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Controls on air pollution over a semi-enclosed basin, Tehran: A synoptic climatological approach

A. R. Saadatabadi[1]*, L. Mohammadian[2] and A. Vazifeh[3]

[1]*Atmospheric Science & Meteorological Research Center, Tehran, Iran*
[2, 3]*Forecasting Department, Meteorological Organization, Tehran, Iran*
E-mails: aranjbar@gmail.com, le_mohammadian@yahoo.com & vazife@gmail.com

Abstract

In this study, a new array of meteorological elements and a synoptic climatologic classification to produce a baseline climate and to derive meteorological factors that are effective on air pollution in Tehran, which is located in a semi-enclosed basin was developed. The data set includes daily sea-level pressure and 500mb geopotential height fields from NCEP-NCAR and Tehran upper air sounding data at 00:00UTC for six months (July-December) of every year in the period 2001-2006. The classification is done through the principal component analysis (PCA) of data from the upper-air station. The results show that three meteorological factors are effective on variations of the Carbon Monoxide (CO) concentrations in the complicated terrain of Tehran basin. Thickness variations of different pressure layers (especially 850mb-700mb), Total totals index (TT) and surface wind speed are the most important dependent variables of these factors. Examination of the Carbon Monoxide (CO) pollution levels in Tehran, where emission sources are high shows that the synoptic classification identifies the patterns that are conducive to high pollution and those that are conducive to low pollutants build up in the basin. The synoptic climatology of events associated with five categories of CO concentrations show the role of synoptic forcings on decreasing CO concentrations. On the other hand, the role of high and thermal low pressure patterns in producing sever polluted episodes in the basin is also shown. These events occurred exclusively under special synoptic situations with high pressure developing on the airflow entrance of the basin and a thermal low pressure on the leeward side of the mountainous region. The coupled pressure system inducing horizontal pressure gradient produces a low level southerly cross wind toward the mountain barrier.

***Keywords**:* Meteorological classification; synoptic climatologic approach; air pollution episode; Semi-enclosed basin; Tehran

1. Introduction

Urbanization, industrialization and population growth have brought about the air pollution problem for residents of megacities. Tehran historical air pollution data indicates increased levels of pollution during recent years. For the millions of motor vehicles jammed in the heavy traffic and due to the large number of houses and industry units in the city and its suburbs, the consumption of fossil fuels is high.

Regarding the above-mentioned reasons, in recent decades as a result of the increasing concentration and related public importance, some studies on Tehran air pollution by synoptic meteorology/statistic approach and case studies of numerical simulations have been carried out. [1-6]. Alijani [7] has studied the relation between pressure and air pollution concentration in Tehran by applying a statistical approach. He has reported that there is a positive correlation between pressure and CO level in Tehran and using the NCEP-NCAR reanalysis, has defined 6 categories of polluted episodes in Tehran. Safavi & Alijani [8] investigated the role of geographical elements on air pollution in Tehran, and reported that these elements are very effective in air pollution and the prevalence of high pressure systems in winter indicate the stability of the atmosphere.

In general, experiments show that variations of physical and dynamical specification of atmospheric systems have a very significant role on air pollution concentrations in the city. Surface wind and vertical temperature gradients are very important in horizontal and vertical dispersion of pollutants [9]. Previous studies have reemphasized the role of the stability of the atmospheric surfac layer in controlling the dispersion of primary pollutants in and around urban areas [10, 11].

Meteorological conditions affect air pollution in numerous ways. However, the most important role of weather is in the dispersion, transformation and removal of air pollutants from the atmosphere.

*Corresponding author
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Study of the relationship between air pollution with individual meteorological variables may be misleading as they do not account for the interrelation between the variables, while air pollutant levels normally respond to all meteorological variables collectively representing an air mass [12]. The synoptic climatologic methodology combines meteorological variables into groups, which represent the macro scale synoptic situations at a time moment, and hence may be able to overcome this shortcoming [13, 14]. This approach is commonly used to analyze impacts of weather and climate on air pollution [15-24].

