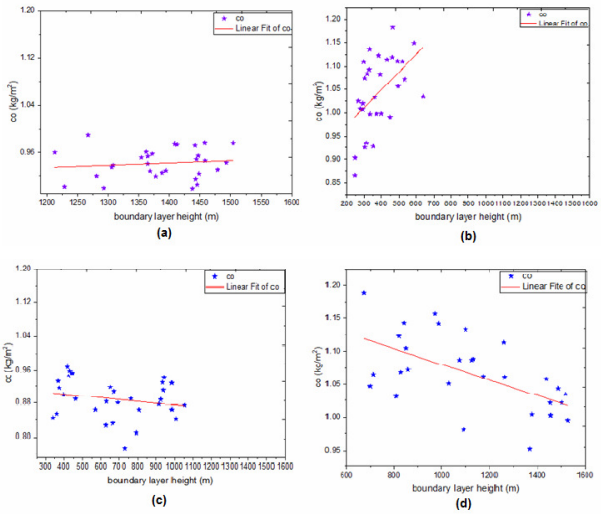
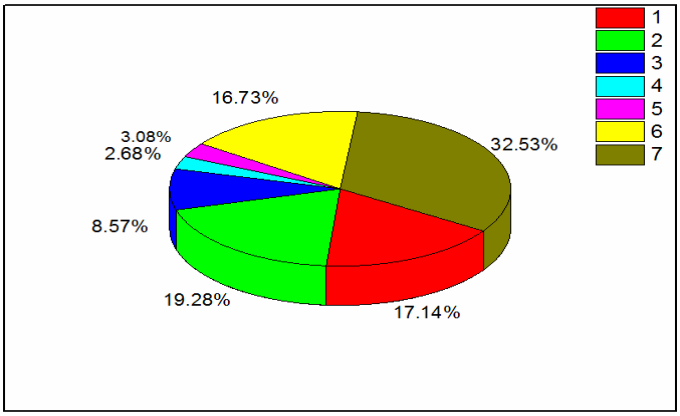


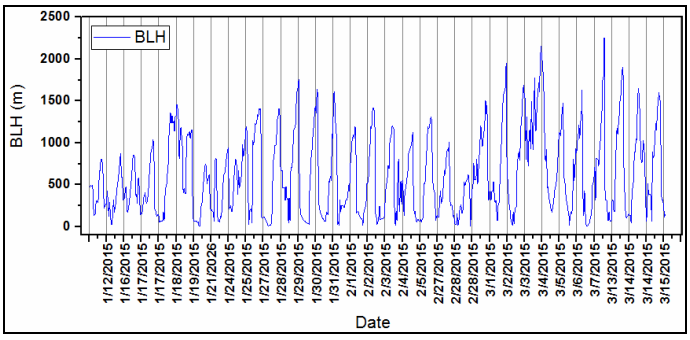
Fig. 8 : Linear Correlation and Regression (R) between CO concentration column and BLH at four seasons for the period (2003-2012). (a) Summer (b) winter (c) autumn (d) spring.

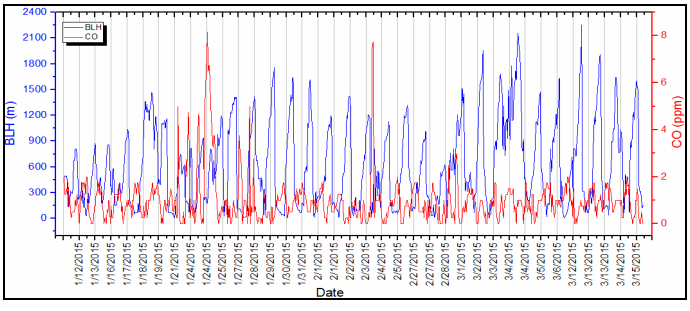
Table 2: Linear Correlation and Regression (R) between CO concentration column and BLH at four seasons for the period (2003-2012) .

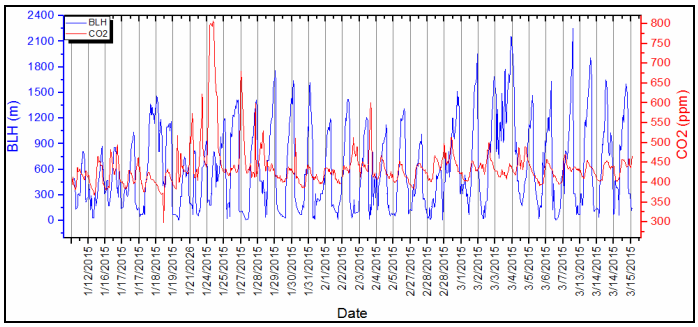
	Slope	Intercept	Equation	Adj. R-Square
(a) Summer	3.9E-5	0.88695	CO=0.8+3.936E-5(BLH)	-0.02078
(b)Winter	3.7E-4	1.03469	CO=1.03+3.79416E-4 (BLH)	0.22313
(c) autumn	-4.2E-5	0.91684	CO=0.9-4.21823E-5 (BLH)	0.0113
(d) spring	-1.2E-4	1.19858	CO=1.1-1.18708E-4 (BLH)	0.32834

Second Part: Empirical Parametrazation by Nozaki Model









Conclusion

This revision was an work to represent a pattern to regulate the effect the boundary layer height on the pollutant gasses especially CO concentration columns using ECMWF. The data was processed by MATLAB, taking daily, monthly, and seasonally averages and a time series was draw for the period (2003-2012), this data trends used to find a empirical equation for each of boundary layer height and CO concentration column.

1. Results show the carbon monoxide, the monthly values were higher during winter and the beginning of spring, the highest value during the first years (2005, 2008), and less during the autumn during the first years (2011, 2012), the daily showed that the relationship is opposite between CO concentration column and boundary layer height, BLH is the maximum at time 12, while the CO concentration is at the minimum.

2. The high CO concentration is due to the combustion of the partial gasoline in the engines of the old cars as the age of the engine and the quality of gasoline has major effects in the CO concentration. And the results show the inverse relationship between the CO concentration and

BLH in the summer while in the spring is nothing while in winter and autumn the relationship is weak.

3. The results also revealed that correlation between the spread of CO concentration and the industrial, residential and commercial activities of the different land uses, and have high amount of anthropogenic activity that is due to the emission of large amount of pollutant concentration from the vehicles and electric generated specially there is high needed to electricity at this period, overall this is don't effected greatly to the values of the TCCO.

4. Although in basic physics there is direct effect of the high convection that represented by the BLH on the pollutant specifically on the TCCO, But the photochemical interaction effected greatly on the observed values of the TCCO, thus may be clear from the trend wave of the track of the line averages of the TCCO values.

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