Christian and Brayson [25], to determine relations of atmospheric systems with air pollution introduced a multi variation statistical classification method based on a combination of PCA and the Lund (1963) [26] dependence method. Later on, this method was revised by Ladd and Driscoll [27]. McGregor and Bamzelis [9], using PCA method, demonstrated that anti-cyclonic systems are the most important effective factor in enhancing pollution concentration. Makra et al. [28] have investigated the relation between large scale atmospheric patterns and surface layer pollutions in Piczle and reported that increase in pollution levels were accompanied exclusively by the dominance of anti-cyclonic circulations in the surface and mid-level troposphere. These situations normally occur in the winter. On the other hand, dilution of pollutants can be experienced not only during cyclonic, but also in ridge of anticyclonic weather types [28].

Consideration of synoptic forces and their combination with local elements which affect air pollution in the area were the main idea behind this study. The local effects were derived by using the upper air sounding data. We think that the achievements in recognition of the synoptic forces, effective on air pollution in the city is considerable. The PCA method was used and relations of many meteorological parameters (including data related to surface level and atmospheric layers) with concentration of air pollutants in the area were investigated in this study. If the procedure applied for weather data is from a single station it is referred to as the temporal synoptic index (TSI) [13, 18]. TSI was used in a number of air pollution studies [16, 17, 19, 21, 12].

2. The study area

The Alborz range stretches from west to east in the north of Iran (Fig. 1). Height of the central parts of the chain increase from west to east and their peaks exceed 4000 meters, reaching to Damavand Mountain with 5671 meters (Fig. 2).

The Caspian Sea is located in the north of the Alborz (Fig. 1). The local topography of Tehran with mountains surrounding the city from three directions along with frequent stagnant air masses, places Tehran among the most polluted cities of the world. Different geographical factors affect the climate of Tehran. The Alborz mountain chain in the north, the Kavir (an arid area) in the southeast and southerly to westerly humid winds are the most important of these factors. The last two factors affect the climate of the region and the former modifies the climate of the mountainous region and nearby valleys. Under calm conditions mountainous areas produce thermally induced winds known as katabatic and anabatic winds. Kavir affects local climate as a source of heat and dust haze. However, in recent decades urbanization has caused remarkable variations in the local climate, which can also have implications on a regional scale [29]. The city is on the southern slopes of the Alborz mountain range (Fig. 1). Most times during the year (about 300 days) the area is under dominant ridge condition. In winter, often extensions of Siberian cold high and in summer south easterlies of low heat are the dominant flows in low levels [30, 31].

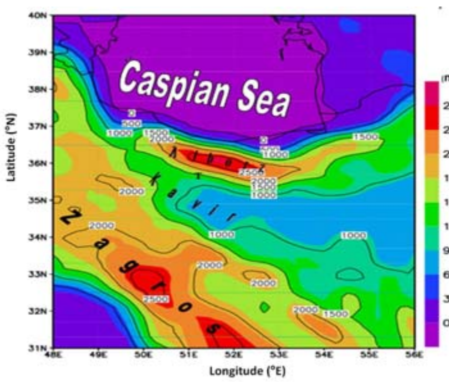

Fig. 1. Terrain height (m) field from the 30″(~1km) grid mesh showing geographical features of the Caspian Sea, Alborz chain, T(Tehran area), Zagros chain and Kavir Desert

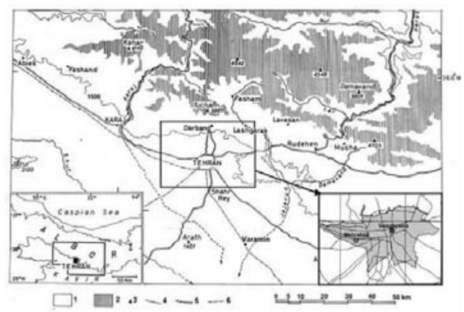

Fig. 2. A site map of the meteorological stations (Mehrabad) for Tehran area. Notice that the Alborz mountain range is in the north of Tehran (1: area north of 1500 m ASL contour; 2: the area above 3000 m; 3: mountain peaks; 4: rivers; 5: high ways; 6: railways), and the present map of built-up area of Tehran is shown in the bottom right corner

3. Methodology

For the meteorological classification and to determine the synoptic patterns responsible for the polluted days (CO>100µg/m^3), 0000 UTC records of atmospheric elements in Tehran upper-air station (Mehrabad) were considered. Also, the grid point data (Sea level Pressure and 500mb) were extracted from the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis dataset [32]. The grid data with 2.5°×2.5° resolution was selected for the area between 0-80°E and 10-60°N for six months (July-December) over a 6-year period (2001-2006). Moreover, related air pollution data and Pollution Standard Index (PSI) from the Air Quality Control Company of Tehran Municipality were collected and analyzed.

Selection of a suitable set of meteorological parameters for synoptic pattern classification is essential for a successful scheme [33]. In this study meteorological parameters were selected to represent both thermodynamic and hydrodynamic characteristics of the air mass and local meteorology. At first, all available meteorological parameters from the sounding were considered and then, by filtering based on Statiscal analysis and relationship of variables with potential air pollution 12 meteorological parameters were extracted. The selected variables include air temperature(°C), convective temperature(°C), surface wind speed (m/s), mean wind speed (m/s) in the 00-500m layer, pressure at 0°C level(mb), surface pressure(mb), height of the 1000mb level(m), thickness of pressure layers(m), Total totals index(°C) and S-index(°C) (Table1).

Table 1. Meteorological Variables and their relevance in the dynamic and thermodynamic processes

T1085	Thickness(m): 1000mb-850mb	Indicates temperature change in low levels of troposphere
T8570	Thickness(m): 850mb-700mb	Explains warm /cold advection in mid troposphere
T7050	Thickness(m): 700mb-500mb	Explains r subsidence inversions
Psfc	Surface pressure (mb)	Explains air mass changes and local effects
Pt0	Pressure at 0°C level(mb)	Explains domination of pressure system considering temperature
TT	Total Totals Index (°C) $TT=T_{850} + Td_{850} - 2T_{500}$	Explains stability between 850-500mb layer and vertical lapse rate change
Tsfc	Surface temperature(°C)	Explains nocturnal inversions
Tc	Convective temperature(°C)	Explains duration of inversions
WsuS	SFC wind speed(m/s)	Explains dispersion, transmission of air parcels
W05S	Mean wind speed (m/s): 0-500m	Explains dispersion, transmission of air pollutants in the 0-500m layer
H10	Height of the 1000mb level(m)	Shows development of pressure system and its change
STT	S-Index (°C)$SI=Td_{850}-(T700-Td700)–T_{500}$	Explains stability in lower atmosphere

Descriptive statistics of the patterns were classified based on CO concentrations. Mean and standard deviations of the 12 meteorological variables were calculated for the days within each category (Tables 2-3). Because of the different magnitudes of the variations of the data in relation to their measurement units (Table 1), the variances of the standardized (correlation matrix) forms were applied.

Before conducting a PCA, correlations between the variables should be checked. If any correlation is more than 0.1, it can be included in the factor analysis. However, this is not enough since the whole point of the analysis is to determine suitable items [34, 35]. To overcome this shortcoming two more tests were applied, the Bartlett and Keiser-Meyer-Olkin (KMO) examinations [35]. The KMO measure of sampling adequacy tests whether the partial correlations among variables are small. Bartlett's test of sphericity tests whether the correlation matrix is an identity matrix, which would indicate that the factor model is inappropriate. The related computed number for the KMO Test is between 0 and 1 and Figs. closer to 1 are desirable and the proposed minimum amount is 0.6 [35, 36]. For the existing data set the computed number is 0.865, indicating that it is appropriate (Table 4).

Table 2. Average meteorological variables for the five-CO categories (July-December, 2001-2006)

Variables	CO categories									
	CO =< 50		51< CO =< 100		101 < CO =<140		141 < CO =< 180		181 < CO	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
T1085(m)	1.3622E3	11.59	1.3843E3	2.54	1.4083E3	2.18	1.4136E3	3.28	1.4130E3	11.63
T8570(m)	1.5912E3	13.52	1.6163E3	2.91	1.6453E3	2.45	1.6520E3	3.69	1.6518E3	11.90
T7050(m)	2.6171E3	17.83	2.6457E3	3.84	2.6796E3	3.20	2.6879E3	4.78	2.6892E3	15.64
Psfc(mb)	8.8450E2	1.78	8.8200E2	0.33	8.8037E2	0.34	8.7998E2	0.52	8.8082E2	1.23
Pt0(mb)	7.6314E2	24.67	6.7104E2	6.62	6.1222E2	4.85	6.0040E2	6.09	5.8755E2	19.57
H10(m)	1.7871E2	23.30	1.2487E2	5.18	87.61	4.85	82.61	7.88	79.27	19.69
W05S(m/s)	3.50	0.61	3.11	0.12	2.81	0.09	2.74	0.19	2.45	0.52
TT (°C)	43.14	1.82	43.64	0.32	41.81	0.33	41.63	0.67	39.49	1.58
STT(°C)	32.28	3.70	30.70	0.63	24.50	0.59	23.06	1.19	22.68	3.13
Tc(°C)	15.82	2.53	25.87	0.73	32.93	0.61	35.48	1.01	37.72	3.22
Tsfc(°C)	6.90	2.03	15.14	0.64	20.61	0.56	21.9	0.89	23.20	2.40

Table 3. Statistical surface wind for the five-CO categories (July-December, 2001-2006)

Carbon Monoxide (CO) (μgm^{-3})	Number of days	Frequency (%) of Wind Speed			Descriptive Statistics	
					Mean	
	N	Calms	0.5-2.5(m/s)	>2.5(m/s)	Statistic(m/s)	Std. Error
CO =< 50	21	27.27%	18.18%	54.55%	2.64	0.41
51< CO =< 100	377	52.91%	14.81%	32.27%	1.69	0.11
101 < CO =<140	316	58.36%	12.30%	29.34%	1.42	0.10
141 < CO =< 180	84	71.43%	7.14%	21.43%	0.97	0.17
181 < CO	13	92.86%	0%	7.14%	0.24	0.23
Total	811	56.53%	12.72%	30.62%	1.51	0.07

Table 4. Kaiser-Meyer-Olkin (KMO) and Bartlett's Test

KMO Measure of Sampling Adequacy.		865
Bartlett's Test of Sphericity	Approx. Chi-Square	11992.847
	df	78
	Sig.	.000

To investigate and determine the main effective factors on air pollution, the PCA method of SPSS9.0 package and a two-stage clustering procedure were applied [35]. Before applying PCA, the meteorological data set was examined for significant outliers that may affect the results [37]. The PCA was applied to the correlation matrix and tailed probability function of the raw meteorological data (Table 5). The number of extracted principal components was selected based on a cut-off eigenvalue of one [34]. The resulting component scores were then segregated to produce meteorologically homogeneous categories using a two-stage clustering approach, the average linkage followed by the k-means technique. The convergent k-means technique, determining category membership based on nearest centroid sorting, allows for the rearrangement of data points after they have been categorized, and produce more compact and discrete categories. This two-stage clustering approach was used in a number of studies, Davis, 1991 [19]; Davis and Kalkstein, 1990b [18]; Eder et al, 1994 [21]; Yarnal, 1992 [38] and Jolliffe, 1990 [36], due to its ability to produce homogeneous categories (small variance within a category) with discrete separation between categories. Selection of a suitable set of meteorological parameters is essential for a successful scheme. In this study, meteorological parameters were selected to represent both thermodynamic and hydrodynamic characteristics of the air mass.

Table 5. Correlation of variables and indices with PSI and Tail probability function

PSI	T1085	T8570	T7050	Psfc	Tsfc	Pt0	H10	Tc	TT	STT	WsuS	W06S
	0.379	0.393	0.364	-0.201	0.362	-.395	-0.282	0.422	-0.119	-0.255	-0.178	-0.113
Sig. (1-ailed)	.000	.000	.000	.000	.000	.000	.000	.000	.003	.000	.004	.000

4. Results and discussion

4.1 Statistical description

Concentration of CO was used to define 5 categories based on the U.S Environmental Prediction Agency's (EPA) pollution concentration classification (clean days CO<50, moderate 51<CO<100, unhealthy 100<CO<200). Moreover, the last category is segregated to 3 sub-categories to examine the synoptic conditions responsible for the severe pollution episodes.

By grouping the days based on the CO concentration, statistical specifications of the variables were surveyed. Comparing the results in each category, the relationship between individual meteorological parameters and the pollution concentration were studied (Tables 2-3). Investigations of the historical data of wind speed indicate that the frequency percentage of calm winds condition is increasing from the first to the fifth group (Table 3). In other words, the wind velocity is an important factor to vary pollution level. On the whole, Table 3 indicates domination of low wind conditions on most days in Tehran and considering the extensions of the megacity, the wind speed must be of enough continuity and speed to offset the air pollution.

The original matrix of row data contains substantial inter- and intra-variable correlations. It is important to minimize this colinearity prior to classification so that a few variables do not exert a disproportionate influence upon the results. Based on correlation matrix (Table 5), results of surveying other variables and indices indicate that:

The variables of Tsfc, Tc, T1085, T8570 and T7050 show a direct relation with increase of CO concentration. TT, STT indices and WsuS, W05S, Pt0, Psfc and H10 variables show a direct relation with decrease of CO concentration (Table 5).

As it is evident, the variables of Tc, Tsfc, Pt0, T1085, T8570 and T7050 have correlations of more than 0.3. So these variables have the greatest correlation with air pollution variations and among them the variables of Tc and Pt0 have the highest correlations that are of prime importance. The Tc rises significantly when in severe inversions, which reflects strong stability. Hence in high pollution episodes the Tc has higher values, thus a positive correlation with the PSI. Pt0 indicates that trend of increasing pressure in ground level or freezing level will result in horizontal pressure gradient force, and hence increased wind speed. In this case the pollution concentration will not have an increasing trend (Table 5).

The point that should be considered is the straightforward use of these correlations which will sometimes result in errors. Thus using correlation coefficients indices to analyze meteorological quantities may result in errors, so to avoid these errors, normally, the PCA method is used [34].

4.2 Meteorological classification

For the selected subset of 12 meteorological variables the PCA has produced the first three components explaining 83.108% of the total variance in the raw data set (Table 6).

The variables with high loading (>0.9) for the first component are the thickness of pressure layers (T8570, T1085, T7050), Tsfc, Tc, Pt0 and H10 (Table 6). The first component, explaining 55.898% of total variance of the data set, appears to represent the regional-scale pressure field. Thickness between pressure layers, Tsfc, Tc, Pt0 and H10 are of prime importance in this component. Thickness between pressure layers, Tsfc, Tc variables have a direct relationship with the increasing concentration of air pollutants and also Pt0 and H10 have a direct relation with a decrease in pollutants concentrations.

The second component explains 17.216% of the data variance and has high loadings (>0.8) of meteorological variables: TT and STT indices (Tables 6). These indices have the maximum effects in the component that are directly related to PSI decrease. When mid troposphere temperature goes down and the difference between 850mb and 500mb increase, then the conditions of instability increase. This situation can be understood by the higher values for TT and STT. Hence high values of TT and STT indicate suitable conditions for instability. Thus it represents the characteristics of the local air mass and possibility of convective processes over the study area.

Table 6. Loadings on the three components obtained from the PCA technique

Variables	Principal component		
	1	2	3
PSI	.423	-.360	.317
STT	-.256	.833	.397
TT	.048	.862	.425
Tc	.914	-.324	-.095
Psfc	-.769	-.285	.094
Tsfc	.967	.068	.093
H10	-.930	-.207	.027
WsuS	.155	.487	-.651
W05S	.142	.440	-.626
Pt0	-.942	.031	-.058
T1085	.973	.061	.098
T8570	.987	.029	.067
T7050	.969	-.055	.015
Eigenvalue	7.267	2.238	1.299
% Variance	55.898	17.216	9.994
% Cumulative	55.898	73.114	83.108

The third component explains 9.994% of total variance for the data set and has high loadings of WsuS and W05S. Surface wind and mean wind speed in the oo-500m layer have the maximum effect in the component and are in reverse relation with PSI. Although these variables are very important, the total variance indicates that the number of windy days is much less than calm days (Tables 3 and 6). By determination of these variables, applications of simple Statistical models to predict air pollution potential becomes possible, especially in the regions without emission inventory data and dispersion model [33].

4.3. Description of synoptic patterns and Levels of CO associated with synoptic categories

The large-scale meteorological conditions appear to control the potential for episodic high CO concentrations in this complex terrain. On a regional scale, during cold seasons the Siberian high-pressure system is intensified and dominates the continent. Sometimes, southern Europe's high pressure moves to the east and extends to central parts of Iran. From time to time these synoptic systems extend a ridge to northern Iran. During warm seasons, when the thermal low pressure is prevailing, Iran is often under the influence of the extended subtropical ridge in mid-troposphere [30, 31]. Stagnant conditions often occur over Tehran basin, limiting pollutants dispersion due to light variable winds (Table 3). In the stationary stage of the ridge, multiple strong inversions (especially, radiation and subsidence types) often occur over the basin at night (Fig. 3). Figure 3 shows strong radiation and subsidence inversions with their base residing on the ground and approximately on 690mb level respectively.

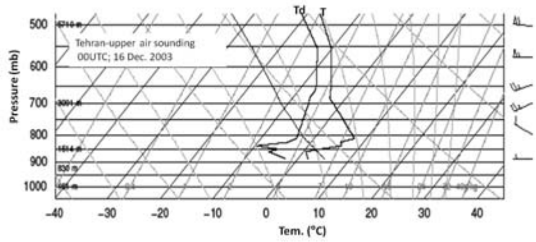

Fig. 3. Skew-T, log p diagrams of temperature and dew point temperature for Tehran at 00UTC on the 16 Dec.2003.

In this study, grouping the days is based on concentrations of CO divided to 5 categories. Synoptic conditions favorable for enhanced concentrations (CO>100) occurred in about 51% of investigated days (Table 3). Fields of Sea level pressure and 500mb geopotential height are discussed and charts for the average days of each category were drawn (Fig. 4).

Pattern 1 (Fig. 4a) is characterized by a high-pressure system dominating north of the Caspian Sea (CS) and a ridge extended to the west and southwest (SW) of the sea. The 1015mb isobar is over south of Tehran area and the ridge axis is oriented along east of the Zagros chain. Besides thermal low pressure over the south of the Persian Gulf, a trough is over the northeast (NE) of Iran that is oriented along Turkmenistan. Also, there are substantial pressure gradients over the south of the Caspian Sea and the Zagros chain. Zonal currents with a good gradient are dominant in mid-troposphere (500mb) and the 5760m contour has crossed over the Tehran area (Fig. 4b).

Pattern 2 (Fig. 4c) is characterized by presence of a high-pressure belt about 47°N and marked difference from the previous pattern that is with weaker high pressure and trough over the north of the Caspian Sea and Turkmenistan, respectively. The 500mb currents are mostly zonal with signs of development toward formation of a mid troposphere ridge (Fig. 4d).

Pattern 3 (Fig. 4e) is characterized by the weakened high-pressure system over the north and gradient pressure over the southwest of the Caspian Sea. The 1015mb isobar is shifted toward north and located over the southern Caspian Sea and Tehran, acquiring an S-shape due to weakened Siberian high and enhanced depression in the southeast of the Caspian Sea and northeast of Iran. The ridge line extends from southwest of the Caspian Sea to the south of the Alborz Mountains with a northwest (NW)–SE axis and a weak pressure field is over the northeast (NE) of Iran with its trough extended to the southeast of the Caspian Sea. This is a unique feature for this pattern, compared with others where the ridge axis is over the south Alborz and a trough over the south Caspian Sea. These are thermal features since the Caspian Sea warm waters as a surface heat source and the Mountain chains play a very important role in their formation [39-41].

Cold air damming (CAD) is characterized by trapping of cold air against the windward side of a mountain range [42, 43]. During CAD, a dome of cold and stable conditions establishes along the south slopes of the Alborz and can be identified via characteristic “U-shaped” isobars in the sea-level pressure field [41].

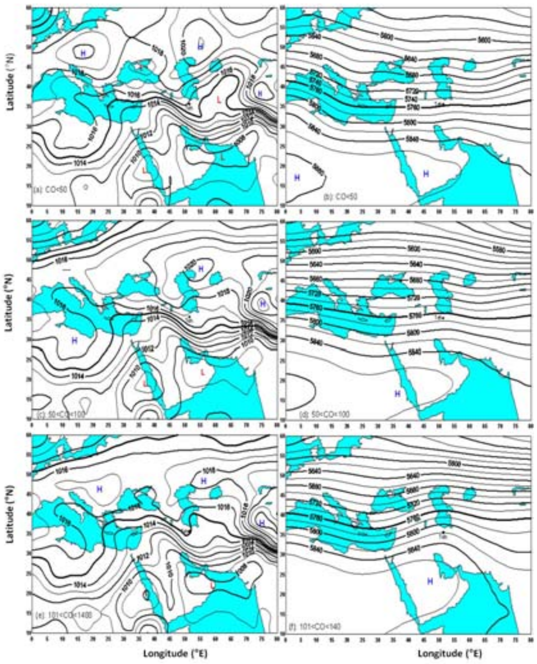

Fig. 4. Average daily sea-level pressure and 500mb geopotential height maps of the first three categories at 00:00UTC for six months (July-December) of every year in the period 2001-2006; left maps (a, c, e), sea level pressure (contour interval, 2mb); right maps (b, d, f), 500mb geopotential height (contour interval, 20m). Pattern1 (a and b), Pattern2 (c and d), Pattern3 (e and f), Teh shows position of Tehran in the maps.

Pattern 4 (Fig. 5a) is characterized by low-pressure system with the weak horizontal pressure gradient over the south of the Caspian Sea and northeast of Iran. The 1015mb isobar stretches deep to the South of the Alborz with almost NW-SE orientation over west and SW of the study area. There is a main ridge over the east of the Zagros mountain and its NW-SE axis crosses the chain.

Pattern 5 (Fig. 5c) exhibits the highest level of CO concentration at Tehran area compared to other identified patterns. A strong expansion of the high-pressure system over sourthern Europe is elongated over the Black Sea, producing a strong ridge. The ridge extends deep into the South Alborz and central Iran and its axis is oriented mainly NW-SE along the Zagros chain. A thermal trough reaches deep into the south of the Caspian Sea and north of the Alborz with the trough axis oriented mainly SE-NW. This situation brings the Alborz area under the influence of a weak pressure gradient and when it continues for a few days and sometimes a week or more it takes on a stationary stage. This Pattern is conducive to extreme pollution episodes due to poor dispersion conditions (weak horizontal pressure gradient, light wind) and likelihood of strong subsidence (high pressure), radiative inversion and light wind (Fig. 3).

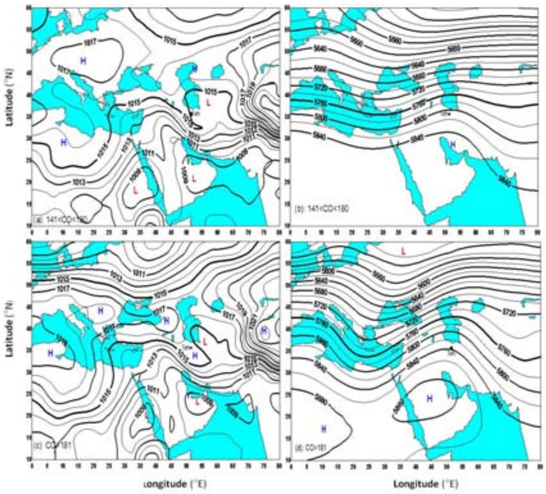

Fig. 5. As in Fig. 4 except for pattern 4(a, b) and pattern 5(c, d)

For the result, synoptic categories analysis indicates that the 1st and 2nd patterns are not producing stable conditions favored for air pollution increase. The 3rd pattern is an average condition which has the potential to create a partially moderate state of air pollution. The 4th pattern can produce a very stable condition, resulting in increased level of high pollutants. Finally, the episodes of synoptic conditions with the pattern of the 5^{th} category are those which are associated with most severe air pollution periods.

In general, the survey indicates that the high pollutant episodes in the Tehran basin are characterized by a thermal low-pressure over the North Alborz chain (over Caspian Sea) and high pressure over the South Alborz chain (over the entrance air flow of the basin). This situation is associated with a strong ridge elongated in mid-troposphere. The coupled pressure systems (thermal low over leeward side and high pressure over windward side of the Alborz) establish a weak horizontal pressure gradient over the range. The pressure gradient induces southerly to southwesterly weak cross winds that, due to mountain blocking intensify pollution concentration over the city.

In cities which are located in a semi-enclosed basin, similar to Tehran, low tropospheric flow towards mountain ranges associated with a strong ridge in mid-troposphere, piles up pollution on the windward side. For better understanding, a graphical presentation of this situation with severe pollution episodes for the two typical cases on 8 Sept. 2002 (with PSI=175) and 16 Dec. 2003 (with PSI=237) are presented (Fig. 6). Thus understanding characteristics for each of the 5 synoptic patterns can improve initial steps in forecasting and analysis of air pollution potential in the region.

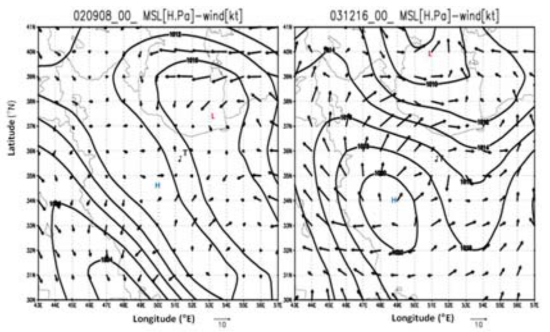

Fig. 6. Maps of sea-level pressure and 10m wind vector in two high polluted episodes in Tehran (L: low pressure; H: high pressure and T: position of Tehran)

Interlinking the three components of the PCA analysis and variations from the type 1 to 5 in the synoptic patterns, one can see many similarities based on the derived results.

Results obtained show the first PCA component has a direct relation with PSI. Besides surface temperature and thickness increase, especially between the 850-500(mb) layer, where there is a pressure decline in the ground level. In comparison, the synoptic analyses indicate declining horizontal pressure gradient and enhancement of upper ridge from group 1 to 5. When the synoptic types 4 and 5 are dominant in the region, the warm ridge is accompanied comparatively with lower pressure gradients.

The second component where the stability indices (TT and STT) have the most significant role has a reverse relation with the PSI rise. In comparison, as mentioned above, the Synoptic analysis indicates the ridge development from type 2 to 5. This is associated with the smaller temperature lapse rate and will result in reduced values of TT (Total Totals Index), in other words, decline in the potential of convection.

In the third component the surface wind and mean wind in the 00-500m layer are the most important parameters with reverse relation with the PSI. Synoptic analysis shows declining surface pressure gradient and wind speed from group 1 to 5 and explain the direct relation with the enhancement of pollution.

In brief, we can show that in the 1-2 patterns, horizontal and vertical pressure gradients are comparatively high with respect to other groups. In these kinds of patterns Psfc, Pt0, Wsfc and H10 have increasing trends, hence declining PSI. The patterns 3 to 5 show gradual increase in thickness of low and mid troposphere layers and Tsfc. In other words, a warm air column becomes dominant in the region with less pressure gradient. Furthermore, since the wind speed has a decreasing trend from the group 3 to 5, the stability indices (TT and STT) will have a declining state, but at night the condition is suitable for formation of inversions, hence Tc increases. In this case, the PSI increases and indicates incidence of a sever pollution episode.

In summery, significant relations between synoptic classified patterns and effective local parameters on air pollution are derived.

5. Conclusions

Past studies on Tehran air pollution are based mainly on 3 methods. Some have adopted synoptic approaches [44] and modeling case studies. They investigated mostly high pollution episodes and do not represent the generality of weather conditions in the city for all seasons including the synoptic conditions with low/medium potentiality of air pollution.

Some others have adopted statistic approach and investigated correlation between a few meteorology elements and PSI. Generally these studies are selective and do not cover all effective factors. Study of the relationship between air pollution with individual meteorological variables may be misleading as they do not account for the interrelation between the variables, while air pollutant levels normally respond to all meteorological variables collectively representing an air mass [12]. The last group emphasize thermodynamic conditions without enough attention to all forcings including synoptic ones, so are mostly considered local conditions.

In this study, we looked at the significance of many meteorological parameters in the PCA method and selected those with significant values in the factor analysis. Also, based on their relation with air pollution potential, the number reduced to 12 variables and their relevance in meteorology was defined in Table 1. The PCA method is developed successfully and three main components responsible for more than 83% of total variances were derived. Meteorological parameters effective on air pollution in a semi-enclosed basin (Tehran) were determined. The developed meteorological classification scheme identified five important synoptic patterns with distinct differences in the typical CO concentration levels at the complicated terrain of the Tehran basin. Significant relations between mean synoptic patterns and local meteorological elements effective on air quality in the region indicate an increasing trend in potential for air pollution from the 1st to the 5th category, so that the 5th pattern can produce a very stable synoptic condition resulting in the highest levels of air pollutants. This pattern results from a coupled pressure system (leeward thermal low and windward high) in surface level and a strong midlevel ridge. With this pattern southerly weak winds are induced and due to blocking by the high terrain in the north of the city, a significant discharge cannot take place. Hence high air pollution concentrations take place over the city and the sever episodes occur. Recognition the characteristics of each synoptic pattern can improve initial steps in forecasting and analysis of air pollution potential in the region.

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